University of Southern Queensland

Faculty of Engineering and Surveying

A Comparison of DGPS Correction Sources in South Eastern Queensland

A dissertation submitted by

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ABSTRACT

Differential Global Positioning Systems (DGPS) correction sources available in south eastern Queensland vary substantially in price, precision and accuracy. These factors were compared for the three most widely accessible real time DGPS correction sources: Virtual Reference Station (VRS) DGPS, OmniSTAR and Australian Maritime Safety Authority (AMSA) Beacon. In addition, a similar analysis was accomplished for a selection of four post processed DGPS correction sources including three stationary reference points and one modelled reference point. Dynamic and static measurements were taken for all of these systems at 17 sites across south eastern Queensland, spanning approximately 6,000 km^2. Statistical analysis of the mean and variance of these results illustrated that regardless of cost, all post processed DPGS correction sources were of similar accuracy and precision. Real time correction sources varied in their accuracy, but not their precision, with the most expensive correction source, VRS DGPS, clearly the most accurate. However, if a bias correction is applied to AMSA Beacon and OmniSTAR DGPS correction sources similar accuracies may be obtained. Within this test area, the distance from the origin of the correction source of each system had little impact on the result. For the first time in south eastern Queensland, this illustrates that less expensive correction sources, if appropriately corrected, produce results as accurate and precise as those from expensive sources.

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ENG4111 & ENG4112 Research Project

Limitations of Use

Certification

I certify that the ideas, designs and experimental work, results, analysis and conclusions set out in this dissertation are entirely my own efforts, except where otherwise indicated and acknowledged.

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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Signature

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Date

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NOMENCLATURE AND ACRONYMNS

The following abbreviations have been used throughout the dissertation and appendices.

AMSA	Australian Maritime Safety Authority
DGPS	Differential Global Positioning System
DMR	Queensland Department of Main Roads
DNRM & W	Queensland Department of Natural Resources Mines and Water
GDA 94	Geocentric Datum of Australia 1994 Geographic Coordinates from the 1994 adjustment/transformation
GPS	Global Positioning System
ICSM	Inter-governmental Committee of Surveying and Mapping
ITRF	International Terrestrial Reference Frame
ITRF2000	The 2000 ITRF adjustment/transformation
Main Roads	Queensland Department of Main Roads
MGA	Map Grid of Australia
MGA94	UTM Map Grid Coordinates from GDA 94
MHz	Megahertz
MSK	Multiple Shift Keying
NEMA	National Electrical Manufacturers Association
PDOP	Position Dilution of Precision
PM	Permanent Mark
RINEX	Receiver Independent Exchange Format
RTCM	Radio Technical Commission for Maritime Services
RTK	Real Time Kinematic (GPS)
SA	Selective Availability
SCDB	Survey Control Data Base
UTM	Universal Transverse Mercator
USQ	The University of Southern Queensland
USB	Universal Serial Bus
WGS84	World Geodetic System 1984
VRS	Virtual Reference Station

CHAPTER 1: Introduction

"Throughout history the science of navigation has played an important role for humanity. Individuals who could reliably travel to and return from distant locations were successful, both militarily and commercially" (Williams, J. 1992).

1.0 Background to the Research

The above statement suggests that knowing one's position accurately has many benefits. The advent of the Global Positioning System and other similar positioning services for civilian use has revolutionised sectors reliant on accurate positioning. Relatively unskilled persons can now know their position to within a few metres with a hand held Global Positioning System (GPS) receiver worth a few hundred dollars or less.

However, more accurate and precise positioning is best achieved using Differential Global Positioning Systems (DGPS), which compares measurements at an unknown point to those at a known point. When spatial data needs to be referenced to a specific accuracy and precision, knowledge of the specifications and characteristics of all available DGPS service providers is essential, especially when different correction service providers become unavailable.

A testing regime was subsequently developed for the purposes of this research to assess the characteristics of several available DGPS correction sources. The accuracy and precision of the results were measured both in real time through a communication medium or post processed following data collection. In addition, other factors that may affect results were assessed, such as the distance from a reference station and the type of correction service being utilised.

1.1 Research Aim

The aim of this research is to compare the accuracy and precision of various DGPS correction sources available in south eastern Queensland to determine if the accuracy and precision of the correction source justifies its cost.

1.2 Research Objectives

The primary objective of this project is to determine the characteristics of different DGPS correction sources. This enables the user to understand the limitations of these correction sources, such as accuracy and precision, when being used for a project to capture spatial data.

It also provides a comparison between the different correction sources to determine the best DGPS correction service to use depending on the user's requirements. Furthermore, it evaluates whether the cost of accessing the service reflects the accuracy and precision of the final results.

The research compares both the static and dynamic characteristics of the DGPS correction sources. This is necessary as users will have requirements for both situations.

1.3 Scope

This dissertation document consists of an examination of existing theory, selection of test region, individual assessment of results, and comparison of results.

A review of existing literature relating to Differential Global Positioning Systems provides a background to the workings of DGPS systems and any limitations associated with their use. A critical appraisal of the expected characteristics and accuracy of different types of DGPS correction sources available in south eastern Queensland was then conducted. A review of previous research into the precision and accuracy of DGPS systems enables a comparison of results and a basis for confirming or extending existing theory.

The south eastern corner of Queensland is one of the fastest developing areas in Australia and has a range of DGPS systems available to users. Together with the Survey Control Database (SCDB) maintained by the Department of Natural Resources Mines and Water (DNRM & W), a testing regime was designed to compare the results obtained from different DGPS correction sources within the south eastern corner of Queensland with the coordinates obtained from the SCDB providing a fixed reference. The control points allow for the comparison of results in relation to the position of the test site and distance to correction source or network.

Precision and accuracy estimates are available through the provided SCDB information (Appendix B) as truth for static positions, or in the case of dynamic testing, Real Time Kinematic (RTK) positions obtained from a dual frequency GPS rover as a truth for the DGPS results comparisons.

A comparison of the precision and accuracy between the tested DGPS correction sources was made and a discussion on the possible reasons for differences was undertaken.

1.4 Project Limitations

The scope of this study is defined by the following factors:

- DGPS correction source testing was only conducted over the south eastern Queensland test site as shown in Figure 3.1.

- The quality of the position data from the SCDB is defined as the Geocentric Datum of Australia coordinates of 1st Order, Class A as per the Standards and Practices for Control Surveys (SP1).

- Dynamic test quality is limited to the accuracy of RTK positions and the inherent problem of accuracy in cornering and latency of correction.

- When tested, the Virtual Reference Station (VRS) DGPS correction source was not available to users and corrections were provided especially for the purposes of this particular study.

- At the time of testing, the VRS system was not operating at its optimum capability as the base station at Beenleigh was inoperable.

- Comparisons were limited to only the tested DGPS correction sources.

- Only one DGPS capable receiver was tested. This project is not a comparison of the quality of GPS receivers.

This dissertation is written under the assumption that the reader possesses a basic knowledge of GPS theory and components.

1.5 Summary

This dissertation aims to compare and determine the accuracy and precision of sources of DGPS corrections available to users in south eastern Queensland. This was achieved using existing coordinated marks from the SCDB for truth in static situations, and a dual frequency RTK receiver for truth in dynamic situations.

The research provides a quantitative analysis of the accuracy and precision of the different DGPS correction sources relative to known coordinates provided by the SCDB in the south eastern Queensland test site. The assessment evaluated whether any type of correction source provided a superior result over others.

The outcome of this research provides a basis for users of DGPS corrections to determine the most suitable correction service based on their requirements.

Chapter Two provides a review of current literature to establish the current level of theory about DGPS correction sources.

CHAPTER 2: Literature Review

2.0 Introduction

Chapter One described some of the DGPS correction sources available to users in south eastern Queensland, and raised the possibility that some corrections may be more effective than others in both precision and accuracy. The primary aim of DGPS is to provide the user with improved GPS positions by reducing known errors. Common correction sources must be investigated to determine the accuracy and precision of different DGPS correction sources.

This chapter provides this information by reviewing existing literature to establish the current body of knowledge about DGPS correction sources. It outlines the DGPS correction provider's claims on the performance statistics for their systems and the specifications of the equipment used to conduct analysis of these systems.

Existing test regimes are also reviewed to give an indication of the type and style of testing that has been undertaken before when testing DGPS correction sources.

2.1 Differential Global Positioning Systems

Differential GPS is a method of positioning that improves pseudorange accuracies. It works by using a second GPS receiver at a known position which measures pseudoranges to all visible satellites. Simultaneously, a roving GPS receiver also measures the pseudoranges.

The roving receivers occupy unknown positions and receive corrections determined by a receiver at a known point. This receiver determines the corrective factors by comparing measured pseudoranges to the coordinates of the occupied known point. These corrective factors are either communicated to the roving GPS receivers in real time by a radio link or other communication medium (real-time DGPS), or are stored to be applied at a later time (post processing). DGPS eliminates common errors such as atmospheric errors and satellite/receiver clock biases.

2.2 DGPS System Architectures

DGPS sources can have a wide variety of architectures as outlined by Retscher (2002). The tested architectures encountered during the research are outlined below:

2.2.1 Single Reference Station Concept

A single reference station concept is where one reference receiver is used to record GPS signals. If used for real time, corrections require the following main components:

- GPS antenna/receiver
- A communication medium to the users (usually a radio link)
- Reference station software on a PC to perform monitoring
- DGPS data correction modelling
- Data archiving

For integrity, monitoring of the reference station usually consists of two independent GPS receivers to limit the possibility of system failure. The Australian Maritime Safety Authority (AMSA) Beacon service uses this type of system and is discussed further in Section 2.4. The observation errors are based on a single position and therefore are not modelled on a wider area. This limits the range of a single reference station DGPS to around 300 kilometres (Van Sickel, 2001).

For post processed applications the need for direct communication with the user is removed. This reduces the required components for DGPS application to:

- GPS antenna/receiver
- Reference Station Software on a PC to perform monitoring
- Data archiving
- This process is used in this research for determining the effects that distance may have on DGPS accuracies and precision.

2.2.2 Virtual Reference Station Network Concept

Another type of architecture is the virtual reference station concept (Retscher, 2002). This approach involves the use of user observations of their current position to generate a "virtual" base station at the user's position. This virtual base is generated from the real observations of a multiple reference station network. This approach should reduce the errors caused by the distance from reference stations which is present in the single reference station concept, as the generated base station is at the user's position. This approach is used by VRS DGPS. A description of the virtual reference station system tested in this research is provided in Section 2.6.

This approach was also used for post processing data to determine the precision and accuracy delivered by this method. Through a virtual base generator, VRS systems are able to generate a virtual base file at the position of the roving receiver. This virtual file is then used for post processing DGPS applications.

2.2.3 Virtual Reference Cell Concept

Virtual reference cell concept is, in all major components, similar to the Virtual Reference Station Concept, except that a correction is supplied for a small cell area, rather than specifically at the rover's position. Correction models are not estimated for specific users location as in the virtual reference station concept. Rather, models are estimated for a given DGPS service area, which is usually a grid pattern. The roving receiver is assigned to a cell within this grid and there is no need for the virtual station to follow the movement of the roving receiver (Retscher, 2002). This approach is most common in wide area DGPS networks such as OmniSTAR.

2.3 DGPS Correction Sources

DGPS correction sources are available from three distinct areas:

2.3.1 Own Base Station

The user can establish a reference station to obtain differential corrections. It is a convenient way of obtaining differential corrections as it can be situated exactly where the user requires. It can be customised to provide the exact requirements of the user. The major problem with this option is the cost of purchasing an additional GPS receiver, associated software and hardware to establish this reference station. It may also be a problem if the user requires real-time corrections, rather than post processing, to obtain licenses to operate high power radio transmitters to provide data link to rovers, which may require a licence or other additional costs for communications.

2.3.2 Community Base Stations

Some government departments, universities and community agencies provide and maintain base stations that provide both real time and post processing facilities at no charge to the user. They are provided to improve safety or other civic activities. An example of this is the AMSA Beacon service that is tested in this research.

2.3.3 Commercial Base Stations

Commercial DGPS providers offer DGPS services at a fee to the user. Usually they cover a wide area, and in the case where the user cannot afford the cost of purchasing and maintaining their own base station or only has a small amount to correct, this method is efficient. In most cases, the user is required to purchase a radio receiver and a subscription to the DGPS service provider. Examples of commercial DGPS correction providers are OmniSTAR and VRS DGPS service provided by the DNRM & W.

2.4 Australian Maritime Safety Authority Beacon Service

The Australian Maritime Safety Authority is Australia's primary maritime administrator. It is charged with enhancing the safety of seafarers and shipping, and also protects the maritime environment from pollution. Through this role, AMSA identified the need for a DGPS service to provide more accurate positioning information for vessels near the coast line (D'Amico, 2006). AMSA has installed 16 DGPS stations in its network in areas covering the entire Barrier Reef and Torres Strait regions, Bass Strait, south eastern ports, and ports in Perth, Brisbane, Darwin, Sydney and Karratha. AMSA's DGPS service is a free-to-air service provided to any user with appropriate equipment. A map showing the coverage of AMSA's DGPS service is shown in Figure 2.1.

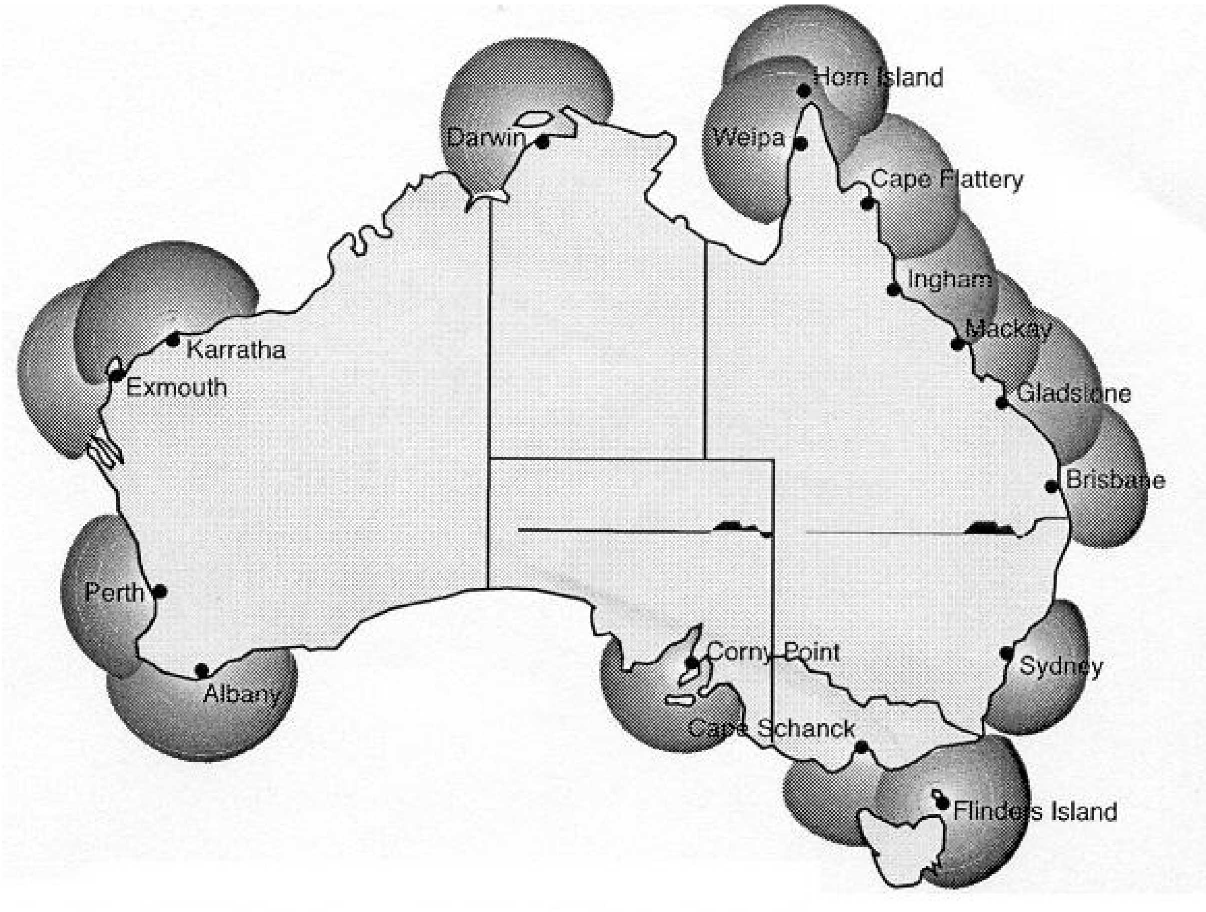

Figure 2.1: AMSA DGPS Service Coverage Map

(Source AMSA (1998))

The correction technique used by the AMSA Beacon service is known as a single reference station, as described in Section 2.2.1.

Corrections from AMSA's DGPS system are sent to the user via radio transmission in the band allocated for maritime radio navigation (AMSA, 1998). The data broadcast by the AMSA stations are in RTCM message format. Satellite corrections are only sent for satellites at an elevation of 5 degrees or greater and the maximum number of corrections sent is for a maximum of nine satellites.

According to AMSA (1998), with a fully operational GPS constellation the position accuracy of AMSA's DGPS service is required to be 10 metres or better with a 95% probability. Through AMSA's internal testing, before the elimination of selective availability, an accuracy of 5 metres or better with a 95% probability was being achieved (D'Amico, 2006).

The AMSA Beacon station used for this research is the Brisbane station, located at Ningi, on the Bribie Island Road, that transmits at a frequency of 294 kHz at a power of

180 watts. This AMSA Beacon transmits RTCM-104 messages. The Brisbane station occupies two reference locations: permanent marks 126400 and 126401.

2.5 OmniSTAR

OmniSTAR is a differential global positioning service that provides a continuous real time positioning for North America, Europe, Africa and the Australia – New Zealand regions. It primarily provides a correction service designed to deliver sub metre accuracies. It uses a wide area network of reference stations to calculate a correction for users based on their location within the network. This solution is weighted on the user's distance from the various reference station locations. The weighted corrections are combined to provide the user with the best solution from the reference network for their current position (OmniSTAR, 2006). This correction type is the reference cell type as discussed in Section 2.2.3. A map of OmniSTAR coverage is shown in Figure 2.2.

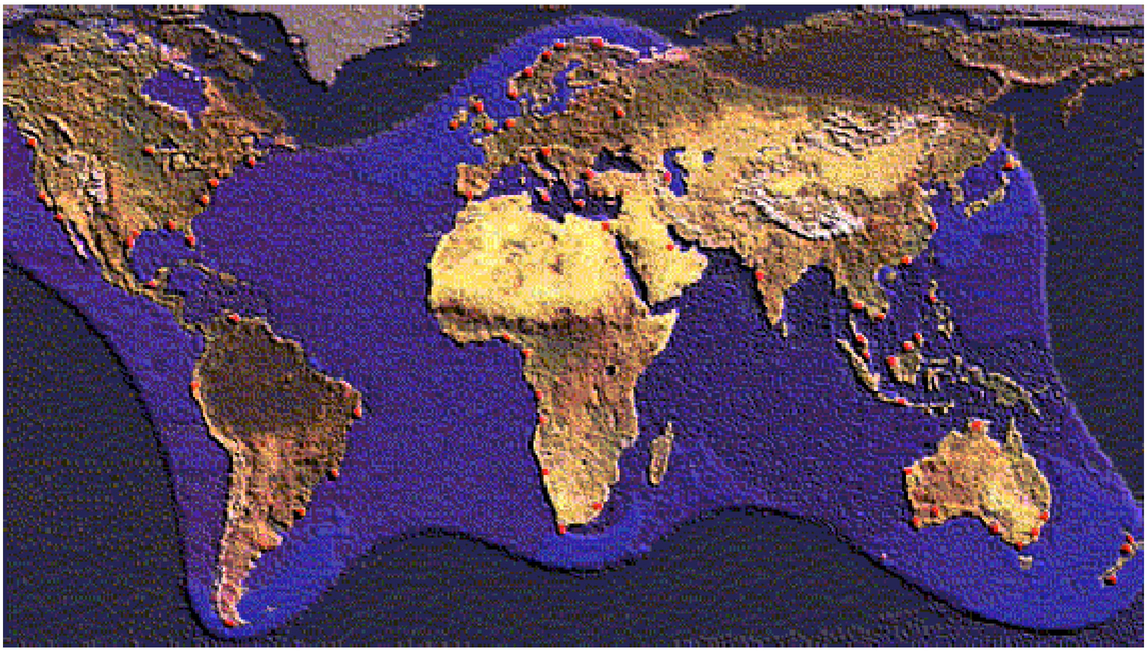

Figure 2.2: Coverage Map of OmniSTAR DGPS System

(Source Ganeshkumar (1999))

The OmniSTAR VBS system, as used in this research was designed to deliver accuracy at the sub-metre level, deliver continental coverage and also be a portable system. It is a single frequency DGPS correction service that uses a network of reference stations to measure and correct errors in stand alone GPS observations, such as atmospheric and timing errors. (OmniSTAR, 2006)

The OmniSTAR system comprises a network of approximately 100 reference stations located around the globe. Eleven of these reference stations are located within Australia, with the nearest to the test area being a reference station at Brisbane. A number of geostationary satellites provide the correction data to users through L-band frequencies, 1535.185 MHz is used at the southeast Queensland test area. Two global network control centres process all reference station's data and provide models for corrections that are provided to users. OmniSTAR (2006) and Ganeshkumar (1999) provide a full description of the OmniSTAR system.

2.6 Virtual Reference Station DGPS

The Virtual Reference Station is designed to provide high precision positioning over a large area, eliminating some of the problems associated with a single reference station. The system that is being utilised for DGPS correction services in this research is the VRS system operated by the Department of Natural Resources, Water and Mines covering the south eastern corner of Queensland. The VRS system involves permanently running GPS reference stations, which allow a model of error corrections to be generated for a unique site. These corrections are then made available to roving receivers via GSM mobile phones. A map of the VRS system as configured at the time of testing is shown in Figure 3.1.

Usually this system operates with CMR+ format corrections, rather than the RTCM-104 format corrections needed for DGPS corrections as used by the author. For the purposes of this study the DNRM & W kindly changed the correction type for a single weekend to enable testing of the accuracy and precision of a VRS DGPS correction source. So it should be noted that at the time of this research VRS DGPS was not commercially available in south eastern Queensland. Figure 2.3 shows a generalised virtual reference station setup.

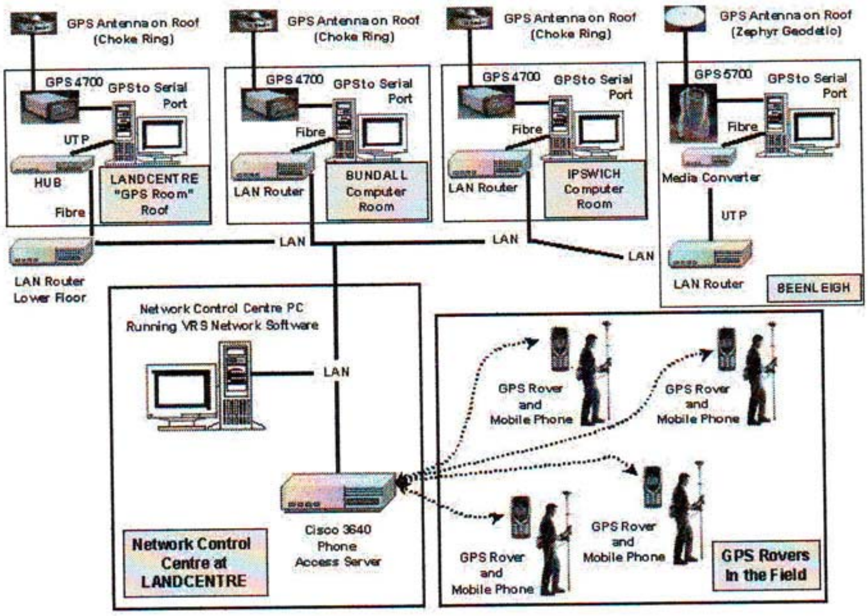

Figure 2.3: Hardware & Software Architecture for the Queensland VRS system circa 2001

(Source: Higgins (2001))

To generate a correction at the rover's position, a phone call is made to the central processing facility, where the rover supplies an approximate position and requests corrections for this position. The rover is then positioned relative to the corrections provided by this virtual reference station at the supplied approximate position. (Higgins, 2001)

As tested, the VRS system included reference stations at Robina (PM753291), Ipswich (PM753164), Caboolture (PM753292) and Woolloongabba (PM753166). There is a station at Beenleigh (PM753165). However this station was undergoing maintenance at the time of testing.

2.7 Post Processed from Single Reference Station

The research also looked into the accuracy and precision of post processed DGPS. This was provided by base stations either installed by the author, supplied by DNRM & W or by the University of Southern Queensland (USQ). Because of the variety of GPS receivers used for reference, a common data format was needed to standardise the post processed correction data. Subsequently, a format called RINEX (Receiver INdependent EXchange) was used to standardise the correction data.

In post processing both the base station and the rover must record data simultaneously as both receivers must observe the same errors in the GPS signals. This allows the correction determined by the base receiver to be common by the roving receiver(s). (Van Sickel, 2001)

2.8 Post Processed from a Virtual Reference Station

Post processing from a Virtual Reference Station is similar to post processing from a single reference station in all aspects, except that the base file is generated virtually from a networked virtual reference station system. This process is designed to eliminate the problems that distance from a correction source can cause. The virtual reference station is generated from archived data from a VRS system for given coordinates and time.

2.9 Previous Studies into DGPS Systems

Investigation of DGPS correction sources has revealed many test schemes used by previous researchers. Most researchers have only tested a single DGPS correction source operating in different conditions for accuracy and precision, and have not made comparisons of DGPS correction sources. In dynamic situations most researchers have utilised the use of designated test tracks to determine differences in DGPS results with control data.

2.10 Previous DGPS Testing

Ganeshkumar (1999) studied the accuracy of OmniSTAR DGPS in regard to a road centreline survey with different quality GPS receivers. This research examined the effects of speed on the final results obtained from the OmniSTAR DGPS systems. Testing was undertaken using a constant offset from a known centreline which was used to calculate the errors within the DGPS system.

A comparison applicable to this study was the predicable accuracy of the OmniSTAR system in dynamic situations, which was 0.8m in both horizontal components. It also identified the possible errors associated with using a fixed control line, particularly considering the ability of controlling the test vehicle to precisely run the control line. This error was overcome in this research by the use of RTK as truth for observations.

The conclusions of Ganeshkumar's study were that the availability of a higher grade receiver improved accuracy and precision through the allowance for more channels to monitor more satellites. It also revealed that the speed of the test vehicle did not affect the accuracy or precision of the final results the DGPS positions.

A study by Yoshimura and Hasegawa (2002) clarified the performance of Global Positioning Systems in forested areas after the discontinuation of selective availability using uncorrected GPS measurements and DGPS measurements. It determined the horizontal and vertical precision and accuracy under different operating conditions of visibility to satellites.

It found that while DGPS had been very effective in reducing the error caused by selective availability, it did not improve horizontal precision compared to uncorrected GPS results but did improve the horizontal accuracy.

The conclusion of this study was that obstructed observations to GPS satellites greatly affected precision, which was not overcome by the used of DGPS corrections. In addition, it was concluded that DGPS improved the horizontal accuracy.

Hale M. et. al (2006) assessed the performance of Victoria's VICpos system of DGPS corrections. VICpos consists of 12 networked reference stations providing DGPS correction to users.

It tested different grade survey controllers to determine accuracy of results obtained when using the VICpos DGPS system. Using a Trimble Geo XT GPS receiver with VICpos DGPS corrections, an accuracy of better than 1 metre was achieved. The research also compared the results of different receivers using carrier wave observations and dual frequency observations. These comparisons will not be covered in this research.

The control points for the test were established using results from one hour of static observations using a dual frequency GPS receiver, which was post-processed to form a network with the GPSnet reference stations.

This study also looked at the costs of operating a GPS receiver with DGPS corrections being received via a GSM mobile phone and the problems encountered with this style of receiving corrections.

From this previous research it can be seen that DGPS results have been compared to control data in the past, and have also been compared uncorrected GPS results. However, a comparison of DGPS correction sources has not been undertaken. Such a comparison was the approach of this research.

2.11 Conclusion

This chapter has established the background of current knowledge with respect to DGPS correction sources. Specifically it noted the different types of DGPS correction sources, VRS DGPS, OmniSTAR, AMSA Beacon, and stand-alone reference stations. It established the two methods of applying DGPS correction sources as either being in real time or post processed.

It established DGPS architecture as being either single reference station, such as AMSA Beacon, virtual reference stations such as VRS DGPS, or virtual reference cells as used by OmniSTAR.

It discussed the errors that DGPS should remove from GPS measurements as being atmospheric and timing errors. Also established was the need to compare uncorrected GPS measurements with DGPS measurements as selective availability has been removed from the GPS system. This was a major error that DGPS corrected for.

Chapter Three will provide an overview of the project site, control data used, equipment needed for data acquisition and the process of reducing data to enable correlation.

CHAPTER 3: Methodology

3.0 Introduction

Chapter Two established the current state of theory with regard to the GPS systems, focusing on to DGPS correction sources and providers. It was recognised that the development of a regime of testing that would adequately evaluate the accuracy and precision of the selected DGPS correction sources was needed.

This chapter provides this guidance by outlining the test area, the source of the control data and the equipment used in data acquisition. It then continues to outline how this equipment was used to capture the data that was used to evaluate the selected DGPS correction sources over the test area in south eastern Queensland.

It provides an explanation of the processes of determining the results from these GPS measurements and the method of providing control coordinates for measurements.

3.1 The Study Area

The location of the study site was the south eastern section of Queensland, from the New South Wales Border in the south, Beerwah in the North and Minden to the west. It contains some of the fastest developing areas in Australia with large amounts of development being undertaken (Southeast Queensland Regional Plan, 2006). A regional map of the study area is given in Figure 3.1.

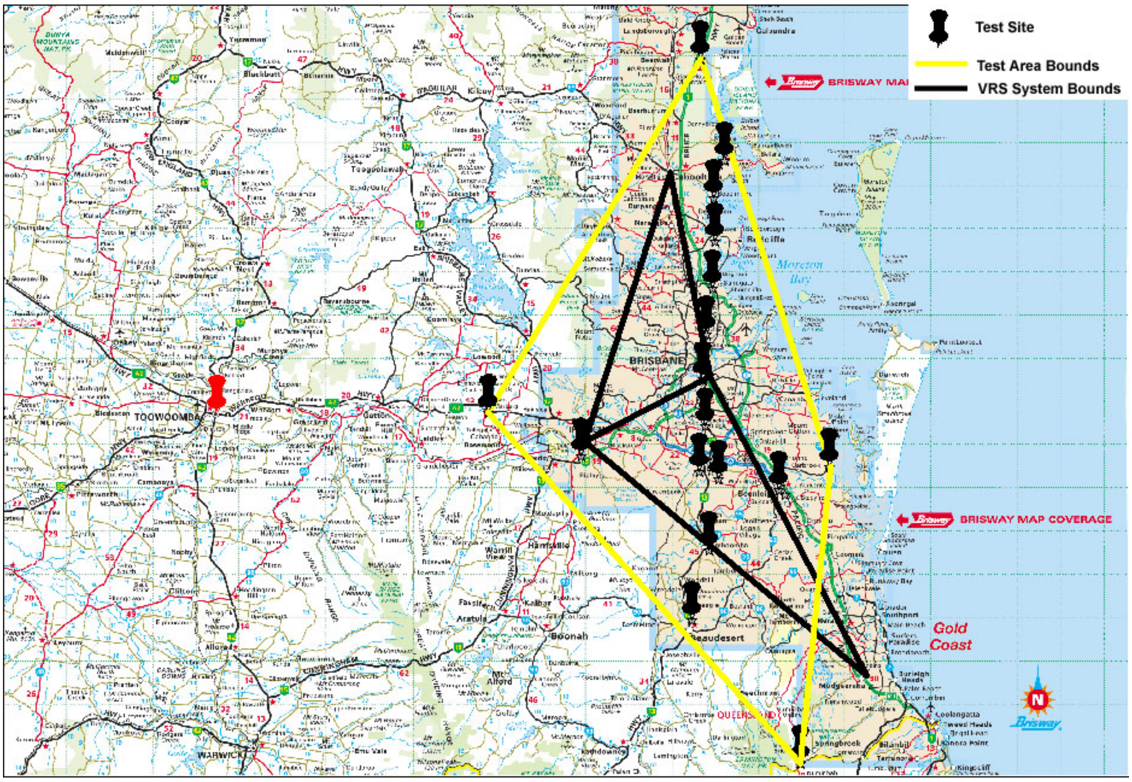

Figure 3.1: Map of Test Area Showing VRS System Bounds and Test Site Bounds

(Source: Edited, Brisway Maps(2005))

A major consideration in this research was the comparison of different DGPS correction sources. This was a major reason for choosing this test site, as it has the only currently operating VRS system in Queensland as described in Section 2.6.

3.2 The Control Network

Horizontal control was provided by the SCDB that is maintained by the DNRM & W, Queensland. This database is maintained in accordance with the standards set out in the *Standards and Practices for Control Surveys Version 1.6.* (ICSM, 2004). To ensure the quality of control marks used for the determination of accuracy and precision used in this research, only marks with 1st order, Class A coordinates were used for control marks. The control marks used are listed in Appendix B. The quality of these marks are superior in quality to results obtained from code DGPS measurements. Class A control coordinates are referred to by the *Standards and Practices for Control Surveys Version 1.6* (2004) as being designed for national and state geodetic surveys.

Control marks were chosen for their location in regard to the DGPS correction sources reference station(s) being tested. In total there were 17 control sites chosen to determine the effects of distance from correction source and if results varied over a significant distance. The location of the test sites is given in Figure 3.1.

In most circumstances, spacing between the test stations was kept around 10km. However, greater or less spacing occurred where there were insufficient coordinated marks at required locations or two different DGPS correction sources intertwined. This spacing of the test sites was to enable a comparison of results with reference to distance from the correction source.

3.3 Equipment

This project involved the use of equipment that was both able to collect GPS pseudorange measurements from GPS satellites and DGPS corrections from different correction sources. The equipment that was used had to be able to collect information from all the different correction sources to enable the comparison of results, so variance in the equipment used could not be used explain the any differences in observations. This was the reason a Trimble Pro-XRS GPS receiver with the ability to receive both the GPS Pseudorange measurements and corrections from both OmniSTAR and AMSA Beacon DGPS sources through an integrated antenna was chosen as the GPS receiver to test the different DGPS correction sources. An explanation of the operation and configuration of the equipment will be supplied in Section 3.6.

The major items of equipment that were used for testing DGPS correction sources were as follows:

3.3.1 GPS Receiver

The GPS receiver used for collecting GPS Pseudorange measurements was a Trimble Pro-XRS, which is a 12 channel GPS receiver for the L1 code and carrier GPS signals (Trimble, 2006). This receiver had integrated GPS/MSK radio beacon (AMSA Beacon)/Satellite Differential (OmniSTAR) correction abilities and it was paired with an integrated GPS/MSK radio beacon (AMSA Beacon)/Satellite Differential (OmniSTAR) antenna. The Pro XRS is shown in Figure 3.2.

3.3.2 Controlling Software

Software was needed for the field computer to communicate with the GPS receiver. For this purpose, Trimble's TerraSync software was selected. TerraSync allowed the changing of GPS parameters such as elevation mask and upper PDOP values to ensure data integrity. It also allowed the user to select the type of correction sources such as AMSA Beacon and OmniSTAR that were integrated into the GPS receiver. It also enabled the GPS receiver to be connected to an external correction source, which for this research was the VRS system correction (Trimble, 2003).

3.3.3 Field Computer

A field computer was needed to monitor the status of the GPS receiver and to store measurements made by it. For this research portability, was not a major issue and to enable the storage of large amount of data and the need to run other controlling software for different GPS hardware an IBM ThinkPad T40 portable computer was used. This computer is illustrated in Figure 3.2. This approach allowed the storage and processing of data to be undertaken on a single computer.

3.3.4 Receiving VRS Corrections

For receiving the external corrections from the VRS system, which only sends correction via the GSM mobile telephone network as mentioned in Section 2.6, a Nokia 6600 mobile phone was used. This phone was able to act as a modem between the controller software on the field computer and the VRS system server to obtain corrections. The phone was connected to the field computer via a Bluetooth connection. This was possible by the use of a Belkin Bluetooth USB adapter connected to a USB port on the computer, and the Bluetooth connection available in the Nokia 6600. This is shown in Figure 3.3.

3.3.5 USB to Serial Converters

The field computer had no RS232 ports to facilitate the direct connection of the Pro XRS directly to the computer. This needed the use of a RS232 serial connection to a USB connection. This needed the use of a Belkin USB to serial converter or an IBM USB to serial converter.

3.3.6 Additional USB Ports

With the use of the two available USB ports for the USB to serial converters for the dynamic testing, additional USB ports were needed for both the optical mouse for ease of use of the computer, and the use of the Belkin Bluetooth USB adapter to allow the connection of the field computer and Nokia 6600 to receive VRS corrections. This equipment is illustrated in Figure 3.3.

3.3.7 User Installed Base Station

A reference station was installed at 33 Harvey St North, Eagle Farm Brisbane, Queensland. This was done to allow for the post processing of GPS observations via a user installed base to show accuracies and precisions from this style of DGPS post processed correction source. This reference station was installed over a coordinated mark GUP103. This mark had been coordinated from a coordination project for the Gateway Bridge duplication project. The mark, although not a registered mark, had been coordinated to the specifications of a 1st order, Class A, mark as per the *Standards and Practices for Control Surveys Version 1.6* (2001). For the static observations undertaken on the weekend of 29/30 of July 2006 a Trimble 4700 GPS receiver, with a micro centred L1/L2 antenna was used to observe static data. For all other times a Leica System 500 GPS receiver system with a Leica AT502 antenna was used to observe static data from this point.

These were the major equipment components used to test the various DGPS correction sources that were common in both the static and dynamic tests.

3.4 Static Test Equipment

The static test involved only one GPS receiver positioned over a known coordinated mark. A pictorial view of the equipment used for static observations is provided in Figure 3.2.

Figure 3.2: Static Test Equipment

3.5 Dynamic Test Equipment

The dynamic test involved the use of a second dual frequency RTK GPS receiver to provide control coordinates. Subsequently, a reference station and associated equipment was required to establish a fix for the ambiguities of the roving control RTK GPS receiver. The use of this additional equipment varied significantly from the static tests. A picture of the dynamic equipment used is shown in Figure 3.3. The dynamic equipment differed from the equipment used for static observations in the following ways:

3.5.1 The use of a Trimble R8 RTK GPS receiver

The R8 was chosen to act as truth for the DGPS observations in this project for these reasons:

- When using RTK with on the fly ambiguity resolution, specifications state the receiver (Trimble, 2005) offers a horizontal accuracy of 20mm + 2 Parts Per Million (PPM). For the longest RTK baseline observed in this study equates to 22mm for the horizontal position accuracy. This is an insignificant level considering the style and accuracy of result being obtained from the test receiver.

- The R8 receiver has the option of exporting NEMA strings (Trimble, 2005), which is vital to record the position of the R8 receiver with reference to the Pro XRS receiver at a period in time. For this project the R8 GPS receiver was configured with Trimble's GPS configurator software to export NEMA GGA strings which contain data on time, position, and fix status.

- The R8 GPS receiver does not require a field computer with controller software to obtain a fix and output coordinates. It automatically searches for any available correction signals through its radio port and uses these corrections to obtain a RTK fix which is then used for the coordinates output in the NEMA string.

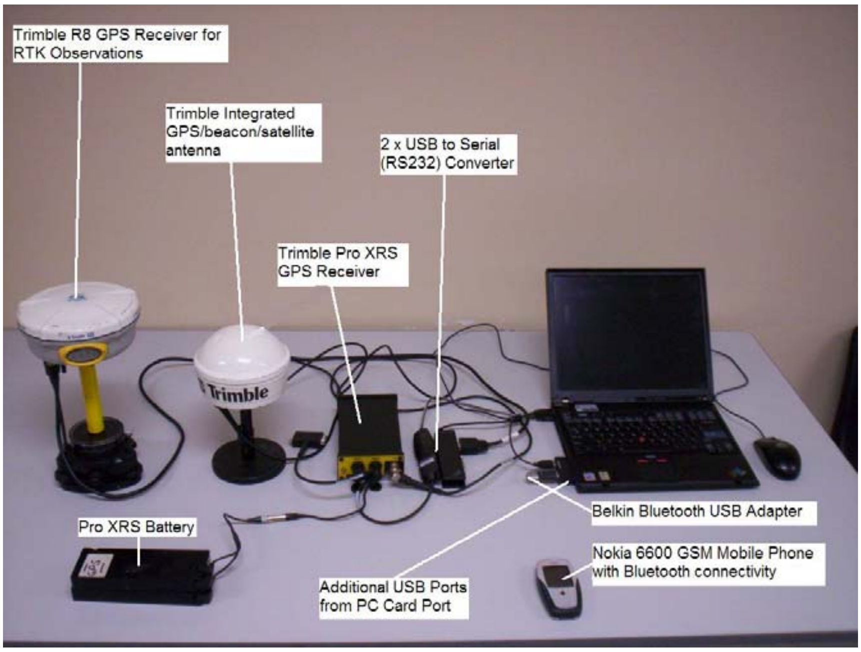

Figure 3.3: Dynamic Test Equipment

3.5.2 The use of a Test Vehicle with GPS antenna mount

In order to maintain the receivers in parallel while moving, the following method was employed. A vehicle was found that was equipped with rails running square from the centreline of the vehicle. A mount was then constructed with welded mild steel and 5/8" threaded rod which was welded vertically from the mount. The threaded rod was welded at a spacing of 501mm, ensuring that the two threaded rods were along the centreline of the mount. This mount was fixed to the vehicle cross rail using high tensile bolts and high density foam to prevent damage to the vehicle. This mount was fixed on the vehicle for the period of testing to prevent the possibility changes in the alignment, so all measurements would be compared to the same baseline alignment. The dynamic antenna mount is shown in Figure 3.4.

Figure 3.4: Dynamic Vehicle Mount

3.5.3 Dynamic Reference Station Setup

In order to use the positions obtained from the Trimble R8 GPS receiver to act as control for the observations, corrections to enable on the fly ambiguity resolution were needed. This was supplied via a user installed reference station at the permanent mark used for static test at each site. A Trimble 4700 GPS receiver with a micro centred L1/L2 GPS antenna with a ground plane coupled with a Trimble Trim Talk 450 radio system for transmitting the correction data was used for this purpose. The system was set up using Trimble TSCe survey controller using survey controller version 10.8 software, with Geocentric Datum of Australia 1994 (GDA 94) coordinates for MGA zone 56. A picture of the reference station setup is provided in Figure 3.5.

Figure 3.5: User Installed Real Time GPS Reference Station

3.6 Data Acquisition

The GPS data used in this study was obtained in a GPS survey campaign. It is important to note that both the control data and GPS data used are not infallible, and cannot be relied on as an unequivocal comparison of different DGPS correction sources. Possible errors are discussed in Section 4.3. It is important then to describe the origins of data and how this it was obtained.

The control data as described in Section 3.2 was obtained from a Map Info database of permanent survey marks supplied by DNRW & M, and accessed through a database maintained by the Department of Main Roads Queensland (DMR). It is important to note the adjustment date of the permanent marks as supplied in Appendix B, and their coordinates. What is also important is the physical inspection of the permanent mark when visited, as any disturbance of the mark could make the coordinates supplied not suitable as a description for the location of the permanent mark.

3.7 Static Data Acquisition

Static data was recorded on the weekend of 29/30 July 2006 for AMSA Beacon, OmniSTAR and uncorrected GPS which was also used for Post Processed DGPS sources. VRS static data was not collected on this weekend as the system was only able to be configured for one weekend to transmit the RTCM corrections required for this research. VRS static data was collected on the weekend of 12/13 August 2006. Figure

3.6 shows a picture of static data being observed at Beerwah at the northern border of the test site.

Figure 3.6: 1 Static DGPS Data Acquisition at PM120502

All data obtained from the Pro XRS GPS receiver were in the following datum;

Datum:	Geocentric Datum of Australia (GDA94)
Grid Coordinates (UTM)	Map Grid of Australia 1994 (MGA94) in zone 56

Table 3-1: Datum for Pro XRS GPS Receiver

To ensure the quality of measurements, the following settings were established for obtaining GPS data in the TerraSync software as obtained from the *Standards and Practices for Control Surveys Version 1.6.* (2004).

Elevation Mask:	15 Degrees
Maximum GDOP:	8
Observation Interval:	1 second epoch

Table 3-2: GPS Receiver Settings

Approximately 10 minutes of data was gathered for each correction source to determine the static position via the DGPS correction source with a level of confidence and eliminate the influence of erroneous outliers in the results. Each of the DGPS correction sources was observed in a series at each site to minimise the effect of changes in variables in error sources like atmospheric and satellite geometry changes.

3.8 Dynamic Data Acquisition

Dynamic data was observed in a GPS survey campaign on the weekend of 5/6 August 2006 for AMSA Beacon, OmniSTAR and uncorrected GPS which is also used for post processed DGPS. VRS DGPS was observed on the weekend of the 12/13 of August 2006 because the VRS system needed to be reconfigured to generate RTCM corrections as it usually is configured for CMR+ corrections.

The major difference from static observations involved the use of a second, dual frequency RTK GPS receiver from which the coordinates were used as truth to compare the results from the DGPS correction sources. This receiver is held at constant offset from the DGPS antenna as described in Section 3.5. For this receiver to work for RTK corrections using on the fly ambiguity resolution, the installation of a user base as described in Section 3.5.3 was needed.

To ensure maximum accuracy of this RTK receiver, the distance from the correction source was kept as small as possible. This was done by utilising the control marks used for the static test as the reference location for the reference receiver. As this mark was in a site with good visibility and open access, it provided an ideal location for the reference station.

The second GPS dual frequency receiver, a Trimble R8, was configured to output NEMA strings containing data on the position of the receiver at one second intervals. To configure the R8 GPS receiver, Trimble's GPS configurator was utilised. This enabled a GGA NEMA string to be output through the serial port on the receiver.

Data from this second GPS receiver was logged as attribute data in the file recording the data from the Pro XRS DGPS receiver. A RS232 cable from the R8 receiver coupled with a USB to serial converter connected the R8 receiver to the field computer.

The TerraSync software is able to log this data by recognising it as an external sensor. With the R8 GPS receiver configured as an external sensor properly, data from the receiver was received as attribute data at a one second interval in TerraSync. A photo of dynamic testing being undertaken is shown in Figure 3.7.

Figure 3.7: Dynamic DGPS testing at PM94371 at Ningi

3.9 Data from Reference Stations for Post Processing

This research also looked at the accuracy and precision that could be achieved from post processed DGPS correction sources. To achieve this, data needed to be obtained from 3 different sources. These three sources are explained below:

3.9.1 User Installed Base

To test the accuracies that could be achieved by installing a reference station to enable post processing, a base station was established at the DMR depot at 33 Harvey St North Eagle Farm, Brisbane. This base station was either a Trimble 4700 for static tests, or a Leica System 500 for dynamic tests. To enable the exchange of data between different GPS systems a common format, RINEX, was used and all data from the Leica System 500 was converted to this format. The data from the Trimble 4700 was already compatible for post processing applications in Trimble Pathfinder Office.

3.9.2 USQ Base

To test for the degradation in accuracies and precision with respect to distance, post processing from a continually operating base station located at the Faculty of Engineering and Surveying at USQ Toowoomba was undertaken. Data from this reference station was in RINEX format. Data was received from this source via an archive of GPS observation data kept by USQ.

3.9.3 Closest VRS Base and Virtual Base

The DNRM & W, at the time GPS observations, had 4 operational continually operating reference stations at Woolloongabba, Robina, Caboolture and Ipswich. By processing GPS measurements with these reference stations gave the possibility of errors due to distance were virtually eliminated. Data from these reference stations was sourced via an archive of GPS observation data kept by DNRM & W. The data was in RINEX format.

Also the DNRM & W offered an option of generating virtual reference stations at any location via their virtual RINEX file generator as part of their Virtual Reference Station network. A request for virtual stations at the control marks via the file generator was submitted. A RINEX file of a reference station at the requested coordinates for the time period was returned. This file was used to post process the GPS data to test the accuracy and precision via this type of DGPS correction source.

3.10 Data Processing

For this project, Trimble Pathfinder Office Version 3.1 was used to interpret the data that was gathered from observations. Pathfinder Office was used to import the raw files generated by the field software, and to directly export data using the dBASE function which is explained in detail in Section 3.11. Pathfinder Office was also used to differentially correct data using the classic differential correction method. The settings for these corrections were as follows:

- Code processing only
- Output corrected positions only
- Elevation mask of 10 degrees
- Standard rover and base processing technique

These settings are the default settings for Pathfinder Office in the classic differential correction panel. A table of the coordinates used for the reference stations is provided below in Table 3-3.

	Easting	Northing	Height	Antenna Ht
LandCenter	503483.980	6959847.652	49.458	0.000
Robina	537459.191	6894212.677	25.189	0.000
Caboolture	495193.402	7003927.263	41.095	0.000
Ipswich	476350.112	6945294.063	48.765	0.000
USQ	394586.985	6946490.639	718.663	0.000
Harvey St	509047.891	6965661.992	3.674	See Below
			29_07=	1.637
			30_07=	1.640
			5_08=	1.336
			6_08=	1.343

Table 3-3: GPS Reference Station Coordinates as used for Post Processing

3.11 Data Export

All data for this research was exported from Pathfinder Office using the dBASE export function. The dBASE export function allows the user to specify the type of output needed, such as easting, northing, PDOP, sensor records, and others. For this research two different dBase export setups were used, firstly for the static observations, and then dynamic observations. The resulting output file was given the dbf extension.

3.12 Processing Dynamic Data

To obtain control coordinates for dynamic tests, the data from the dbf file generated from Pathfinder Office had to be processed. The reason for this was because the NEMA string placed the coordinates as a single text line in the dbf file as shown below:

$GPGGA,090708.00,2733.51234011,S,15232.79611219,E,4,7,1.0,63.256,M,36.856,M,1.0,

The parts of the NEMA string needed were the latitude and longitude. Latitude and longitude from the NEMA strings needed to be extracted so they could be converted into GDA94 coordinates.

To reformat the text string, it was copied from the dbf file to a blank text file in the UltraEdit-32 text editor. UltraEdit-32 had the ability to a run pre-recorded macro through an entire length of a text file. This macro changed the format of the GGA NEMA string as shown above to;

-27,33,. 51234011,S,152,32,. 79611219,E

It is important to note that the seconds were in decimal degrees and due to the process to convert these coordinates to GDA94 coordinates the latitude and longitude needed to be in converted from decimal degrees.

The latitude and longitude needed to be converted to GDA94 coordinates for use as control in the comparison. This was done by using Redfearn's formula. This formula can be used to convert between latitude and longitude to easting, northing and zone for a Transverse Mercator projection, such as the Map Grid of Australia. This formula is accurate to better than 1mm in any zone of the Map Grid of Australia, according the *Geocentric Datum of Australia Technical Manual Version 2.2 (2002)*. To calculate the easting and northing for each site, the Redfearns's Formula excel spread sheet was used. This spreadsheet was obtained from the Geoscience Australia website (2006).

This spreadsheet needed to be edited in order to remove some of the repetitive tasks from the calculation that would have made the reduction impossible in any reasonable period of time. A Visual Basic program was written to remove some of the repetitive tasks. This program enabled the efficient calculation of the control coordinates.

These control coordinates were still at the 501mm offset from the DGPS coordinates as recorded from the Pro XRS GPS receiver. To correct for this offset, the surveying processing software 12d was used. The control coordinates were input into 12d using the point number, easting and northing function. The traverse line as defined by these coordinates was then paralleled using the parallel string option at -0.501mm to correct for the offset caused by the antenna mount. The offset line was exported as a comma delineated file with the point number, corrected easting and corrected northing coordinates.

The comma delineated file that was output from the 12d software was used for the control reference in all measurements observed in dynamic situations.

3.13 Conclusion

This chapter reflected on the methods of obtaining DGPS measurements and processing the data from these GPS surveys. It outlined the process of post processing data and the sources for the reference station data and the coordinates used for these reference stations.

Chapter Four will now discuss the results of these measurements to determine relative accuracy and precision with reference to the control coordinates.

CHAPTER 4: Results from Observations

4.0 Introduction

Chapter Three described the process of obtaining data from field observations and the process of reducing the control data for dynamic tests. This data was then used to calculate accuracy and precision of the different DGPS correction sources.

This chapter outlines the process of determining this accuracy and precision achieved from the selected DGPS correction sources. It examines the process of comparing the results to control data and the statistical tests used to check for similar accuracy and precision in the mean of values and variance of values for each DGPS correction source. It will show the results of both the static and dynamic tests for accuracy and precision and provide a discussion on the effects of distance from the correction source.

4.1 Static Tests

The results for precision using RMS for static tests for the different DGPS correction sources are shown in Table 4-1. This table is graphically interpreted in Appendix C. Also included in this table is the accuracy of the results obtained from the DGPS correction sources. The results are compared to the control value derived from the SCDB value.

Correction Source	Precision (m)	Accuracy (m)	Precision +/- 95% Confidence Interval	Accuracy +/- 95% Confidence Interval
Post Processed Closest VRS Base	0.196	0.060	0.063	0.051
VRS DGPS	0.221	0.008	0.049	0.064
Post Processed Harvey St Base	0.266	0.107	0.117	0.097
Post Processed USQ Base	0.280	0.080	0.054	0.065
AMSA Beacon	0.285	1.267	0.048	0.098
OmniSTAR	0.319	0.748	0.071	0.145
Post Processed Virtual Base	0.329	0.028	0.070	0.118
Uncorrected	1.375	0.549	0.060	0.475

Table 4-1: Precision & Accuracy of Different DGPS Correction Sources in Static Situations

The results used in this table are the average values obtained from the 17 different test sites in the test area. The 95% confidence intervals are obtained from comparing the results from these test sites. It can be seen that for the real time DGPS correction sources VRS DGPS is superior in accuracy. OmniSTAR and AMSA Beacon DGPS correction sources are far less accurate. Reasons for this will be discussed in Section 5.3. A full list of results from static testing is provided in Appendix D.

4.2 Dynamic Tests

The results of the dynamic accuracies and precisions that were obtained from dynamic testing is provided in Table 4-2. This table is graphically interpreted in Appendix C.

Correction Source	Precision (m)	Accuracy (m)	Precision +/- 95% Confidence Interval	Accuracy +/- 95% Confidence Interval
VRS DGPS	0.277	0.052	0.055	0.097
OmniSTAR	0.286	0.582	0.060	0.111
AMSA Beacon	0.298	1.229	0.053	0.094
Post Processed Closest VRS Base	0.373	0.120	0.060	0.117
Post Processed Harvey St Base	0.439	0.157	0.059	0.117
Post Processed USQ Base	0.462	0.105	0.053	0.099
Post Processed Virtual Base	0.554	0.232	0.076	0.227
Uncorrected	1.219	0.802	0.110	0.313

Table 4-2: Precision & Accuracy of Different DGPS Correction Sources in Dynamic Situations

Dynamic results are similar to that obtained from static observations. There is an overall increase in the size of the accuracy and precisions error values, equating to approximately 100mm. This could be explained through the propagation of error as described in Section 4.3. It can be determined that there is no significant difference in accuracy and precision from both static and dynamic measurements. A full list of results for dynamic tests is provided in Appendix E.

4.3 The Propagation of Error

For this research it was important to understand the possible errors that could be imported into the data. For the static tests the known possible sources of error were eliminated, minimised or taken into account. An example might be the incorrect positioning of GPS antenna over the coordinate mark. This was overcome by calibrating the survey equipment to ensure accuracy before the observations were undertaken. The sources of error that could not be eliminated for the dynamic test were as follows:

The error caused by the inevitable cornering of the test vehicle. This error was calculated by taking into account the sampling interval for GPS measurements at 1 second intervals and the maximum speed of 1.7 m/s. The minimum turning radius of the test vehicle was determined to be 7.5 meters, from which the maximum possible error, if the sample was taken at the worst possible scenario at the middle of two averaged vertices, was 0.089m. The other error from the dynamic tests was the error caused from the initialisation of the R8 GPS receiver. From technical specifications this error was determined to be 0.022 metres. This was calculated by using the propagation of error as shown in Equation 4-1.

$$\sigma_{Total}^2 = \sigma_{Antenna}^2 + \sigma_{Initialisation}^2$$

Equation 4-1: Propagation of Error

From this equation the total error that was present in the control for the dynamic environment was determined to be 0.092m. No judgement on the accuracy and precision for dynamic results could be made within a limit 0.092 metres.

4.4 Results of Statistical Tests for Static Situations

The results were compared using Student's T test to test the mean of the easting and northing of two DGPS correction sources at 95% confidence interval. In addition, Fisher's F test was used to compare the variances of the different DGPS correction sources also at a 95% confidence interval. The following table shows the results of comparing the easting and northing of the different DGPS correction sources to each other. A pass in variance would indicate that the variances for the two corrections sources are similar at a 95% confidence level. A pass in mean would indicate that the means are similar at a 95% confidence interval. A pass for both variance and mean would indicate that the results from the different correction sources are similar at the 95% confidence level. The results are shown in Table 4-3.

	Uncor-rected	Real Time Processed			Post Processed			
		VRS DGPS	AMSA	Omni-STAR	VRS	Harvey St	USQ	Virtual
Uncorrected		Mean	Fail	Fail	Fail	Mean	Mean	Mean
VRS DGPS	Mean		Variance	Variance	Pass	Mean	Mean	Mean
AMSA	Fail	Variance		Variance	Variance	Variance	Variance	Fail
OmniSTAR	Fail	Variance	Variance		Fail	Fail	Fail	Fail
VRS	Fail	Pass	Variance	Fail		Fail	Mean	Mean
Harvey St	Mean	Mean	Variance	Fail	Fail		Pass	Pass
USQ	Mean	Mean	Variance	Fail	Mean	Pass		Pass
Virtual	Mean	Mean	Fail	Fail	Mean	Pass	Pass	

Table 4-3: Static DGPS Correction Sources Statistical Results

4.5 Results of Statistical Tests for Dynamic Situations

The same statistical analysis of results from DGPS correction sources were used for dynamic situations. The results of these tests are shown in Table 4-4.

	Uncor-rected	Real Time Processed			Post Processed			
		VRS DGPS	AMSA	Omni-STAR	VRS	Harvey St	USQ	Virtual
Uncorrected		Fail	Fail	Fail	Fail	Fail	Fail	Fail
VRS DGPS	Fail		Variance	Variance	Mean	Mean	Mean	Mean
AMSA	Fail	Variance		Variance	Fail	Fail	Fail	Fail
OmniSTAR	Fail	Variance	Variance		Fail	Fail	Fail	Fail
VRS	Fail	Mean	Fail	Fail		Pass	Pass	Mean
Harvey St	Fail	Mean	Fail	Fail	Pass		Pass	Pass
USQ	Fail	Mean	Fail	Fail	Pass	Pass		Pass
Virtual	Fail	Mean	Fail	Fail	Mean	Pass	Pass	

Table 4-4: Dynamic DGPS Correction Sources Statistical Results

4.6 Distance from Correction Source

This research also took into account the errors that could be introduced due to the increasing distance from the correction source. The results for all correction sources in the test area gave no evidence that the distance from correction source had a significant effect on accuracy or precision.

This is illustrated in the results of the post processed DGPS correction sources from stand-alone base stations. This result was typical for all correction sources, with no strong evidence supporting the degradation of results due to distance from correction source for the test area. Figure 4.1 illustrates the results from stand-alone reference stations for the degradation of accuracy depending on distance from correction source within the test area. There is a small decrease in accuracy degradation of approximately 100mm over the entire test area. However, considering the applications DGPS is used for, this amount is considered negligible.

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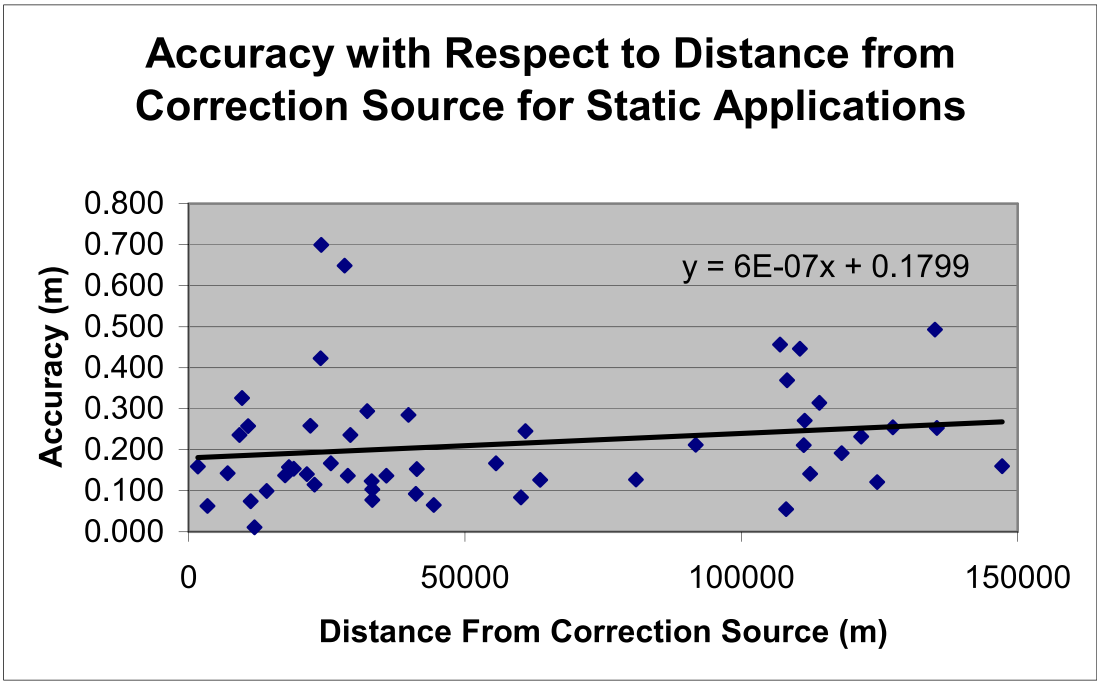

Figure 4.1 Accuracy with Respect to Distance from Correction Source for Static Situations

Similarly, the precision of results was not affected by distance from correction source. This is illustrated in Figure 4.2 by the lack of increase or decease in precision.

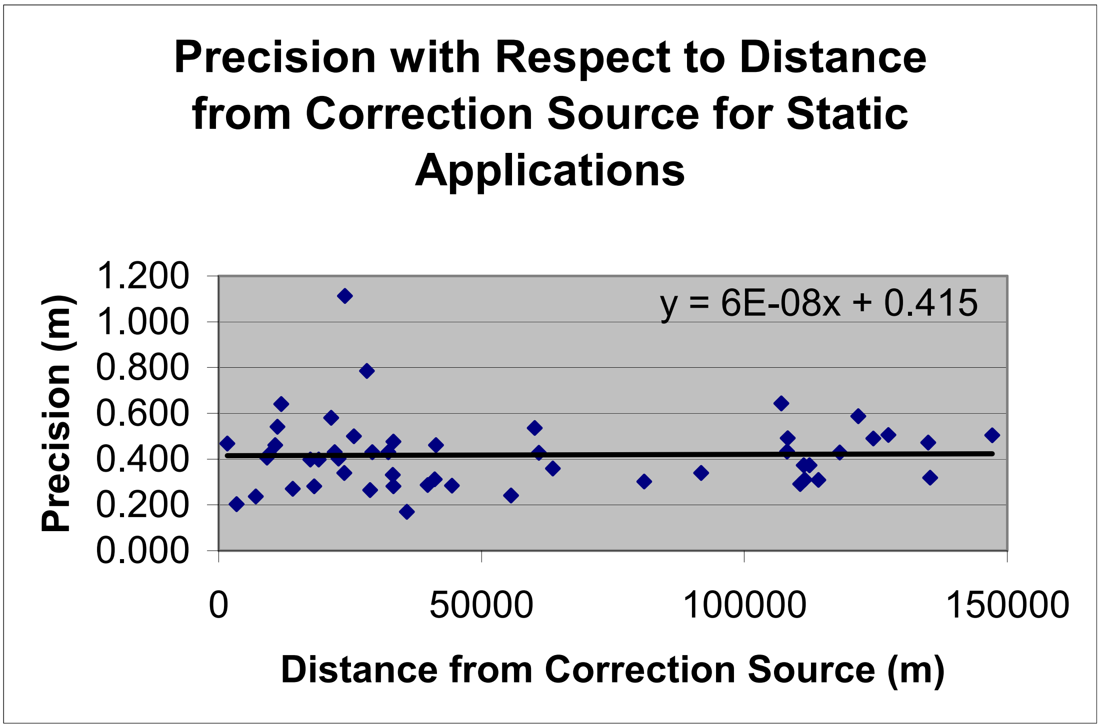

Figure 4.2 Precision with Respect to Distance from Correction Source for Static Situations

These results are based only on the post processed DGPS correction sources from a single reference station. However, the results are commiserate with results obtained from the different DGPS correction sources either real time or post processed. In this research, it was found that distance from the correction source is not a major factor in increasing or decreasing the relative accuracy and precision of any DGPS correction source.

4.7 Conclusion

This chapter focused on the physical results of GPS observations from the various DGPS correction sources. It provided values for precision and accuracy for the different DGPS correction sources. It provided the results for tests of significance in values for the mean using Student's T test at a 95% confidence level. It also analysed the variances of the different correction sources for similarity at the 95% confidence level using Fisher's F distribution.

It showed the errors that needed to be taken into account when making conclusions on results by examining the propagation of errors in dynamic measurements as being caused by the method of providing control. It also demonstrated the minimal effect that distance had on DGPS correction within the limits of the test area by providing an example of common results.

Chapter Five will now focus on the reasons for and implications that these results have on the different DGPS correction sources.

CHAPTER 5: Discussion

5.0 Introduction

Chapter Four provided the results of the DGPS correction sources for accuracy and precision. It determined the results for tests on variance and mean for these results. It provided a common example of the errors caused by distance.

This chapter will analyse the reasons for these results. It will rank the DGPS correction sources in both accuracy and precision and will analyse the variances as determined by Fisher's F test and the mean as determined by Student's T test.

5.1 Static Results

Precision

The static results are displayed in Figure 5.1 ranked in order of precision (error bars indicates the 95% confidence intervals for the 17 test sites). There was little difference in the results obtained from different DGPS correction sources regardless of the techniques they used. All precisions were within 0.4 metres except for uncorrected GPS observations which was 1.4 meters. From this chart it can be easily recognised that DGPS improves the precision of GPS measurements, with minimal differences between the different correction sources.

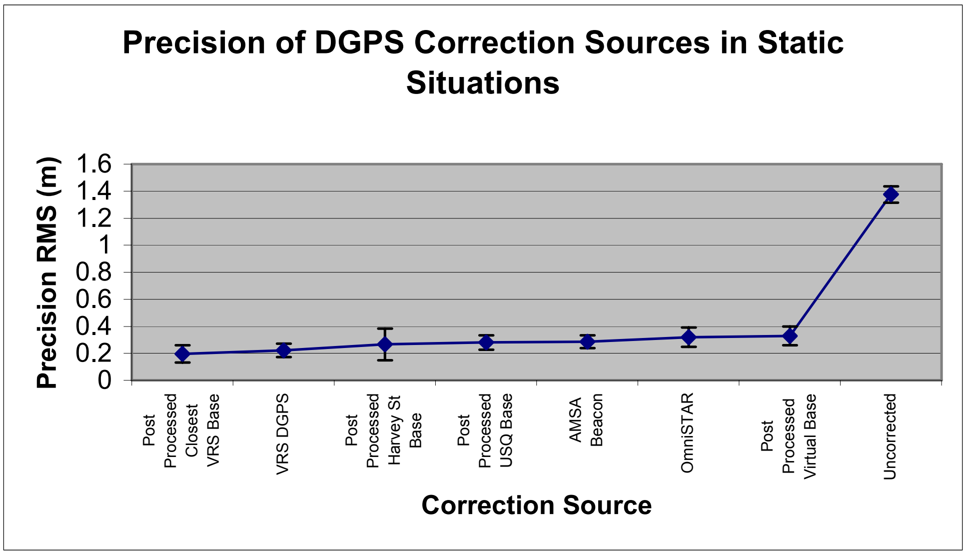

Figure 5.1: Ranked Precision of Static Results

Accuracy

For the static results, the accuracies are displayed in Figure 5.2 in a ranking of smallest to largest. There was little difference in the accuracy of results obtained from correction sources that are known to be linked to GDA94 coordinates. The most interesting fact is the lack of accuracy in measurements obtained from both OmniSTAR and AMSA Beacon DGPS correction sources.

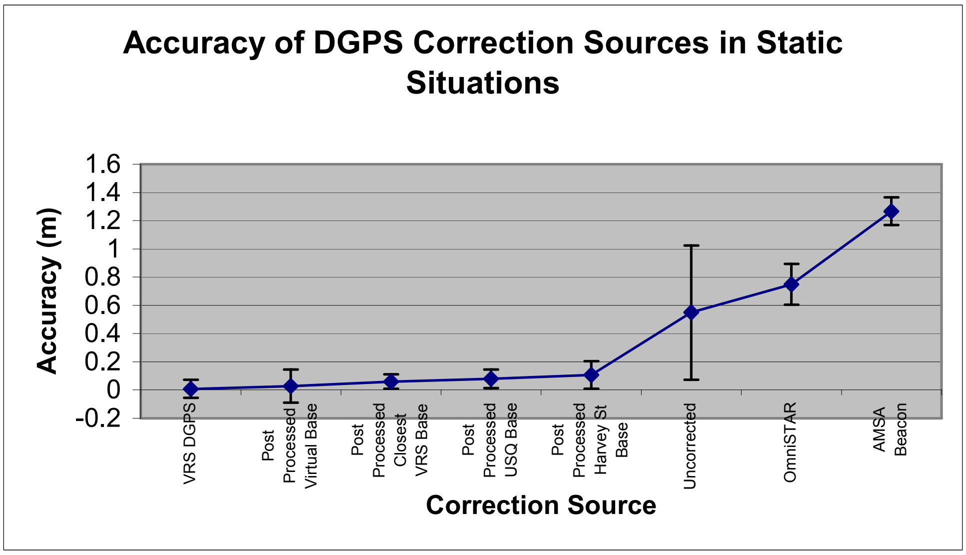

Figure 5.2: Ranked Accuracy of Static Results

As the variances of AMSA Beacon, OmniSTAR and VRS DGPS are similar according to results obtained from the F test, it can be argued that the coordinates used at the reference station of these DGPS correction sources is not true GDA94 coordinates. This may be caused either from a poor transformation of coordinates or the use of a different datum other than the specified GDA94 in their technical specifications as explained in section 5.3.

5.2 Dynamic Results

Precision

The precision of the dynamic results are displayed in Figure 5.3, ranked from most precise to least precise. The results are similar to those obtained through static observations. This once again shows that DGPS gives better precision than uncorrected GPS observations.

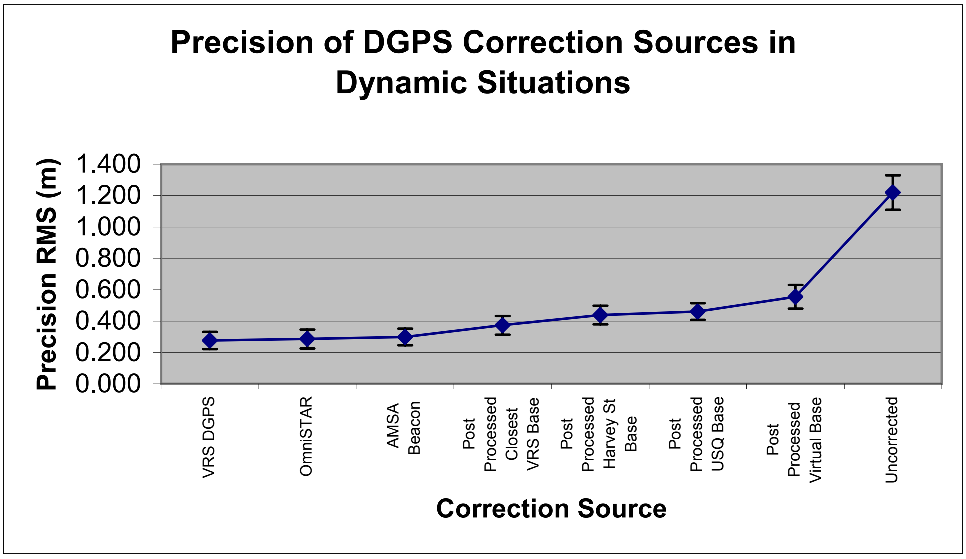

Figure 5.3: Ranked Precision of Dynamic Results

Accuracy

The results of the accuracy of the DGPS result in dynamic situations are shown in Figure 5.4. This shows similar trends to those observed for static results.

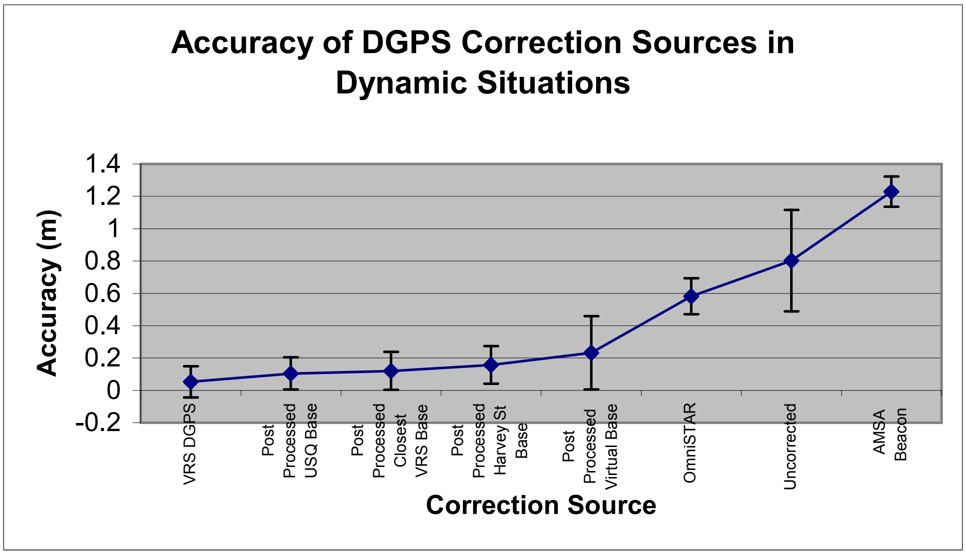

Figure 5.4: Ranked Accuracy of Dynamic Results

This confirms that there is little difference in the accuracy and precision of the different DGPS correction sources when they are used for static or dynamic measurements. This is significant because the two measurement types are used for different data acquisition projects. Static measurement is used for point positioning where multiple readings at the same position are available allowing for averaging to improve accuracy. Dynamic measurement relies on the positions being precise, accurate and especially up to date if used in conjunction with a real time DGPS correction source.

5.3 Accuracy comparison of AMSA Beacon and OmniSTAR

From the results obtained it appears that the accuracy of both the AMSA Beacon and the OmniSTAR DGPS correction sources are poor. This is a trend that was present across all test sites. The use of the same equipment under similar conditions at all test sites indicates that the reference station data provided by these correction sources is different to that provided by VRS DGPS.

This was confirmed by investigating the datum used by the AMSA Beacon and OmniSTAR DGPS correction sources. It was found that they are not based on GDA 94. VRS DGPS and post processed DGPS correction sources are based on GDA 94. This explains the decreased accuracy of AMSA Beacon, which is based on WGS84, and OmniSTAR which is based on ITRF2000, as the corrections received from these sources make results based on the respective datum.

5.3.1 OmniSTAR Datum

OmniSTAR uses the ITRF2000 coordinate datum for determining corrections to users. This means correction received ITRF2000 is a dynamic datum that is used by OmniSTAR correction reference stations. The coordinates for these reference stations are updated ever six months by OmniSTAR (Walford 2006). Results obtained from the OmniSTAR DGPS correction source are also based on the ITRF2000 datum. ITRF2000 is approximately 0.77 meters different to GDA94 positions at the end of 2005.

This difference can explain the accuracy error of OmniSTAR results. With the knowledge of this error and with the variance of OmniSTAR and VRS DGPS being similar at the 95% confidence level, VRS DGPS, as shown in Table 4-3 and Table 4-4. Applying a correction to correct the bias will provide a result of similar accuracy and precision to VRS DGPS. From the research Table 5-1 gives a value that would improve accuracy if applied to results.

OmniSTAR Suggested Correction	
Easting	**Northing**
-0.359	-0.656

Table 5-1 OmniSTAR Suggested Correction

The implications of the use of ITRF2000 as a datum are that it is a dynamic datum. Unlike the GDA 94 datum, which is fixed at point in time, ITRF2000 is revised at certain time increments. OmniSTAR stated that it revises ITRF2000 datum coordinates at an increment of six months. This does not affect the results of low accuracy positioning requirements. It does however affect the precise positioning requirements of the user if they require to replicate or return to previously measured sites accurately. OmniSTAR states that they update their coordinates on the 1st of January and 1st of July. If measurements were made during this time it would be important to take this shift in datum and therefore coordinates into account. This also makes OmniSTAR not as useful in for position requirements that require repeatable results over time.

Because the datum shifts to maintain a link to ITRF2000 coordinates, the suggested correction provided by this section will change as of 1st January 2007

5.3.2 AMSA Beacon Datum

AMSA Beacon is based on the WGS84 datum (AMSA, 2006). This means that all results obtained from AMSA Beacon DGPS correction sources is also based on the WGS84 datum. From the results of test it appears that AMSA Beacon DGPS is not a true representation of the WGS84 datum. WGS84 is regularly updated to minimise the difference between it and ITRF2000. This was last done in 2002. If this was the case the accuracy of AMSA Beacon should be similar to the accuracy of OmniSTAR DGPS. The difference should be within the order of 150mm. From testing it was determined to be 520mm different in accuracy. The reason for this greater discrepancy in accuracy compared to OmniSTAR coordinates, which should be within a few centimetres, is unknown.

AMSA Beacon is provided primarily to meet the needs of mariners as an aid in safe navigation. The AMSA Beacon service already meets this requirement with an accuracy of a few meters. AMSA rates the alignment of its DGPS correction service with ITRF as a low priority. With this knowledge, users of AMSA Beacon DGPS corrections need to be aware of possible changes in datum epochs for WGS84 datum by AMSA. AMSA has no explicit policy of revising in WGS84 datum at set dates, such as OmniSTAR. With this knowledge, if high accuracy DGPS was needed monitoring of the AMSA Beacon service would be needed to detect any changes in datum values.

AMSA Beacon, because it is the only free real time DGPS correction service, is still effective. Results in the variances of easting and northing are similar to VRS DGPS correction source by applying a simple offset correction, AMSA Beacon's accuracy can be vastly increased. From this research Table 5-2 suggests a correction for easting and northing when it is used in this test area.

AMSA Beacon Suggested Correction	
Easting	**Northing**
-1.207	-0.384

Table 5-2: AMSA Beacon Suggested Correction

This correction should improve the coordinates obtained from AMSA Beacon results so they closely match the GDA94 value.

5.4 Differences Between Real Time DGPS Correction Sources

The only difference between real time DGPS correction sources is the accuracy. The precision or variance of results obtained from these different DGPS correction sources within the test area is very small. This was confirmed by the different DGPS Correction sources passing the F test for variance being similar at a 95% confidence level for Easting and Northing.

By applying the correction for AMSA Beacon and OmniSTAR as shown in Table 5-1 and Table 5-2 a user can obtain similar results. The best system clearly is the VRS DGPS correction source for the reason the accuracy is very good compared to AMSA Beacon and OmniSTAR DGPS corrections. However, with the application of the correction for easting and northing, both AMSA Beacon and OmniSTAR will have similar accuracy. With knowledge of a correction to apply to results all real time DGPS correction sources are similar in accuracy and precision.

5.5 Differences Between Post Processed DGPS Correction Sources

There was no significant difference in the accuracy and precision of the different sources of post processed DGPS correction sources. The only source that differed significantly was the comparison between the post processing between the closest VRS base and post processing from the user installed base. This is shown as a failure in the static statistical tests in Table 4-3. The only other possible source of post processed data which does not pass for both statistical tests is the virtual reference station which could indicate a problem with reference stations within the Virtual Reference Station system at the time of testing. Comparing Table 4-1 and Table 4-2 shows the accuracy of the different post processed DGPS systems is very similar.

5.6 Cost versus Accuracy and Precision of Real Time DGPS Correction Sources

The cost of acquiring the different real time corrections appears to have an effect on the accuracy of the results obtained. With VRS DGPS and OmniSTAR being far more accurate than AMSA Beacon, which is the free to air service. However, as discussed in section 5.4 with the application of a correction to the results all three tested real time correction sources within the test area have similar accuracy and precision. With this knowledge it is difficult to suggest the costs as outlined in Table 3-1 of accessing the different DGPS real time correction sources reflects obtainable precision and accuracy for the test area.

	Range	**Correction Type**	**Communication Medium**	**Cost**
VRS DGPS	SE Qld Only	For exact position	GSM Mobile Phone	Subscription fee? $3000 + Call costs? $120/day
OmniStar	Australia	For region	Geostationary Satellite	$2,500 per year
AMSA Beacon	150 – 200 km radius	None, optimised for reference location	Radio Antenna	Free

Table 5-3: Costs for Accessing DGPS Real Time Correction Sources

With the knowledge of section 5.3, that by applying a bias correction to overcome the accuracy degradation, the price of the DGPS correction source does not refect a superior accuracy and precision over the less expensive DGPS correction sources. From this the price to access the DGPS correction sources does not refect a superior obtainable result. It does however reflect the use of the GDA 94, which is the datum that ICSM recommends all coordinates should be based on for the Australian mainland.

5.7 Cost versus Accuracy and Precision of Post Processed DGPS Correction Sources

All post processed DGPS correction sources offered similar accuracy and precision. Each different DGPS correction source offered different costs, either through the requirement of purchase of extra GPS receivers, cost of purchasing reference data from commercial suppliers, or time and cost of accessing free correction data. For small amounts of data correction requirements the use of a commercial correction supplier is certainly an effective correction source. For a large amount of corrections the use of a user installed reference station would become and economically viable correction means. Access to a community or free correction source would be the most economically viable situation. Some of the issues with this correction source may be no guarantee of service, no guarantee of accuracy and precision. This may be acceptable for small projects; larger projects may no be suited to this correction source. A table of costs is provided in Table 5-4.

Post Processed DGPS Correction Source	**Base Station Location**	**Cost**
Single Reference Station	User Installed (Harvey St, Main Roads, Brisbane)	Second set of equipment
	Community (USQ)	Free
	Commercial (Closest VRS System Base)	$60 / hr
Modelled Correction	Commercial (Virtual (VRS network))	$60 / hr

Table 5-4 Post Processed DGPS Correction Sources Costs

With this information it is seen that no one post processed DGPS correction source provides a superior service with accuracy and precision. Cost of accessing data or generating data for the selected DGPS correction sources does not influence the quality of accuracy and precision to a significant level.

5.8 Differences in Accuracy for Post Processed Data and Real Time Data

The only explanation for the improved accuracy of all post processed DGPS correction sources in the reference station coordinates are better, and are certainly all on GDA94 datum. As discussed in sections 5.3.1 and 5.3.2, the datum of the correction source it influences the accuracy of results obtained. All post processed DGPS correction sources data supplied to the user are on GDA94 datum. The user installed base and the VRS system reference stations are without doubt on GDA94 datum as it is the governing agency for coordinate datum(s) in Queensland. The USQ base is on GDA.94 coordinates as it was tested for this by comparing control data provided by USQ to coordinates processed through AUSpos, which is part of Geoscience Australia, from which reduced coordinates are output in GDA94. This is the reason for the similar accuracy from all post processed DGPS correction sources.

5.9 The Optimum Post Processed DGPS Correction Source

This is entirely dependant on the user's current equipment or location. If the user has access to a free community base station, as the USQ base has been classed as, and a method for efficiently obtaining this data, this source would be considered the most economical. If the user has a spare GPS receiver, capable of acting as a reference station, this method is both economical and portable. This portability increases the potential coverage area to being virtually limitless. This method could be very expensive to setup if the user did not have a spare GPS receiver and had to purchase one to act as a reference station. Commercial reference stations, such as that provided by NRMW & E are very economical if the user only corrects small amounts of data per year, or is an infrequent user.

Virtual Reference station does not increase the accuracy or precision that is obtained from post processing from a single base. It sometimes is slightly less precise and accurate. This type of correction source is probably not designed for the accuracies and precisions of a lower quality DGPS obtains.

No one post processed DGPS correction source is superior to another. They achieve similar accuracy and precision regardless of cost of accessing or distance from correction source within the south eastern Queensland test area.

5.10 Conclusion

This chapter outlined the relative precisions and accuracies of the different sources of DGPS corrections sources and provided commentary on accuracy and precision. It provided insight into the possible causes of the degradation of accuracy in AMSA Beacon and OmniSTAR results, mainly the use of different datum like WGS84 and ITRF2000.

It showed that in this test area, a high price for correction source did not always reflect an improved level of accuracy and precision.

Chapter Six will provide a conclusion to the project and a comment on further research required to quantify some of the lessor points of the research.

CHAPTER 6: Conclusion

6.0 Introduction

Chapter Five discussed the results obtained in the test regime. This chapter provides a summary of the outcomes of the research and a guide for further research. This research was undertaken to assess the accuracy, precision and access prices for a selection of DGPS correction sources in south eastern Queensland. It assessed the accuracy and precision of three real time DGPS correction sources and five post processed DGPS correction sources available to users in south eastern Queensland.

6.1 Conclusions

This research established a method for comparing the selected DGPS correction sources, both in static and dynamic environments. Static measurements were compared against marks of known value and dynamic results were compared to a control line as determined by a second dual frequency RTK GPS receiver. From these control values, the relative accuracy and precision of the different DGPS correction sources was assessed.

While the source of correction did not significantly impact the precision, the accuracy of different real time DGPS correction sources differed greatly. It was found that differences in accuracy arose because of different datum used by the correction providers. All post processed DGPS correction sources and VRS real time DGPS were based on GDA94 datum, as was the control coordinates. However, the OmniSTAR DGPS correction source is based on ITRF2000 datum and AMSA Beacon on WGS84 datum. It was found that applying a basis correction to these two DGPS correction sources can provide the user with a result as accurate and precise as the VRS DGPS correction source. Application of these corrections over the test area did not improve precision regardless of the cost of accessing the correction source. Never the less, the higher cost for VRS DGPS was reflected in improved accuracy of the results, as it provided a correction on the correct datum. The cost of correction did not alter the quality of accuracy and precision for post processed DGPS correction sources.

There was no significant difference in the results obtained from static observations and dynamic observations. However, a slight degradation of precision and accuracy of 100mm was recorded between these observations for each correction source. No conclusions could be drawn on the significance of this result as the method for providing control to the results would have introduced an error of this magnitude. This result is acceptable for most applications for DGPS positioning applications.

The distance from the correction source within the south eastern Queensland test area did not significantly impact on the accuracy or precision obtained from the different DGPS correction sources. The largest distance examined was 150 kilometres from the correction source. It must be remembered that errors will rise exponentially with the distance from the correction source.

6.2 Recommendations

This research found with proper treatment all tested DGPS correction sources provide a similar accuracy and precision for users. The cost of receiving correction from a DGPS correction source was not an indication of superior accuracy and precision. The difference between static and dynamic application precision and accuracy was not significant for the main uses of DGPS. From this research a potential user of DGPS correction sources will be able to determine the most suitable correction source for their application in south eastern Queensland.

6.3 Possible Further Research

A range of further experiments may be conducted to extend this research. This may include: an investigation into the effect of the use of different datum by DGPS correction providers, similar studies within other regions, examination of greater distances from the correction sources and a study of different AMSA Beacons.

The DGPS correction providers use a range of datum which can have a major impact on the results. The reasons behind their selection of datum could be investigated. For example, the post processed DGPS correction providers and VRS real time DGPS are all based on GDA 94 datum. On the other hand, OmniSTAR is based on ITRF 2000 datum and AMSA Beacon on WGS 84 datum. While GDA 94 is static, WGS 84 and ITRF 2000 are both updated regularly. This aspect means that the user needs to be aware when the datum is updated. The method of informing the user of these changes in datum needs to be investigated.

The methods outlined in this study could also be extended beyond south eastern Queensland. While the results of this research are only applicable to users within the studied region, an investigation of more regions would provide potential users with a greater comparison of accuracy, precision and cost.

The distance from the correction source may also have a large impact on the accuracy and precision of the readings. While this study examined sites up to 150 km from the correction source, errors caused by distance from correction source may rise exponentially and this may be studied further.

Different AMSA Beacon correction sources also need to be investigated to check the quality of the AMSA Beacon network. AMSA Beacon sites operate as standalone correction sources that are not linked to provide a networked solution. This would determine if the characteristics of AMSA Beacon correction sources is common across all of their reference sites.

6.4 Summary

This chapter outlined the conclusions of the research. It reflected on the relative accuracy, precision and costs of a selection DGPS correction sources in south eastern Queensland. It examined both real time and post processed DGPS correction sources in dynamic and static situations.

This research will enable users of DGPS correction sources in south eastern Queensland to make a more informed selection of correction provider when correcting their data. It showed that there was little difference in precision between the correction sources. However, the use of different datum by OmniSTAR and AMSA Beacon DGPS correction sources significantly affected the accuracy obtained from these correction sources, which can be corrected through an application of a bias correction. While the results of this research are most applicable to users within the south eastern Queensland test area, the main outcome of this research is that with adjustment, all DGPS correction sources are similar in accuracy and precision. No single DGPS correction source is superior. The user can therefore decide the optimum correction source based on other factors than precision and accuracy.

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Appendix A. Project Specification

University of Southern Queensland
Faculty of Engineering and Surveying

ENG4111/2 Research Project
PROJECT SPECIFICATION

FOR: David Gordon ROLPH
TOPIC: VRS versus AMSA DGPS
SUPERVISOR: Glenn Campbell
TECHNICAL ADVISOR:

SPONSORSHIP: Faculty of Engineering and Surveying, USQ

PROJECT AIM: To compare the accuracy, precision and efficiency of different differential global positioning system's (DGPS) correction sources in both static and dynamic environments.

PROGRAMME: **Issue A, 27 March 2006**

1. Research information on the characteristics of various DGPS sources & techniques to determine possible users and their required accuracy, precision and efficiency with respect to best practice.

2. Determine the accuracies and precision that can be achieved in static situations with respect to existing coordinated survey marks.

3. Determine accuracies and precision that can be achieved in a dynamic environment with respect to RTK standard.

4. Recommend different DGPS techniques or sources to current or potential DGPS users with respect to their accuracy and precision requirements and cost limitations.

As time Permits

5. Test more diverse locations further away from initial readings to determine if there are possible losses in accuracy, precision and efficiency based on distance from base stations, and the effect latency of DGPS corrections have on accuracy & precision.

6. Develop a of measure efficiency with respect to both time and costs.

AGREED: ______________________________(student) ______________________(Supervisors)

(dated)____/_____/_________

Appendix B. Control Marks

QUEENSLAND - DEPARTMENT OF NATURAL RESOURCES

PERMANENT MARK SKETCH PLAN

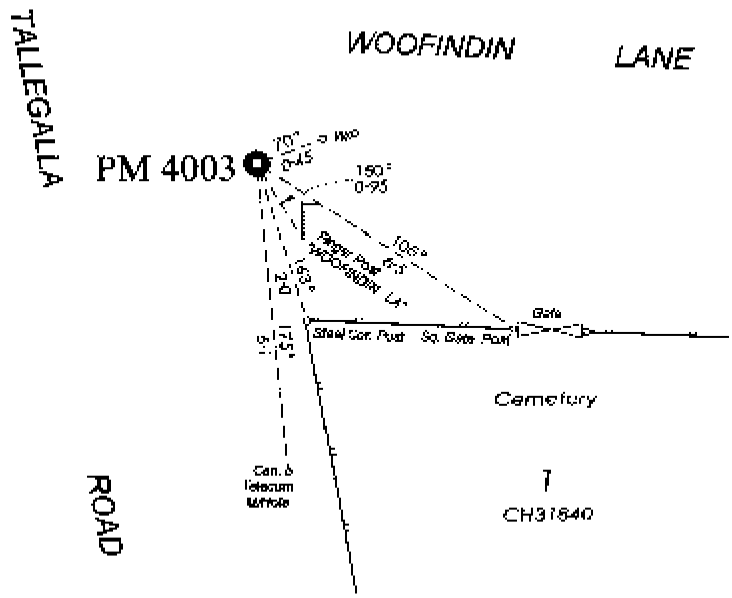
REGD NO. 4003

QUEENSLAND GOVERNMENT

NATURAL RESOURCES

Bearings are **Magnetic** (Magnetic, AMG) Distances are metres

Sketch plan to be completed in accordance with the Department's QA document: "Completion of Permanent Mark Sketch Plans"



REDRAW

Sealed to GPS
Yes/No Yes (3)
Date 15/8/98

SCDB DETAILS ON REVERSE ARE TO BE COMPLETED

I certify that the permanent mark sketch has been prepared in accordance with the "The Survey Co-ordination Act of 1952-1989".

Date 27/7/98 Signature

15/04/96

pm_4003

```
Permanent Mark Number : 4003
SCDB current at : 07/09/2006

----------------------------------------

ADMINISTRATION DETAILS

Alternative Name :
Type : STAND
Job Number : 04/1570
Mark Condition : GOOD
Locality Description : TALLEGALLA RD & WOOFINDIN LA
Installed By : HARGREAVES
Date Installed : 23/5/1962     Last Visited : 5/11/2003
Parish : WALLOON     Town :
Local Authority : ESK     Map Reference : 9442 44422
Form 6 : Y     Cadastral Connection : Y

----------------------------------------

VERTICAL DETAILS

Height : 98.085     Datum : AHD     Fixed By : SPIRIT LEVELLING
NLN Section : 208-219
Order : 3rd ORDER     Class : Class C
Registered Number :
Geo/Sph N : 0     Datum :
Model :
Source :

----------------------------------------

HORIZONTAL DETAILS - GDA94

Access :
Latitude : 27 33 31.1448     Longitude : 152 32 47.8442     Datum : GDA94
Easting : 455242.299     Northing : 6951604.590     Zone : 56
Horizontal Adjustment : GDA - TOOWOOMBA TO IPSWICH CONTROL
Order : 1st ORDER     Class : CLASS A
Adjustment Date : 7/12/1999
Fixed By : GPS
Climb On Time : 0:0
Checked By : NRM

----------------------------------------

CADASTRAL CONNECTIONS DETAILS

Cadastral Connection 1 : SP164611
Cadastral Connection 2 : SP154109
Cadastral Connection 3 : CC2978
Cadastral Connection 4 : CC2140
Cadastral Connection 5 : RP194277

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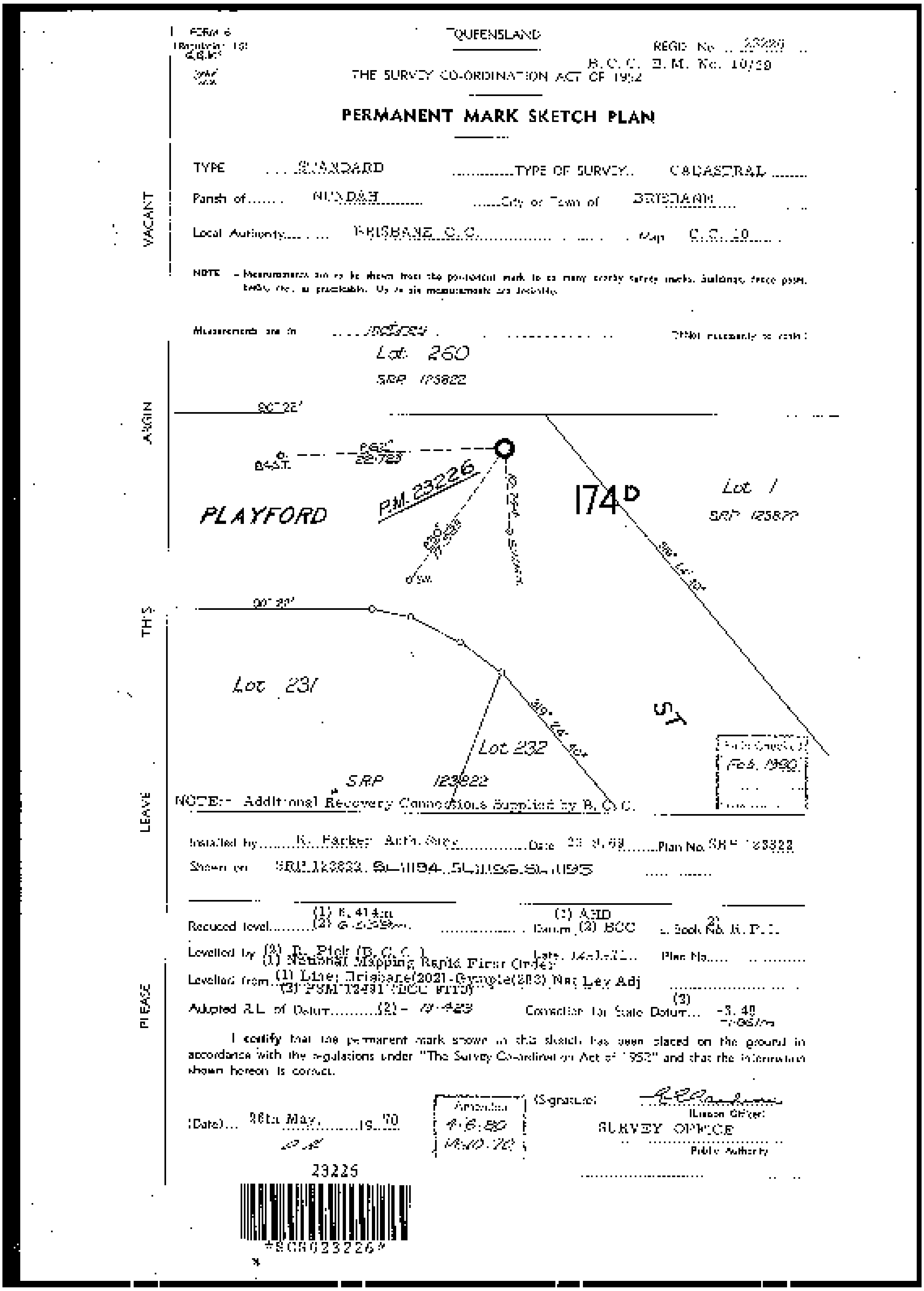
Page 1



FORM 6

QUEENSLAND

REGD. No. 23226

B. C. C. B. M. No. 10/59

THE SURVEY CO-ORDINATION ACT OF 1952

PERMANENT MARK SKETCH PLAN

TYPE ... STANDARD ... TYPE OF SURVEY ... CADASTRAL

Parish of ... NUNDAH ... City or Town of ... BRISBANE

Local Authority ... BRISBANE C. C. ... Map ... C. C. 10

NOTE – Measurements are to be shown from the permanent mark to as many nearby survey marks, buildings, fence posts, kerbs, etc. as practicable. Up to six measurements are desirable.

Measurements are in ... METRES ... (Not necessarily to scale)

NOTE:- Additional Recovery Connections Supplied by B. C. C.

Installed by ... K. Parker Auth. Surv. ... Date 23.9.69 ... Plan No. SRP 123822

Shown on ... SRP 123822, SL 1194, SL 1196, SL 1195

Reduced level ... (1) 8.414m (2) 6.255m ... Datum (1) AHD (2) BCC ... L. Book No. R. P. L.

Levelled by (1) National Mapping Rapid First Order (2) D. Pick (B. C. C.)

Levelled from (1) Line: Brisbane(2021)-Gympie(283) Nat Lev Adj (3) PSM 12491 (BCC FITD)

Adopted R.L. of Datum ... (2) – 19.429 ... Correction to State Datum ... (3) –3.40

I certify that the permanent mark shown on this sketch has been placed on the ground in accordance with the regulations under "The Survey Co-ordination Act of 1952" and that the information shown hereon is correct.

(Date) ... 26th May ... 19 70 ... Amended 4.6.80 14.10.78 ... (Signature) ... (Liaison Officer) ... SURVEY OFFICE ... Public Authority

23226

pm_23226

Permanent Mark Number : 23226
SCDB current at : 07/09/2006

ADMINISTRATION DETAILS

Alternative Name : BCC 10/29
Type : STAND
Job Number : 000000
Mark Condition : GOOD
Locality Description : PLAYFORD ST - BRACKEN RIDGE
Installed By : R PARKER
Date Installed : 22/9/1969   Last Visited : 15/5/2003
Parish : NUNDAH   Town : BRISBANE
Local Authority : BRISBANE   Map Reference : 9543 34314
Form 6 : Y   Cadastral Connection : Y

VERTICAL DETAILS

Height : 5.401   Datum : AHD   Fixed By : SPIRIT LEVELLING
NLN Section : 202-283
Order : 1st ORDER   Class : Class A
Registered Number :
Geo/Sph N : 0   Datum :
Model :
Source :

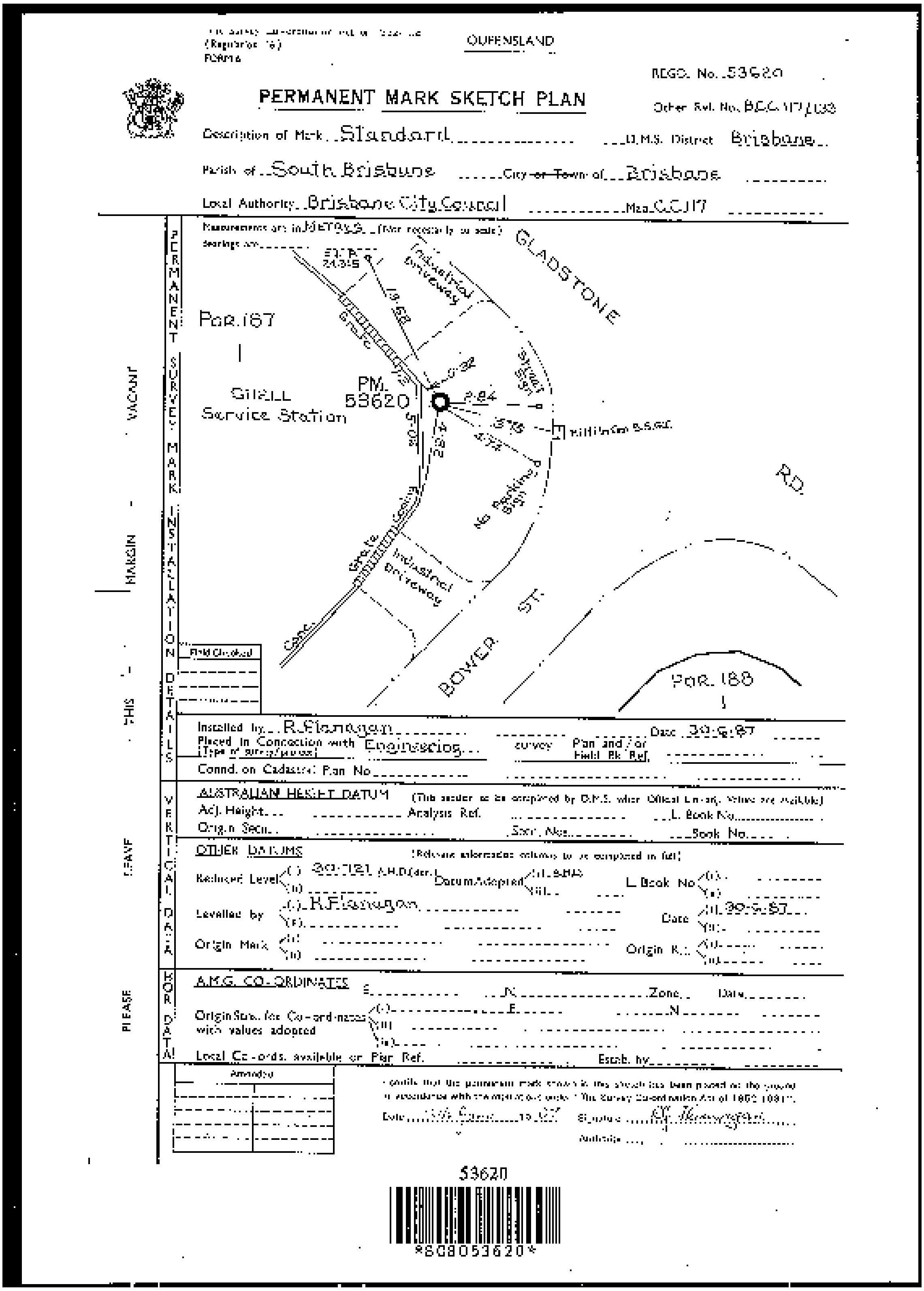
HORIZONTAL DETAILS - GDA94

Access :
Latitude : 27 18 49.2623   Longitude : 153 2 25.4488   Datum : GDA94
Easting : 503997.354   Northing : 6978819.950   Zone : 56
Horizontal Adjustment : SANDGATE ZILLMERE 1KM 1999
Order : 1st ORDER   Class : CLASS A
Adjustment Date : 15/3/2000
Fixed By : GPS
Climb On Time : 0:0
Checked By : NRM

CADASTRAL CONNECTIONS DETAILS

Cadastral Connection 1 : RP896523
Cadastral Connection 2 : IS121626
Cadastral Connection 3 : SL11195
Cadastral Connection 4 : SL11194
Cadastral Connection 5 : SL11196

Page 1


QUEENSLAND

REGD. No. 53620

PERMANENT MARK SKETCH PLAN

Other Ref. No. BCC 117/033

Description of Mark Standard D.M.S. District Brisbane

Parish of South Brisbane City or Town of Brisbane

Local Authority Brisbane City Council Map CCJ17

Measurements are in METRES (Not necessarily to scale)

PERMANENT SURVEY MARK INSTALLATION DETAILS

Installed by R. Flanagan Date 30-6-87

Placed in Connection with Engineering survey

Plan and/or Field Bk Ref.

Connd. on Cadastral Plan No

VERTICAL DATA

AUSTRALIAN HEIGHT DATUM

Adj. Height Analysis Ref.

Origin Sectn. L. Book No.

OTHER DATUMS

Reduced Level (i) 30.721 A.H.D.(derived) Datum Adopted

Levelled by (i) R. Flanagan Date (i) 30-6-87

Origin Mark Origin R.L.

HOR. DATA

A.M.G. CO-ORDINATES E N Zone Date

Origin Stns. for Co-ordinates with values adopted

Local Co-ords. available on Plan Ref. Estab. by

Amended

I certify that the permanent mark shown in this sketch has been placed on the ground in accordance with the requirements under The Survey Co-ordination Act of 1952-1981.

Date 5th June 1987 Signature

53620

80805 3620

pm_53620

Permanent Mark Number : 53620
SCDB current at : 07/09/2006

ADMINISTRATION DETAILS

Alternative Name : BCC 117/133
Type : STAND
Job Number : 872970
Mark Condition : GOOD
Locality Description : GLADSTONE RD - HIGHGATE HILL
Installed By : R FLANAGAN
Date Installed : 30/6/1987   Last Visited : 11/8/2006
Parish : SOUTH BRISBANE   Town : BRISBANE
Local Authority : BRISBANE   Map Reference : 9543 33332
Form 6 : Y   Cadastral Connection : Y

VERTICAL DETAILS

Height : 30.741   Datum : AHD D   Fixed By : GPS
NLN Section :
Order : 4th ORDER   Class : Class A
Registered Number : 71501
Geo/Sph N : 12   Datum : ANS
Model : AUSGEOID93   INTERPOLATED
Source :

HORIZONTAL DETAILS - GDA94

Access :
Latitude : 27 29 35.9886   Longitude : 153 1 17.9681   Datum : GDA94
Easting : 502139.327   Northing : 6958921.795   Zone : 56
Horizontal Adjustment : GDA - BRISBANE TO IPSWICH CONTROL
Order : 1st ORDER   Class : CLASS A
Adjustment Date : 8/12/1999
Fixed By : GPS
Climb On Time : 0:0
Checked By : NRM

CADASTRAL CONNECTIONS DETAILS

Cadastral Connection 1 : SP189625
Cadastral Connection 2 : IS197681
Cadastral Connection 3 : SP180427
Cadastral Connection 4 : SP133438
Cadastral Connection 5 : SP139876

Page 1

QUEENSLAND GOVERNMENT

QUEENSLAND - DEPARTMENT OF NATURAL RESOURCES

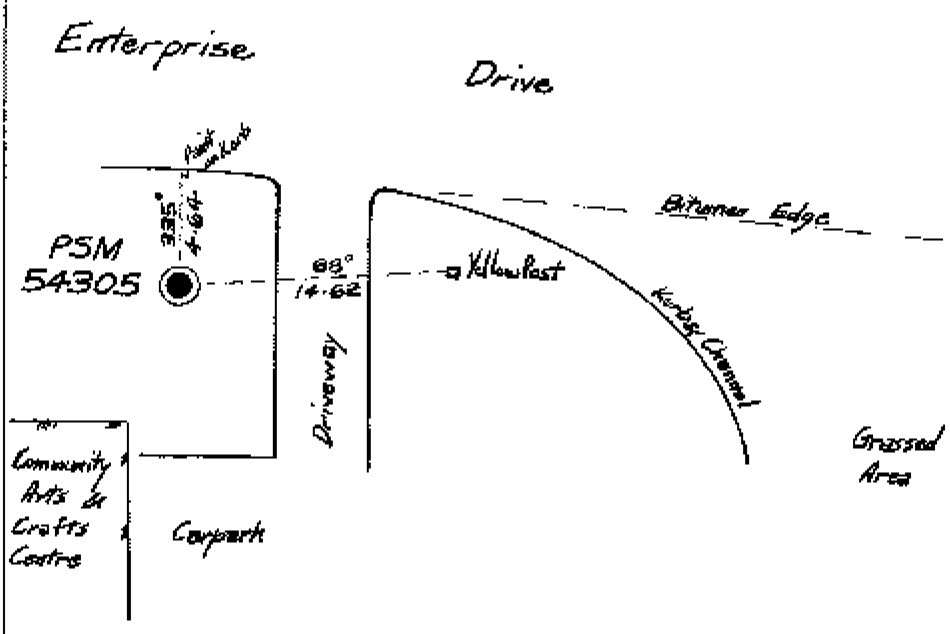
PERMANENT MARK SKETCH PLAN

REGD NO. 54305

NATURAL RESOURCES

Bearings are Magnetic (Magnetic, AMG) Distances are metres

Sketch plan to be completed in accordance with the Department's QA document: "Completion of Permanent Mark Sketch Plans"



Note: Mark in Datum Box.

Suited to GPS
Yes/No
Date

SCDB DETAILS ON REVERSE ARE TO BE COMPLETED

I certify that the permanent mark sketch has been prepared in accordance with the 'The Survey Co-ordination Act of 1953-1989'.

Date 22/5/97 Signature ....

pm_54305

Permanent Mark Number : 54305
SCDB current at : 07/09/2006

ADMINISTRATION DETAILS

Alternative Name : ENTERPRISE
Type : STAND
Job Number : 2005/04
Mark Condition : GOOD
Locality Description : MT LINDESAY HWY/ENTERPRISE RD
Installed By : R HUME
Date Installed : 1/11/1980   Last Visited : 8/2/2005
Parish : LOGAN   Town :
Local Authority : BEAUDESERT   Map Reference : 9442 22221
Form 6 : Y   Cadastral Connection : Y

VERTICAL DETAILS

Height : 66.272   Datum : AHD D   Fixed By : SPIRIT LEVELLING
NLN Section :
Order : 4th ORDER   Class : Class D
Registered Number : 34521
Geo/Sph N : 0   Datum :
Model :
Source :

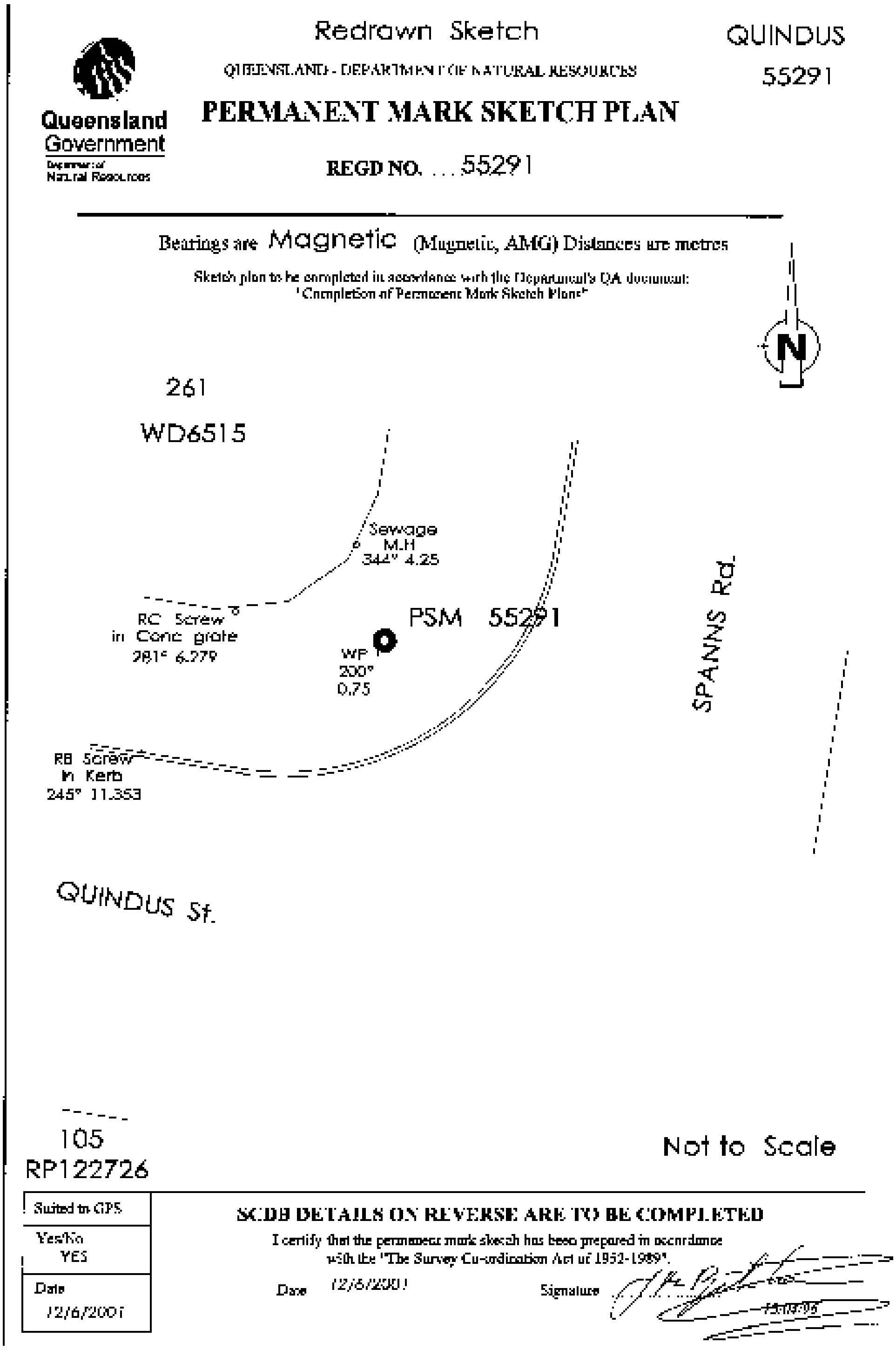
HORIZONTAL DETAILS - GDA94

Access :
Latitude : 27 58 6.0154   Longitude : 152 59 44.7120   Datum : GDA94
Easting : 499582.335   Northing : 6906305.018   Zone : 56
Horizontal Adjustment : GDA - QLD SUPPLEMENTARY AREA 1
Order : 1st ORDER   Class : CLASS A
Adjustment Date : 6/12/1999
Fixed By : GPS
Climb On Time : 0:0
Checked By : NRM

CADASTRAL CONNECTIONS DETAILS

Cadastral Connection 1 : SP179923
Cadastral Connection 2 : SP131520
Cadastral Connection 3 : SP123966
Cadastral Connection 4 : SP122648
Cadastral Connection 5 : SP103424

Page 1


Redrawn Sketch

QUINDUS
55291

Queensland Government
Department of Natural Resources

QUEENSLAND - DEPARTMENT OF NATURAL RESOURCES

PERMANENT MARK SKETCH PLAN

REGD NO. 55291

Bearings are Magnetic (Magnetic, AMG) Distances are metres

Sketch plan to be completed in accordance with the Department's QA document: 'Completion of Permanent Mark Sketch Plans'

Suited to GPS
Yes/No YES
Date 12/6/2001

SCDB DETAILS ON REVERSE ARE TO BE COMPLETED

I certify that the permanent mark sketch has been prepared in accordance with the "The Survey Co-ordination Act of 1952-1989".

Date 12/6/2001 Signature

pm_55291

Permanent Mark Number : 55291
SCDB current at : 07/09/2006

ADMINISTRATION DETAILS

Alternative Name : QUINDUS
Type : STAND
Job Number : 2006/BE
Mark Condition : GOOD
Locality Description : QUINDUS ST/SPANNS RD
Installed By : HEILBRONN
Date Installed : 1/1/1980   Last Visited : 26/10/2005
Parish : BOYD   Town : BEENLEIGH
Local Authority : GOLD COAST   Map Reference : 9542 423
Form 6 : Y   Cadastral Connection : Y

VERTICAL DETAILS

Height : 9.028   Datum : AHD   Fixed By : SPIRIT LEVELLING
NLN Section :
Order : 4th ORDER   Class : Class D
Registered Number :
Geo/Sph N : 0   Datum :
Model :
Source : LEAD106

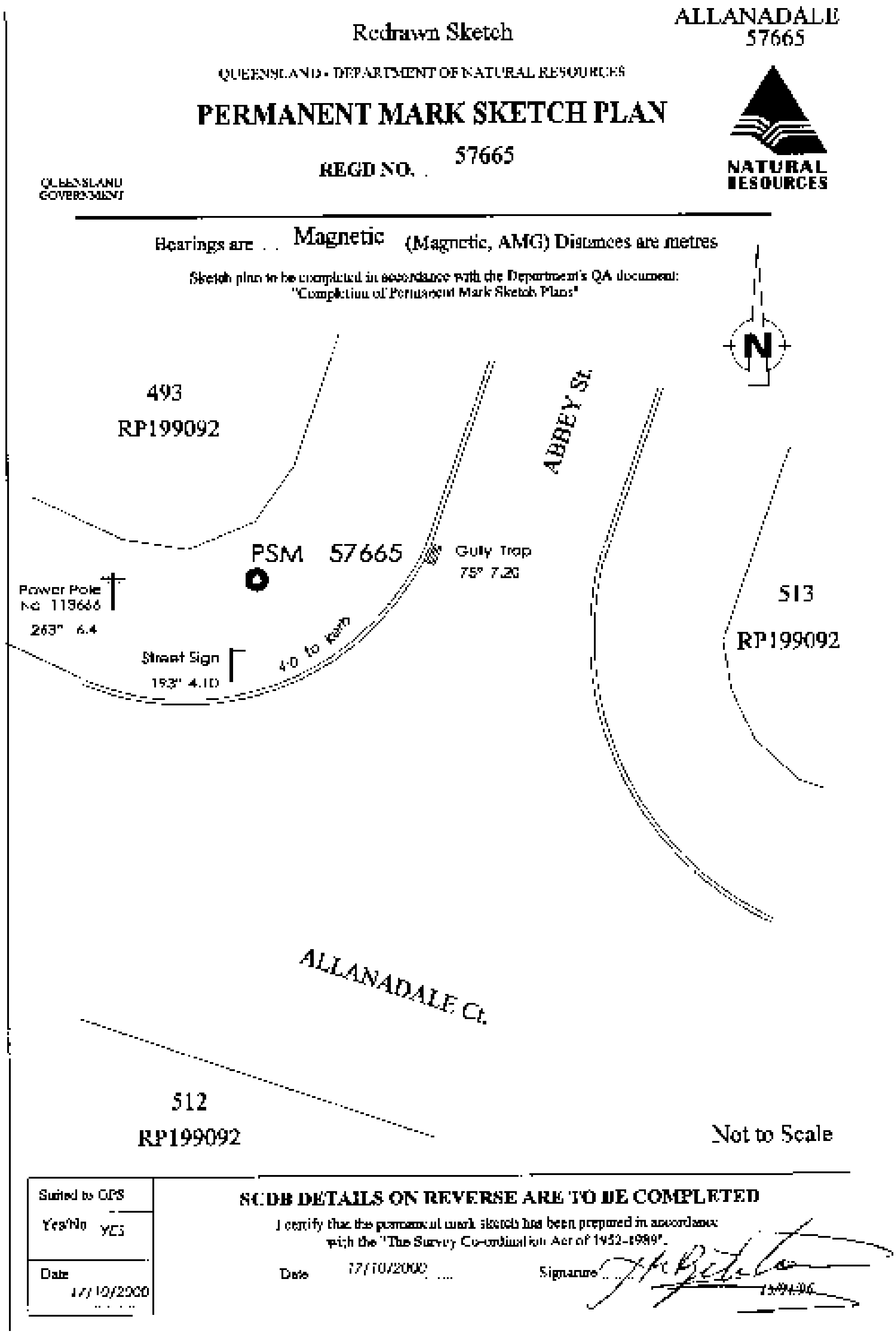
HORIZONTAL DETAILS - GDA94

Access :
Latitude : 27 42 40.3967   Longitude : 153 11 18.2625   Datum : GDA94
Easting : 518573.746   Northing : 6934772.253   Zone : 56
Horizontal Adjustment : WEST LOGAN NRM GPS_0601
Order : 1st ORDER   Class : CLASS A
Adjustment Date : 1/6/2001
Fixed By : GPS
Climb On Time : 0:0
Checked By : NRM

CADASTRAL CONNECTIONS DETAILS

Cadastral Connection 1 : SP185872
Cadastral Connection 2 : SP163688
Cadastral Connection 3 : SP163687
Cadastral Connection 4 : SP152182
Cadastral Connection 5 : SP145848

Page 1


ALLANADALE
57665
Redrawn Sketch
QUEENSLAND - DEPARTMENT OF NATURAL RESOURCES
PERMANENT MARK SKETCH PLAN
REGD NO. 57665
QUEENSLAND GOVERNMENT
NATURAL RESOURCES
Bearings are Magnetic (Magnetic, AMG) Distances are metres
Sketch plan to be completed in accordance with the Department's QA document: "Completion of Permanent Mark Sketch Plans"
N
493
RP199092
ABBEY St.
PSM 57665
Gully Trap
75° 7.20
Power Pole No 119666
263° 6.4
Street Sign
193° 4.10
4.0 to Kerb
513
RP199092
ALLANADALE Ct.
512
RP199092
Not to Scale
Suited to GPS
Yes/No YES
Date 17/10/2000
SCDB DETAILS ON REVERSE ARE TO BE COMPLETED
I certify that the permanent mark sketch has been prepared in accordance with the "The Survey Co-ordination Act of 1952-1989".
Date 17/10/2000
Signature

pm_57665

```
Permanent Mark Number : 57665
SCDB current at : 07/09/2006

----------------------------------------

ADMINISTRATION DETAILS

Alternative Name : ALLANADALE
Type : STAND
Job Number : 2001/1
Mark Condition : GOOD
Locality Description : ABBEY/ALLENDALE AVE
Installed By : K F & MCGHIE
Date Installed : 1/9/1985     Last Visited : 12/6/2001
Parish : MITCHELL     Town : LOGAN
Local Authority : LOGAN     Map Reference : 9542 43433
Form 6 : Y     Cadastral Connection : N

----------------------------------------

VERTICAL DETAILS

Height : 50.201     Datum : AHD D     Fixed By : SPIRIT LEVELLING
NLN Section :
Order : 4th ORDER     Class : Class D
Registered Number : 57653
Geo/Sph N : 0     Datum :
Model :
Source :

----------------------------------------

HORIZONTAL DETAILS - GDA94

Access :
Latitude : 27 40 37.6740     Longitude : 153 0 46.7511     Datum : GDA94
Easting : 501280.643     Northing : 6938562.503     Zone : 56
Horizontal Adjustment : WEST LOGAN NRM GPS_0601
Order : 1st ORDER     Class : CLASS A
Adjustment Date : 1/6/2001
Fixed By : GPS
Climb On Time : 0:0
Checked By : NRM

----------------------------------------

CADASTRAL CONNECTIONS DETAILS

Cadastral Connection 1 :
Cadastral Connection 2 :
Cadastral Connection 3 :
Cadastral Connection 4 :
Cadastral Connection 5 :

----------------------------------------
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Page 1

FORM 5
(Regulation 16)

QUEENSLAND

REGD. No. 59916
Public Auth. or Other Ref.

PERMANENT MARK SKETCH PLAN

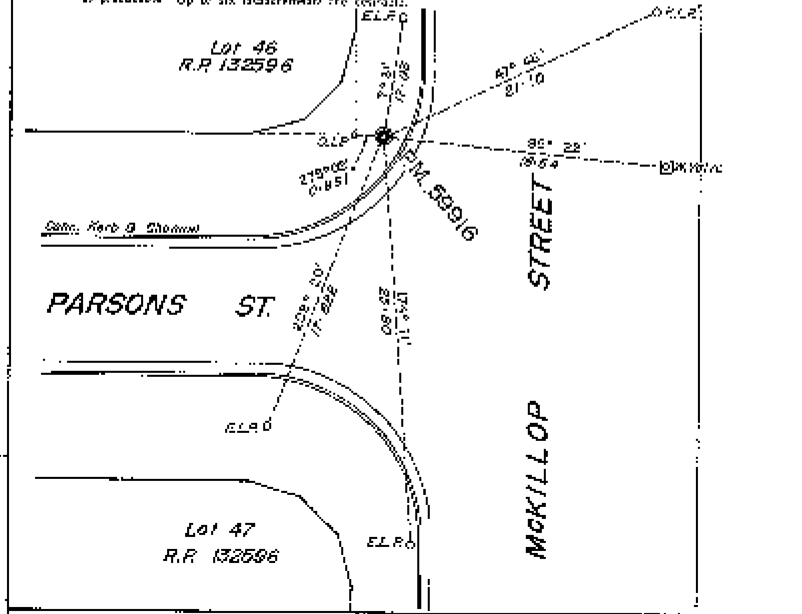
Description of Mark STANDARD

Parish of REDCLIFFE City or Town of REDCLIFFE

Local Authority REDCLIFFE CITY COUNCIL Map 9543-43324 (1:2500)

NOTE - Measurements are to be shown from the permanent mark to as many nearby survey marks, buildings, fence posts, kerbs, etc., as practicable. Up to six measurements are desirable.

Measurements are in Metres (Not necessary to scale)



Installed by Redcliffe City Council Date 7-9-1981
On plan nos. S.R.P. 176252

CO-ORDINATES (other than A.M.G.) System Accuracy Class'n
E. N. Units Date
Source of Co-ordinates
(Quote specific plan or document reference)

A.M.G. CO-ORDINATES (Metres) Accuracy Class'n
E. N. Zone Date
Source of Co-ordinates
(Quote specific plan or document reference)

Reduced Level 6.848 Datum adopted AHD L. Book No.
Levelled by Date
Origin bench Redcliffe Update K5/267 Amd. Ref. 1578 R.L.
(Give full description)
Correction to District Level Datum = metres. Accuracy Class'n
(to be completed in Survey Office)

I certify that the permanent mark shown in this sketch has been placed on the ground in accordance with the regulations under "The Survey Co-ordination Act of 1952" and that the information shown hereon is correct.

Amended 11-4-84

(Signature) (Liaison Officer)

(Date) 22 Sept 1981

Redcliffe City Council
(Public Authority)

* Against "Accuracy Class'n" delete

59916

SC8059916

pm_59916

Permanent Mark Number : 59916
SCDB current at : 07/09/2006

ADMINISTRATION DETAILS

Alternative Name : PARSONS
Type : STAND
Job Number : 000000
Mark Condition : GOOD
Locality Description : PARSONS/MCKILLOP STS/ROTHWELL
Installed By : REDCLIFFE
Date Installed : 1/4/1981 Last Visited : 11/10/2005
Parish : REDCLIFFE Town :
Local Authority : REDCLIFFE Map Reference : 9543 43324
Form 6 : Y Cadastral Connection : Y

VERTICAL DETAILS

Height : 6.84 Datum : AHD Fixed By : SPIRIT LEVELLING
NLN Section : 202-283
Order : 1st ORDER Class : Class A
Registered Number :
Geo/Sph N : 0 Datum :
Model :
Source :

HORIZONTAL DETAILS - GDA94

Access :
Latitude : 27 13 8.2578 Longitude : 153 2 50.2678 Datum : GDA94
Easting : 504683.420 Northing : 6989311.605 Zone : 56
Horizontal Adjustment : GDA - QLD SUPPLEMENTARY AREA 2 AND 3
Order : 1st ORDER Class : CLASS A
Adjustment Date : 7/12/1999
Fixed By : GPS
Climb On Time : 0:0
Checked By : NRM

CADASTRAL CONNECTIONS DETAILS

Cadastral Connection 1 : SP179379
Cadastral Connection 2 : SP179306
Cadastral Connection 3 : IS181642
Cadastral Connection 4 : IS181592
Cadastral Connection 5 : SP146753

Page 1

Regulation 161
FORM 6

QUEENSLAND

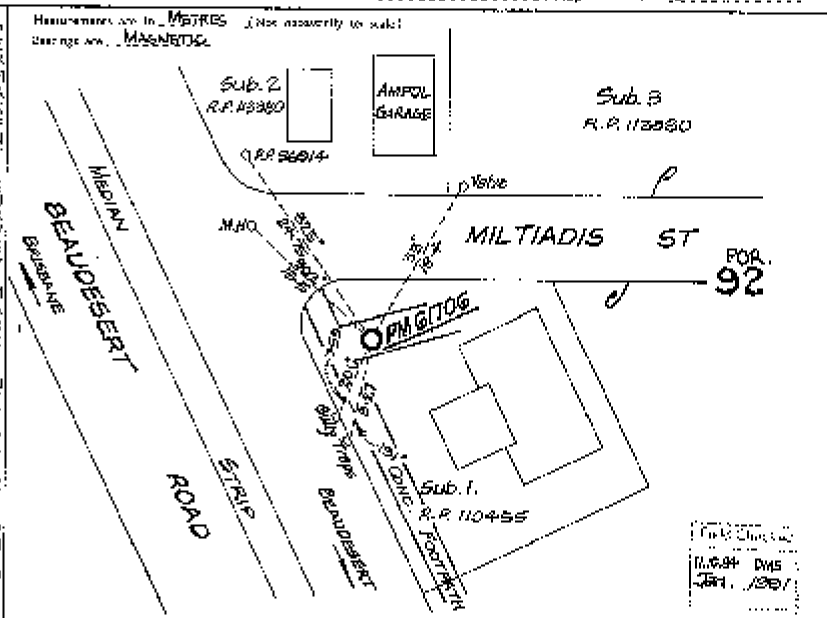
REGD. No. 61706
Other Ref. BCC 187/123

PERMANENT MARK SKETCH PLAN

Description of Mark: Deep Driven Mark (Sx) C.M.S. District: Brisbane
Parish of: Yeeronggpilly City or Town of: Brisbane
Local Authority: Brisbane C.C. Map: C.C. 187

PERMANENT SURVEY MARK INSTALLATION DETAILS

Measurements are in Metres (Not necessarily to scale)
Bearings are Magnetic



Installed by: D.M.S. Date: August 1979
Placed in Connection with (type of survey/project): 3rd Order Levelling. Plan and/or Field Bk. Ref.: Form 78A
Connd. or Cadastral Plan No.

VERTICAL DATA

AUSTRALIAN HEIGHT DATUM (This section to be completed by D.M.S. when Official Co-adj. Values are available)
Adj. Height: 23.193 Analysis Ref.: 14852 L. Book No.
Origin Sen.: Rocklea–Acacia Ridge Sen. Nos.: 625/635 Book No.

OTHER DATUMS (Relevant columns to be completed in full)
Reduced Level (i) A.H.D. (ii) Datum Adopted (i) A.H.D. (ii) Book No. (i) (ii)
Levelled by (i) (ii) Date (i) (ii)
Origin Mark (i) (ii) Origin R.L. (i) (ii)

HOR. DATA

A.M.G. CO-ORDINATES E. N. Zone Date
Origin Sens. for Co-ordinates with values adopted (i) E. N. (ii) (iii)
Local Co-ords. available on Plan Ref. Estab. by

I certify that the permanent mark shewn in this sketch has been placed on the ground in accordance with the regulations under "The Survey Co-ordination Act of 1952."

(Date) 14 . 8 . 1979 (Signature)
Authority: Dept. Mapping & Surveying

61706
SC8061706

pm_61706

Permanent Mark Number : 61706
SCDB current at : 07/09/2006

ADMINISTRATION DETAILS

Alternative Name : BCC 187/129
Type : DDM
Job Number : 000000
Mark Condition : DAMAGED
Locality Description : MILTIADIS/BEAUDESERT-ACACIA RG
Installed By : DMS
Date Installed : 1/8/1979   Last Visited : 1/9/2004
Parish : YEERONGPILLY   Town : BRISBANE
Local Authority : BRISBANE   Map Reference : 9542 44342
Form 6 : Y   Cadastral Connection : Y

VERTICAL DETAILS

Height : 28.42   Datum : AHD   Fixed By : SPIRIT LEVELLING
NLN Section : 4247-4249
Order : 3rd ORDER   Class : Class C
Registered Number :
Geo/Sph N : 0   Datum :
Model :
Source :

HORIZONTAL DETAILS - GDA94

Access :
Latitude : 27 35 8.3040   Longitude : 153 1 36.5844   Datum : GDA94
Easting : 502647.916   Northing : 6948696.742   Zone : 56
Horizontal Adjustment : GDA - SUNNYBANK TO DREWVALE 1KM CONTROL
Order : 1st ORDER   Class : CLASS A
Adjustment Date : 7/12/1999
Fixed By : GPS
Climb On Time : 0:0
Checked By : NRM

CADASTRAL CONNECTIONS DETAILS

Cadastral Connection 1 : IS189349
Cadastral Connection 2 : SP134920
Cadastral Connection 3 : SP128686
Cadastral Connection 4 : SP110533
Cadastral Connection 5 : IS133665

Page 1

Land Survey Co-ordination Act of 1962-1981
(Regulation 16)
FORM 6

QUEENSLAND

REGD. No. 64595

PERMANENT MARK SKETCH PLAN

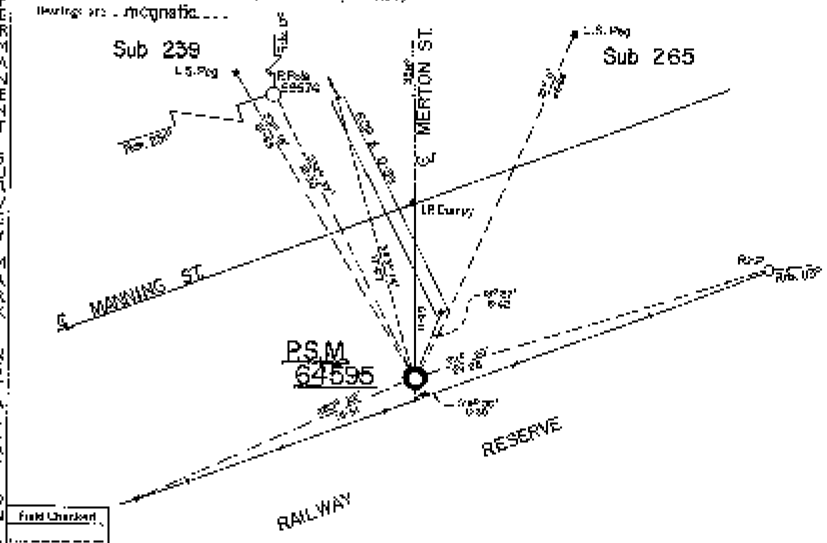
Other Ref. No. ______

Description of Mark ____STAR__PICKET__________ D.M.S. District BRISBANE

Parish of ____JIMBOOMBA______ City or Town of __JIMBOOMBA______

Local Authority _Beaudesert__Shire_Council______ Map 1:2500__9542-34313

Measurements are in Metres__ (Not necessarily to scale)
Bearings are _magnetic___



PERMANENT SURVEY MARK INSTALLATION DETAILS

Field Checked

Installed by ___J. Mobbry________ Date __20-11-85
Placed in Connection with (Type of survey/purpose) __Engineering______ survey Plan and / or Field Bk. Ref.
Council on Cadastral Plan No__________

VERTICAL DATA

AUSTRALIAN HEIGHT DATUM (This section to be completed by D.M.S. when Official Ltd adj Values are available)
Adj. Height_______ Analysis Ref ________ L. Book No......
Origin Secn.________ Secn. Nos. ________ Book No.

OTHER DATUMS (Relevant information column to be completed in full)
Reduced Level (i) 32·667 A.H.D. (der.) (ii) ____ Datum Adopted (i) A.H.D____ (ii) ______ L. Book No. (i) L 285 (ii) ____
Levelled by (i) J. Mobbry___ (ii) ____ Date (i) 22-11-85 (ii) ____
Origin Mark (i) P.S.M. 36751____ (ii) ____ Origin R.L. (i) 42·602 (ii) ______

HOR DATA

A.M.G. CO-ORDINATES E____ N ____________ Zone____ Date ______
Origin Stns. for Co-ordinates with values adopted (i) ____ E ____ N ____ (ii) ____ (iii) ____
Local Co-ords. available on Plan Ref._______ Estab. by ______

Amended

I certify that the permanent mark shown in this sketch has been placed in the ground in accordance with the regulations under "The Survey Co-ordination Act of 1962-1981".

Date....8/4/85.........19....

Signature [signature]

Authority Beaudesert S/C.......

THIS MARGIN VACANT

PLEASE LEAVE THIS MARGIN VACANT

64595

SCS064595

pm_64595

Permanent Mark Number : 64595
SCDB current at : 07/09/2006

ADMINISTRATION DETAILS

Alternative Name : MERTON ROAD
Type : S/PIC
Job Number : 2006/BE
Mark Condition : GOOD
Locality Description : MANNING ST
Installed By : J MAHONY
Date Installed : 1/11/1985   Last Visited : 21/2/2006
Parish : JIMBOOMBA   Town : JIMBOOMBA
Local Authority : BEAUDESERT   Map Reference : 9542 34313
Form 6 : Y   Cadastral Connection : Y

VERTICAL DETAILS

Height : 32.663   Datum : AHD D   Fixed By : SPIRIT LEVELLING
NLN Section :
Order : 4th ORDER   Class : Class D
Registered Number : 34751
Geo/Sph N : 0   Datum :
Model :
Source :

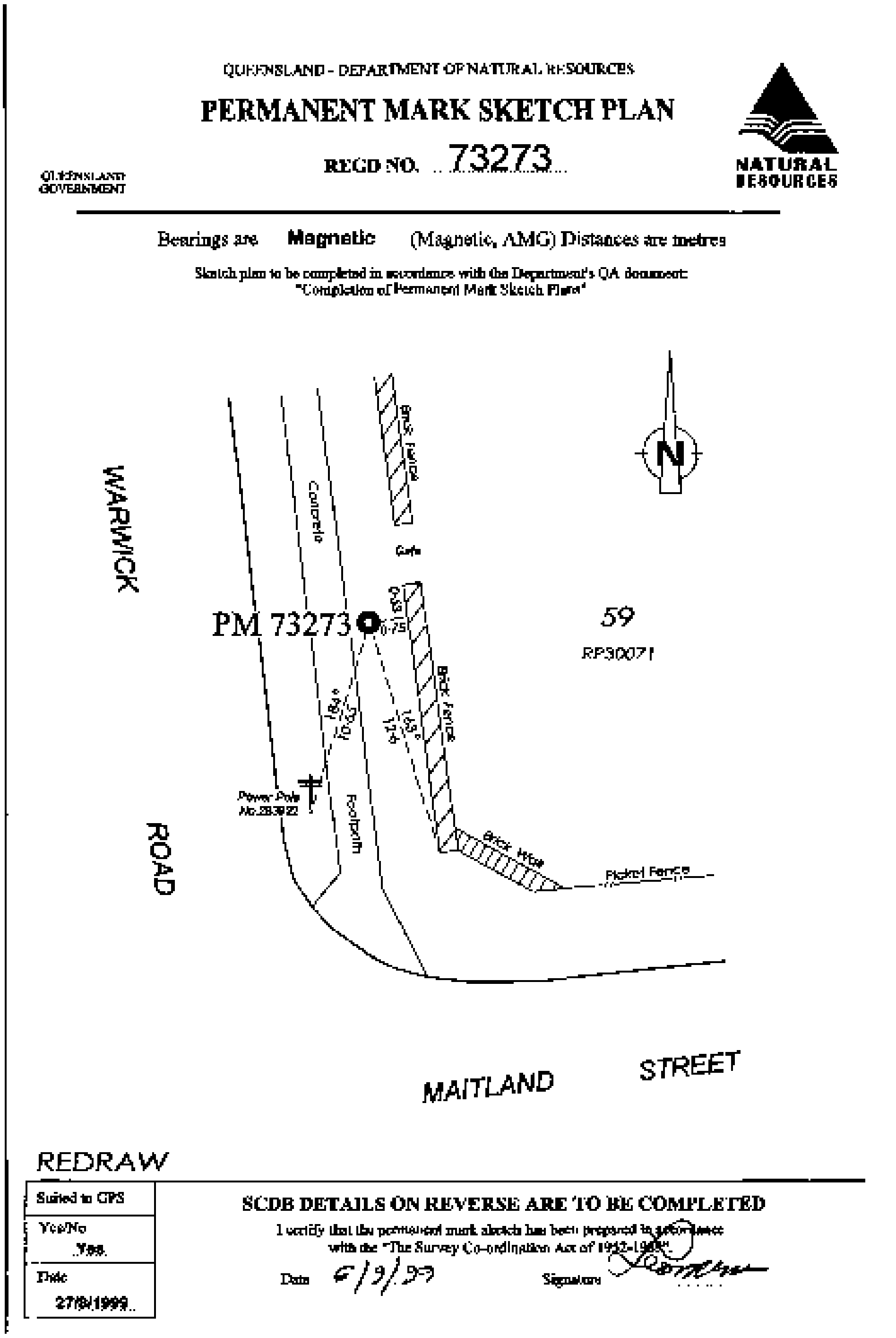
HORIZONTAL DETAILS - GDA94

Access :
Latitude : 27 49 46.5617   Longitude : 153 1 58.9821   Datum : GDA94
Easting : 503254.714   Northing : 6921672.987   Zone : 56
Horizontal Adjustment : GDA - QLD SUPPLEMENTARY AREA 1
Order : 1st ORDER   Class : CLASS A
Adjustment Date : 6/12/1999
Fixed By : GPS
Climb On Time : 0:0
Checked By : NRM

CADASTRAL CONNECTIONS DETAILS

Cadastral Connection 1 : SP190953
Cadastral Connection 2 : SP181422
Cadastral Connection 3 : SP185447
Cadastral Connection 4 : SP142996
Cadastral Connection 5 : SP173836

Page 1



QUEENSLAND - DEPARTMENT OF NATURAL RESOURCES
PERMANENT MARK SKETCH PLAN
REGD NO. 73273
QUEENSLAND GOVERNMENT
NATURAL RESOURCES
Bearings are Magnetic (Magnetic, AMG) Distances are metres
Sketch plan to be completed in accordance with the Department's QA document: "Compilation of Permanent Mark Sketch Plans"
WARWICK
ROAD
Concrete
Gate
PM 73273
59
RP30071
Brick Fence
Power Pole No.283922
Footpath
Brick Wall
Picket Fence
MAITLAND
STREET
REDRAW
Suited to GPS
Yes/No
Yes
Date
27/9/1999
SCDB DETAILS ON REVERSE ARE TO BE COMPLETED
I certify that the permanent mark sketch has been prepared in accordance with the "The Survey Co-ordination Act of 1952-1985"
Date 6/9/99
Signature

pm_73273

Permanent Mark Number : 73273
SCDB current at : 07/09/2006

ADMINISTRATION DETAILS

Alternative Name : CHURCHILL
Type : STAND
Job Number : 99/1646
Mark Condition : GOOD
Locality Description : WARWICK RD & MAITLAND ST
Installed By : DMS
Date Installed : 1/10/1981   Last Visited : 27/8/1999
Parish : PURGA   Town : IPSWICH
Local Authority : IPSWICH   Map Reference : 9442 421
Form 6 : Y   Cadastral Connection : Y

VERTICAL DETAILS

Height : 52.246   Datum : AHD D   Fixed By :
NLN Section :
Order : 4th ORDER   Class :
Registered Number : 30884
Geo/Sph N : 0   Datum :
Model :
Source :

HORIZONTAL DETAILS - GDA94

Access :
Latitude : 27 38 44.6657   Longitude : 152 45 3.2931   Datum : GDA94
Easting : 475429.640   Northing : 6942014.983   Zone : 56
Horizontal Adjustment : GDA - QLD SUPPLEMENTARY AREA 1
Order : 1st ORDER   Class : CLASS A
Adjustment Date : 6/12/1999
Fixed By : GPS
Climb On Time : 0:0
Checked By : NRM

CADASTRAL CONNECTIONS DETAILS

Cadastral Connection 1 : CPS9442-253
Cadastral Connection 2 : CPS9442-244
Cadastral Connection 3 : CPS9442-240
Cadastral Connection 4 : CPS9442-251
Cadastral Connection 5 : CPS9442-245

Page 1

The Survey Co-ordination Act of 1952
(Regulation 16)
FORM 6

QUEENSLAND

REGD. No. 94371

Other Ref.

PERMANENT MARK SKETCH PLAN

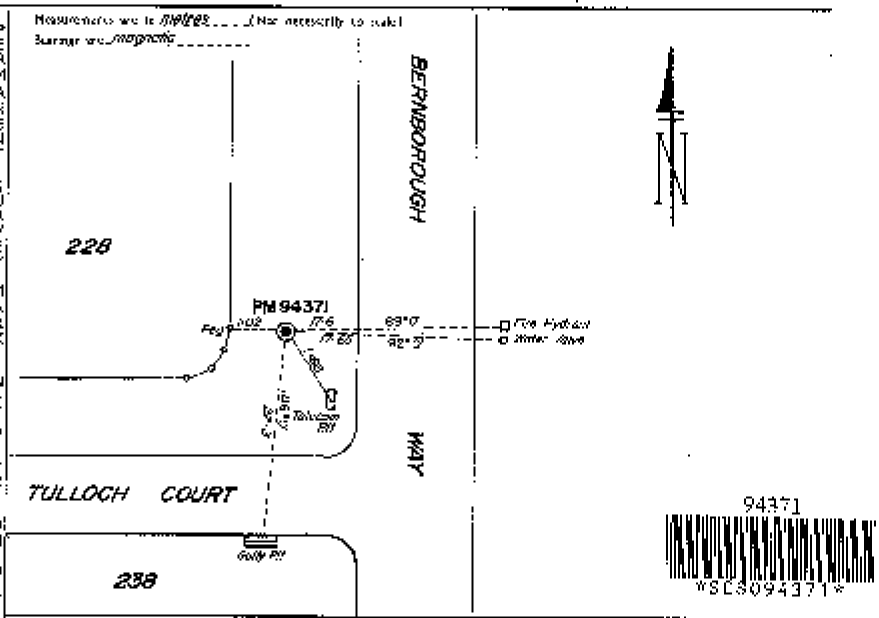
Description of Mark STANDARD BRASS PLAQUE D.M.S. District Brisbane

Parish of Toorbul City or Town of

Local Authority Caboolture Shire Council Map 9543-08

Measurements are in metres (Not necessarily to scale)

Bearings are magnetic



PERMANENT SURVEY MARK INSTALLATION DETAILS

Installed by KEILAR FOX & McGHIE PTY LTD Date 2-2-86

Placed in Connection with (Type of survey/project) CADASTRAL SURVEY Plan and / or Field Bk. Ref. LG 455

Connd. on Cadastral Plan No. RP 213032

VERTICAL DATA

[redacted]

OTHER DATUMS (Relevant information columns to be completed in full)

Reduced Level (i) 3.952 (ii) Datum Adopted (i) A.H.D (iii) Book No. (i) 458 (ii)

Levelled by (i) Keilar Fox & McGhie Pty Ltd (ii) Date (i) 5/2/87 (ii)

Origin Mark (i) PSM 52053 (ii) Origin R.L. (i) 5.369 (ii)

HOR DATA

A.M.G. CO-ORDINATES E N Zone Date

Origin Stns. for Co-ordinates with values adopted (i) E N (ii) (iii)

Local Co-ords. available on Plan Ref. Estab. by

I certify that the permanent mark shown in this sketch has been placed on the ground in accordance with the regulations under "The Survey Co-ordination Act of 1952"

(Date) 1-2-1987

(Signature)

Authority Keilar Fox & McGhie Pty Ltd

pm_94371

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Permanent Mark Number : 94371
SCDB current at : 07/09/2006

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ADMINISTRATION DETAILS

Alternative Name : BERNBOROUGH
Type : STAND
Job Number : 000000
Mark Condition : GOOD
Locality Description : TULLOCH COURT/BERNBOROUGH WAY
Installed By : KF&M
Date Installed : 1/2/1986     Last Visited : 15/2/2001
Parish : TOORBUL     Town :
Local Authority : CABOOLTURE     Map Reference : 9543 008
Form 6 : Y     Cadastral Connection : Y

----------------------------------------

VERTICAL DETAILS

Height : 3.947     Datum : AHD D     Fixed By :
NLN Section :
Order : NO ORDER     Class : NO CLASS
Registered Number : 52853
Geo/Sph N : 0     Datum :
Model :
Source :

----------------------------------------

HORIZONTAL DETAILS - GDA94

Access :
Latitude : 27 3 36.0058     Longitude : 153 4 4.4664     Datum : GDA94
Easting : 506733.860     Northing : 7006917.183     Zone : 56
Horizontal Adjustment : GDA - QLD SUPPLEMENTARY AREA 2 AND 3
Order : 1st ORDER     Class : CLASS A
Adjustment Date : 7/12/1999
Fixed By : GPS
Climb On Time : 0:0
Checked By : NRM

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CADASTRAL CONNECTIONS DETAILS

Cadastral Connection 1 : RP213032
Cadastral Connection 2 :
Cadastral Connection 3 :
Cadastral Connection 4 :
Cadastral Connection 5 :

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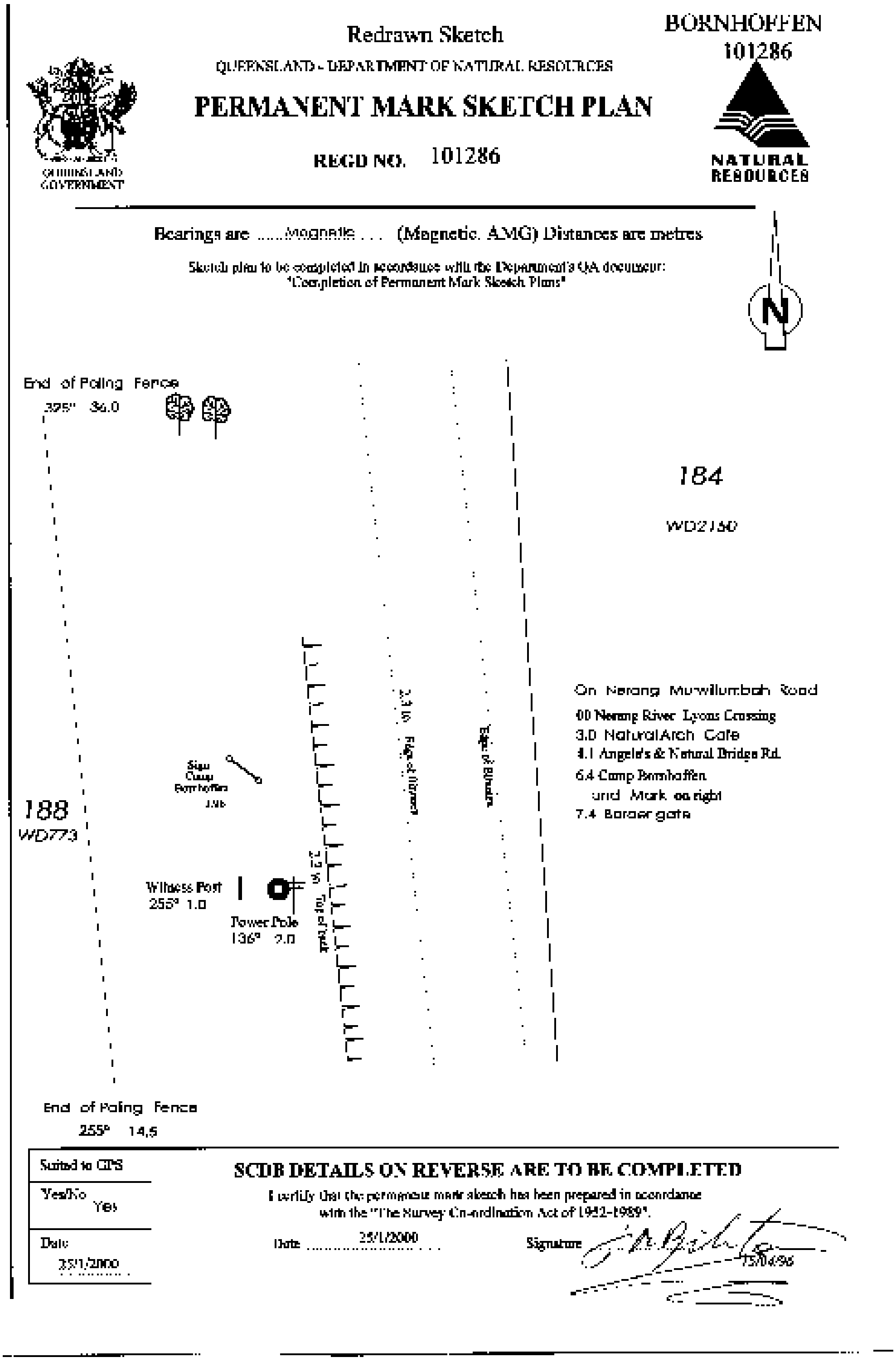
Page 1


Redrawn Sketch
BORNHOFFEN
101286
QUEENSLAND - DEPARTMENT OF NATURAL RESOURCES
PERMANENT MARK SKETCH PLAN
REGD NO. 101286
QUEENSLAND GOVERNMENT
NATURAL RESOURCES
Bearings are ......Magnetic . . . (Magnetic, AMG) Distances are metres
Sketch plan to be completed in accordance with the Department's QA document: "Completion of Permanent Mark Sketch Plans"
N
End of Paling Fence
325° 34.0
184
WD2150
On Nerang Murwillumbah Road
0.0 Nerang River Lyons Crossing
3.0 NaturalArch Cafe
4.1 Angela's & Natural Bridge Rd.
6.4 Camp Bornhoffen
and Mark on right
7.4 Border gate
188
WD773
Witness Post
255° 1.0
Power Pole
136° 2.0
End of Paling Fence
255° 14.5
Suited to GPS
Yes/No
Yes
Date
25/1/2000
SCDB DETAILS ON REVERSE ARE TO BE COMPLETED
I certify that the permanent mark sketch has been prepared in accordance with the "The Survey Co-ordination Act of 1952-1989".
Date 25/1/2000
Signature
15/04/96

pm_101286

Permanent Mark Number : 101286
SCDB current at : 07/09/2006

ADMINISTRATION DETAILS

Alternative Name : BORNHOFFEN
Type : STAND
Job Number : 97/047
Mark Condition : GOOD
Locality Description : NERANG MURWILLUMBAH RD
Installed By : GOLD COAST
Date Installed : 11/3/1997   Last Visited : 30/5/2002
Parish : NUMINBAH   Town :
Local Authority : GOLD COAST   Map Reference : 9541 31114
Form 6 : Y   Cadastral Connection : Y

VERTICAL DETAILS

Height : 370.613   Datum : AHD D   Fixed By : GPS
NLN Section :
Order : 4th ORDER   Class : Class D
Registered Number : 75373
Geo/Sph N : 12   Datum : ANS
Model : AUSGEOID93   RIGOROUS
Source :

HORIZONTAL DETAILS - GDA94

Access :
Latitude : 28 15 2.3513   Longitude : 153 14 12.5028   Datum : GDA94
Easting : 523229.334   Northing : 6875008.269   Zone : 56
Horizontal Adjustment : GDA - QLD SUPPLEMENTARY AREA 1
Order : 1st ORDER   Class : CLASS A
Adjustment Date : 6/12/1999
Fixed By : GPS
Climb On Time : 00:00
Checked By : NRM

CADASTRAL CONNECTIONS DETAILS

Cadastral Connection 1 : SP128541
Cadastral Connection 2 :
Cadastral Connection 3 :
Cadastral Connection 4 :
Cadastral Connection 5 :

Page 1

QUEENSLAND

REGD. No. 103234

Other Ref. No.

PERMANENT MARK SKETCH PLAN

Description of Mark STANDARD

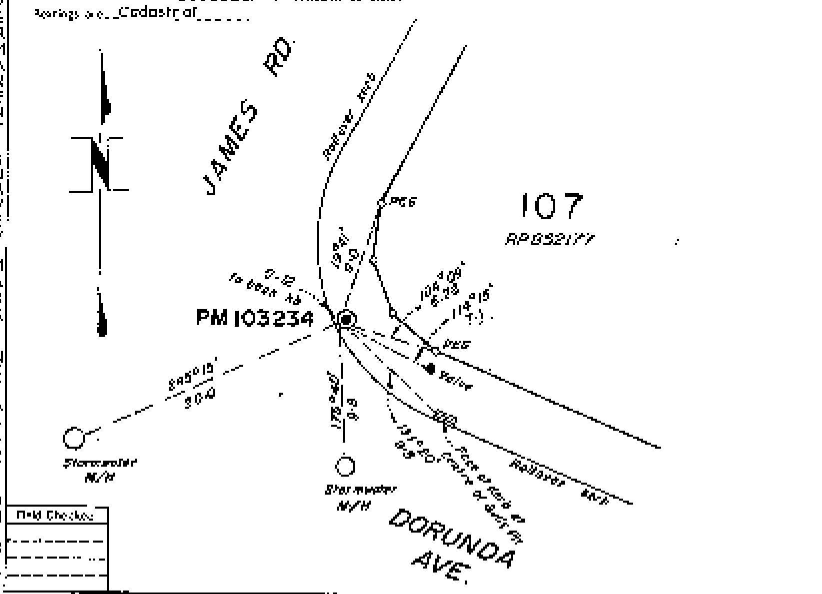
District Sunshine Coast

Parish of TOORBUL City or Town of

Local Authority Caboolture S.C. Map T.M. BEACHMERE

Measurements are in Metres (Not necessarily to scale)

Bearings are Cadastral



Field Checked

Installed by G.P. Adcock Licensed Surveyor Date 28/10/92

Placed in Connection with CADASTRAL survey Plan and / or Field Bk. Ref.

Connd. on Cadastral Plan No. RP852177

AUSTRALIAN HEIGHT DATUM

Adj. Height Analysis Ref. L. Book No.

Origin Stn. Stn. Nos. Book No.

OTHER DATUMS

Reduced Level (i) 11.977 A.H.D.(der.) Datum Adopted (i) AHD L. Book No.

Levelled by (i) G.P. Adcock Licensed Surveyor Date (i) 28/10/92

Origin Mark (i) PM 76080 Origin R.L. (i) 2.789 AHD der.

A.M.G. CO-ORDINATES E 504420 N 6993875 Zone Date

Origin Stns. for Co-ordinates with values adopted

Local Co-ords. available Plan Ref. ✓ Estab. by

MAP

I certify that the permanent mark shown in this sketch has been placed on the ground in accordance with the regulations under "The Survey Co-ordination Act of 1952-1981".

Dated 17 Dec. 1992 Signature

103234

SCS103234

pm_103234

Permanent Mark Number : 103234
SCDB current at : 07/09/2006

ADMINISTRATION DETAILS

Alternative Name : DORUNDA
Type : STAND
Job Number : 92/5059
Mark Condition : GOOD
Locality Description : JAMES/DORUNDA
Installed By : G ADCOCK
Date Installed : 28/10/1992 Last Visited : 22/4/2005
Parish : TOORBUL Town : BEACHMERE
Local Authority : CABOOLTURE Map Reference : 9543 43414
Form 6 : Y Cadastral Connection : Y

VERTICAL DETAILS

Height : 1.977 Datum : AHD D Fixed By :
NLN Section :
Order : 4th ORDER Class :
Registered Number : 76020
Geo/Sph N : 0 Datum :
Model :
Source :

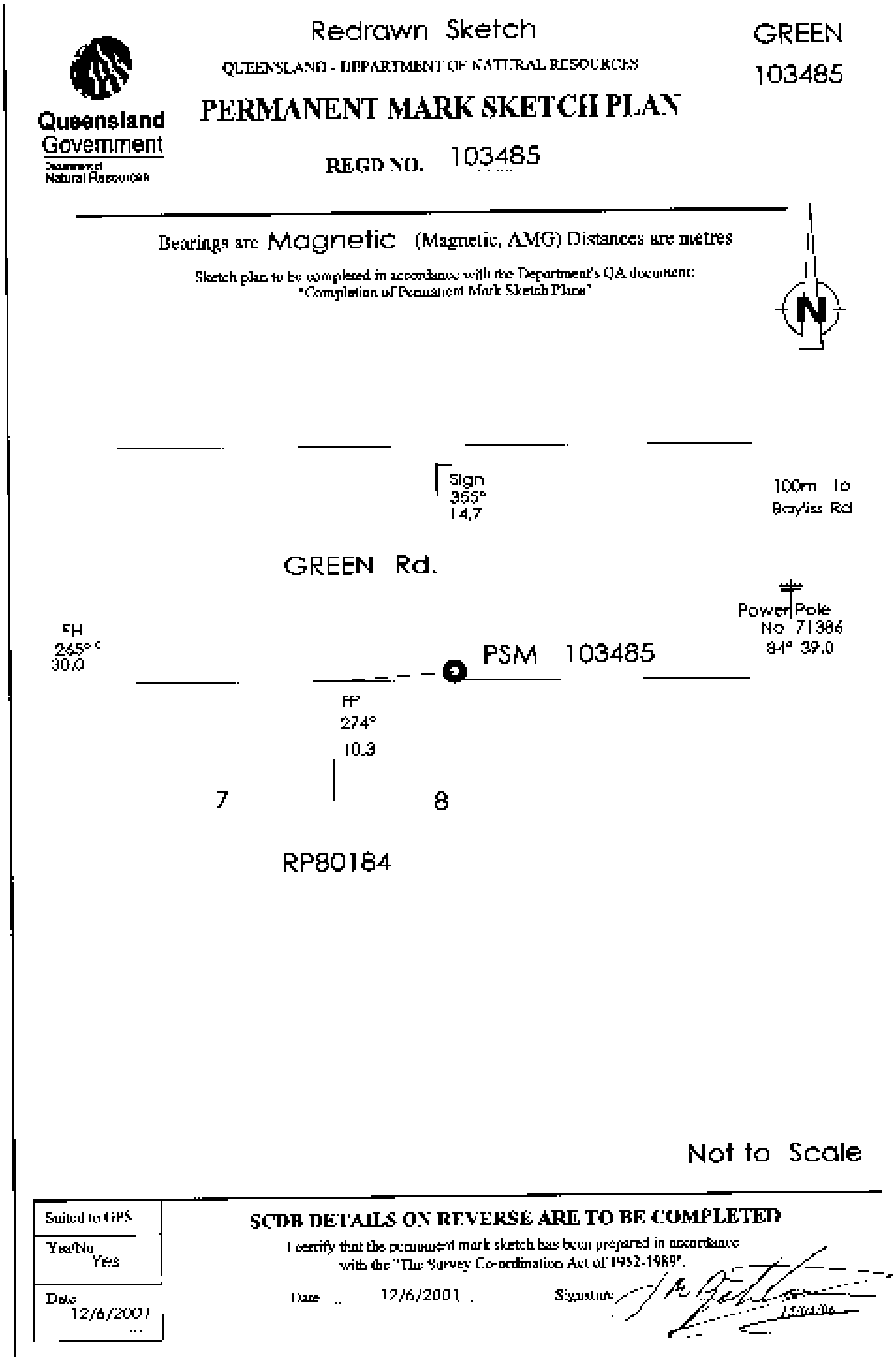
HORIZONTAL DETAILS - GDA94

Access :
Latitude : 27 8 6.4982 Longitude : 153 2 43.9058 Datum : GDA94
Easting : 504511.795 Northing : 6998595.975 Zone : 56
Horizontal Adjustment : GDA - QLD SUPPLEMENTARY AREA 2 AND 3
Order : 1st ORDER Class : CLASS A
Adjustment Date : 7/12/1999
Fixed By : GPS
Climb On Time : 00:00
Checked By : NRM

CADASTRAL CONNECTIONS DETAILS

Cadastral Connection 1 : SP180812
Cadastral Connection 2 : SP172958
Cadastral Connection 3 : SP158737
Cadastral Connection 4 : IS177318
Cadastral Connection 5 : SP152329

Page 1



Redrawn Sketch

GREEN
103485

Queensland Government
Department of Natural Resources

QUEENSLAND - DEPARTMENT OF NATURAL RESOURCES

PERMANENT MARK SKETCH PLAN

REGD NO. 103485

Bearings are Magnetic (Magnetic, AMG) Distances are metres

Sketch plan to be completed in accordance with the Department's QA document:
"Completion of Permanent Mark Sketch Plans"

Suited to GPS
Yes/No Yes
Date 12/6/2001

SCDB DETAILS ON REVERSE ARE TO BE COMPLETED

I certify that the permanent mark sketch has been prepared in accordance with the "The Survey Co-ordination Act of 1952-1989".

Date 12/6/2001 Signature

pm_103485

```
Permanent Mark Number : 103485
SCDB current at : 07/09/2006

----------------------------------------

ADMINISTRATION DETAILS

Alternative Name : GREEN
Type : STAND
Job Number : 2005/12
Mark Condition : GOOD
Locality Description : GREEN RD/100M TO BAYLISS RD
Installed By : LOGAN CC
Date Installed : 28/2/1992     Last Visited : 8/11/2005
Parish : MITCHELL     Town :
Local Authority : LOGAN     Map Reference : 9542 433
Form 6 : Y     Cadastral Connection : Y

----------------------------------------

VERTICAL DETAILS

Height : 41.014     Datum : AHD D     Fixed By : SPIRIT LEVELLING
NLN Section :
Order : 4th ORDER     Class : Class D
Registered Number : 102162
Geo/Sph N : 0     Datum :
Model :
Source :

----------------------------------------

HORIZONTAL DETAILS - GDA94

Access :
Latitude : 27 41 24.7906     Longitude : 153 3 20.4624     Datum : GDA94
Easting : 505490.569     Northing : 6937111.578     Zone : 56
Horizontal Adjustment : WEST LOGAN NRM GPS_0601
Order : 1st ORDER     Class : CLASS A
Adjustment Date : 1/6/2001
Fixed By : GPS
Climb On Time : 00:00
Checked By : NRM

----------------------------------------

CADASTRAL CONNECTIONS DETAILS

Cadastral Connection 1 : SP181386
Cadastral Connection 2 : SP144489
Cadastral Connection 3 : SP144488
Cadastral Connection 4 : SP144487
Cadastral Connection 5 : SP131928

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Page 1

QUEENSLAND – DEPARTMENT OF NATURAL RESOURCES

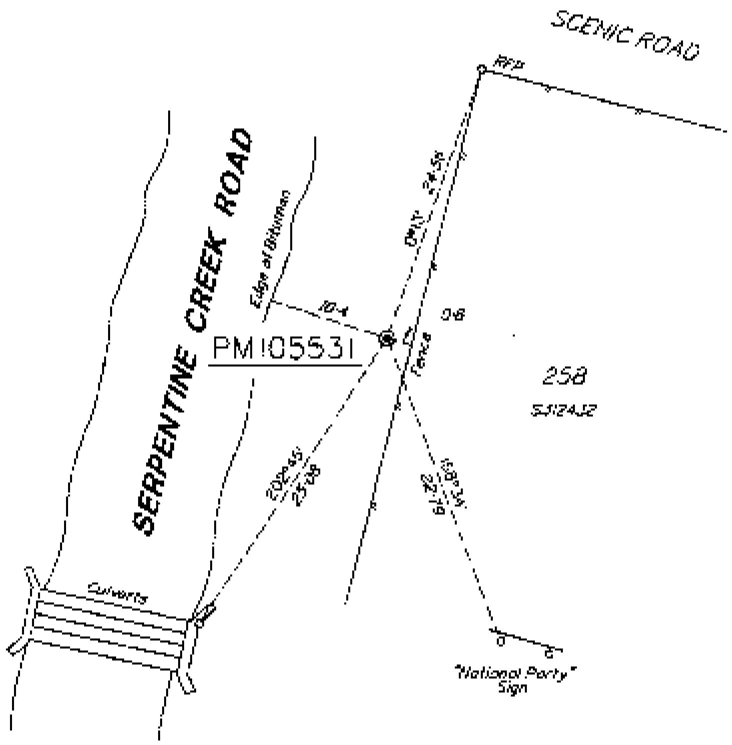
PERMANENT MARK SKETCH PLAN

REGD NO. 105531

NATURAL RESOURCES QUEENSLAND GOVERNMENT

Bearings are Magnetic (Magnetic, AMG) Distances are metres

Sketch plan to be completed in accordance with the Department's QA document: "Compilation of Permanent Mark Sketch Plans"



Suited to GPS	
Yes/No	
Date	

SCDB DETAILS ON REVERSE ARE TO BE COMPLETED

I certify that the permanent mark sketch has been prepared in accordance with the "The Survey Co-ordination Act of 1957-1997".

Date 12/3/97 Signature

15/04/95

pm_105531

```
Permanent Mark Number : 105531
SCDB current at : 07/09/2006

----------------------------------------

ADMINISTRATION DETAILS

Alternative Name : SCENIC
Type : STAND
Job Number : 2000/1
Mark Condition : GOOD
Locality Description : SERPENTINE CREEK ROAD
Installed By : REDLAND SC
Date Installed : 1/4/1993     Last Visited : 27/7/2000
Parish : REDLAND     Town :
Local Authority : REDLAND     Map Reference : 9542 13421
Form 6 : Y     Cadastral Connection : Y

----------------------------------------

VERTICAL DETAILS

Height : 12.459     Datum : AHD D     Fixed By : GPS
NLN Section :
Order : 4th ORDER     Class : Class D
Registered Number : 62490
Geo/Sph N : 40     Datum : GRS80
Model : AUSGEOID98     INTERPOLATED
Source :

----------------------------------------

HORIZONTAL DETAILS - GDA94

Access :
Latitude : 27 40 1.1479     Longitude : 153 18 6.2361     Datum : GDA94
Easting : 529757.858     Northing : 6939650.074     Zone : 56
Horizontal Adjustment : GDA - QLD SUPPLEMENTARY AREA 1
Order : 1st ORDER     Class : CLASS A
Adjustment Date : 6/12/1999
Fixed By : GPS
Climb On Time : 00:00
Checked By : NRM

----------------------------------------

CADASTRAL CONNECTIONS DETAILS

Cadastral Connection 1 : SP128322
Cadastral Connection 2 :
Cadastral Connection 3 :
Cadastral Connection 4 :
Cadastral Connection 5 :

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Page 1

QUEENSLAND - DEPARTMENT OF NATURAL RESOURCES

QUEENSLAND GOVERNMENT

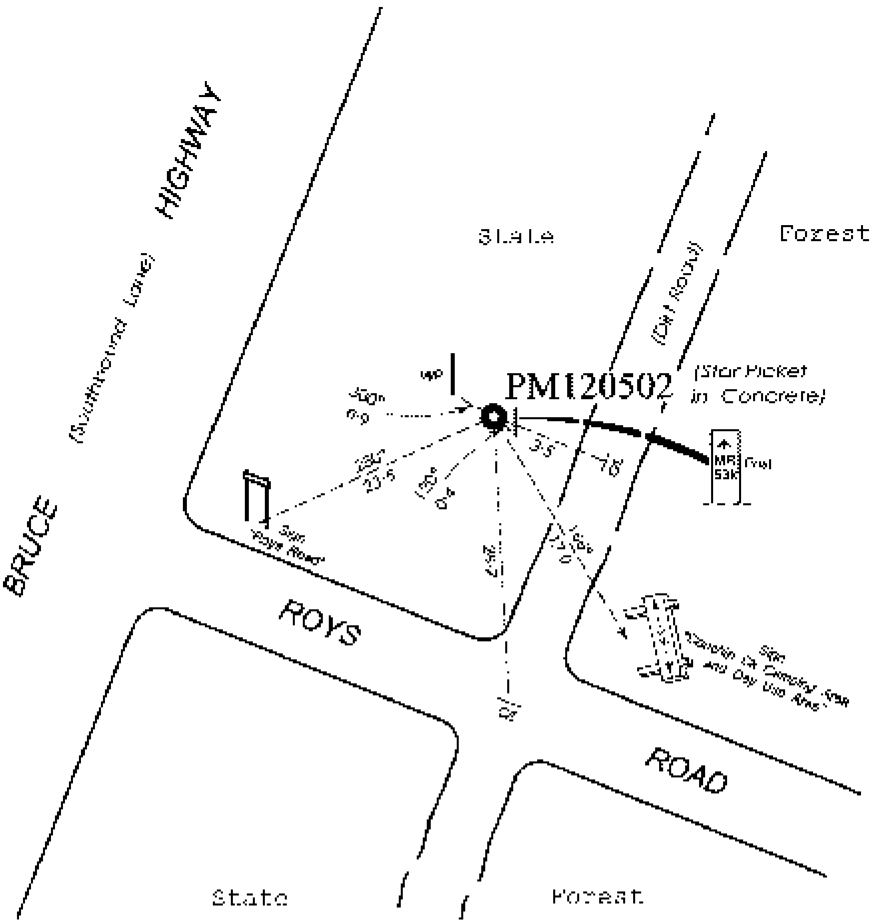
PERMANENT MARK SKETCH PLAN

REGD NO. 120502

NATURAL RESOURCES

Bearings are **Magnetic** (Magnetic, AMG) Distances are metres

Sketch plan to be completed in accordance with the Department's QA document:
"Completion of Permanent Mark Sketch Plans"



Suited to GPS	**SCDB DETAILS ON REVERSE ARE TO BE COMPLETED**
Yes/No: Yes	I certify that the permanent mark sketch has been prepared in accordance with the "The Survey Co-ordination Act of 1952-1989".
Date: 16/03/98	Date 16.6.1998 Signature

pm_120502

Permanent Mark Number : 120502
SCDB current at : 07/09/2006

ADMINISTRATION DETAILS

Alternative Name :
Type : S/PIC
Job Number : 98/5505
Mark Condition : GOOD
Locality Description : ROYS ROAD
Installed By : MRD
Date Installed : 1/1/1985   Last Visited : 20/8/2002
Parish : BRIBIE   Town :
Local Authority : CALOUNDRA   Map Reference : 9544 34
Form 6 : Y   Cadastral Connection : Y

VERTICAL DETAILS

Height : 9.501   Datum : AHD D   Fixed By : GPS
NLN Section :
Order : 4th ORDER   Class : Class A
Registered Number :
Geo/Sph N : 43   Datum : GRS80
Model : AUSGEOID98   INTERPOLATED
Source : CALOUNDRA CITY 3-5KM GPS APRIL 2000

HORIZONTAL DETAILS - GDA94

Access :
Latitude : 26 51 44.7467   Longitude : 153 0 58.4474   Datum : GDA94
Easting : 501612.753   Northing : 7028801.689   Zone : 56
Horizontal Adjustment : GDA - QLD SUPPLEMENTARY AREA 2 AND 3
Order : 1st ORDER   Class : CLASS A
Adjustment Date : 7/12/1999
Fixed By : GPS
Climb On Time : 00:00
Checked By : NRM

CADASTRAL CONNECTIONS DETAILS

Cadastral Connection 1 : SP134696
Cadastral Connection 2 :
Cadastral Connection 3 :
Cadastral Connection 4 :
Cadastral Connection 5 :

Page 1

QUEENSLAND GOVERNMENT

QUEENSLAND - DEPARTMENT OF NATURAL RESOURCES

PERMANENT MARK SKETCH PLAN

REGD NO. 120980

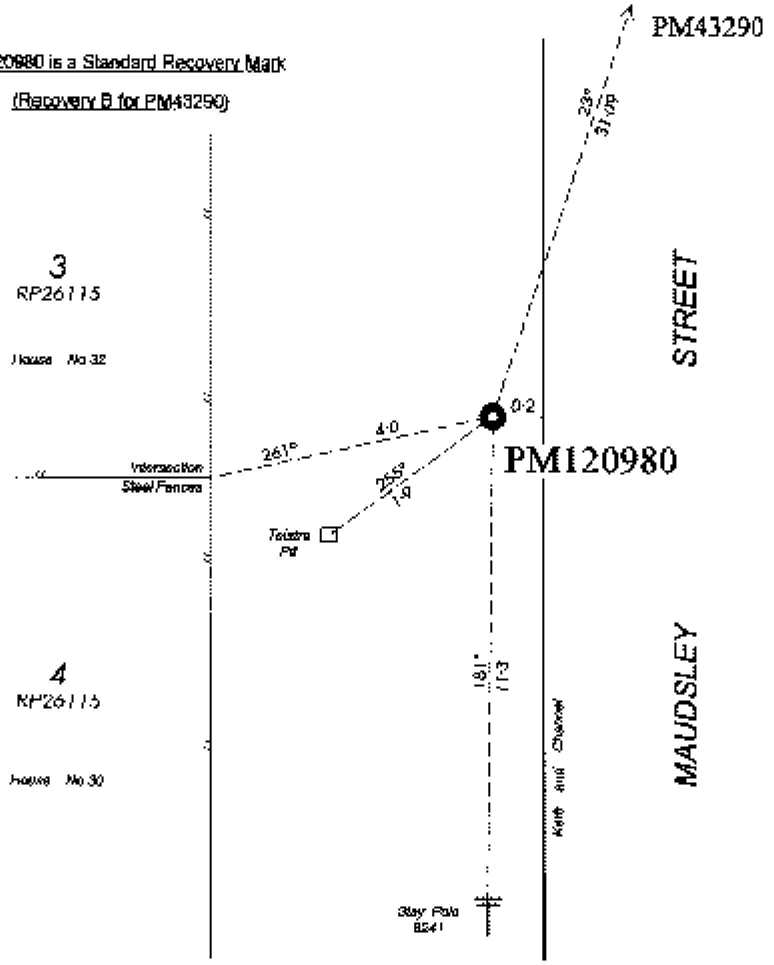
NATURAL RESOURCES

Bearings are magnetic (Magnetic, AMG) Distances are metres

Sketch plan to be completed in accordance with the Department's QA document:
"Completion of Permanent Mark Sketch Plans"

PM120980 is a Standard Recovery Mark

(Recovery B for PM43290)



Suited to GPS
Yes/No: Yes
Date: 19/3/1996

SCDB DETAILS ON REVERSE ARE TO BE COMPLETED

I certify that the permanent mark sketch has been prepared in accordance with the "The Survey Co-ordination Act of 1952-1989".

Date 30 - 7 - 98. Signature

15/04/96

pm_120980

Permanent Mark Number : 120980
SCDB current at : 07/09/2006

ADMINISTRATION DETAILS

Alternative Name : BR 269 RB
Type : OTHERBRASSRECOVERY MIN CONC
Job Number :
Mark Condition : GOOD
Locality Description : MAUDSLEY STREET - KEDRON
Installed By : DMS
Date Installed : 1/4/1976 Last Visited : 14/6/2005
Parish : KEDRON Town : BRISBANE
Local Authority : BRISBANE Map Reference : 9543 33442
Form 6 : Y Cadastral Connection : Y

VERTICAL DETAILS

Height : 31.373 Datum : AHD Fixed By : GPS
NLN Section :
Order : 4th ORDER Class : Class A
Registered Number : 10400
Geo/Sph N : 12 Datum : ANS
Model : AUSGEOID93 INTERPOLATED
Source :

HORIZONTAL DETAILS - GDA94

Access :
Latitude : 27 24 7.0079 Longitude : 153 1 44.4634 Datum : GDA94
Easting : 502868.681 Northing : 6969043.861 Zone : 56
Horizontal Adjustment : GDA - BRISBANE TO IPSWICH CONTROL
Order : 1st ORDER Class : CLASS A
Adjustment Date : 8/12/1999
Fixed By : GPS
Climb On Time : 00:00
Checked By : NRM

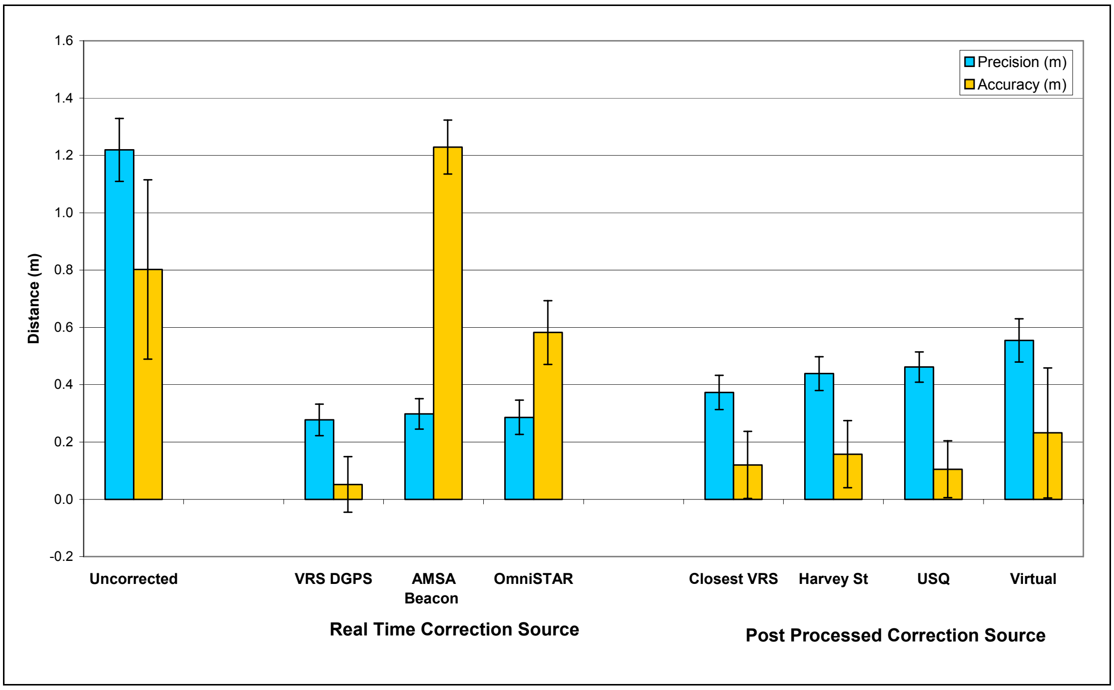
CADASTRAL CONNECTIONS DETAILS

Cadastral Connection 1 : SP160097
Cadastral Connection 2 : IS164723
Cadastral Connection 3 : SP145866
Cadastral Connection 4 : SP131710
Cadastral Connection 5 : SP131709

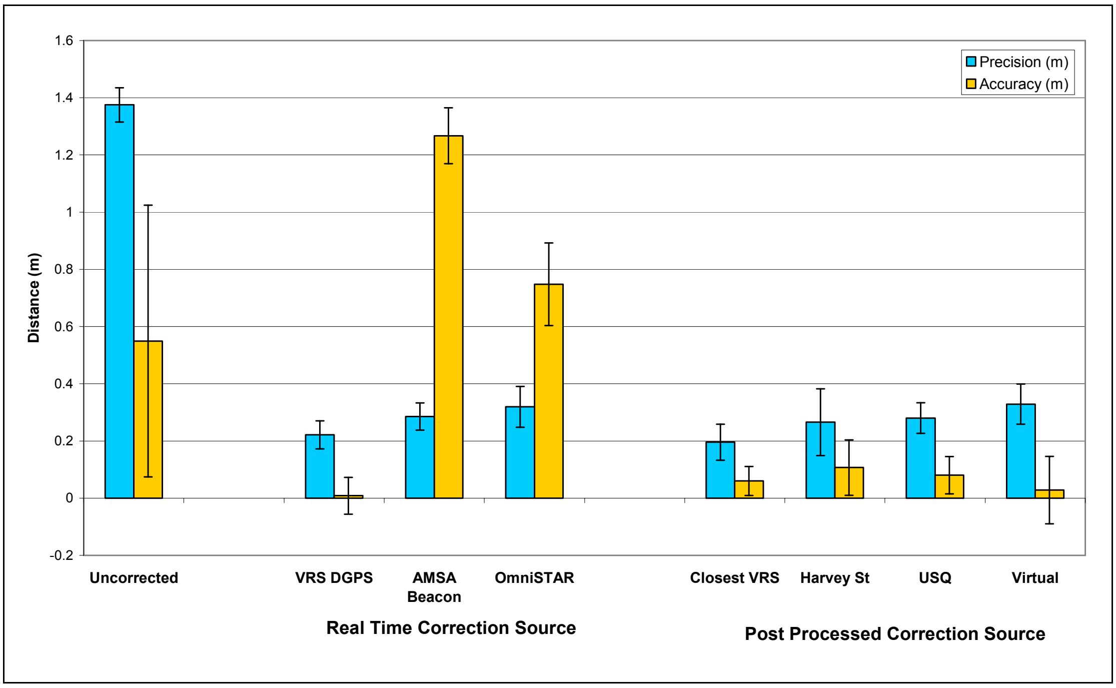
Page 1

Appendix C. Graphical Results

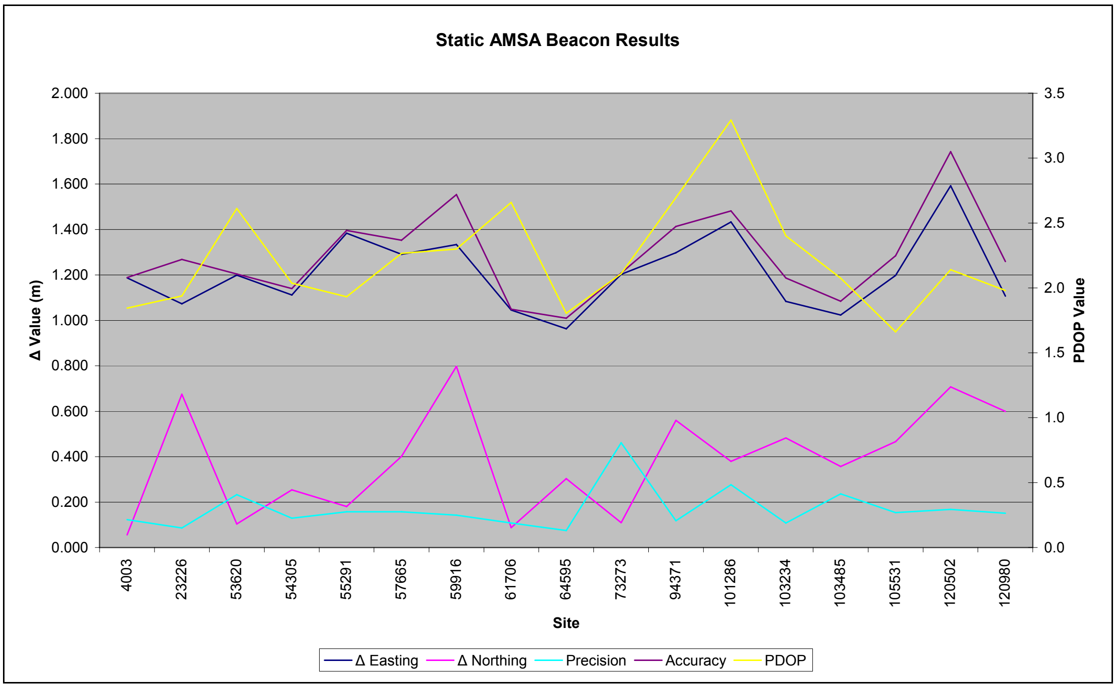
Dynamic Test Results

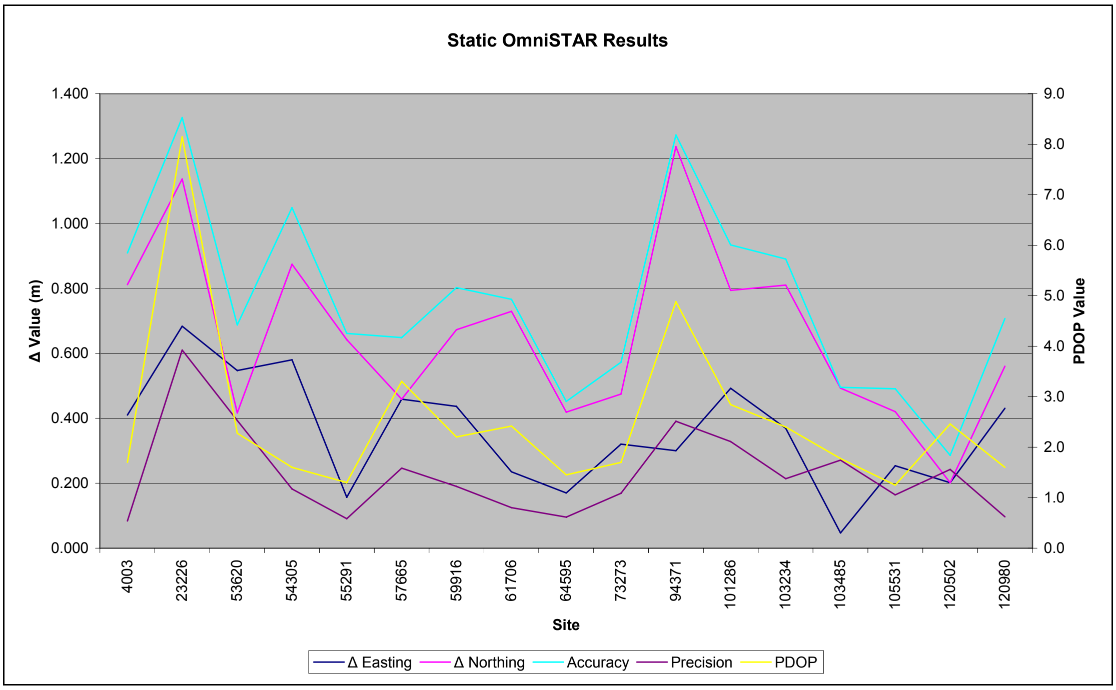


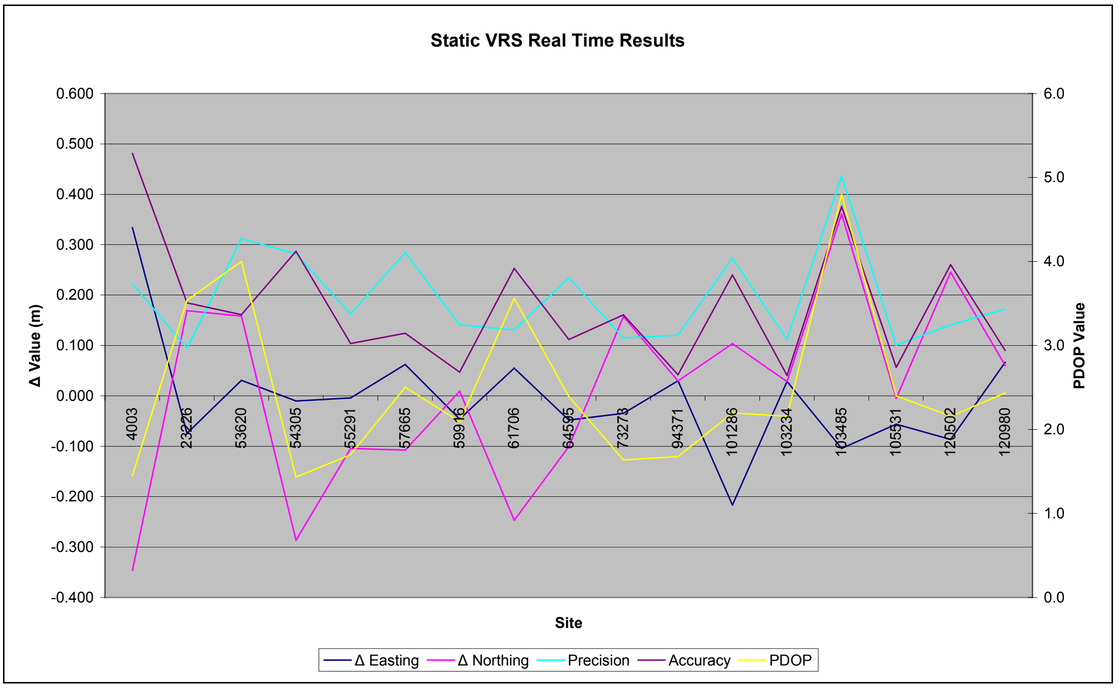
Static Test Results

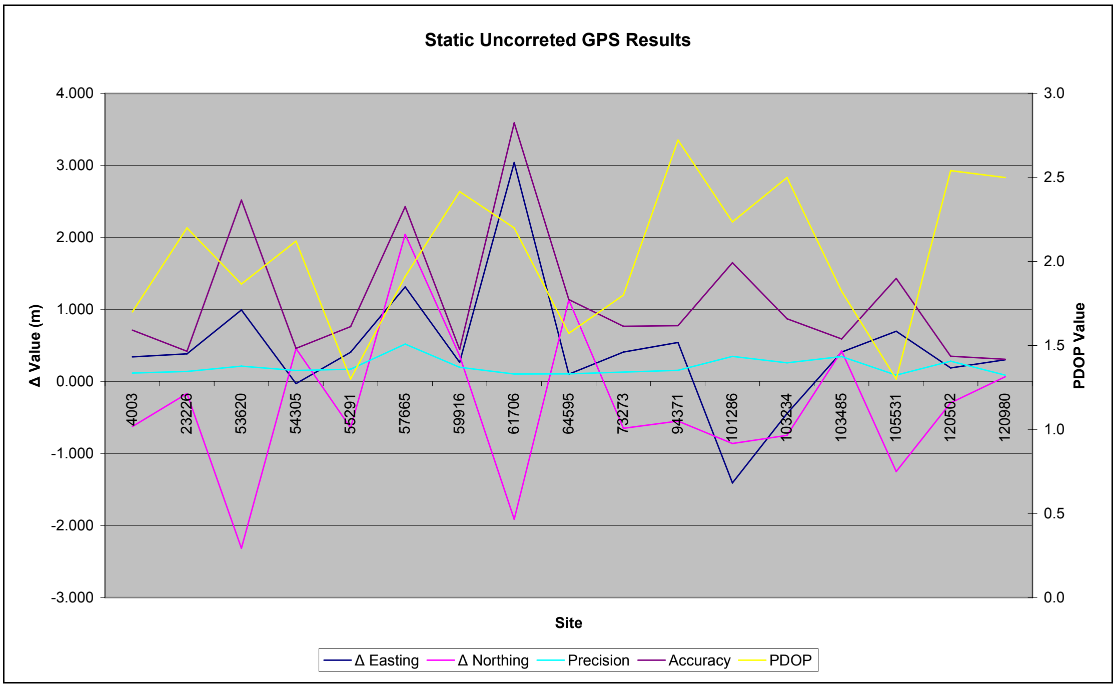


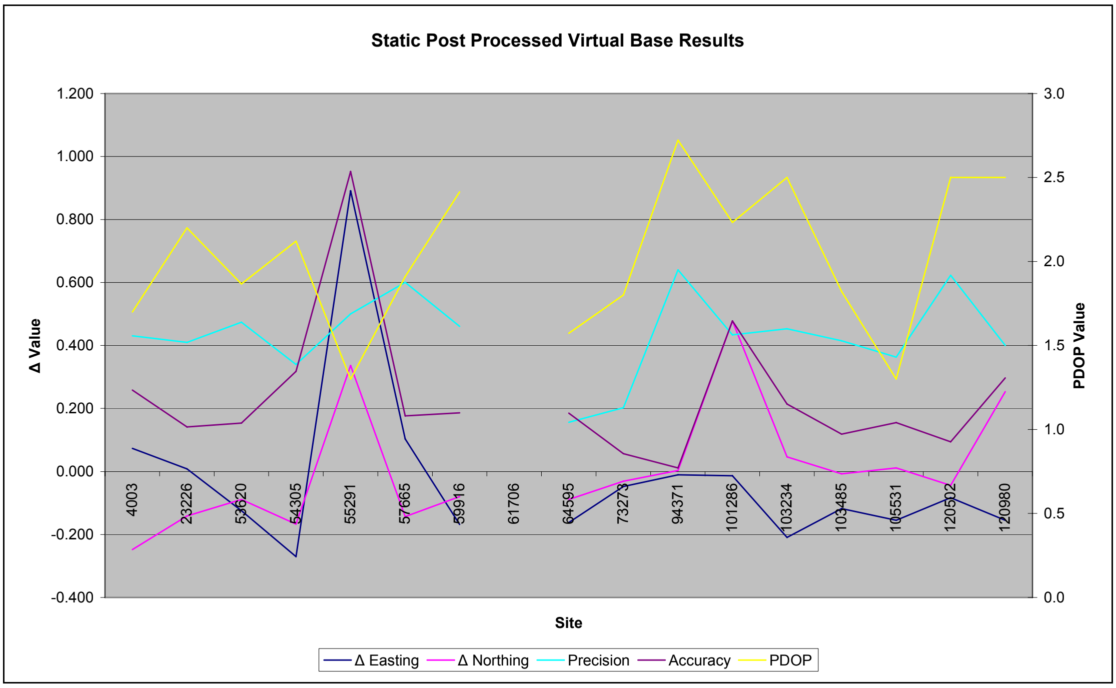
Appendix D. Static DGPS Results

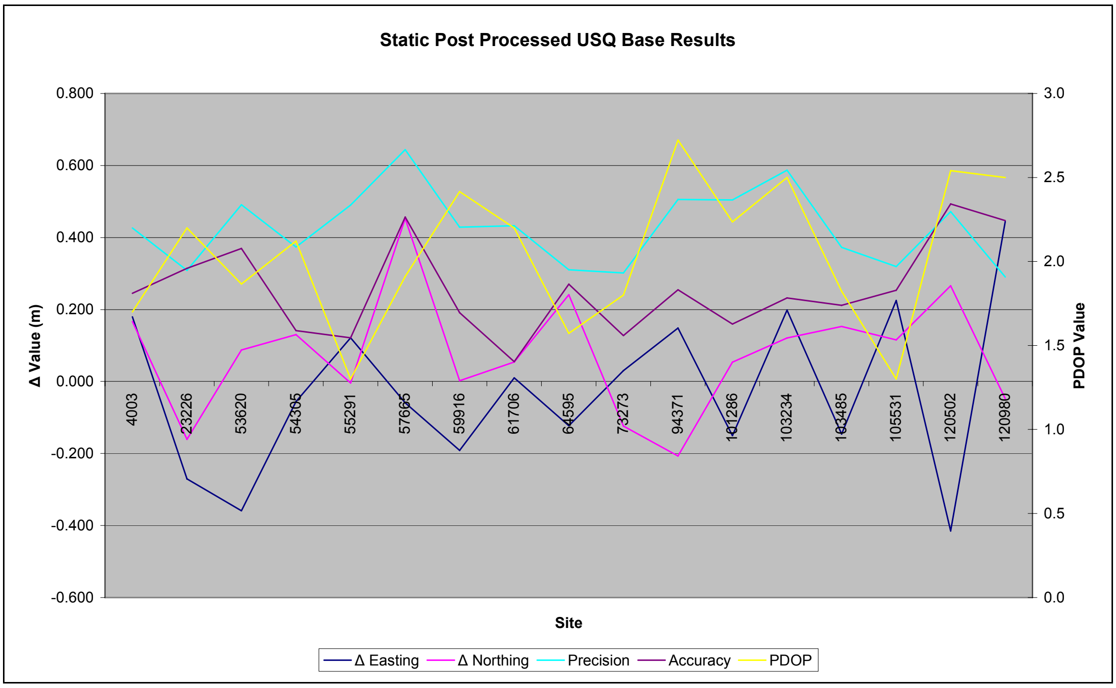

Static AMSA Beacon Results
Δ Value (m)
PDOP Value
Site
2.000
1.800
1.600
1.400
1.200
1.000
0.800
0.600
0.400
0.200
0.000
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
4003
23226
53620
54305
55291
57665
59916
61706
64595
73273
94371
101286
103234
103485
105531
120502
120980
Δ Easting
Δ Northing
Precision
Accuracy
PDOP

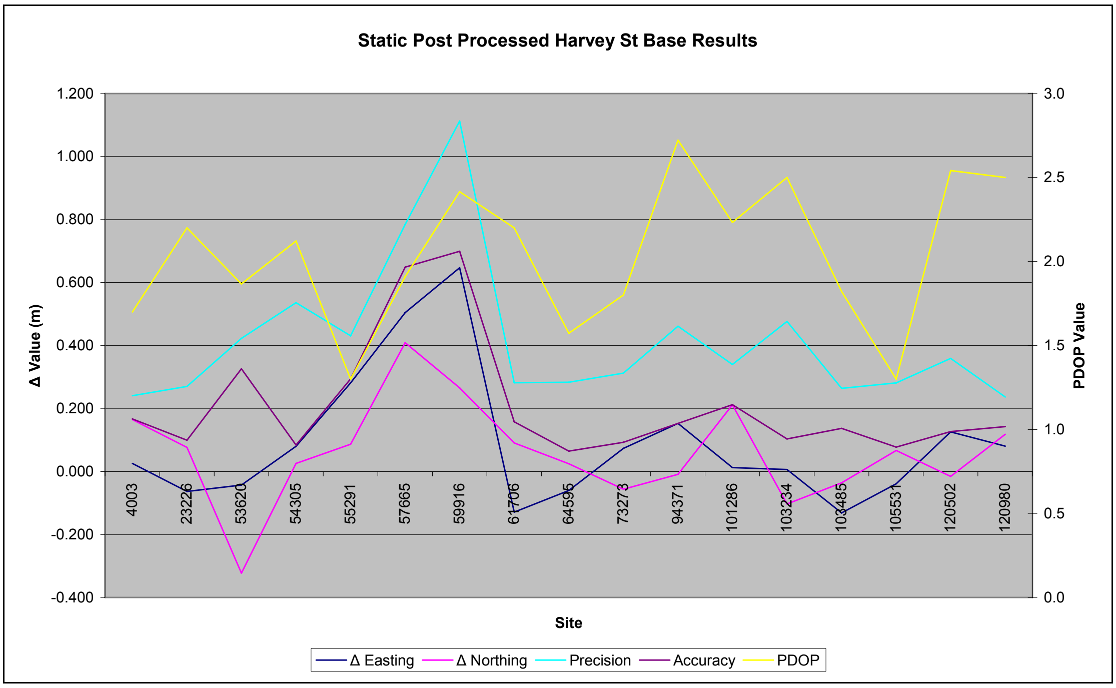

Static OmniSTAR Results
Δ Value (m)
PDOP Value
Site
1.400
1.200
1.000
0.800
0.600
0.400
0.200
0.000
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
4003
23226
53620
54305
55291
57665
59916
61706
64595
73273
94371
101286
103234
103485
105531
120502
120980
Δ Easting
Δ Northing
Accuracy
Precision
PDOP

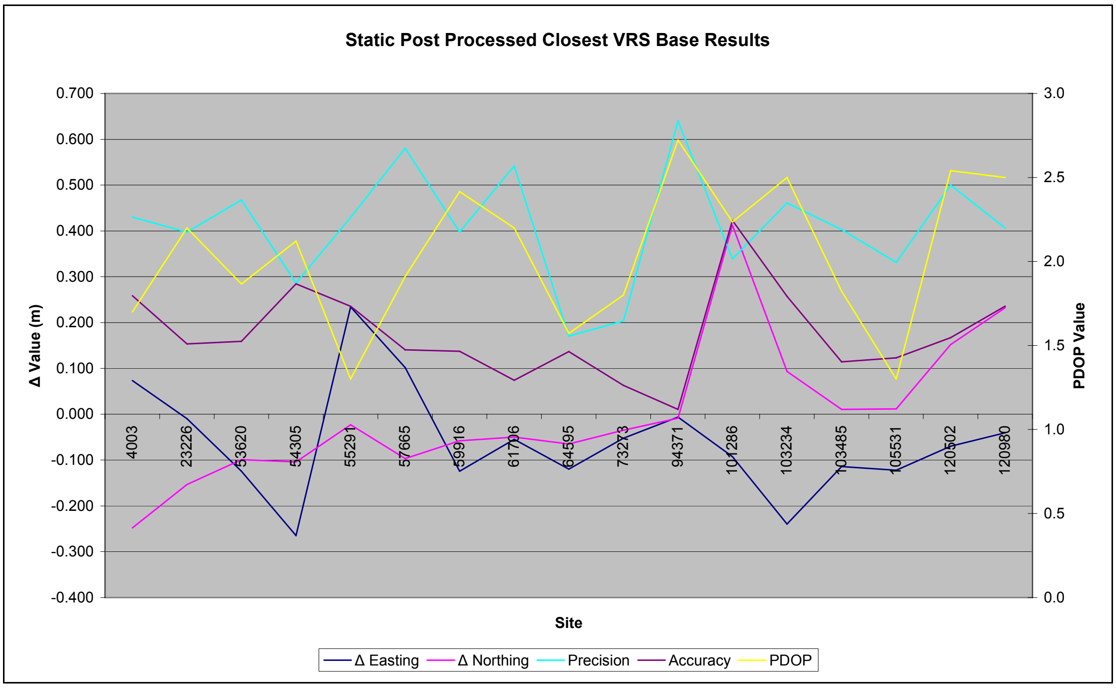

Static VRS Real Time Results
Δ Value (m)
PDOP Value
Site
0.600
0.500
0.400
0.300
0.200
0.100
0.000
-0.100
-0.200
-0.300
-0.400
6.0
5.0
4.0
3.0
2.0
1.0
0.0
4003
23226
53620
54305
55291
57665
59916
61706
64595
73273
94371
101286
103234
103485
105531
120502
120980
Δ Easting
Δ Northing
Precision
Accuracy
PDOP


Static Uncorreted GPS Results
Δ Value (m)
PDOP Value
Site
4.000
3.000
2.000
1.000
0.000
-1.000
-2.000
-3.000
3.0
2.5
2.0
1.5
1.0
0.5
0.0
4003
23226
53620
54305
55291
57665
59916
61706
64595
73273
94371
101286
103234
103485
105531
120502
120980
Δ Easting
Δ Northing
Precision
Accuracy
PDOP

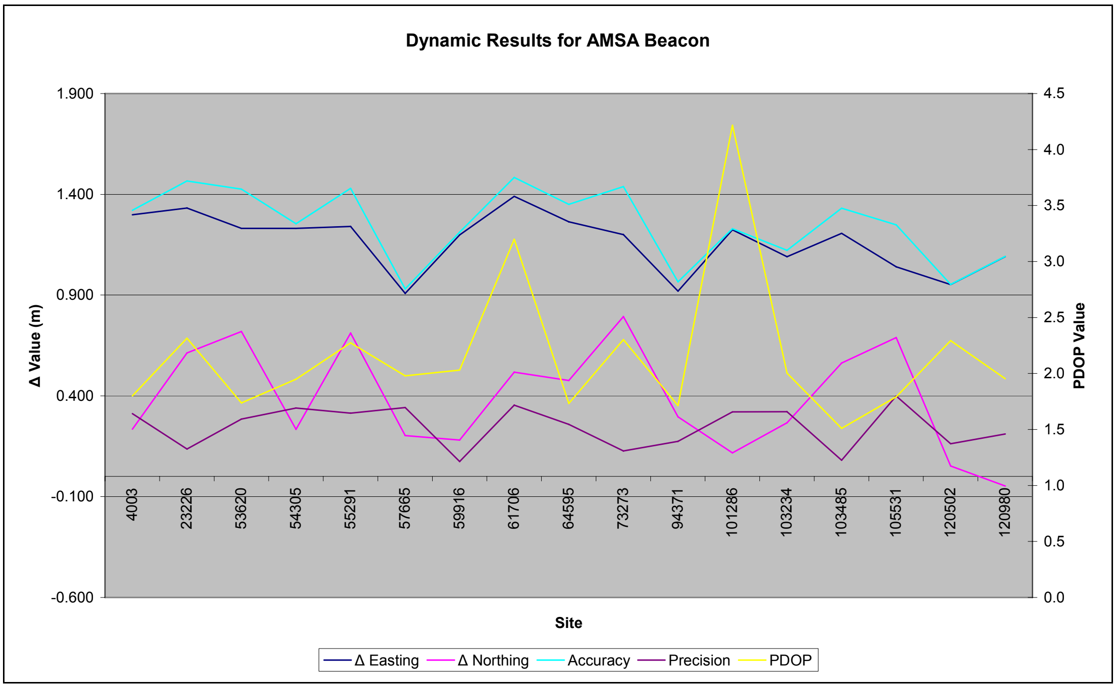

Static Post Processed Virtual Base Results
Δ Value
PDOP Value
1.200
1.000
0.800
0.600
0.400
0.200
0.000
-0.200
-0.400
3.0
2.5
2.0
1.5
1.0
0.5
0.0
4003
23226
53620
54305
55291
57665
59916
61706
64595
73273
94371
101286
103234
103485
105531
120502
120980
Site
Δ Easting
Δ Northing
Precision
Accuracy
PDOP

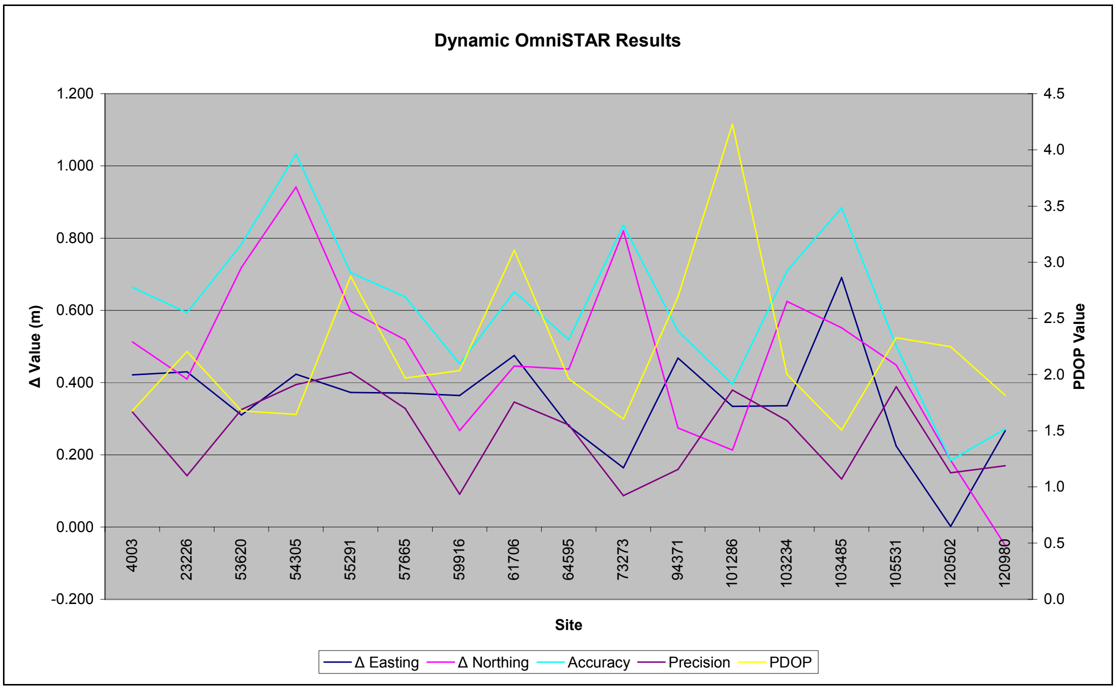

Static Post Processed USQ Base Results
Δ Value (m)
PDOP Value
0.800
0.600
0.400
0.200
0.000
-0.200
-0.400
-0.600
3.0
2.5
2.0
1.5
1.0
0.5
0.0
4003
23226
53620
54305
55291
57665
59916
61706
64595
73273
94371
101286
103234
103485
105531
120502
120980
Site
Δ Easting
Δ Northing
Precision
Accuracy
PDOP

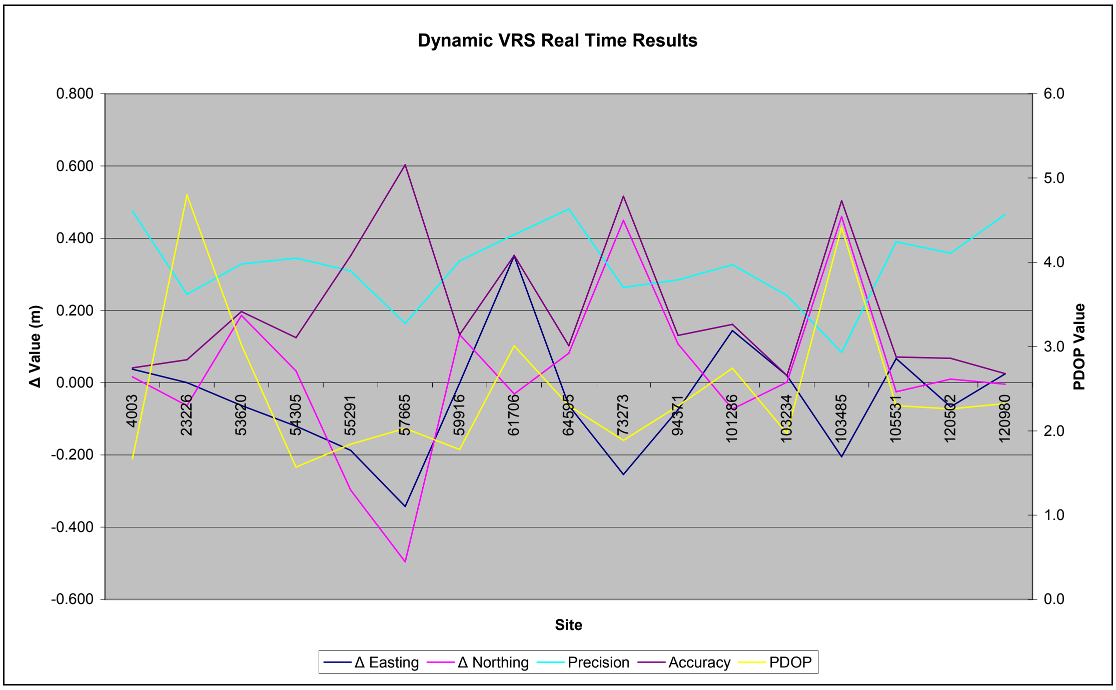

Static Post Processed Harvey St Base Results
Δ Value (m)
1.200
1.000
0.800
0.600
0.400
0.200
0.000
-0.200
-0.400
PDOP Value
3.0
2.5
2.0
1.5
1.0
0.5
0.0
4003
23226
53620
54305
55291
57665
59916
61706
64595
73273
94371
101286
103234
103485
105531
120502
120980
Site
Δ Easting
Δ Northing
Precision
Accuracy
PDOP

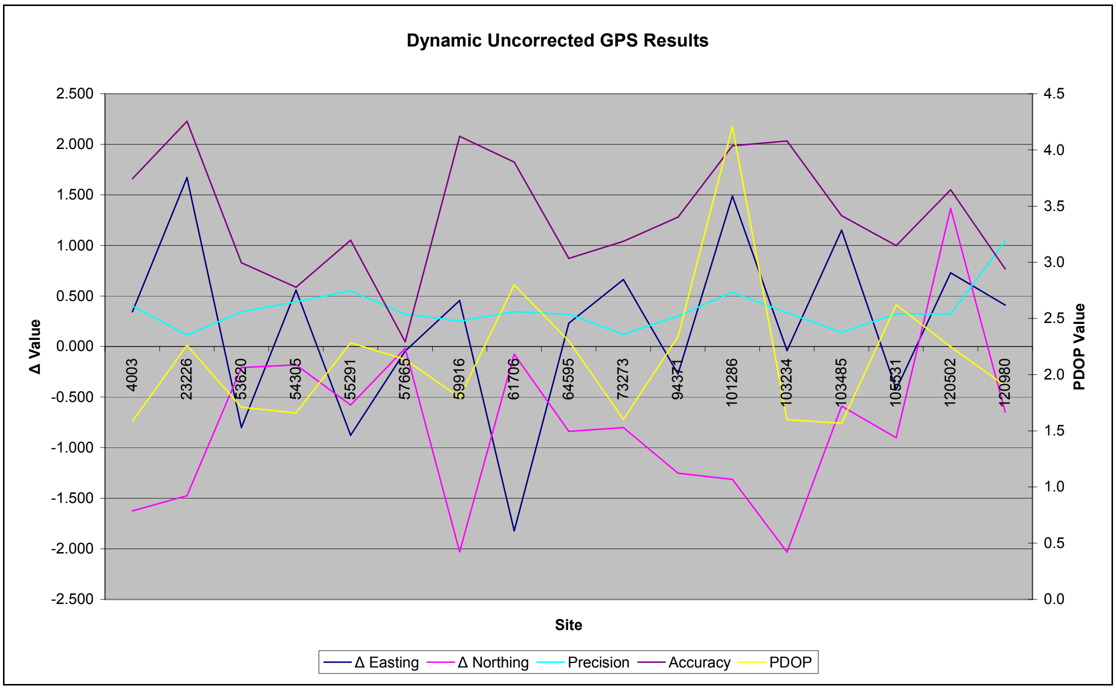

Static Post Processed Closest VRS Base Results
Δ Value (m)
0.700
0.600
0.500
0.400
0.300
0.200
0.100
0.000
-0.100
-0.200
-0.300
-0.400
PDOP Value
3.0
2.5
2.0
1.5
1.0
0.5
0.0
4003
23226
53620
54305
55291
57665
59916
61706
64595
73273
94371
101286
103234
103485
105531
120502
120980
Site
Δ Easting
Δ Northing
Precision
Accuracy
PDOP

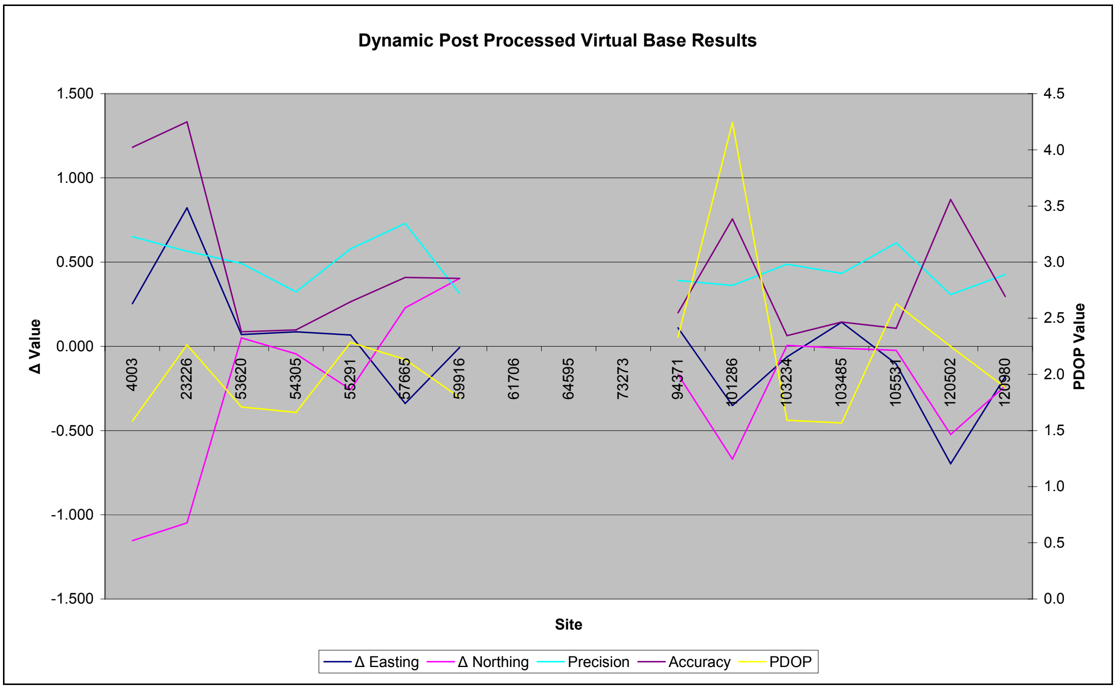
Appendix E. Dynamic DGPS Results


Dynamic Results for AMSA Beacon
Δ Value (m)
PDOP Value
1.900
1.400
0.900
0.400
-0.100
-0.600
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
4003
23226
53620
54305
55291
57665
59916
61706
64595
73273
94371
101286
103234
103485
105531
120502
120980
Site
Δ Easting
Δ Northing
Accuracy
Precision
PDOP

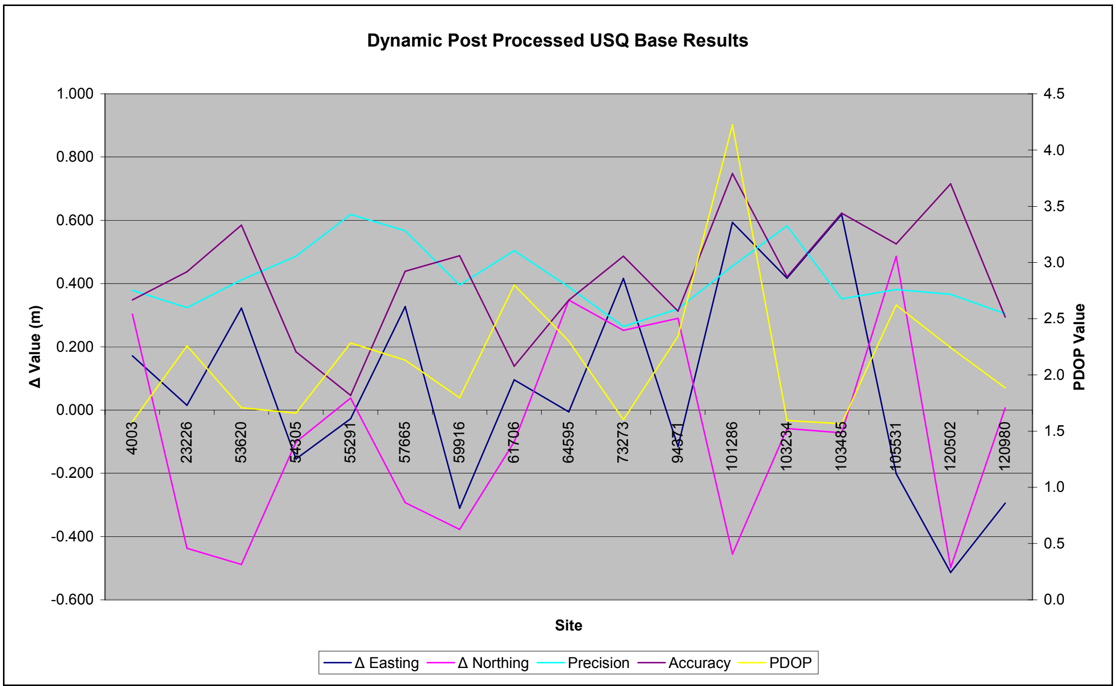

Dynamic OmniSTAR Results
Δ Value (m)
PDOP Value
1.200
1.000
0.800
0.600
0.400
0.200
0.000
-0.200
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
4003
23226
53620
54305
55291
57665
59916
61706
64595
73273
94371
101286
103234
103485
105531
120502
120980
Site
Δ Easting
Δ Northing
Accuracy
Precision
PDOP


Dynamic VRS Real Time Results
Δ Value (m)
0.800
0.600
0.400
0.200
0.000
-0.200
-0.400
-0.600
PDOP Value
6.0
5.0
4.0
3.0
2.0
1.0
0.0
4003
23226
53620
54305
55291
57665
59916
61706
64595
73273
94371
101286
103234
103485
105531
120502
120980
Site
Δ Easting
Δ Northing
Precision
Accuracy
PDOP

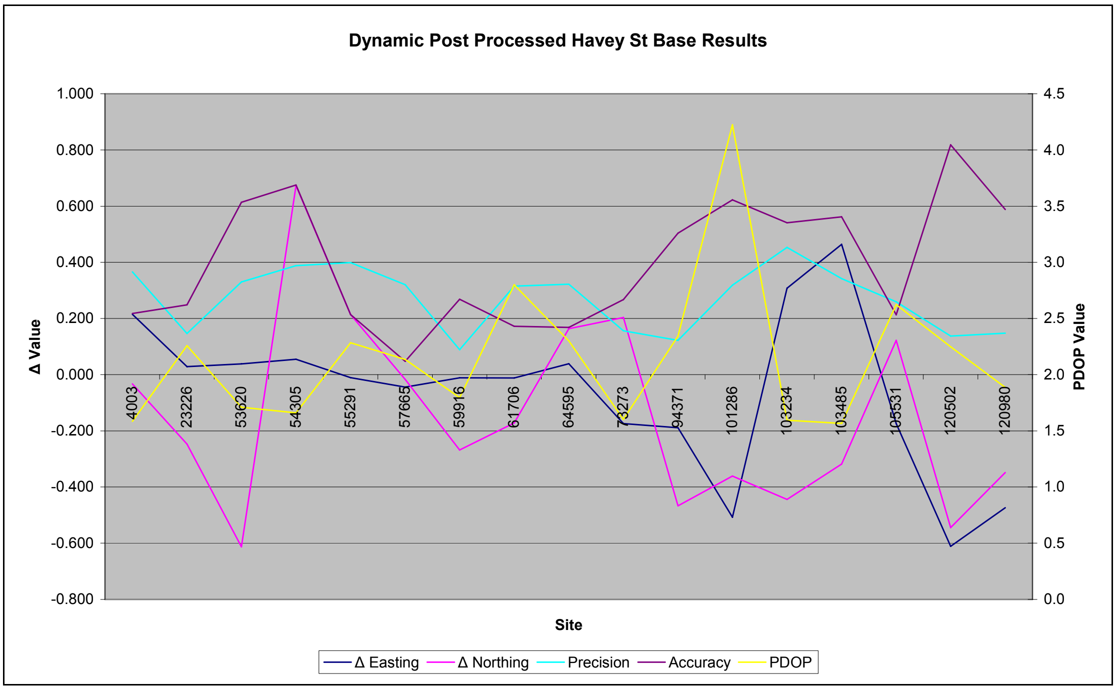

Dynamic Uncorrected GPS Results
Δ Value
2.500
2.000
1.500
1.000
0.500
0.000
-0.500
-1.000
-1.500
-2.000
-2.500
PDOP Value
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
4003
23226
53620
54305
55291
57665
59916
61706
64595
73273
94371
101286
103234
103485
105531
120502
120980
Site
Δ Easting
Δ Northing
Precision
Accuracy
PDOP

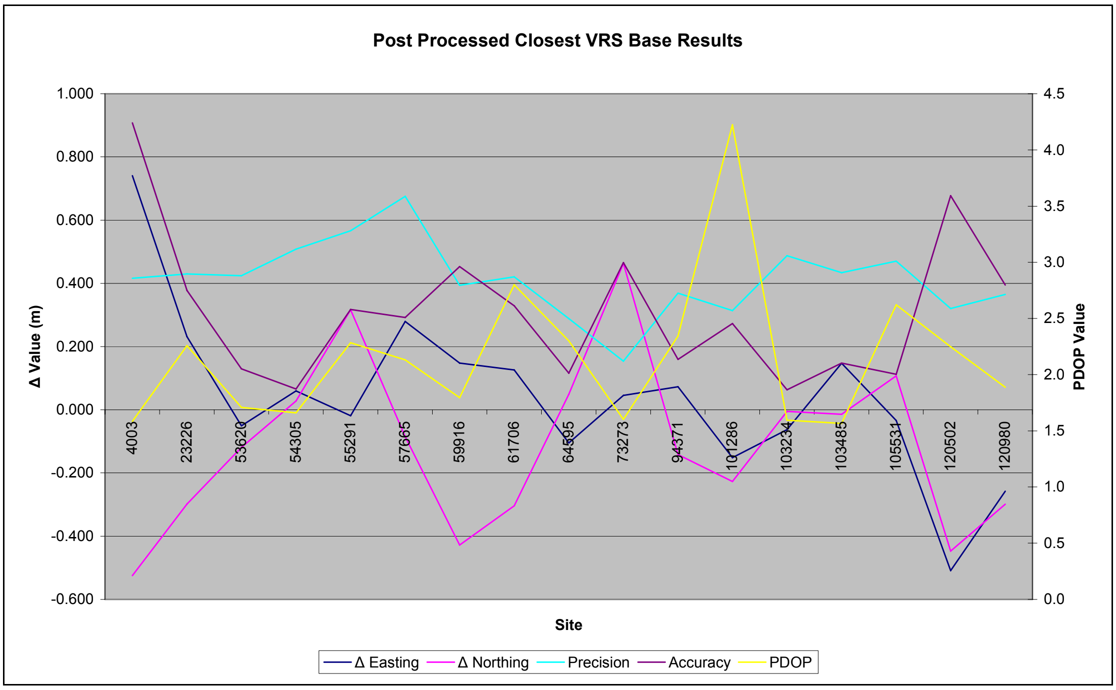


Dynamic Post Processed Virtual Base Results
Δ Value
PDOP Value
Site
1.500
1.000
0.500
0.000
-0.500
-1.000
-1.500
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
4003
23226
53620
54305
55291
57665
59916
61706
64595
73273
94371
101286
103234
103485
105531
120502
120980
Δ Easting
Δ Northing
Precision
Accuracy
PDOP



Dynamic Post Processed USQ Base Results
Δ Value (m)
PDOP Value
Site
1.000
0.800
0.600
0.400
0.200
0.000
-0.200
-0.400
-0.600
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
4003
23226
53620
54305
55291
57665
59916
61706
64595
73273
94371
101286
103234
103485
105531
120502
120980
Δ Easting
Δ Northing
Precision
Accuracy
PDOP


Dynamic Post Processed Havey St Base Results
Δ Value
PDOP Value
1.000
0.800
0.600
0.400
0.200
0.000
-0.200
-0.400
-0.600
-0.800
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
4003
23226
53620
54305
55291
57665
59916
61706
64595
73273
94371
101286
103234
103485
105531
120502
120980
Site
Δ Easting
Δ Northing
Precision
Accuracy
PDOP


Post Processed Closest VRS Base Results
Δ Value (m)
PDOP Value
1.000
0.800
0.600
0.400
0.200
0.000
-0.200
-0.400
-0.600
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
4003
23226
53620
54305
55291
57665
59916
61706
64595
73273
94371
101286
103234
103485
105531
120502
120980
Site
Δ Easting
Δ Northing
Precision
Accuracy
PDOP