University of Southern Queensland
Faculty of Engineering and Surveying

Evaluation of Ashtech ProMark2 Survey System

A dissertation submitted by

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ABSTRACT

The use of GPS receivers in surveying has become widespread. The limiting factor for many firms remains the relatively high cost of the equipment. This project evaluates the performance of the Ashtech ProMark2 survey system. The Ashtech system comprises two single frequency (L1) receivers and a suite of software for processing, mission planning and file conversions. At the time of purchase the system was approximately 1/6th of the price of a pair of RTK receivers. The Ashtech ProMark2, however the Ashtech system provides post processed results only (no real time capabilities).

The objective of the project is to establish what level of accuracy is achievable using the Ashtech ProMark2. Also to determine the effect of changes in baseline length, number of available satellites, dilution of precision and observation duration. Some recommendations as to appropriate observation durations depending on existing conditions are also made.

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Certification

I certify that the ideas, designs and experimental work, results, analysis and conclusions set out in this dissertation are entirely my own effort, 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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GLOSSARY

Almanac:	Data sent to receiver by satellite to allow determination of satellite positions on future dates/times. Used for planning the best time for satellite observations on a particular date.
Baseline:	Direct line between two survey marks, which is measured by data collection at both points simultaneously, and subsequent processing of this data.
Broadcast Ephemerides:	Satellite data downloaded during observation, which is then processed to solve for the baseline length and bearing. The signal gives the satellites time and location according to the satellite.
DOPs:	Dilutions of Precision; are related to the satellite configuration in the sky. If the satellites are spread out evenly across the sky then the DOP will be low. If the satellites are tightly grouped in one part of the sky then the DOPs will be high. Lower DOPs will give better results for the baseline.
GPS:	Global Positioning System, space based navigation system using satellite signals to determine the position of a receiver on the Earth's surface.
L1 and L2	GPS carrier signal wavelengths. The satellites broadcast ephemerides on both L1 and L2 frequencies.
MGA94	UTM grid coordinates (easting, northing and RL) based on the Geocentric Datum of Australia (GDA). For this project all coordinates are in Zone 55.

Post Processing:	Recorded data is loaded onto a PC after the observation and the baseline is then computed.
Precise Ephemerides:	More accurate satellite position information that is available for download from the Internet approximately 15 days after the observation date. This data is based on adjustments made to correct the satellite positions relative to ground control stations.
PSM:	Permanent Survey Mark, usually a brass plaque set in a concrete block buried in the ground.
RTK:	Real Time Kinetic, survey system that allows for solving of baseline in real time. A radio link between receivers is used to transmit satellite data for immediate baseline determination.
SVs:	Space Vehicles, refers to the GPS satellites themselves.
WGS84	Geocentric datum used for GPS ephemerides (broadcast and precise).

CHAPTER 1
INTRODUCTION

1.1 Outline of Study.

This study aims to evaluate the Static Mode performance of the Ashtech ProMark 2 GPS survey system (including two receivers, antennae, cables and software packages). Evaluation will be carried out with respect to variance in baseline length, number of satellites or space vehicles (SV's), dilutions of precision (DOP's) and observation times. It was hoped that the evaluation would have used both broadcast and precise ephemeredes for comparison. The author was unable to process downloaded precise files in the software (support from the manufacturer was unavailable in time to include in this report).

1.2 Introduction.

The Global Positioning System is a system of satellites and ground based monitoring stations designed to enable users to determine their position on the Earth's surface. The system was designed and implemented by the US military for navigation and coordination of military assets.

Many civilian companies have since produced commercially available navigation and surveying tools. Civilian use of GPS extends to:

- Navigation of ships, aircraft and other vehicles (including satellite navigation systems available for cars).

- Hand held personal location and navigation devices for use by campers and hikers.
- Tracking devices to locate company assets such as trucks, ships and trains. Or security tracking devices to locate stolen vehicles.
- Land surveying to locate specific features on the Earth for the purposes of mapping, design work, setout for construction etc.

The global positioning system consists of three segments: The space segment of GPS is a constellation of 24 satellites. The control segment consists of a control centre and access to overseas command stations and the user segment includes GPS receivers and associated equipment. (Pace *et al*. 1995).

GPS survey equipment is capable of making baseline measurements using static, rapid static, kinematic and real-time kinematic (RTK).

Static surveying is where two or more locations (one receiver at each) are occupied simultaneously for a length of time to collect data. A minimum of 4 common (to both receiver locations) satellites must be observed at each site. The coordinate differences between the two points can then be determined with sufficient accuracy. Observation processing requires the data to be post-processed (uploaded to computer for software processing to determine the coordinate differences between the two points).

Rapid Static surveying uses a base station fixed on a known point and a rover (a separate receiver) attached to a pole such that it can be carried from point to point. This method requires an initialisation period that measures a known baseline length for a length of time sufficient to remove most errors from the solution. This method requires the data to be post-processed.

Kinematic surveying also uses a rover and base station similar to rapid static (including the requirement for initialisation) but it measures points approximately every second while the rover is in motion. The data collected can then be processed to determine the path the rover took. This method requires the data to be post-processed.

Real Time Kinematic (RTK) surveying is similar to kinematic surveying but utilises a radio or other communication link between receivers to allow computer processing for coordinate differences (and hence the rover location) in real time.

The advantages that GPS based survey systems have over conventional total-station survey equipment include:

- No requirement for direct line of sight between occupied points.
- Long baselines (many kilometres) can be observed in one observation.

Disadvantages include:

- The need for an unobstructed ‘view’ of the sky at each occupied position.
- Many factors can introduce errors into GPS observations such as; multipath (satellite signals that have been reflected off buildings etc.) and atmospheric variations.
- Requirement for at least 4 common satellites to be visible at both locations.

1.3 The Problem.

The focus of this work is the Ashtech ProMark 2 survey system (see figure 1.1). The system comprises two hand-held type single frequency (L1) receivers each with an external antenna. A full version of Ashtech Solutions processing software (minus the ability to process L2 carrier phase observations) is also supplied.

Figure 1.1 Ashtech ProMark2 GPS surveying system receiver pack.

Figure 1.1 (left) shows the contents of one receiver pack. This includes:

- Ashtech receiver.
- External antenna.
- Connecting cable.
- Tripod bracket.
- Tribrach adapter.
- Calibrated tape for antenna height measurement (calibrated for antenna phase centre above mark).

Figure 1.2 Ashtech ProMark2 GPS surveying system set up on tripod.

This equipment was purchased in mid 2004 as a relatively low cost (approximately 1/6th the cost of a full RTK system) GPS survey system, and has been used for contour and engineering surveying applications. The static mode use of the system for control survey work has provided some inconsistent results when checked against more traditional total-station traversing.

The aim of this project is to confirm that the equipment is suitable for the accurate placement and measuring of survey control points. Also, to make recommendations as to the observation times necessary to produce acceptable results depending on satellite availability and baseline length.

1.4 Research Objectives.

For any given baseline observation there are several variables that can be controlled to some degree by the operator. Mission planning software (included with Ashtech Solutions) can determine the optimum time (based on satellite availability) at which to perform an observation. The duration of the observation is infinitely variable and care must be taken that the observation is long enough to provide sufficient data to process an accurate result.

This project aims to determine the accuracy possible using the equipment with variations in the number of satellites, DOP's, baseline length and observation duration.

The research methodology is divided into five subparts these being…

1. Research information relevant to the problem.
2. Perform field observations of different length baselines under controlled conditions.
3. Reduce and analyse the fieldwork for each baseline using varied combinations of observation times, number of satellites and DOP's.
4. Determine recommended minimum observation times depending on variations in each tested condition.

1.5 Conclusion.

This project aims to confirm the suitability of the Ashtech ProMark 2 survey system for static mode control survey work and to determine the required observation times with respect to varying baseline length, number of available satellites, and the corresponding variations in DOP's.

CHAPTER 2
LITERATURE REVIEW

2.1 Introduction.

This chapter will review literature to establish the need for reliably accurate GPS measurements. This review will describe how survey observations are made using GPS equipment. This review will identify what regulations are in place to control the type and condition of survey equipment used, as well as the accuracy required for survey measurements in Victoria, New South Wales and Queensland. The review will also determine what recommended best practices exist for performing static GPS surveys, as well as methods for evaluating the accuracy of GPS receivers. Finally this review will establish the accuracy of permanent survey marks available for baseline measurement in this project.

2.2 Need for evaluation.

Each GPS surveying system exhibits varying characteristics due to the differences in the hardware and software utilised. There is a need then to test each different system to ensure that consumers are being offered a competent surveying tool.

The Federal (USA) Geodetic Control Subcommittee (FGCS) have tested all GPS surveying instrumentation as it has been released onto the market. The tests have been carried out using single and dual frequency receivers. No other country has systematically tested GPS surveying receivers in this way (SNAP-UNSW 1999a). This suggests that the Ashtech Promark2 has already been tested in North America; however the difference in location can have an effect on equipment performance. Some GPS errors/biases are a function of geographic location – "how can a test be considered conclusive if it is carried out in only one location?" (SNAP-UNSW 1999b).

This project is aimed at determining the accuracy achievable using the Ashtech ProMark2 system. The assumption is made that the FGCS has already tested the equipment in North America. However local error sources may be affecting the equipment and therefore the results. The fact that the equipment has been previously tested in the USA does not provide conclusive evidence of its performance in southern Australia.

2.3 GPS Surveying.

The Survey Board of Victoria states that GPS is suitable for a broad range of surveying applications including; cadastral/engineering setout, topographic mapping, and geodetic control (Survey Board Victoria 2006).

Traditionally, GPS has been used for high precision geodetic survey, engineering and topographical surveys (via post processing and real time techniques) (Survey Board Victoria 2006). In reality GPS is just another surveying tool and as such may be used in conjunction with traditional methods to provide sufficient information to fix boundaries, marks and occupation (Survey Board Victoria 2006).

The Surveyors (Cadastral Survey) Regulations 1995 (for Victoria) state that a licensed surveyor must:

1. use survey equipment which has been compared to a standard of measurement in units specified in Part A schedule 6 of the Survey Coordination (Surveys) Regulations 1992
2. ensure that the process and basis of comparison are adequate to obtain the accuracy for a cadastral survey under Regulation 6, and
3. retain records of comparisons and make them available to the Surveyor-General if requested.

The above information suggests that GPS equipment may be used at the surveyor's discretion providing that accuracy requirements for the work are met.

2.3.1 Differential GPS Observations.

The basic GPS positioning technique relies on a distance resection computation. A receiver on the earth tracks the signals transmitted from orbiting satellites. Using these signals the range, or distance, to each satellite is determined (Survey Board Victoria 2006). In order to process for the baseline between two points a minimum of four satellites must be observed simultaneously at both receivers.

The locations of the satellites must be known at the instant the satellite signal is transmitted. Each GPS satellite broadcasts its location in terms of an ephemeris (the broadcast ephemeris), which is generally accurate to better than 10 metres (Survey Board Victoria 2006).

By using two GPS receivers tracking the same satellites simultaneously, it is possible to remove many systematic errors and improve the relative position estimates to metre- or millimetre-level (Survey Board Victoria 2006).

GPS surveying equipment is capable of tracking the carrier phase signals. The GPS L1 and L2 bands have wavelengths of approximately 19 and 24 centimetres respectively (Survey Board Victoria 2006). The Ashtech ProMark2 system observes the 19cm L1 carrier signal only. Given that the carrier wavelengths can be tracked to within a few percent of the wavelength, this means that millimetre-level positioning is possible. Unfortunately, carrier phase measurements contain a cycle ambiguity term that must be resolved to obtain accurate results (Survey Board Victoria 2006). Cycle ambiguity is the unknown number of whole carrier wavelengths between the satellite and receiver (USACE 2003). Successful ambiguity resolution is required for baseline formulations. Generally, in static surveying, ambiguity resolution can be achieved through long-term averaging and simple geometric calibration principles, resulting in solutions to a linear equation that produces a resultant position. Thus 30 minutes or more of observations may be required to resolve the ambiguities in static surveys (USACE 2003).

2.3.2 Static Mode Observations.

Static observations are made by occupying two (or more) survey points with a receiver each. The simultaneous satellite observations can then be processed to provide coordinate differences in X, Y and Z based in the WGS84 geocentric ellipsoid (USACE 2003). The coordinate differences can then be computed as differences in a local coordinate system such as MGA94.

Static observing sessions can range from 20 minutes to 3 hours in length. A single epoch of data (one set of satellites ranges) is sufficient to achieve centimetre-level results once the carrier phase ambiguities are resolved. The long observation times are to ensure that the phase ambiguity can be calculated (Survey Board Victoria 2006).

2.3.3 GPS ephemerides.

An ephemeris as defined by Webster as "*a table giving the coordinates of a celestial body at a number of specific times within a specific period*". For the purpose of making GPS observations the orbiting satellites are treated the same as any other celestial body.

In order to record our positions relative to these man-made celestial bodies, we need to know where the satellites are at a given time, hence the need for an ephemeris. GPS ephemerides are available in two general types—the broadcast ephemeris, and the precise ephemeris (Martin 2003).

The computed accuracy of the broadcast ephemeris is approximately 260 centimetres, and approximately 7 nanoseconds. The final precise orbits are available approximately two weeks after the data is collected and have a reported accuracy of less than five centimetres, and 0.1 nanoseconds (Martin 2003).

The improvement in accuracy between the broadcast and precise ephemerides suggests that using the latter will improve the accuracy of the computed baselines.

It was hoped that a comparison of results processed using broadcast and precise ephemerides could be included in this project. The downloaded precise files, however, were not recognized by the Ashtech Solutions processing software. At the time of writing this dissertation this issue had not been resolved with the manufacturer.

2.4 Survey Accuracy Regulations.

The measurements made by surveyors are subject to standards of accuracy. These standards vary slightly from state to state. The Inter-Governmental Committee on Surveying and Mapping (ICSM) also provides standards of accuracy for survey work. These accuracy standards are summarised in table 2.1 below. Note the manufacturer's claimed accuracy is also included. Full descriptions of the individual accuracy standards can be found in appendix B.

Table 2.1 Summary of accuracy standards.

Standard of accuracy.	Allowable misclose.	Sample (1km)
Survey regulations for Victoria.	15mm + 100ppm	115mm
Survey regulations for New South Wales.	15mm + 100ppm	115mm
Survey regulations for Queensland.	10mm + 200ppm	210mm
ISCM class 3A	(d + 0.2)mm	1.2mm
ISCM class 2A	3(d + 0.2)mm	3.6mm
ISCM class A	7.5(d + 0.2)mm	9mm
ISCM class B	15(d + 0.2)mm	18mm
ISCM class C	30(d + 0.2)mm	36mm
ISCM class D	50(d + 0.2)mm	60mm
ISCM class E	100(d + 0.2)mm	120mm
Manufacturer’s claimed accuracy	5mm + 1ppm	6mm (Horiz.)

2.5 Recommended Static Surveying Practices.

The practice of surveying is regulated to maintain a suitably high standard of accuracy. The high value attached to land and improvements such as buildings, roads and other constructions requires that their position be carefully established and marked. The methods employed by surveyors are left to the individual surveyor, however there are some guidelines provided by the regulating authorities.

From Natural Resources Information Management Toolkit Section 10.2 Best practice guidelines for GPS surveys, sub-section 10.2.6 General requirements:

Include recording the point identifier at the time of the observation to ensure that there is no confusion when processing the observation. The dilution of precision should be less than 8 to minimise the effect or poor satellite geometry. Mission planning should be carried out to ensure sufficient satellites are available (minimum of four). In Australia the elevation mask should be set at 15 degrees above the horizon (satellites below this elevation should be disregarded). Known reference marks used should have high quality coordinates and heights (when required). All field observations should be recorded on field observation sheets as a reference. Measurements must form a closed figure, and be connected to at least 2 known marks. Accuracy should be checked by performing a least squares adjustment of the observed network, these adjustments should be three dimensional in nature.

From Natural Resources Information Management Toolkit Section 10.2 Best practice guidelines for GPS surveys, sub-section 10.2.6.1 Static Surveying:

Include keeping observations to a minimum of 30 minutes and in duration. The recording interval should be 15 or 30 seconds. The satellite geometry should alter significantly over the course of the observation. The use of single frequency receivers (such as the Ashtech ProMark2 receivers) should be kept to short lines for non high precision applications.

It is interesting to note that these recommendations state that single frequency receivers are suitable only for short baseline observations in non high precision applications. This project aims to evaluate a range of baseline measurements (up to fifteen kilometres) for accuracy.

2.6 Validation Methods for GPS Receivers.

The equipment used for a particular survey is left to the surveyor. Only the accuracy and precision of the end result is subject to regulation. The equipment used by a surveyor should be selected and maintained such that it is capable of producing results that pass the requirements of the regulatory body. Any testing procedure may be adopted by the surveyor as long as it can be established that the measurements have been compared to appropriate standards, and can be made within appropriate accuracy tolerances (Survey Board Victoria 2006).

There exist two separate tests for evaluating GPS receivers in static mode. These are the zero baseline test and the test network observation.

2.6.1 Zero Baseline Test.

This can be carried out to check the correct operation of a pair of GPS receivers, associated antennas/cabling, and data processing software. A zero baseline test involves connecting two GPS receivers to the same antenna via an antenna splitter (as recommended by the manufacturer). The computed baseline should be theoretically equal to zero and any variation will represent a vector of receiver errors (should give sub millimetre results).

This is a very simple and inexpensive process which:

- verifies the precision of the GPS receiver measurements,
- proves that the receiver is operating correctly, and also
- validates the processing software (Survey Board Victoria 2006).

2.6.2 Static Mode Evaluation.

From: Surveyors Registration Board of Victoria, Survey Practice Handbook, Part 2, Section 12, Subsection 12.1.2 (2006):

A High Accuracy GPS Test Network (Static Techniques)

This can be undertaken to ensure that the operation of GPS receivers, associated cabling, and data processing software, give high accuracy baseline/coordinate results. Satellite ephemeris errors, clock biases and atmospheric effects must be removed or minimised during baseline processing. Network validation allows GPS equipment to be tested under realistic field conditions which includes the dynamic nature of the satellite constellation and the atmosphere (Survey Board Victoria 2006).

The test network should consist of extremely stable ground marks with almost perfect sky visibility and be of very high precision (e.g. first or second order). The stations should be coordinated in both the local geodetic system (AGD/GDA φ, λ, h or x, y, z) and plane projection (MGA E, N and AHD elevations). Observed baselines should have a variety of baseline lengths and directions, and consist of points with varying elevations (to check for the correct modeling of the atmosphere as well as geoid determination to obtain AHD values) (Survey Board Victoria 2006).

After observing the network, the surveyor can process the data to produce a network of vectors. These vectors can then be reviewed, adjusted and analysed against the known mark coordinates.

As all marks observed in this project have known horizontal coordinates and known elevation the observed vectors will be analysed against the coordinate differences for the each pair of permanent survey marks.

2.7 Satellite orbit period.

Ideally the test observations would be carried at the same time such that the satellite configuration in the sky was the same (eliminating a further variable in the results). This was not possible, as the author only had access to two receivers.

It was necessary to know the time it takes for the satellites to complete 1 orbit. This is so that the observations can be taken at the same point in the satellite orbit to keep the satellite configuration close to constant for all observations.

Their orbital period is approximately 11hrs 58mins, so that each satellite makes two revolutions in one sidereal day (the period taken for the earth to complete one rotation about its axis with respect to the stars). (SNAP-UNSW 1999c).

At the end of a sidereal day (approximately 23hrs 56mins in length) the satellites are again over the same position on earth. (SNAP-UNSW 1999c).

Reckoned in terms of a solar day (24hrs in length), the satellites are in the same position in the sky about four (4) minutes earlier each day. (SNAP-UNSW 1999c).

If the observations are made as close to 23 hours 56 minutes apart then the satellite configuration should stay reasonably constant.

2.8 Control Mark Accuracy.

The coordinates assigned to a survey station have accuracies dependent on the survey used to connect them to the network. (ICSM 2004). The survey marks used in this project are supplied with 3rd order coordinates and as such have an error tolerance attached to them. The ISCM sets the order of a survey mark according to the class of the survey used to connect the mark and the fit of this connection with the rest of the network.

Order is a function of the Class of a survey, the conformity of the new survey data with an existing network coordinate set and the precision of any transformation process required to convert results from one datum to another.
(ICSM 2004).

The order assigned to the stations in a new survey network following constraint of that network to the existing coordinate set may be;

a) not higher than the order of existing stations constraining that network, and
b) not higher than the class assigned to that survey.

The highest order that may be assigned to a station from a survey of a given class is shown (ICSM 2004).

Table 2.2 Survey of a class – Highest order relationship (ICSM, 2004)

CLASS	ORDER
3A	00
2A	0
A	1
B	2
C	3
D	4
E	5

This shows that the 3rd order coordinates supplied with the PSMs used in this project were most likely connected to the network by a survey passing class C accuracy.

2.9 Conclusion.

This chapter has established the need to ensure that survey equipment performs accurately and reliably. The need for this project has been outlined. The basics of GPS surveying have been described, particularly in static mode.

Victoria, New South Wales and Queensland regulations as well as ICSM standards have been reviewed and the accuracies required for cadastral surveying have been found to be less stringent than the manufacturer's quoted accuracy.

General guidelines for successful GPS observations have been reviewed, along with more specific recommendations relating to static mode observations, including equipment test procedures.

The accuracies of coordinates associated with established survey marks have also been outlined.

CHAPTER 3
PROJECT METHODOLOGY

3.1 Introduction.

The methodology of the project has been established by the findings of the Literature Review. The tests selected to establish that the Ashtech ProMark2 receivers (and associated processing software) were the zero baseline test and the test network observation.

The performance of a Zero Baseline observation was dependent on the availability of a splitter connection to allow two receivers to record data from a single antenna. This piece of equipment was unable to be acquired during the course of the study and as such, the zero baseline test was not performed.

The network observations were processed with varied numbers of satellites (and corresponding variations in DOP's) and observation times for each baseline.

The baseline observations were made in the City of Greater Bendigo spanning the suburbs between Epsom and Kangaroo Flat (see appendix C for map).

3.2 Expectations.

The study is expected to provide a definitive answer as to the achievable accuracy of results using the Ashtech ProMark2. These results will then be used to determine what types of survey work the equipment is suitable for, as well as forming the basis for recommendations about appropriate observation durations.

3.3 Reference Marks.

The availability of first or second order survey marks in the local area is very limited. This has meant that the test network will consist of permanent survey marks with 3rd order coordinated attached to them. The locations of these marks are illustrated in appendix C.

The survey mark enquirery service accessed at http://land.vic.gov.au/smes provides a search function (to locate survey marks) as well as providing sketch plans and coordinates for these marks. The sketch plans for the permanent marks utilised for this project are included as appendix D.

3.4 Fieldwork.

3.4.2 Network observations.

Each baseline is to be observed for 2 hours at the same time of day on consecutive days to ensure similar satellite configuration and motion.

The procedure for each observation was:

1. Set up over the PSM taking care to ensure that the antenna is level and directly over the centre of the mark. Measure the height of the antenna using the Ashtech supplied tape (calibrated for the phase centre of the antenna).
2. Turn on the receiver and set as follows:
    a. Select static survey mode.
    b. Enter point identifier (different for each receiver).
    c. Select 30 second observation interval.
    d. Enter antenna height.
    e. Set units to metres.
3. Leave the receiver running and proceed to the next mark and repeat the setup procedure.
4. Collect 2 hours of overlapping data.
5. Turn off and pack up the first receiver and return to the first mark to pack up.

3.6 Analysis.

The post processing and data analysis steps are:

1. Upload data files from receivers to PC for processing.
2. Create files for different baselines, satellite numbers and observation times. The Ashtech Solutions software package allows the observation data to be trimmed prior to processing. For each file the data was trimmed to create an observation of the required length. The software also allows specific satellites to be removed from the processed data; satellites were removed to generate files with 4, 5, 6, and 8 satellites present in the data.

3. Trim data and remove satellites from files to create varied conditions as per table 3.1 below.

Table 3.1 Vectors to be processed.

Obs.	1km Baseline					2km Baseline					5km Baseline					10km Baseline					15km Baseline				
Time	Number of SVs					Number of SVs					Number of SVs					Number of SVs					Number of SVs				
Min.	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
10																									
15																									
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110																									
115																									
120																									

Each blank square in the table represents a vector to be processed.

4. Process files to determine measured baselines.
5. Compare the measured baselines with the known coordinates to determine the misclose for each condition.
6. Determine the accuracy of the observations against the standards defined in chapter 2.
7. Plot the misclose against the observation time for each combination of baseline length/number of satellites.

3.7 Data Analysis.

By plotting the misclose against the observation time for each condition it is possible to see if there is some relationship between the length of the observation and the achieved accuracy. Then it is also possible to recommend minimum observation durations for each combination of number of satellites and baseline length.

The level of accuracy achieved can also be assessed to determine if the equipment is suitable for use for cadastral (by comparison with survey regulations) and other work.

If there is an observed correspondence between observation time and accuracy, and the accuracy can be shown to comply with the regulations, then a recommended observation time can be determined for each condition.

3.8 Conclusion.

The methodology for this project can be broken down into the following components:

1. Research information relating to the global positioning system, GPS surveying, static survey techniques, accuracy requirements, reference mark accuracies and GPS receiver evaluation techniques.
2. Field observations were made measuring baselines between coordinated permanent survey marks. The baselines measured were be of varied lengths.

3. The recorded data was processed to produce resultant baseline vectors which were then compared to the known coordinates for the stations to determine the accuracy for each set of conditions.
4. Recommendations were made as to the observation time required for variations in baseline length, number of visible satellites and dilutions of precision.

CHAPTER 4
RESULTS

4.1 Introduction.

The literature review identified two tests to determine whether or not a GPS survey system is performing as it should. The first of these was the zero baseline test which was not performed due to the lack of a cable splitter.

The results presented in this chapter are for the second test, the observation of known survey points. The observations performed form a closed loop to provide a further check on the system performance.

The author has decided that, in the absence of the zero baseline test, if the results achieved around the baseline network are suitably accurate then the system can be said to be functioning correctly.

4.2 Results compared with Known Coordinates.

4.2.1 Permanent Mark Coordinates.

The permanent marks used to define the baselines for this test each carry assigned third order MGA coordinates (see appendix D). These coordinates are shown in table 4.1 below.

Table 4.1 Known PSM coordinates.

Permanent Mark.	Easting (Zone 55)	Northing (Zone 55)	RL (AHD)
PM22	260402.546	5935515.250	182.374
PM56	253575.556	5921434.301	273.460
PM872	260964.054	5928409.319	243.520
PM1013	260746.861	5934403.227	186.827
PM1927	260082.548	5933428.672	190.217

The baselines measured were:

1. PM1013 to PM22 approximately one kilometre.
2. PM22 to PM1927 approximately two kilometres.
3. PM1927 to PM872 approximately five kilometres.
4. PM872 to PM56 approximately ten kilometres.
5. PM56 to PM1013 approximately fifteen kilometres.

The vectors for each baseline 1 to 5 are expressed as differences in Easting, Northing and RL in table below.

Table 4.2 Observed vectors calculated from known coordinates.

Baseline	Δ Easting.	Δ Northing.	Δ RL
1.	-344.315	1112.023	-4.453
2.	-319.998	-2086.578	7.843
3.	881.506	-5019.353	53.303
4.	-7388.498	-6975.018	29.940
5.	7171.305	12968.926	-86.633

4.2.2 Observed Vectors

The GPS observations were split up as described in chapter 3 to provide raw data for observations meeting each of the requirements in table 4.3 below.

Table 4.3 Vectors to be processed.

Obs.	1km Baseline					2km Baseline					5km Baseline					10km Baseline					15km Baseline				
Time	Number of SVs					Number of SVs					Number of SVs					Number of SVs					Number of SVs				
Min.	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
10																									
15																									
20																									
25																									
30																									
35																									
40																									
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75																									
80																									
85																									
90																									
95																									
100																									
105																									
110																									
115																									
120																									

Each blank square represents a vector to be analysed (total 575).

Each vector was reduced using Ashtech Solutions version 2.60 to provide ΔE, ΔN and ΔRL for comparison against the vectors in table. The analysis involved the calculation of 3-dimensional misclose, horizontal misclose and vertical misclose compared to the permanent mark coordinates.

4.2.3 Sample Calculations.

The processed vector was compared against the known vector to provide miscloses as follows.

The tables 4.4 and 4.5 show the computations conducted to create the miscloses for each vector.

The columns in these tables can be described thus:

1. Represents the observation duration in minutes.
2. The difference in the Easting measured between the survey marks.
3. The difference in the Northing measured between the survey marks.
4. The difference in the elevation measured between the survey marks.
5. The computed slope distance between the survey marks.
6. The difference between the measured ΔE and the known ΔE.
7. The difference between the measured ΔN and the known ΔN.
8. The difference between the measured ΔRL and the known ΔRL.
9. The misclose of the measured and known vectors in 3 dimensions.
10. The misclose considering only ΔEs and ΔNs (horizontal).
11. The misclose in vertical direction (magnitude of ΔRL).

Table 4.4 Sample calculation of miscloses for 1km baseline using 4 Satellites.

1	2	3	4	5	6	7	8	9	10	11
Obs. Time	ΔE	ΔN	ΔRL	Length	Diff. E	Diff. N	Diff. RL	3D Misclose	Horiz. M/C	Vert. M/C
10	-346.422	1112.891	-7.150	1165.584	-2.107	0.868	-2.697	3.531	2.279	2.697
15	-345.885	1112.695	-6.494	1165.233	-1.570	0.672	-2.041	2.661	1.708	2.041
20	-345.384	1112.445	-5.835	1164.842	-1.069	0.422	-1.382	1.797	1.149	1.382
25	-345.374	1112.431	-5.792	1164.826	-1.059	0.408	-1.339	1.755	1.135	1.339
30	-344.786	1112.199	-5.033	1164.427	-0.471	0.176	-0.580	0.768	0.503	0.580
35	-344.683	1112.160	-4.900	1164.358	-0.368	0.137	-0.447	0.595	0.393	0.447
40	-344.536	1112.101	-4.706	1164.258	-0.221	0.078	-0.253	0.345	0.234	0.253
45	-344.382	1112.041	-4.506	1164.154	-0.067	0.018	-0.053	0.087	0.069	0.053
50	-344.338	1112.024	-4.450	1164.124	-0.023	0.001	0.003	0.023	0.023	0.003
55	-344.323	1112.017	-4.428	1164.113	-0.008	-0.006	0.025	0.027	0.010	0.025
60	-344.346	1112.023	-4.461	1164.126	-0.031	0.000	-0.008	0.032	0.031	0.008
65	-344.351	1112.023	-4.466	1164.127	-0.036	0.000	-0.013	0.038	0.036	0.013
70	-344.351	1112.021	-4.466	1164.126	-0.036	-0.002	-0.013	0.038	0.036	0.013
75	-344.349	1112.022	-4.464	1164.126	-0.034	-0.001	-0.011	0.036	0.034	0.011
80	-344.338	1112.020	-4.453	1164.121	-0.023	-0.003	0.000	0.023	0.023	0.000
85	-344.330	1112.019	-4.444	1164.117	-0.015	-0.004	0.009	0.018	0.016	0.009
90	-344.325	1112.017	-4.439	1164.114	-0.010	-0.006	0.014	0.018	0.012	0.014
95	-344.324	1112.016	-4.440	1164.113	-0.009	-0.007	0.013	0.017	0.011	0.013
100	-344.326	1112.016	-4.443	1164.113	-0.011	-0.007	0.010	0.016	0.013	0.010
105	-344.327	1112.016	-4.446	1164.114	-0.012	-0.007	0.007	0.016	0.014	0.007
110	-344.328	1112.017	-4.447	1164.115	-0.013	-0.006	0.006	0.016	0.014	0.006
115	-344.326	1112.016	-4.445	1164.113	-0.011	-0.007	0.008	0.015	0.013	0.008
120	-344.326	1112.015	-4.446	1164.112	-0.011	-0.008	0.007	0.015	0.014	0.007

Table 4.5 Sample calculation of miscloses for 1km baseline using 8 Satellites.

1	2	3	4	5	6	7	8	9	10	11
Obs. Time	ΔE	ΔN	ΔRL	Length	Diff. E	Diff. N	Diff. RL	3D Misclose	Horiz. M/C	Vert. M/C
10	-344.319	1112.015	-4.434	1164.110	-0.004	-0.008	0.019	0.021	0.009	0.019
15	-344.319	1112.015	-4.436	1164.110	-0.004	-0.008	0.017	0.019	0.009	0.017
20	-344.319	1112.014	-4.436	1164.109	-0.004	-0.009	0.017	0.020	0.010	0.017
25	-344.320	1112.014	-4.438	1164.110	-0.005	-0.009	0.015	0.018	0.010	0.015
30	-344.320	1112.014	-4.439	1164.110	-0.005	-0.009	0.014	0.017	0.010	0.014
35	-344.320	1112.014	-4.437	1164.110	-0.005	-0.009	0.016	0.019	0.010	0.016
40	-344.320	1112.014	-4.438	1164.110	-0.005	-0.009	0.015	0.018	0.010	0.015
45	-344.320	1112.014	-4.439	1164.110	-0.005	-0.009	0.014	0.017	0.010	0.014
50	-344.320	1112.014	-4.439	1164.110	-0.005	-0.009	0.014	0.017	0.010	0.014
55	-344.320	1112.015	-4.439	1164.111	-0.005	-0.008	0.014	0.017	0.009	0.014
60	-344.320	1112.014	-4.439	1164.110	-0.005	-0.009	0.014	0.017	0.010	0.014
65	-344.321	1112.015	-4.440	1164.111	-0.006	-0.008	0.013	0.016	0.010	0.013
70	-344.320	1112.014	-4.439	1164.110	-0.005	-0.009	0.014	0.017	0.010	0.014
75	-344.320	1112.014	-4.440	1164.110	-0.005	-0.009	0.013	0.017	0.010	0.013
80	-344.320	1112.014	-4.440	1164.110	-0.005	-0.009	0.013	0.017	0.010	0.013
85	-344.320	1112.014	-4.439	1164.110	-0.005	-0.009	0.014	0.017	0.010	0.014
90	-344.320	1112.014	-4.439	1164.110	-0.005	-0.009	0.014	0.017	0.010	0.014
95	-344.320	1112.014	-4.439	1164.110	-0.005	-0.009	0.014	0.017	0.010	0.014
100	-344.320	1112.014	-4.439	1164.110	-0.005	-0.009	0.014	0.017	0.010	0.014
105	-344.320	1112.014	-4.440	1164.110	-0.005	-0.009	0.013	0.017	0.010	0.013
110	-344.320	1112.014	-4.439	1164.110	-0.005	-0.009	0.014	0.017	0.010	0.014
115	-344.320	1112.014	-4.439	1164.110	-0.005	-0.009	0.014	0.017	0.010	0.014
120	-344.320	1112.014	-4.439	1164.110	-0.005	-0.009	0.014	0.017	0.010	0.014

This table represents calculations for 23 separate vectors. These calculations were performed for each of the 575 vectors outlined in table 4.3.

4.2.4 Analysis.

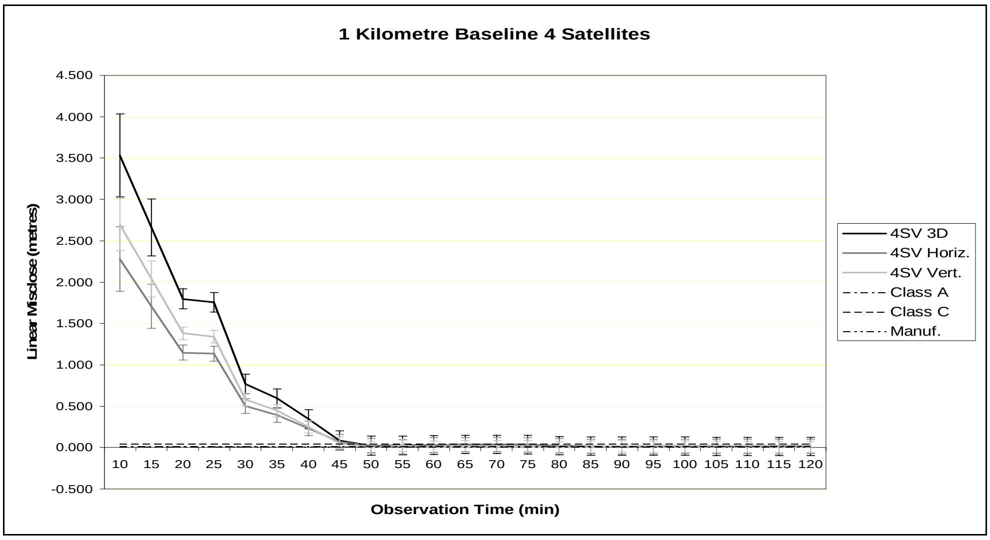
The allowable misclose for the various accuracy standards vary depending on the length of the observation. The accuracy limits for various standards for each baseline are shown in table 4.6 below.

Table 4.6 Accuracy limits for each baseline.

Accuracy Standard	1km Baseline. 1164.117m		2km Baseline. 2110.987m		5km Baseline. 5096.450m		10km Baseline. 10160.791m		15km Baseline. 14819.857m	
	Horiz.	Vert.	Horiz.	Vert.	Horiz.	Vert.	Horiz.	Vert.	Horiz.	Vert.
ICSM 3A	0.001	0.001	0.002	0.002	0.005	0.005	0.010	0.010	0.015	0.015
ICSM 2A	0.004	0.004	0.007	0.007	0.016	0.016	0.031	0.031	0.045	0.045
ICSM A	0.010	0.010	0.017	0.017	0.040	0.040	0.078	0.078	0.113	0.113
ICSM B	0.020	0.020	0.035	0.035	0.079	0.079	0.155	0.155	0.225	0.225
ICSM C	0.041	0.041	0.069	0.069	0.159	0.159	0.311	0.311	0.451	0.451
ICSM D	0.068	0.068	0.116	0.116	0.265	0.265	0.518	0.518	0.751	0.751
ICSM E	0.136	0.136	0.231	0.231	0.530	0.530	1.036	1.036	1.502	1.502
Manuf.	0.006	0.012	0.007	0.014	0.010	0.020	0.015	0.030	0.020	0.040
VIC	0.131		0.226		0.525		1.031		1.497	
NSW	0.131		0.226		0.525		1.031		1.497	
QLD	0.126		0.221		0.520		1.026		1.492	

From the sample calculation tables in section 4.2.3 it can be seen that the miscloses decrease with increases in both observation duration particularly in the 1 kilometre/4 satellite table, and with increases in number of satellites (look at the shorter observation times in both tables). Each set of miscloses produced has been plotted against the observation time as per the calculation tables. Sample plots are shown below (the dashed lines represent accuracy requirements for ICSM class A and class C surveys as well as the manufacturers claimed horizontal accuracy). The error bars on the charts represent the 95% confidence interval for the processed baseline vector.

Figure 4.1 Misclose – Observation Time 1km 4 satellites.



Four satellites is the minimum allowable to obtain a solution. The above chart shows that with the relatively small amount of data to process the solutions do not stabilise until the observation duration reaches 50 minutes. This is enough for the accuracy to pass class C. Class A and the manufacturers accuracy claim are not achieved even with 120 minutes of data. Figure 4.2 below shows the same results but expands the vertical scale to better show the results from 50 – 120 minute durations.

Figure 4.2 Misclose – Observation Time 1km 4 satellites expanded scale.

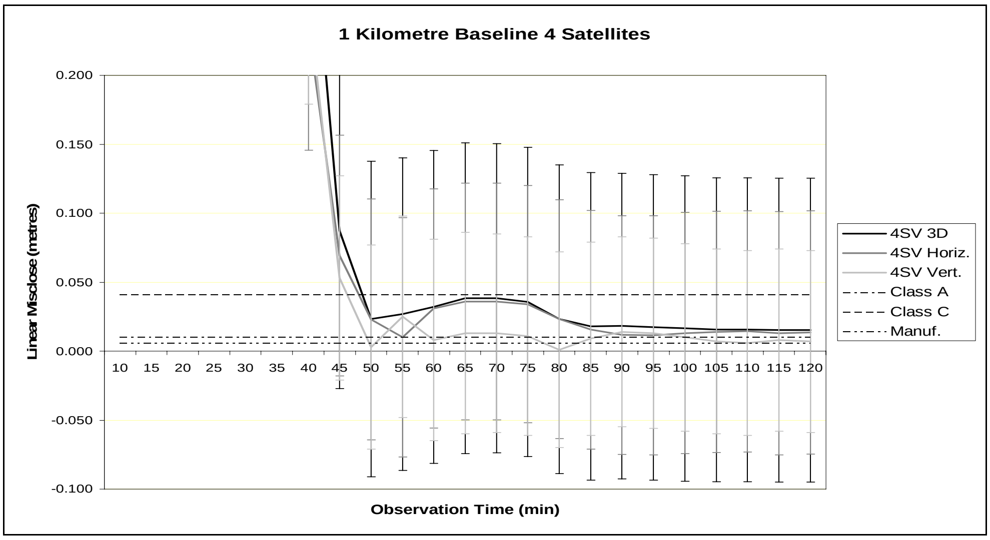
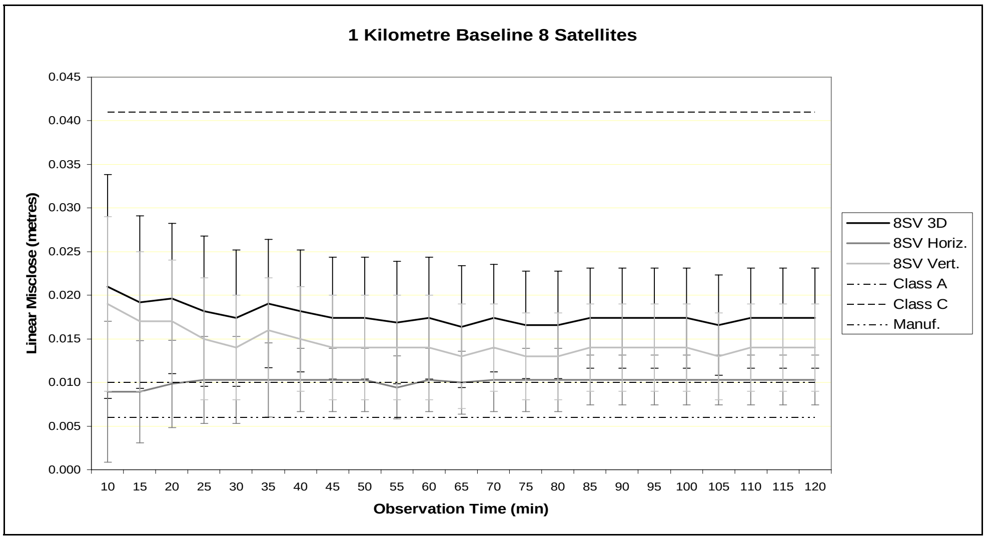


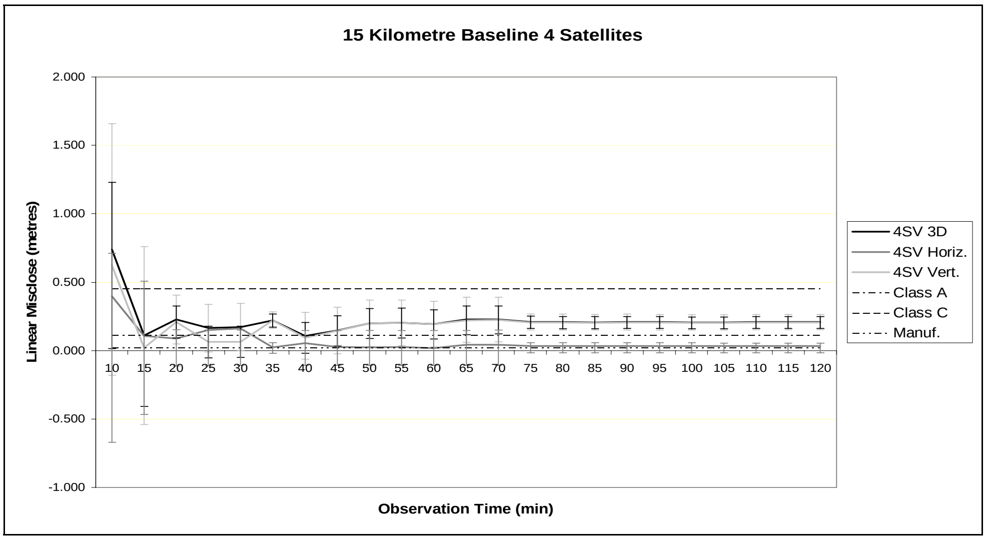
Figure 4.3 Misclose – Observation Time 1km 8 satellites.



This chart represents processing the same vector with the full 8 satellites data to process. The extra information has lead to stable results from only ten minutes of data. Class C is achieved with 10 minutes of data but class A and the manufacturers claim are not achieved in 2 hours.

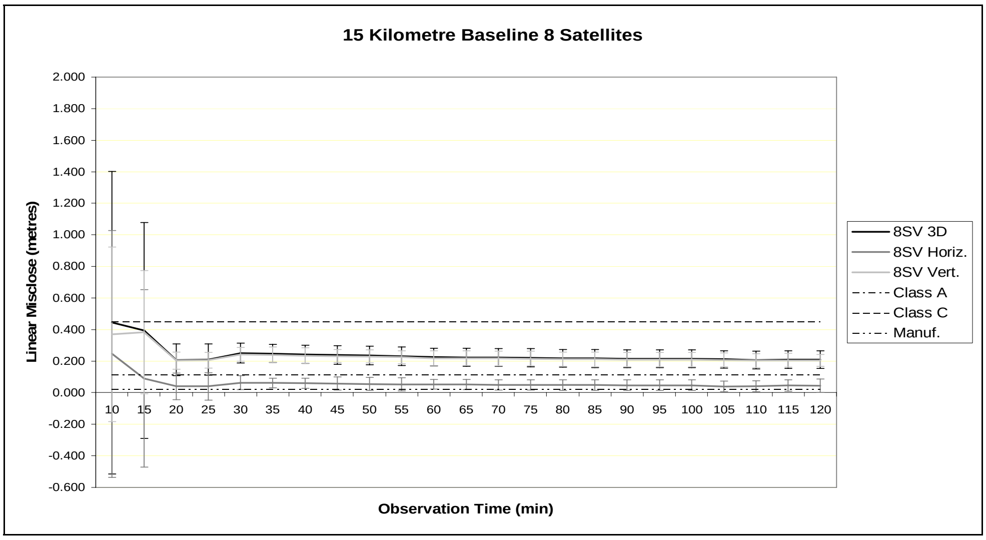
The following chart shows the results using 4 satellites on the longest (15 kilometre) baseline.

Figure 4.4 Misclose – Observation Time 15km 4 satellites.



In this case the observations pass class C after only 15 minutes but do not stabilise until 50 minutes of data is processed. Class A is again only achieved horizontally and takes 35 minutes of data. The manufacturers claimed accuracy is not achieved in 2 hours. There is also a consistent 200mm vertical misclose from 50 minutes to 120 minutes of observation duration. This misclose is also evident on the 10 kilometre baseline.

Figure 4.5 Misclose – Observation Time 15km 8 satellites.



Class C is achieved with ten minutes of data but the results do not stabilise until 30 minutes of data is used. Class A is achieved horizontally after 15 minutes. The 200mm error in the vertical persists even with the additional satellites used. The manufacturers claimed accuracy is not achieved in 2 hours.

The full set of results can be expressed in terms of the observation time required to pass each accuracy threshold for each combination of conditions. This is shown below in table 4.7.

Table 4.7 Minimum observation times using known coordinates.

	Using known PSM Coordinates: Minimum Observation time (min). ICSM Accuracy classes for survey														Manuf. Quoted Accuracy	
	3A Horiz.	3A Vert.	2A Horiz.	2A Vert.	A Horz.	A Vert.	B Horiz.	B Vert.	C Horiz.	C Vert.	D Horiz.	D Vert.	E Horiz.	E Vert.	Horiz.	Vert.
1km 4 SVs	NA	NA	NA	NA	NA	100	85	60	50	50	50	45	45	45	NA	100
1km 5 SVs	NA	NA	NA	NA	NA	NA	10	10	10	10	10	10	10	10	NA	NA
1km 6 SVs	NA	NA	NA	NA	10	NA	10	10	10	10	10	10	10	10	NA	NA
1km 7 SVs	NA	NA	NA	NA	NA	NA	10	10	10	10	10	10	10	10	NA	NA
1km 8 SVs	NA	NA	NA	NA	10	NA	10	10	10	10	10	10	10	10	NA	NA
2km 4 SVs	NA	NA	NA	NA	NA	95	NA	85	60	40	30	35	30	35	NA	115
2km 5 SVs	NA	NA	NA	NA	NA	NA	90	10	10	10	10	10	10	10	NA	NA
2km 6 SVs	NA	NA	NA	NA	NA	NA	10	10	10	10	10	10	10	10	NA	NA
2km 7 SVs	NA	NA	NA	NA	NA	NA	15	10	10	10	10	10	10	10	NA	NA
2km 8 SVs	NA	NA	NA	NA	NA	NA	10	10	10	10	10	10	10	10	NA	NA
5km 4 SVs	NA	NA	NA	NA	60	65	55	55	30	40	30	30	20	20	90	65
5km 5 SVs	NA	NA	NA	NA	40	110	40	40	30	30	25	25	15	15	NA	NA
5km 6 SVs	NA	NA	30	100	25	60	25	60	25	60	15	10	10	10	NA	95
5km 7 SVs	NA	NA	30	100	20	20	15	20	15	10	15	10	10	10	NA	90
5km 8 SVs	NA	NA	30	90	15	15	15	15	15	15	15	15	10	10	NA	75
10km 4 SVs	95	NA	80	NA	65	NA	50	NA	35	15	15	15	10	10	95	75
10km 5 SVs	80	NA	45	NA	45	NA	25	NA	25	45	10	30	10	10	65	NA
10km 6 SVs	NA	NA	65	NA	40	NA	30	NA	10	45	10	30	10	10	NA	NA
10km 7 SVs	NA	NA	70	NA	45	NA	30	NA	10	45	10	25	10	10	NA	NA
10km 8 SVs	NA	NA	55	NA	45	NA	30	NA	10	45	10	30	10	10	NA	NA
15km 4 SVs	NA	NA	45	NA	35	NA	15	15	10	15	10	10	10	10	NA	NA
15km 5 SVs	NA	NA	10	NA	10	NA	10	10	10	10	10	10	10	10	NA	NA
15km 6 SVs	NA	NA	15	NA	10	NA	10	15	10	15	10	10	10	10	NA	NA
15km 7 SVs	NA	NA	10	NA	10	NA	10	10	10	10	10	10	10	10	NA	NA
15km 8 SVs	NA	NA	105	NA	15	NA	15	55	10	10	10	10	10	10	NA	NA

4.2.5 Discussion.

The graphs show that there appears to be a threshold of data required to produce consistent results. If the number of satellites is low then the observation duration needs to be increased to provide sufficient data to produce an accurate result. The longer the baseline the greater the amount of information required to produce a consistent result. Table 4.7 also shows the accuracy improving with increases in observation duration and with increases in the number of available satellites. The results also appear to improve with increased baseline length. It is important to remember that the allowable error for each standard varies with increased distance (the misclose may increase but result may pass a higher accuracy standard). Table 4.6 shows the allowable error for each accuracy standard for all baseline lengths measured. The allowable misclose to pass each class of accuracy varies significantly with increases in baseline length. The state regulations for cadastral surveying appear to be in line (approximately) with the ICSM class E accuracy standard. The manufacturer's claimed accuracy is reasonably close to the ICSM class 2A for longer baselines and nearer to ICSM class 3A for shorter baselines.

The 200mm error in the vertical direction over both the 10 and 15 kilometre baselines could be due to a number of causes:

- The GPS system is less accurate in calculating vertical coordinate differences than horizontal. This is due to the fact that the satellites are all above the receiver. Having all the satellites in roughly the same vertical direction from the receivers creates a weaker geometric solution for the elevation.
- An incorrect antenna height may have been recorded on each observation.
- The coordinates supplied for the permanent survey marks, while satisfying 3rd order constraints, are inaccurate against the GPS observations.

It is unlikely that the antenna height was recorded incorrectly on two separate days and by approximately the same amount (the error occurred on both the 10km and 15 km baselines recorded 24 hours apart).

The other possibilities can be tested by examining the closure of the traverse loop. If the misclose around the loop is small then the PSM coordinates are likely to blame. If the misclose is large then the GPS system may be the source of the error.

4.2.6 Loop Analysis.

The loop analysis involved the addition of all the values of ΔE, ΔN and ΔRL to create a value in each direction for the misclose (similarly to the vector analysis).

The loop closure using 8 satellites is shown below in table 4.8.

Table 4.8 Loop closure using 8 Satellites.

Misclose					
ΔE	ΔN	ΔRL	3D Misclose	Horiz. Misclose	Vert. Misclose
0.210	0.310	0.412	0.557	0.374	0.412
-0.021	0.189	-0.095	0.213	0.190	0.095
-0.143	0.185	-0.444	0.502	0.234	0.444
-0.164	0.094	-0.330	0.380	0.189	0.330
-0.003	0.071	-0.132	0.150	0.071	0.132
-0.018	0.037	-0.101	0.109	0.041	0.101
0.112	0.029	-0.107	0.158	0.116	0.107
0.015	-0.021	0.052	0.058	0.026	0.052
0.013	-0.021	0.047	0.053	0.025	0.047
0.014	-0.020	0.046	0.052	0.024	0.046
0.016	-0.022	0.040	0.048	0.027	0.040
0.015	-0.020	0.039	0.046	0.025	0.039
0.016	-0.020	0.040	0.047	0.026	0.040
0.015	-0.019	0.038	0.045	0.024	0.038
0.015	-0.019	0.035	0.043	0.024	0.035
0.014	-0.019	0.033	0.041	0.024	0.033
0.013	-0.019	0.029	0.037	0.023	0.029
0.013	-0.019	0.030	0.038	0.023	0.030
0.013	-0.018	0.029	0.037	0.022	0.029
0.013	-0.007	0.029	0.033	0.015	0.029
0.012	-0.008	0.025	0.029	0.014	0.025
0.011	-0.016	0.025	0.032	0.019	0.025
0.011	-0.014	0.024	0.030	0.018	0.024

The misclose for the closed loop of vectors expressed in terms of Easting Northing and ΔRL are:

- ΔE = 11mm
- ΔN = 14mm
- ΔRL = 24mm

This level of accuracy, over ~33km of observed traverse loop, suggests that an error of 200mm vertically in 2 vectors is unlikely. The more likely cause is an error in the coordinates of one or both of these marks. Note: The coordinates supplied are only 3^{rd} order and the difference of 200mm over the 10km baseline is acceptable at this accuracy tolerance.

4.3 Results compared with Adjusted Coordinates.

The closures suggest that the GPS survey may be more accurate than the 3^{rd} order coordinates associated with the permanent survey marks. The full observations, using 120 minutes of data and all ten visible satellites were then processed and the network adjusted to provide a new set of base coordinates (the adjustment passed the processing software's chi-square test at the ICSM class 2A accuracy level).

The observed baseline analysis will now be carried out against these new adjusted PSM coordinates. This method is not recommended by the author as essentially the observations are being analysed against observation data. However, to get around the inaccuracy of the permanent marks used there was no alternative method to establish the overall accuracy of the results.

4.3.1 Adjusted Permanent Mark Coordinates.

The new set of adjusted base coordinates is shown in table 4.10 below.

Table 4.9 Adjusted coordinates.

Permanent Mark.	Easting (Zone 55)	Northing (Zone 55)	RL (AHD)
PM22	260402.473	5935515.837	199.792
PM56	253575.468	5921434.926	290.675
PM872	260963.994	5928409.939	260.920
PM1013	260746.793	5934403.824	204.231
PM1927	260082.495	5933428.276	207.612

The following vectors are shown in table below.

1. PM1013 to PM22 approximately one kilometre.
2. PM22 to PM1927 approximately two kilometres.
3. PM1927 to PM872 approximately five kilometres.
4. PM872 to PM56 approximately ten kilometres.
5. PM56 to PM1013 approximately fifteen kilometres.

Table 4.10 Adjusted vectors.

Baseline	Δ Easting.	Δ Northing.	Δ RL
1.	-344.320	1112.013	-4.439
2.	-319.978	-2086.561	7.820
3.	881.499	-5019.337	53.308
4.	-7388.525	-6975.013	29.755
5.	7171.325	12968.898	-86.444

4.3.2 Analysis.

The reduced vectors were then compared with these new adjusted vectors giving a second set of 575 results. The observation duration required to pass the accuracy standards (when compared to the new adjusted coordinates) are table below in table 4.10.

Table 4.11 Minimum observation times using adjusted coordinates.

	Using Adjusted GPS Traverse Coordinates: Minimum Observation time (min). ICSM Accuracy classes for survey														Manuf. Quoted Accuracy	
	3A Horiz.	3A Vert.	2A Horiz.	2A Vert.	A Horz.	A Vert.	B Horiz.	B Vert.	C Horiz.	C Vert.	D Horiz.	D Vert.	E Horiz.	E Vert.	Horiz.	Vert.
1km 4 SVs	NA	NA	NA	NA	90	85	80	80	50	50	45	45	45	45	NA	85
1km 5 SVs	NA	NA	110	105	35	10	10	10	10	10	10	10	10	10	85	10
1km 6 SVs	110	110	10	10	10	10	10	10	10	10	10	10	10	10	10	10
1km 7 SVs	110	110	10	10	10	10	10	10	10	10	10	10	10	10	10	10
1km 8 SVs	70	70	10	15	10	10	10	10	10	10	10	10	10	10	10	10
2km 4 SVs	NA	NA	NA	NA	70	85	65	60	40	40	35	35	30	30	NA	NA
2km 5 SVs	NA	115	105	60	10	10	10	10	10	10	10	10	10	10	105	10
2km 6 SVs	110	NA	10	10	10	10	10	10	10	10	10	10	10	10	10	10
2km 7 SVs	NA	NA	25	90	15	10	15	10	10	10	10	10	10	10	25	15
2km 8 SVs	45	NA	20	10	10	10	10	10	10	10	10	10	10	10	25	10
5km 4 SVs	NA	NA	90	65	65	65	55	55	30	40	30	30	20	20	100	65
5km 5 SVs	NA	NA	105	NA	40	100	40	40	30	30	25	25	15	15	NA	NA
5km 6 SVs	NA	NA	25	95	25	95	25	95	25	95	20	20	10	10	70	85
5km 7 SVs	115	115	20	90	20	20	20	15	15	10	15	10	10	10	70	80
5km 8 SVs	15	110	15	75	15	15	15	15	10	15	10	10	10	10	15	15
10km 4 SVs	NA	NA	NA	75	75	55	55	45	35	35	30	15	10	10	NA	75
10km 5 SVs	NA	NA	90	NA	45	75	30	45	10	30	10	25	10	10	NA	NA
10km 6 SVs	65	80	65	65	40	65	30	45	10	30	10	10	10	10	65	65
10km 7 SVs	55	80	45	55	45	55	30	45	10	25	10	10	10	10	45	55
10km 8 SVs	45	60	45	45	45	45	30	45	10	30	10	10	10	10	45	45
15km 4 SVs	75	70	50	50	35	35	15	15	10	10	10	10	10	10	75	50
15km 5 SVs	10	NA	10	10	10	10	10	10	10	10	10	10	10	10	10	10
15km 6 SVs	15	15	15	15	10	15	10	15	10	10	10	10	10	10	15	15
15km 7 SVs	45	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
15km 8 SVs	70	NA	20	45	15	20	15	10	10	10	10	10	10	10	20	55

4.4 Effects of observation time.

The charts in sections 4.2 and 4.3 show misclose vs. observation time for some sample conditions. The effect of observation time on the accuracy is most prominent when the number of satellites used in processing is low i.e. 4 satellites or when the baselines are longer i.e. 10-15 kilometres. In these cases the short observation times give relatively poor accuracy results. Increasing the observation time improves accuracy which can generally pass ICSM class A requirements even with only 4 satellites available (using the adjusted coordinates as reference).

The results for 8 satellites over the 1 and 2 kilometre baselines showed little effect of observation time over the accuracy. The results for 8 satellites over 5 kilometres showed an initial inaccurate result at 10 minutes but all following results pass ISCM class A. This can be attributed to the shorter baseline requiring less data collection to process accurate (or consistent) results. As the length of the baseline increases the amount of data needed to process an accurate result also increases.

Over the 10 and 15 kilometre baselines the effect of observation time becomes negligent after approximately 45 minutes when 8 satellites are observed.

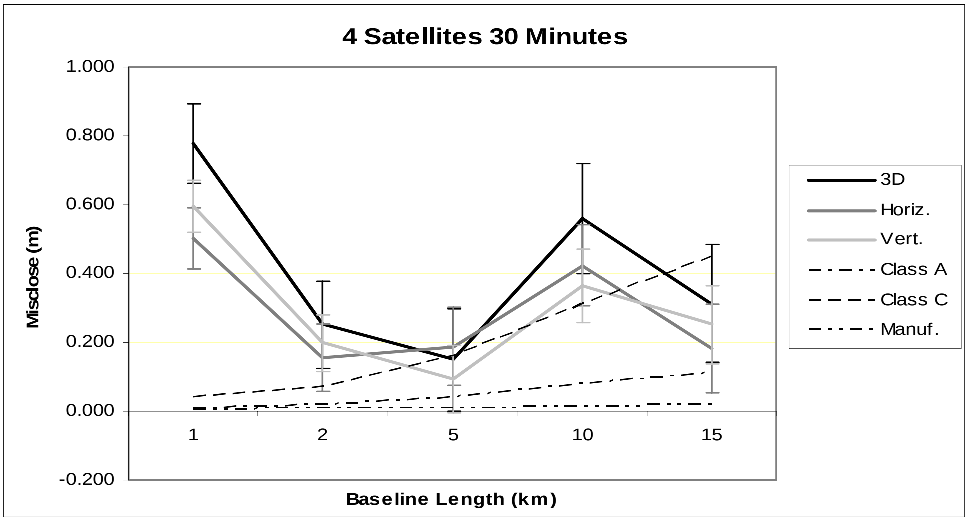
Table 4.11 also shows the effect of variations in observation duration. For any given combination of baseline length and number of satellites the accuracy typically improves for longer observations. For example the 10 kilometre baseline using 7 satellites; the results pass class C with a 10 minute observation, class B with 30 minutes, class 2A with 45 minutes and class 3A with 55 minutes of observation duration.

4.5 Effects of baseline length.

The length of the baseline is expected to have an effect on the absolute accuracy, with the longer baselines expected to have greater miscloses than those for the shorter baselines. The allowed misclose for the varied classes of accuracy all change with baseline length as can be seen in table 4.6 this means that, though the misclose may increase, the class of accuracy may remain the same or even improve.

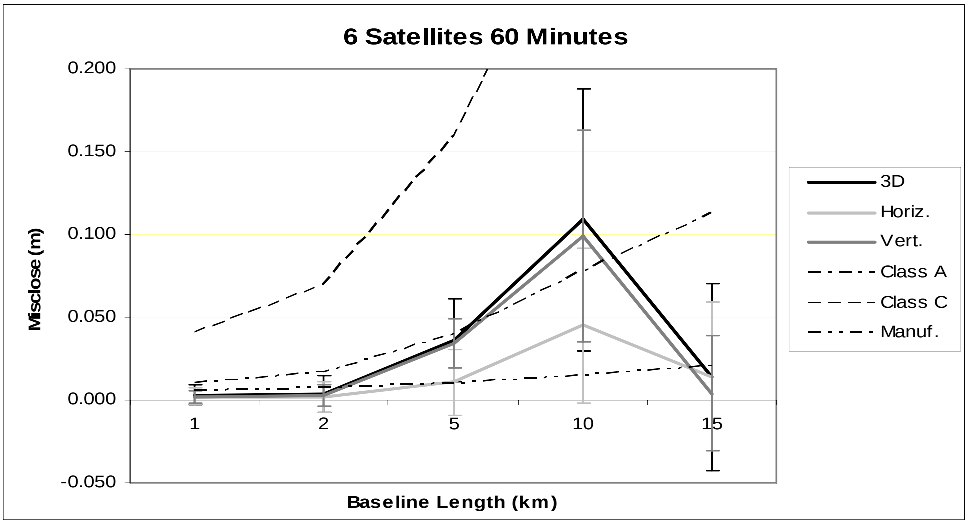
The following charts show the effect of increasing the baseline length whilst keeping the number of satellites and the observation time constant.

Figure 4.6 Misclose – Baseline Length 4 satellites 30 minutes.



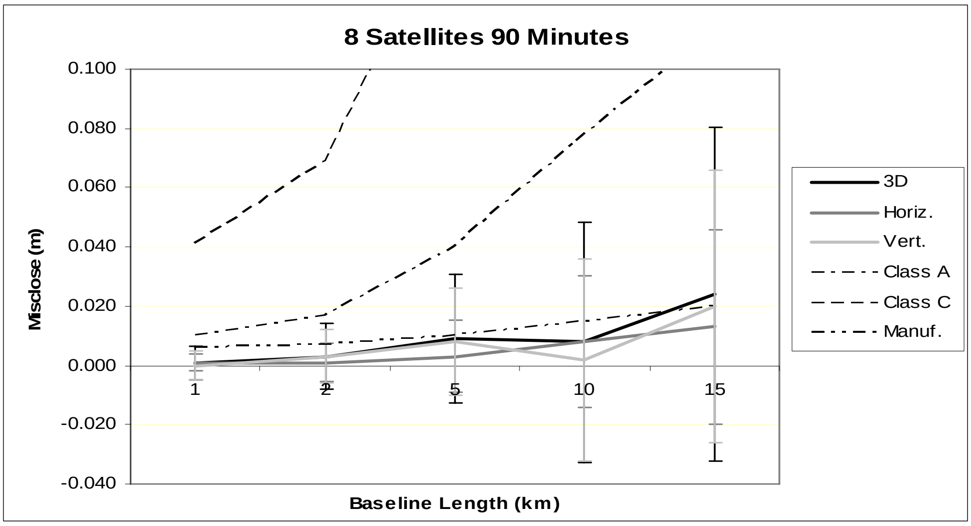
The small number of satellites and relatively short observation time is probably having more effect on the results than the changes in baseline length. There appears to be no consistent trend across the results.

Figure 4.7 Misclose – Baseline Length 6 Satellites 60 minutes.



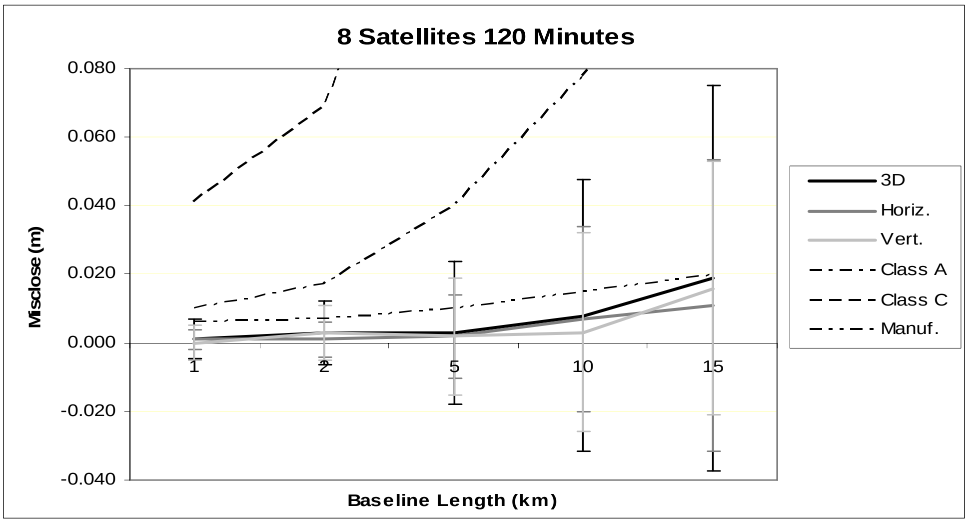
There appears to be a trend of increasing misclose in this chart though the result for the 15 kilometre baseline defies this by being very accurate. Using a single observation there is no way of determining the cause for this result.

Figure 4.8 Misclose – Baseline Length 8 satellites 90 minutes.



With more data used to process each baseline the chart exhibits increasing misclose with increasing baseline length. The results still pass the manufacturer's claimed accuracy (horizontally and vertically). The horizontal misclose parallels the manufacturer's accuracy very closely.

Figure 4.9 Misclose – Baseline Length 8 satellites 120 minutes.



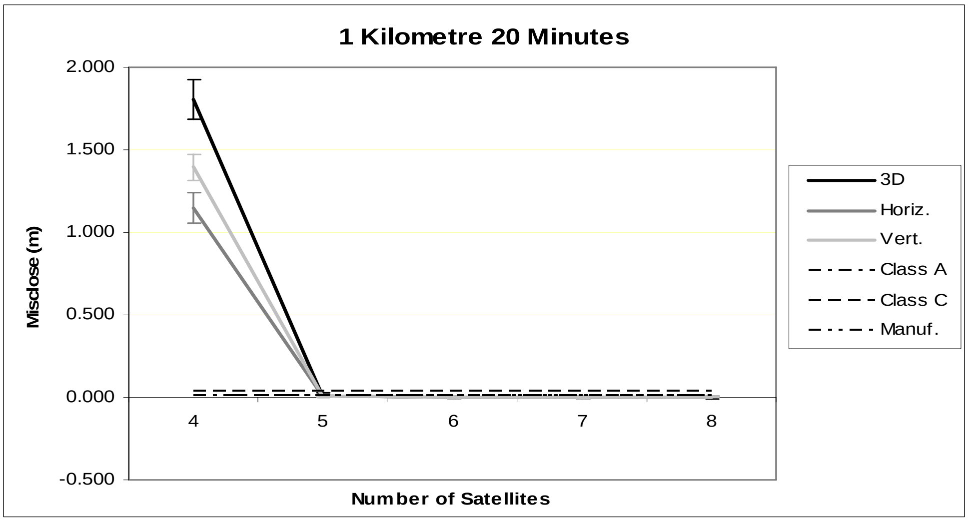
Once again with the greater amount of data processed the chart shows increasing misclose with increasing baseline length. The accuracy relative to the manufacturer’s claims seems to worsen with baseline length (the miscloses converge with the manufacturer’s claimed accuracy).

4.6 Effects of number of available satellites.

The minimum number of satellites required to fix the baseline is four, each additional satellite provides extra information that should enable more accurate results to be determined. The effect of using more satellites should also enable more accurate results to be produced using shorter observation durations.

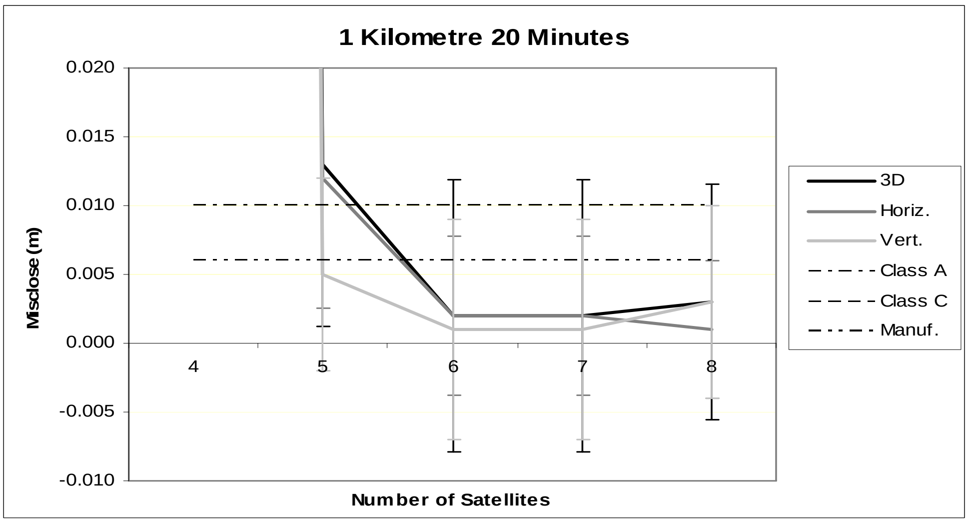
The following charts show the resultant misclose against number of satellites for a fixed baseline length/observation duration.

Figure 4.10 Misclose – Number of Satellites 1 kilometre 20 minutes.



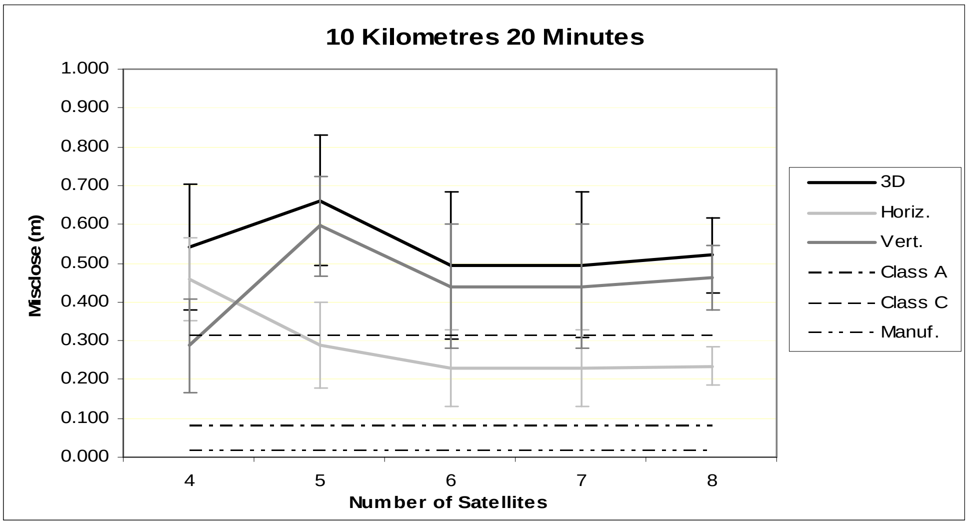
This chart shows an initial large misclose but the results using 5 to 8 satellites are difficult to make out. The following chart (Figure 4.) shows the same results but the vertical scale has been expanded to show the variation in results using 5 to 8 satellites.

Figure 4.11 Misclose – Number of Satellites 1 kilometre 20 minutes expanded scale.



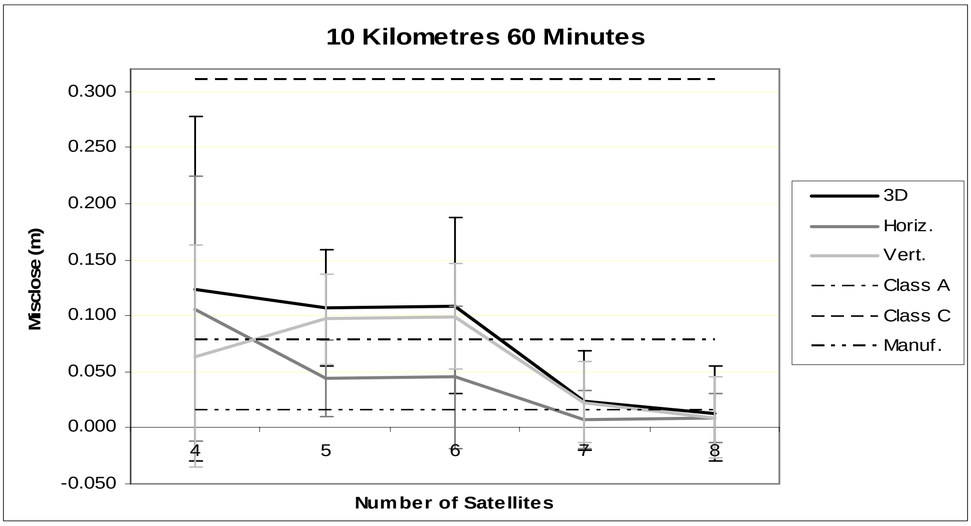
With a short baseline and short observation time the minimum four satellites do not provide an accurate result. Using an additional satellite in the processing has a dramatic effect with the misclose passing class C. Increasing the number of satellites to 6 sees the misclose pass class A and the manufacturer's claimed accuracy. Additional satellites have little effect after this point.

Figure 4.12 Misclose – Number of Satellites 10 kilometres 20 minutes.



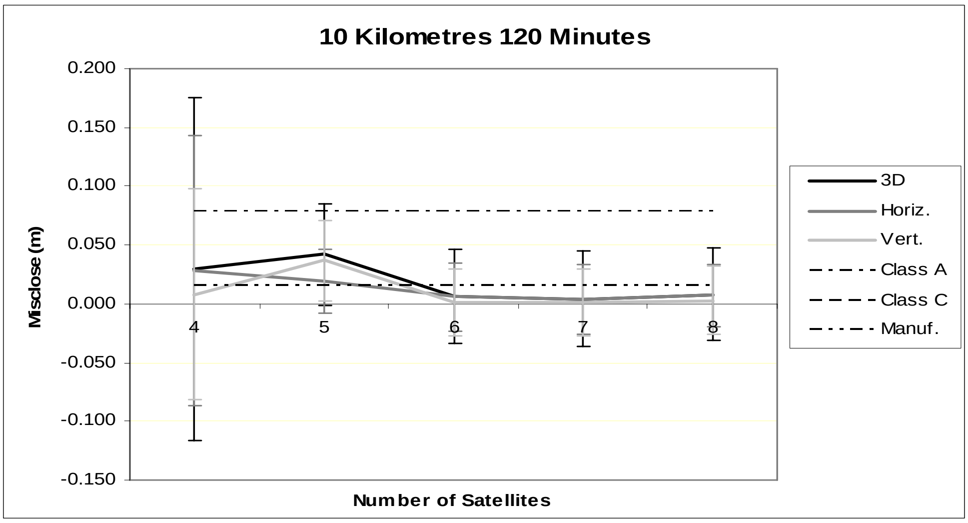
Maintaining the short observation time but using the longer 10 kilometre baseline the results still improve with increasing number of satellites, though ultimately the accuracy is only good enough for class C in the horizontal direction. It appears that the short observation time is having the greatest effect over this distance.

Figure 4.13 Misclose – Number of Satellites 10 kilometres 60 minutes.



Using an hour of data, the accuracy improves consistently with each additional satellite used. Initially the results pass class C improving to pass class A with the use of 7 satellites and finally achieving the manufacturer's claimed accuracy with 8 satellites used.

Figure 4.14 Misclose – Number of Satellites 10 kilometres 120 minutes.



Increasing the observation duration to 120 minutes sees the misclose reduced to the point that it now passes class A with 4 satellites and improves to pass the manufacturer's claims with 6 satellites.

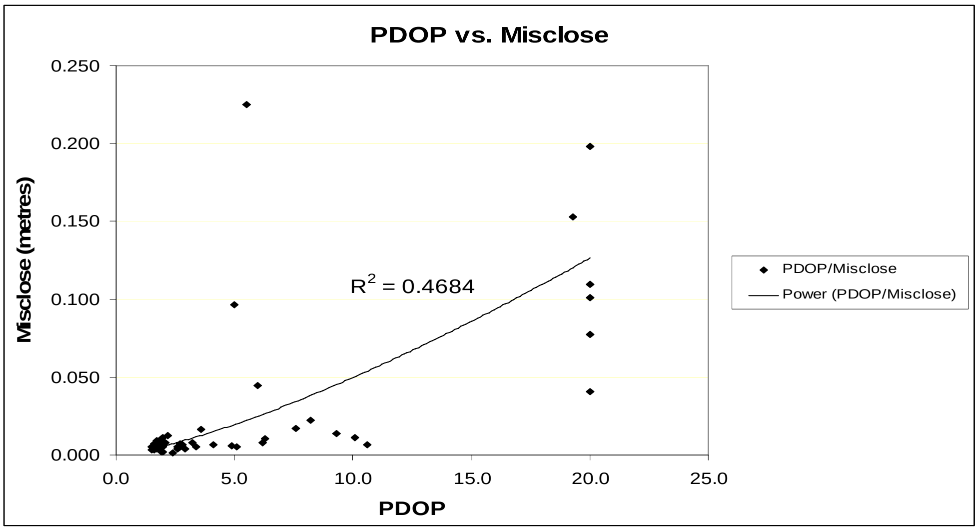
Increasing the number of satellites used in the processing of each baseline can improve the accuracy of the result providing that the observation time or the baseline length do not become more critical to the result.

4.7 Effects of PDOP.

The Positional Dilution Of Precision (PDOP) is related to the position of the satellites in the sky. If the satellites are spread evenly around the sky the PDOP is lower and the results are expected to be improved. If the satellites are clustered in one part of the sky or lined up the PDOP will be greater and the results are expected to be less accurate.

The following chart shows the misclose and PDOP plotted for each of 12 separate 10 minute observations. These observations have been created by splitting each 120 minute observation into 10 individual observations.

Figure 4.15 PDOP vs. Misclose.



The R^2 value of 0.4684 for the trend line in the above chart shows that there is little correlation between the PDOP and the misclose. The PDOP cannot be said to have a definite effect on the accuracy of the results from these charts.

4.8 Conclusion.

The Ashtech ProMark2 survey system is capable of producing results that pass the claimed accuracy limits. This may only be achieved when enough observed data is collected for processing given a certain baseline length. The amount of data increases with increasing number of satellites and with longer observation times.

The results compared reasonably against the known 3rd order permanent survey mark coordinates. All results passing ICSM class C accuracy limits (which is the maximum class that can be claimed when connecting to 3rd order marks).

The closed loop, made up of the 5 baselines measured, passed the chi-square test (included in the processing software) at the ISCM class 2A accuracy level. It was determined that the 3rd order coordinates attached to the PSMs were less accurate then the measured baselines. A new coordinate set produced by adjusting the observed loop was produced and each of the observed vectors analysed against them.

The effects of varying the observation times, baseline lengths, number of satellites and PDOP were examined with all but the PDOP having a direct impact on observation accuracy.

CHAPTER 5
CONCLUSION

5.1 Introduction.

This chapter will look at the results of chapter 4 and draw conclusions as to the suitability of the Ashtech ProMark2 survey system for accurate survey work.

Some recommendations as to the minimum observation time necessary to achieve results of a required accuracy will also be made.

5.2 Results.

The observed baselines passed ICSM class C survey accuracy requirements when analysed against the known permanent mark coordinates. This level of accuracy is sufficient for survey coordination projects (connecting survey control to coordinated marks), and is generally acceptable accuracy for most engineering and cadastral work.

When the traverse loop was analysed in Ashtech Solutions the observed baselines passed the chi-square test at the ICSM class 2A accuracy level. This level of accuracy is acceptable for use in high precision national geodetic surveys, which far exceeds typical work carried out by consulting surveyors.

It was decided that GPS observations provided more accurate baseline vectors than the 3rd order coordinates attached to the permanent survey marks. Consequently the analysis was repeated using an adjusted set of PSM coordinates derived using the full observation files (10 satellites and 120 minutes duration).

The accuracy of the observed baselines compared to these new base coordinates improved so that ICSM class A and manufacturer's claimed accuracy were achieved on all baselines. With sufficient observation data the baseline observations passed ICSM class 2A and in some cases class 3A. The accuracy of the results produced by the Ashtech ProMark2 GPS survey system in this study suggest that it is quite suitable for typical survey control placement and connections.

5.3 Recommendations.

It has been shown that acceptable results can be achieved over the various baseline lengths and with different numbers of available satellites. The different combinations of number of satellites and baseline length have been tabulated against the accuracy standards in table 4.11, which is reproduced as table 5.1 below. The values represent the minimum observation time required to achieve the corresponding accuracy for each condition.

Table 5.1 Minimum observation times.

	Using Adjusted GPS Traverse Coordinates:														Manuf.	
	Minimum Observation time (min).														Quoted	
	ICSM Accuracy classes for survey														Accuracy	
	3A Horiz.	3A Vert.	2A Horiz.	2A Vert.	A Horz.	A Vert.	B Horiz.	B Vert.	C Horiz.	C Vert.	D Horiz.	D Vert.	E Horiz.	E Vert.	Horiz.	Vert.
1km 4 SVs	NA	NA	NA	NA	90	85	80	80	50	50	45	45	45	45	NA	85
1km 5 SVs	NA	NA	110	105	35	10	10	10	10	10	10	10	10	10	85	10
1km 6 SVs	110	110	10	10	10	10	10	10	10	10	10	10	10	10	10	10
1km 7 SVs	110	110	10	10	10	10	10	10	10	10	10	10	10	10	10	10
1km 8 SVs	70	70	10	15	10	10	10	10	10	10	10	10	10	10	10	10
2km 4 SVs	NA	NA	NA	NA	70	85	65	60	40	40	35	35	30	30	NA	NA
2km 5 SVs	NA	115	105	60	10	10	10	10	10	10	10	10	10	10	105	10
2km 6 SVs	110	NA	10	10	10	10	10	10	10	10	10	10	10	10	10	10
2km 7 SVs	NA	NA	25	90	15	10	15	10	10	10	10	10	10	10	25	15
2km 8 SVs	45	NA	20	10	10	10	10	10	10	10	10	10	10	10	25	10
5km 4 SVs	NA	NA	90	65	65	65	55	55	30	40	30	30	20	20	100	65
5km 5 SVs	NA	NA	105	NA	40	100	40	40	30	30	25	25	15	15	NA	NA
5km 6 SVs	NA	NA	25	95	25	95	25	95	25	95	20	20	10	10	70	85
5km 7 SVs	115	115	20	90	20	20	20	15	15	10	15	10	10	10	70	80
5km 8 SVs	15	110	15	75	15	15	15	15	10	15	10	10	10	10	15	15
10km 4 SVs	NA	NA	NA	75	75	55	55	45	35	35	30	15	10	10	NA	75
10km 5 SVs	NA	NA	90	NA	45	75	30	45	10	30	10	25	10	10	NA	NA
10km 6 SVs	65	80	65	65	40	65	30	45	10	30	10	10	10	10	65	65
10km 7 SVs	55	80	45	55	45	55	30	45	10	25	10	10	10	10	45	55
10km 8 SVs	45	60	45	45	45	45	30	45	10	30	10	10	10	10	45	45
15km 4 SVs	75	70	50	50	35	35	15	15	10	10	10	10	10	10	75	50
15km 5 SVs	10	NA	10	10	10	10	10	10	10	10	10	10	10	10	10	10
15km 6 SVs	15	15	15	15	10	15	10	15	10	10	10	10	10	10	15	15
15km 7 SVs	45	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
15km 8 SVs	70	NA	20	45	15	20	15	10	10	10	10	10	10	10	20	55

It is best if the observation can be made at a time when the maximum number of satellites is visible in the sky. A minimum of six satellites will ensure that the required observation time to achieve class C accuracy is kept to around 30 minutes and class A in around 45 minutes.

5.4 Limitations.

This study is subject to some limitations that may have some bearing on the results.

The first of these is that the permanent survey marks only carry 3rd order coordinates and can only be used to analyse for class C accuracy in the observed results. The use of adjusted coordinates is not an ideal solution as they are based on the very observations that are being analysed. This was only deemed appropriate as the closure of the traverse loop was suitably accurate. The assumption being made is that, if the loop closure is accurate within ICSM class 2A constraints then the individual baselines should be of similar accuracy.

The omission of the zero baseline test from the study due to hardware unavailability places some doubt on whether or not the two receivers perform identically. The accuracy of the end results, particularly the comparison of the shorter baselines against the known permanent mark coordinates, show that the receivers are operating correctly.

The locations of the permanent marks were chosen to achieve the necessary differences in baseline length as well as their view of the sky. To achieve a reasonable view of the sky in the Bendigo area means using marks placed within road reserves, this means that almost all of the marks used were under or near overhead power lines. There were also some trees close to marks PM872 (to the south) and PM56 (to the east). The observations still represent real world surveying conditions and, as the end accuracy exceeds the manufacturer’s claims, it is assumed that the trees had little effect on this evaluation.

In an ideal test network the baselines will be of varied length but also in varied directions. The marks used in this study allowed baselines in a predominantly north-east to south-west direction. This is due to the lack of suitable marks further to the east and west of the main highway and railway through the centre of the city.

5.5 Further Work.

It was hoped to evaluate results produced using both broadcast and precise ephemerides in this project. A software issue prevented this comparison being conducted in time. The effect of using the downloaded precise data may be examined in the future.

This project has analysed the performance of the Ashtech ProMark2 GPS survey system in static survey mode only. The equipment is also capable of measuring points in both stop and go (rapid static) and kinematic modes. These procedures have not been analysed in this work and represent a future possibility for exploration.

5.6 Conclusion.

The Ashtech ProMark2 GPS survey system has been shown to perform as claimed by the manufacturer. It is suitable for applications in cadastral, engineering and even geodetic surveying.

The analysis of the results from this project has allowed some recommendations on observation duration to be made depending on the satellite availability and the length of the baseline to be observed (see table 5.1).

Though the work is based on some limiting factors and assumptions the results obtained provide a realistic and representative evaluation of the equipment in question.

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APPENDIX A
PROJECT SPECIFICATION

University of Southern Queensland

Faculty of Engineering and Surveying

ENG4111/4112 Research Project

PROJECT SPECIFICATION

FOR:	**Neil Geoffrey SHAW**
TOPIC:	Evaluation of Ashtech ProMark 2 survey system.
SUPERVISOR:	Mr. Glenn Campbell.
PROJECT AIM:	This project aims to evaluate the performance of the Ashtech ProMark 2 GPS survey system in static mode.

PROGRAMME: **Issue A, 9th March 2004**

1. Select PSMs for different length baseline measurements.

2. Measure baselines on consecutive days at the same time each day.

3. Process results for each baseline varying the observation time and number of satellites (and hence DOPs).

4. Analyse the results to determine the accuracy for each of the different baseline lengths, observation times, number of satellites and DOPs.

5. Repeat analysis using downloaded precise ephemerides.

6. Compare accuracy of results for each of the different variables (baseline length, observation time, number of satellites, DOPs and broadcast or precise ephemerides).

7. Draw conclusions as to the required observation times for given baseline lengths and number of satellites.

AGREED: ______________(student) _____________(Supervisor)

____/____/____ ____/____/____

APPENDIX B
ACCURACY STANDARDS

Accuracy Regulations for Victoria.

Surveyors (Cadastral Surveys) Regulations 1995:

Regulation 6:

Classification and accuracy of surveys

(1) A licensed surveyor must ensure that—

(a) The internal closure of any cadastral survey is such that the length of the misclose vector does not exceed—

(i) 15 millimetres + 100 parts per million of the perimeter for boundaries crossing level or undulating land.

(ii) 15 millimetres + 150 parts per million of the perimeter for boundaries crossing steep or mountainous land; and

(b) The misclose vector is determined as [radical]($a^2 + b^2$) where "a" is the misclose in eastings and "b" is the misclose in northings; and

(c) All lengths are measured or determined to an accuracy of 10 millimetres + 60 parts per million.

Accuracy Regulations for New South Wales.

Surveying Regulation 2001:

Part 25: Determination of angular close:

(1) Whenever possible, a complete angular close must be obtained.
(2) The observed angular misclose must not exceed 20 seconds plus $10\sqrt{n}$ seconds or 2 minutes (whichever is the lesser):
    (a) for the whole surround, and
    (b) between stations at which astronomical observations for azimuth have been made, and
    (c) between pairs of established permanent survey marks.
(3) In subclause (2), “n” is the number of traverse angular stations.

Part 26: Checking and accuracy of all measurements:

(1) A surveyor must, if the nature of a survey permits, check all measurements made in a survey by closure of the eastings and northings of the lines in all surrounds in the survey computed in metres to 3 decimal places.
(2) The internal closure of any survey must be such that the length of the misclose vector must not exceed:
    (a) 15mm + 100ppm of the perimeter, for boundaries crossing level or undulating terrain, or
    (b) 15mm + 150ppm of the perimeter, for boundaries crossing steep or mountainous terrain.
(4) The misclose vector must be determined as $\sqrt{(a^2 + b^2)}$, where “a” is the misclose in eastings and “b” is the misclose in northings.

Part 27: Accuracy of length measurements:

When making a survey, a surveyor must measure all lengths to an accuracy of 6mm + 30ppm or better at a confidence level of 95%.

Accuracy Regulations for Queensland.

Surveyors Regulation 1992:

Section 31.

(2) This section applies to angular and linear measurement only.

(3) A surveyor must calibrate and standardise survey equipment used on a cadastral survey to ensure that the standard deviation-

   (a) in the case of angular measurement – does not exceed 10 seconds of arc: or

   (b) in the case of distance measurement – does not exceed 10mm plus 1 part in 10000 of the distance.

(4) The standard deviation must be assessed by a method approved by the Board.

(5) The accuracy of a cadastral survey must be determined-

   (a) by computation of the angular and linear misclosure in a surround; or

   (b) by comparison with coordinated permanent marks.

(6) The angular misclosure in a surround or the angular deviation from the adopted meridian must not exceed the lesser of-

   (a) 2.5 times the adopted standard deviation of angular measure multiplied by the square root of the number of angles; or

   (b) 2 minutes.

(7) The linear misclosure in a surround must not exceed-

(b) 10mm plus 1 part in 5000 of the total distance traversed; or

(c) 20mm plus 1 part in 2500, if the survey is in rough or broken terrain; or

(d) 20mm plus 1 part in 2000, if another surveyors work is included in the surround; or

(e) 20mm plus 1 part in 1000, if a survey effected before 1890 is included in the surround.

(8) The registering authority may approve accuracies inconsistent with subsections (2) and (4) to (6), if it is appropriate for the purposes of the survey.

Manufacturers Quoted Accuracy.

Ashtech ProMark2 Technical Specifications:

Accuracy Specifications:

Static Survey Performance (rms)

- Horizontal: 0.005m + 1ppm
- Vertical: 0.010m + 2ppm
- Azimuth: < arcsecond

ICSM Accuracy standards.

The Inter-Governmental Committee on Surveying and Mapping (ISCM 2004) has determined seven classes of survey accuracy which are recommended for different types of survey work.

Class is a function of the planned and achieved precision of a survey network and is dependent upon the following components:

- The network design,
- The survey practices adopted,
- The equipment and instruments used, and
- The reduction techniques employed,

All of which are usually proven by the results of a successful, minimally constrained least squares network adjustment. (ICSM 2004).

This project aims to determine the suitability of the equipment and processing software by analysis of results against a known network.

The allocation of class to a survey may generally be achieved by assessing whether the semi-major axis of each relative standard error ellipse or ellipsoid (i.e. one sigma), is less than or equal to the length of the maximum allowable semi-major axis (r) using the following formula:

$$r = c\,(d + 0.2)$$

Where:

r = length of maximum allowable semi-major axis in mm

c = an empirically derived factor represented by historically accepted precision for a particular standard of survey.

d = distance to any station in km.

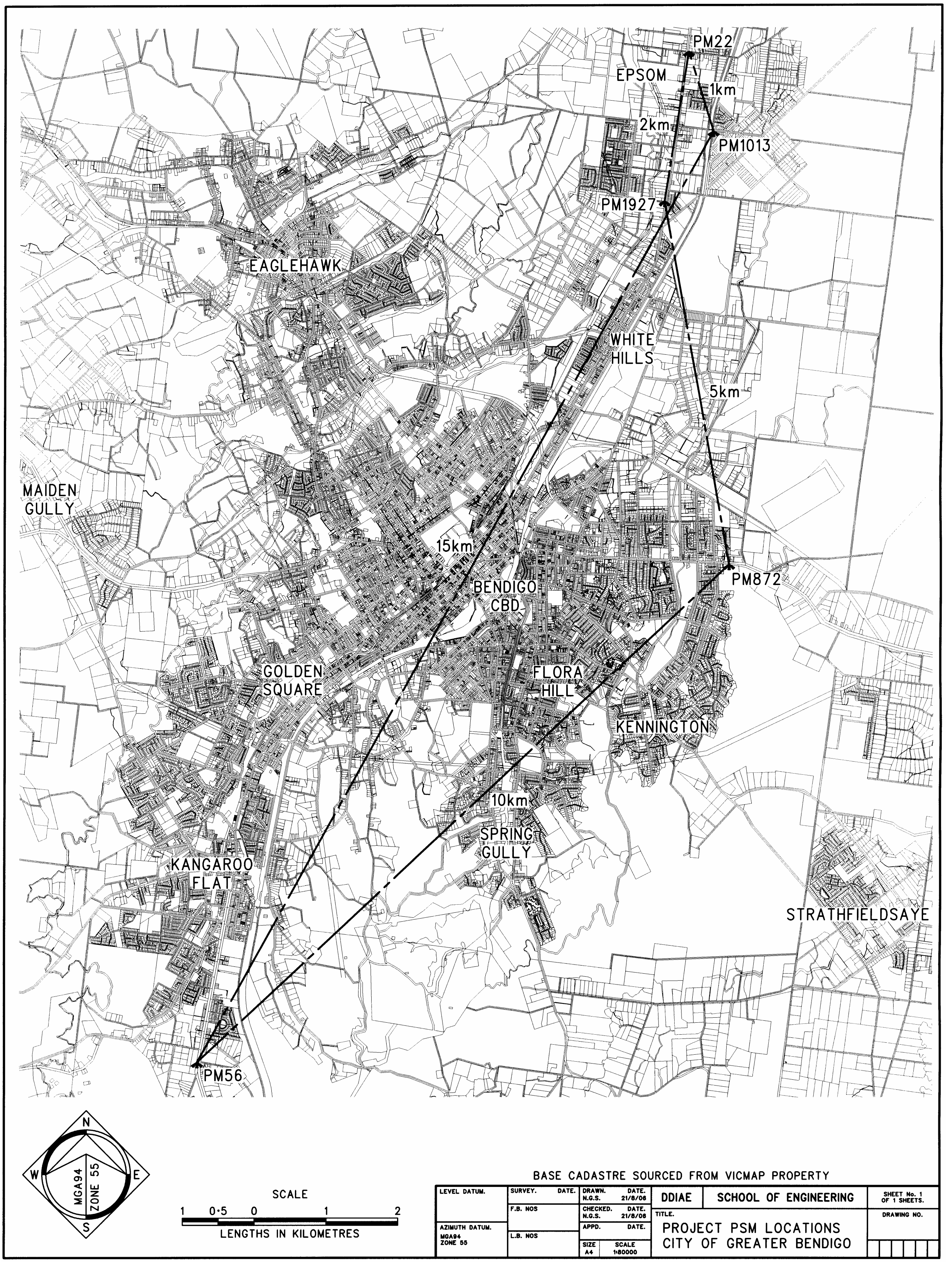
Classification of horizontal control survey.

Class	C (for one sigma)	Typical applications
3A	1	Special high precision surveys.
2A	3	High precision National geodetic surveys.
A	7.5	National and State geodetic surveys.
B	15	Densification of geodetic survey.
C	30	Survey coordination projects.
D	50	Lower class projects.
E	100	Lower class projects.

APPENDIX C

LOCALITY MAP

Appendix C Locality Map.



APPENDIX D
PERMANENT SURVEY MARK
SKETCH PLANS

Survey Mark Sketch **HUNTLY PM 22** Sketch 2 of 2

Data Source: Vicmap Control - SMES

Number	277000220		**Status**	OK			**MGA94 Easting/Northing**		
Zone 55	**Easting**	260402.546	**Northing**	5935515.250	**AHD Height**	182.374	**CSF**	1.0002787	
Zone 54	**Easting**	796450.795	**Northing**	5933734.727			**CSF**	1.0006542	
Plan Ref:									

5

SEC. 6 (1) (c) SURVEY CO-ORDINATION ACT 1940

PERMANENT MARK SKETCH PLAN

Township .... Parish HUNTLY

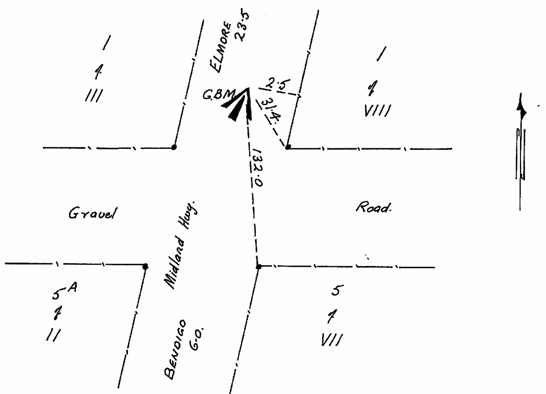
NOTE :— Not necessarily to Scale

(1) Measurements to be shown from the Permanent Mark to as many near-by survey marks, buildings, fence posts, hydrants, trees, &c., as practicable. Up to six such measurements are desirable.

(2) Except where verified by a Licensed Surveyor in this survey, all boundaries in this sketch plan are to be shown by broken lines. The symbols for fences, buildings, &c., to be shown on the broken lines.

(3) Description of Permanent Mark and, where possible, Crown Abuttals are to be shown.

MEASUREMENTS ARE IN LINKS



Established in connection with* First Order Level (Geodetic) Ref. No. G.BM 254

*Type of Survey of Works.

IF LEVELLED :—

Reduced level of Mark .... to Datum† ....

†e.g., Railways, Board of Works, Sewerage Authority, &c., or Arbitrary.

I certify that the Permanent Marks shown in this sketch have been established on the ground by me in accordance with the Regulations under the Survey Co-ordination Act 1940 and that the information shown hereon is correct.

Department or Authority Lands & Survey Signature [signature] †

Date 26 May '66

†If a Licensed Surveyor the letters L.S. to be added.

TO BE FILLED IN BY THE CENTRAL PLAN OFFICE

XXXXX	SqXXXX	XXXXXX	State Datum R.L.	Number 22
Surveys connected to this P.M			R.L.	22
PS 145599 CP. 108909 LP 2204-11			Copied from	

Noted on Record Plan H107 [illegible] 6-1-67

A.1300/10.52—30015

28 DEC 1966

Date of Report: 12:44 PM on Jul 6, 2006

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Appendix D Permanent Survey Mark Sketch Plans.

Survey Mark Sketch **MANDURANG PM 56** Sketch 2 of 3

Data Source: Vicmap Control - SMES

Number	305100560		**Status**	OK			**MGA94 Easting/Northing**	
Zone 55	**Easting**	253575.556	**Northing**	5921434.301	**AHD Height**	273.460	**CSF**	1.0003052
Zone 54	**Easting**	788752.311	**Northing**	5920104.814			**CSF**	1.0005844
Plan Ref:								

6

SEC. 6 (1) (c) SURVEY CO-ORDINATION ACT 1958

PERMANENT MARK SKETCH PLAN

Township ______ *Parish* MANDURANG

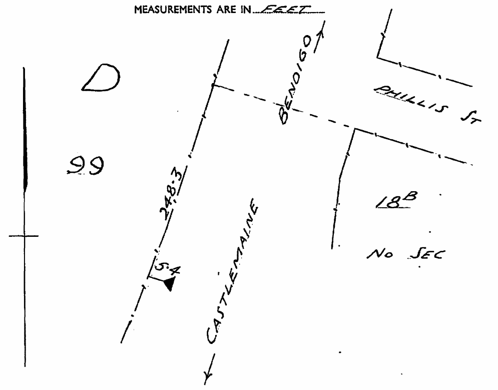
NOTE:— Not necessarily to Scale

(1) Measurements to be shown from the Permanent Mark to as many near-by survey marks, buildings, fence posts, hydrants, trees, &c., as practicable. Up to six such measurements are desirable.

(2) Except where verified by a Licensed Surveyor in this survey, all boundaries in this sketch plan are to be shown by broken lines. The symbols for fences, buildings, &c., to be shown on the broken lines.

(3) Description of Permanent Mark and, where possible, Crown Abuttals are to be shown.

MEASUREMENTS ARE IN FEET



Established in connection with* PRECISION LEVELLING Ref. No. G.B.M.233

*Type of Survey of Works.

IF LEVELLED:—

Reduced level of Mark ______ to Datum † ______

†e.g., Railways, Board of Works, Sewerage Authority, &c., or Arbitrary.

I certify that the Permanent Marks shown in this sketch have been established on the ground by me in accordance with the Regulations under the *Survey Co-ordination Act* 1958 and that the information shown hereon is correct.

Department or Authority LANDS & SURVEY *Signature* [signature] †

Date 4-2-1965

†If a Licensed Surveyor the letters L.S. to be added.

TO BE FILLED IN BY THE CENTRAL PLAN OFFICE

			Same Datum R.L.	Number 56
Surveys connected to this PM: LP.26130			R.L. Copied from	56

Noted on Record Plan M 28¹⁰ [initials] 2·7·65

See also SUPPLEMENTARY Sketch

-1 MAR 1965

Date of Report: 7:52 PM on Jul 6, 2006

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Survey Mark Sketch **SANDHURST PM 872** Sketch 2 of 2

Data Source: Vicmap Control - SMES

Number	347308720	**Status**	OK			**MGA94 Easting/Northing**	
Zone 55	**Easting** 260964.054	**Northing**	5928409.319	**AHD Height**	243.520	**CSF**	1.0002658
Zone 54	**Easting** 796566.260	**Northing**	5926604.890			**CSF**	1.0006455
Plan Ref:	772424						

STRATHFIELDSAYE

SEC. 6 (1) (c) SURVEY CO-ORDINATION ACT 1940

PERMANENT MARK SKETCH PLAN

Township .... Parish SANDHURST

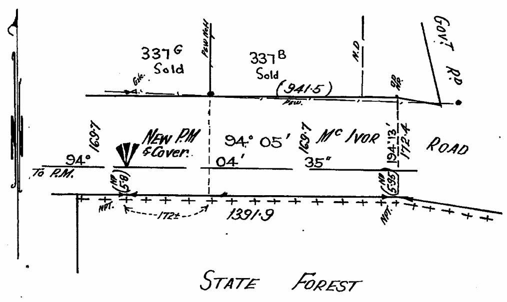
NOTE :— Not ~~necessarily~~ to Scale

(1) Measurements to be shown from the Permanent Mark to as many near-by survey marks, buildings, fence posts, hydrants, trees, &c., as practicable. Up to six such measurements are desirable.

(2) Except where verified by a Licensed Surveyor in this survey, all boundaries in this sketch plan are to be shown by broken lines. The symbols for fences, buildings, &c., to be shown on the broken lines.

(3) Description of Permanent Mark and, where possible, Crown Abuttals are to be shown.

MEASUREMENTS ARE IN links



Established in connection with* Cadastral Survey Ref. No. W84330 8/104
*Type of Survey of Works.

IF LEVELLED :—

Reduced level of Mark .... to Datum† ....
†e.g., Railways, Board of Works, Sewerage Authority, &c., or Arbitrary.

I certify that the Permanent Marks shown in this sketch have been established on the ground by me in accordance with the Regulations under the Survey Co-ordination Act 1940 and that the information shown hereon is correct.

Department or Authority Lands & Survey Signature [signature] LS †

Date 29-7-58

O-P 57179 †If a Licensed Surveyor the letters L.S. to be added.

TO BE FILLED IN BY THE CENTRAL PLAN OFFICE

Zone	Square	Subdivision	State Datum R.L.	Number
Surveys connected to this PM: LP.82514 OP.101687 SP.15239(CRB) P/S 144758 OP 108011			R.L. Copied from	872

Noted on Record Plan S 371 20 17-10-58
A.1590/10.52.—10015

Date of Report: 7:54 PM on Jul 6, 2006

Survey Mark Sketch **SANDHURST PM 1013** Sketch 2 of 3

Data Source: Vicmap Control - SMES

Number	347310130	**Status**	OK			**MGA94 Easting/Northing**	
Zone 55	**Easting** 260746.861	**Northing**	5934403.227	**AHD Height**	186.827	**CSF**	1.0002759
Zone 54	**Easting** 796724.946	**Northing**	5932602.909			**CSF**	1.0006555
Plan Ref:							

Shire of Huntly D.S.Sandhurst 4

SEC. 6 (1) (c) SURVEY CO-ORDINATION ACT 1940

PERMANENT MARK SKETCH PLAN

Township .... *Parish* SANDHURST

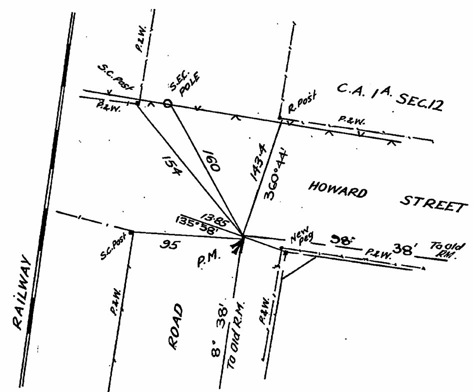
NOTE :— Not necessarily to Scale

(1) Measurements to be shown from the Permanent Mark to as many near-by survey marks, buildings, fence posts, hydrants, trees, &c., as practicable. Up to six such measurements are desirable.

(2) Except where verified by a Licensed Surveyor in this survey, all boundaries in this sketch plan are to be shown by broken lines. The symbols for fences, buildings, &c., to be shown on the broken lines.

(3) Description of Permanent Mark and, where possible, Crown Abuttals are to be shown.

MEASUREMENTS ARE IN LINKS



Established in connection with* Cadastral Survey Ref. No. W 80356.
*Type of Survey of Works.

IF LEVELLED :—

Reduced level of Mark .... to Datum† ....
†e.g., Railways, Board of Works, Sewerage Authority, &c., or Arbitrary.

I certify that the Permanent Marks shown in this sketch have been established on the ground by me in accordance with the Regulations under the Survey Co-ordination Act 1940 and that the information shown hereon is correct.

Department or Authority Dept of Lands & Survey Signature [signature] L.S. †

O.P. 59747 Date 3-3-53

†If a Licensed Surveyor the letters L.S. to be added.

TO BE FILLED IN BY THE CENTRAL PLAN OFFICE

Zone	Square	Subdivision	State Datum R.L.	Number
Surveys connected to this PM: OP.102176 OP.104749			R.L. Copied from	1013

Noted on Record Plan S371(21) ... 1-5-61 SEE ALSO SUPPLEMENTARY
A.1599/10.52.—10015 H107(8)

Date of Report: 12:43 PM on Jul 6, 2006

Page 2 of 3

Survey Mark Sketch **SANDHURST PM 1927** Sketch 1 of 3

Data Source: Vicmap Control - SMES

Number 347319270		**Status** OK			**MGA94 Easting/Northing**	
Zone 55	**Easting** 260082.548	**Northing** 5933428.672	**AHD Height** 190.217		**CSF** 1.0002793	
Zone 54	**Easting** 796000.661	**Northing** 5931671.499			**CSF** 1.0006497	

Plan Ref:

SEC. 6 (1) (c) SURVEY CO-ORDINATION ACT 1958

PERMANENT MARK SKETCH PLAN

5

Township EPSOM *Parish* SANDHURST

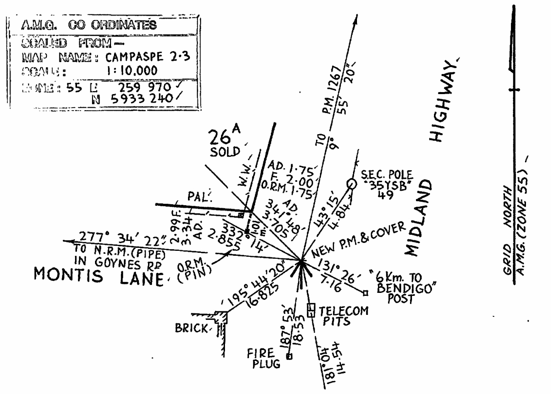
NOTE :— Not necessarily to Scale

(1) Measurements to be shown from the Permanent Mark to as many near-by survey marks, buildings, fence posts, hydrants, trees, etc., as practicable. Up to six such measurements are desirable.

(2) Except where verified by a Licensed Surveyor in this survey, all boundaries in this sketch plan are to be shown by broken lines. The symbols for fences, buildings, etc., to be shown on the broken lines.

(3) Description of Permanent Mark and, where possible, Crown Abuttals are to be shown.

MEASUREMENTS ARE IN METRES



Established in connection with* CADASTRAL SURVEY Ref. No. 3711/174

*Type of Survey of Works

IF LEVELLED :—

Reduced level of Mark ________ to Datum† ________

†e.g., Railways, Board of Works, Sewerage Authority, etc., or Arbitrary

I certify that the Permanent Marks shown in this sketch have been established on the ground by me in accordance with the Regulations under the *Survey Co-ordination Act* 1958 and that the information shown hereon is correct.

Department ~~or Authority~~ of CROWN LANDS & SURVEY *Signature* R.J. O'Brien L.S. ‡

Date 10-11-80

105675 ‡If a Licensed Surveyor the Letters L.S. to be added

TO BE FILLED IN BY THE CENTRAL PLAN OFFICE

Zone	Square	Subdivision	Same Datum R.L.	Number
Surveys Connected To This P.M. CP 116383			R.L. Copied from	1927

Noted on Record Plan 119(2) 11.5.82 **SEE ALSO SUPPLEMENTARY**

T.O. S.R. & W.S.C. C.R.B. D.S.Sandhurst Shire of: HUNTLY

22 JAN 1982

Date of Report: 7:55 PM on Jul 6, 2006