University of Southern Queensland

Faculty of Engineering and Surveying

Testing Mapping Grade GPS Carrier Phase Accuracy

A dissertation submitted by

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Abstract

In recent years there as been a move to the extensive use of Geographic Information Systems (GIS) software packages for the storage of spatial data. Much of the spatial data that is stored relates to services and other resources that need careful management. Because of the increasing use of digital methods to store and retrieve data a GIS, has become a popular tool for achieving this. Data that is used within the GIS is often captured using Global Positioning Systems (GPS) receivers because of their fast and effective methods of capturing the relevant data.

A problem exists when data of uncertain accuracy is used within the GIS. This causes problems for the end user who relies on the ability to retrieve data that is of a high accuracy. Each GPS receiver has its own accuracies which depend on a variety of environmental factors. The data captured by GPS can contain a number of errors which will affect the accuracy of the data collected.

This project investigated the accuracy of two Mapping Grade Receivers that are manufactured by Trimble, namely the Pro XR and Pro XH mapping grade GPS receivers. These two receivers were used to take a series of observations on Permanent Survey Marks (PSMs) of known position. The data collected was post-processed a number of ways. The post-processing was undertaken using one and three bases. The use of varying base configurations allows conclusions to be made regarding how base station weighting can affect the results gained from post-processing.

University of Southern Queensland

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Limitations of Use

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Candidates 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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Abbreviations

CBS = Community Base Station

DNRW = Department of Natural Resources and Water

GIS = Geographical Information System

GPS = Global Positioning System

HRMS = Horizontal Root Mean Square

NSSDA = National Standard for Spatial Data Accuracy

PDOP = Position Dilution of Precision

PPA = Predicted Post-processed Accuracy

PSM = Permanent Survey Mark

RMS = Root Mean Square

SEQ = Southeast Queensland

US = United States of America

USQ = University of Southern Queensland

VRMS = Vertical Root Mean Square

VRS = Virtual Reference Station

WAAS = Wide Area Augmentation System

WGS 84 = World Geocentric Datum of 1984

Chapter 1

Introduction

1.1 Background

In recent years there has been a requirement for public utilities and assets (i.e. sewerage, electricity and telecommunication cables) to be mapped. This is required to ensure that new services can be integrated with existing services. For this to take place it is of utmost importance that the spatial location of these features is recorded to a high accuracy and within allowable tolerances to assist in efficient decision making.

Global Positioning Systems (GPS) are continually proving themselves to be an accurate and cost effective method of recording data of a spatial nature, and in particular mapping grade receivers.

GPS is an ingenious system that uses signals transmitted from satellites orbiting the earth to position features on the surface of the earth. The signals transmitted by satellites are either code or carrier phase wavelengths. Code signals are a very complicated digital code, which is represented as a sequence of "on" and "off" pulses (Trimble 2006g). Carrier phase signals are wavelengths that are right-hand circular polarised. Carrier phase signals are of two different wavelengths L1 and L2 (Natural Resources Canada, 1993).

The GPS receiver on the earth's surface 'counts' the number of wavelengths received from a number of satellites. The GPS receiver is able to compute the position on earth by using trilateration. Results from this process can be displayed in real-time or be post-processed. Real-time results use the anticipated satellite positions as a basis to calculate the position on the earths’ surface and require a radio link with the roving receiver. Post-processed results require reduction in software packages.

Since GPS receivers are being used to map a wide range of physical features, which are most likely to be used within a Geographic Information System (GIS), the accuracy of the spatial location of these features needs to be known so there can be some estimate as to the accuracy of the system as a whole. Often the data used within a GIS comes from a number of sources, each of these have differing accuracies as a result of their capture methods. By knowing the accuracy of the GPS receivers used in the data capturing process the accuracy of the GIS can be determined as it is based on the quality of the data it contains.

Independent testing needs to be undertaken in order to verify the claims made by the manufacturer in this case Trimble. Independent testing will develop techniques that will not be biased to produce ‘favourable’ results, and as a result alter the quality of the conclusions that prospective buyers may have drawn from the results. Favourable results refers to the fact that manufacturer’s may only test in conditions that are known to give consistent results, which will lure consumers into a false sense of security.

1.2 Research Aim and Objectives

1.2.1 Research Aim

The aim for this project is to compare the accuracy of Trimble’s Mapping Grade GPS Receivers against the manufacturer’s claims using static carrier phase observations.

1.2.2 Research Objectives

This project will undertake testing using the carrier phase observable. The testing will involve receivers manufactured by Trimble, namely the Pro XR and Pro XH. Testing will involve varying baseline lengths and occupation times. Post processed results will be gained from single and multiple base station post-processing. Base station data will be obtained form the University of Southern Queensland USQ base station (Ananga) and the Southeast Queensland (SEQ) Virtual Reference Station Network (VRS network). The zephyr antenna will also be used with the Pro XH receiver. Results will be processed in Trimble Geomatics Office and Trimble Path Finder Office; H-Star processing will be also conducted with the Pro XH receiver.

1.3 Justification

Justification for this project comes from the fact that more infrastructure is being mapped, and the location of these features needs to be known, in order to fit within client specified tolerances. It is important that client specifications are met, so planning and decision making that will be undertaken by the client and associated parties will be based on the best spatial data available. For clients to receive the best possible data it is important for the collectors of this data, namely surveyors, to know the practical limitations of the equipment and processes used during the collection and processing of this data. With these limitations known the surveyor is in a position to be able to implement strategies to ensure accurate data is collected while out in the field. Further justification comes from the fact that there are a variety of software packages and post-processing methods available, as well as large variety of mapping grade GPS receivers on the market. To be able to use data from a GPS receiver within a GIS, the accuracy of that data needs to be of a set standard to ensure that client specifications are met. If data is used and the accuracy is not known the credibility of this data for accurate future planning will be diminished.

1.4 Scope of Research

The testing which the author will undertake will be with mapping grade GPS receivers manufactured by Trimble only. The receivers that will be tested are the Pro XR, Pro XH and Pro XH with a Zephyr antenna. Testing will be of a static nature; receivers will be stationary during the observation regime. Data will be processed using single and multiple base station systems. Processing will be carried out using Trimble Geomatics Office and Trimble Path Finder Office. Varying baseline lengths and observation times will be used to validate the manufacturer’s claims (refer to

Appendices B and C) with respect to the accuracy of the carrier phase observable. It is also assumed that the basic concepts of GPS surveying and usage are understood by the reader, and as a result only difficult concepts will be discussed in detail from this point onwards.

1.5 Conclusion

This dissertation aims to compare the accuracy of Trimble Mapping Grade GPS Receivers using carrier phase observations against manufacturer's claims. It is important that independent testing is undertaken to ensure that unbiased procedures and reduction methods are used. By using independent testing procedures and reduction methods future users will be able to compare the author's results to those undertaken by other parties, and make an informed choice regarding the practical limitations of the equipment.

To ensure consistency between existing testing and reduction methods and the proposed testing and reduction methods, a literature review will be undertaken. A literature review will reveal several concepts that will be essential to the successful completion of this project, such as.

- Manufacturer's claims on the receivers
- Previous testing regimes, and
- Results from these testing regimes.

A literature review will be used to gain an understanding of existing published testing procedures. The procedures that have been found will be critically analysed to find some guidelines as to what a testing procedure should contain. A wide variety of references will be perused to include the differing options of what an optimum procedure should contain. Once all the previous testing procedures have been examined, a project specific regime will be designed to compare the claims made by the manufacturer.

Chapter 2

Literature Review

2.1 Introduction

The purpose of this chapter is to gain an understanding of previously published information regarding GPS receiver testing procedure. Before testing of existing products can commence, it is important to examine previous tests that have been carried out and the results that have been obtained. By undertaking a literature review, ‘overlaps’ in the proposed testing procedure can be minimised. This will allow results gained from this testing to be compared directly with existing results.

The aim of this literature review is the give the reader an understanding of the concepts that are important to analysing the results that the testing will produce. The literature review involved the gathering of information from a variety of different sources, which were Trimble Navigation, The United States (US) Forest Service and Serr, Weber and Windholz. These sources have been used to clarify the important concepts. By investigating a variety of sources, this will ensure that differing opinions in the information published to date can be reviewed and allow the testing procedure developed for this project to be based on a wide selection of previous testing procedures.

2.2 Receivers being used

2.2.1 Pro XH Receiver

The Pro XH GPS receiver is capable of collecting H-Star data. H-Star technology is based on improved field and office software and H-Star post-processing, which is the use of multiple base stations. H-Star data allows the receiver to achieve post-processed results within 30cm with the internal antenna, or within 20cm with the optional Zephyr antenna. EVEREST multipath rejection technology is part of the onboard software for this receiver. The EVEREST multipath rejection software works by examining the polarity of GPS signals, which will have right hand polarity if undisturbed and left hand polarity if affected by multipath (Chamberlain, 2002). Multipath or the reflection of satellite signals off nearby objects, causes inaccuracies to occur with the calculated position. Since the satellite signal does not take a direct route to the GPS receiver, the number of wavelengths to reach the receiver is ‘miscounted’. The counting of wavelengths is an integral part of using carrier phase observations; the ‘miscounting’ of wavelengths creates inaccuracies in the calculated positions. Sub metre accuracy can be achieved with this receiver in real-time, which is useful in the field. See Appendix B for Pro XH Specifications

Figure 2.1: Photograph of Pro XH Receiver

2.2.2 Pro XR Receiver

The Pro XR receiver is capable of real-time sub metre accuracy and is also fitted with EVEREST multipath rejection technology. The difference between the Pro XR and Pro XH receivers is that the Pro XR is unable to collect H-Star data or be post-processed using multiple base stations. Post-processed carrier phase accuracy for this receiver ranges from 30cm after 5 min of tracking satellites to 1 cm after 45 min of satellite tracking, this is the accuracy claim stated by Trimble. See Appendix C for Pro XR Specifications.

Figure 2.2: Photograph of Pro XR Receiver

2.2.3 Zephyr Antenna

The Zephyr antenna is designed to track both L1 and L2 wave lengths. The monitoring of both L1 and L2 wavelengths allows the effects of ionosphere delays to be modelled and errors minimised. This antenna contains sophisticated multipath rejection technology and the ability to track low elevation satellite signals. These features make this antenna ideal for data collection in areas where satellite signals may be degraded due to environmental conditions. A screw thread allows for easy mounting on a pole, tribrach or backpack. The zephyr antenna will be used with the Pro XH receiver. The reason this antenna is used instead of the internal antenna of the Pro XH, is the increased accuracy that the zephyr antenna can provide. This antenna cannot be used with the Pro XR receiver.

Figure2.3: Photograph of Zephyr Antenna

2.3 Grades of GPS Receivers

Currently there are three grades for GPS receivers on the market available for civilian use. These are known as survey, mapping or resource and recreational grade receivers (Wisconsin Department of Natural Resources, 2001). The main differences in these grades are accuracy, price, memory and primary use.

2.3.1 Survey Grade

Survey grade GPS receivers have the highest accuracy of the three grades, with typical accuracy of <2cm in real-time and after post-processing can reach <1cm. Typical survey grade receivers will have a purchase price of $35,000 to $70,000. The primary uses for receivers of this quality are resource mapping, surveying, stakeout and vertical measurement. These receivers undertake measurements by using carrier phase wave lengths.

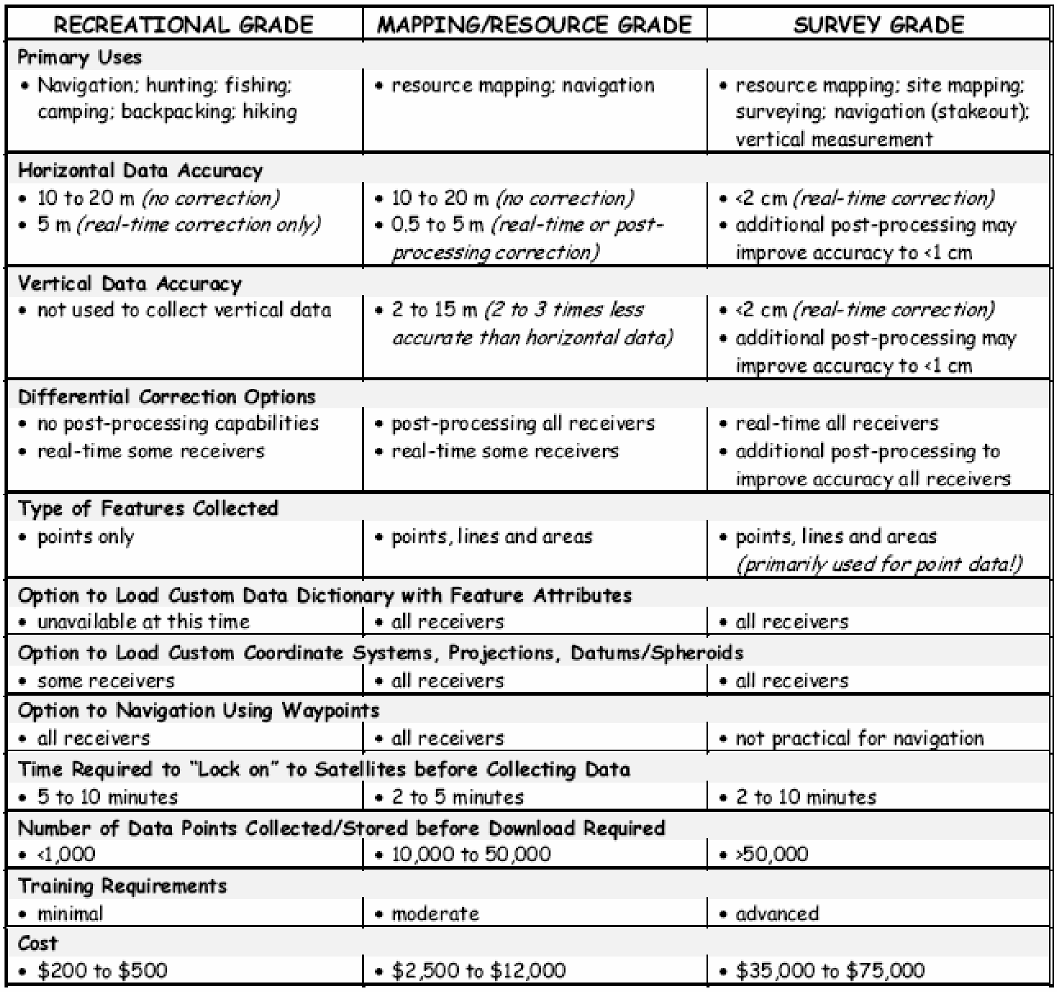
2.3.2 Mapping/Resource Grade

Mapping grade receivers have reasonable accuracy of 0.5 to 5.0m for either real-time or post-processed corrections. $2,500 to $12,000 is the typical price range for receivers of this grade. The main use of this receiver type is, as its name suggests, for mapping resources which is used to provide spatial information for GIS.

2.3.3 Recreational Grade

Recreational grade receivers are used by hunters, fisherman and other outdoor activities where navigation is important. Typical receivers will cost up to $500 and have and accuracy of up to 5 m after a real-time correction has been made. These receivers are used predominantly to navigate safety back to a predetermined point such as a cabin or deer hide.

Figure 2.4 shows the differences between the three grades of GPS receivers as described above.



RECREATIONAL GRADE	MAPPING/RESOURCE GRADE	SURVEY GRADE
Primary Uses		
• Navigation; hunting; fishing; camping; backpacking; hiking	• resource mapping; navigation	• resource mapping; site mapping; surveying; navigation (stakeout); vertical measurement
Horizontal Data Accuracy		
• 10 to 20 m *(no correction)* • 5 m *(real-time correction only)*	• 10 to 20 m *(no correction)* • 0.5 to 5 m *(real-time or post-processing correction)*	• <2 cm *(real-time correction)* • additional post-processing may improve accuracy to <1 cm
Vertical Data Accuracy		
• not used to collect vertical data	• 2 to 15 m *(2 to 3 times less accurate than horizontal data)*	• <2 cm *(real-time correction)* • additional post-processing may improve accuracy to <1 cm
Differential Correction Options		
• no post-processing capabilities • real-time some receivers	• post-processing all receivers • real-time some receivers	• real-time all receivers • additional post-processing to improve accuracy all receivers
Type of Features Collected		
• points only	• points, lines and areas	• points, lines and areas *(primarily used for point data!)*
Option to Load Custom Data Dictionary with Feature Attributes		
• unavailable at this time	• all receivers	• all receivers
Option to Load Custom Coordinate Systems, Projections, Datums/Spheroids		
• some receivers	• all receivers	• all receivers
Option to Navigation Using Waypoints		
• all receivers	• all receivers	• not practical for navigation
Time Required to "Lock on" to Satellites before Collecting Data		
• 5 to 10 minutes	• 2 to 5 minutes	• 2 to 10 minutes
Number of Data Points Collected/Stored before Download Required		
• <1,000	• 10,000 to 50,000	• >50,000
Training Requirements		
• minimal	• moderate	• advanced
Cost		
• $200 to $500	• $2,500 to $12,000	• $35,000 to $75,000

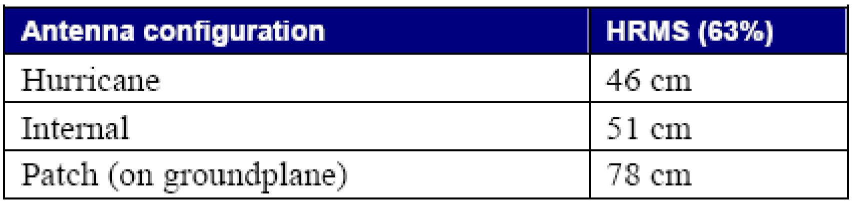
Figure 2.4: The comparisons between the three grades of GPS receivers (Source: Wisconsin Department of Natural Resources, 2001)

2.4 Past Testing Procedures

2.4.1 Testing by Trimble

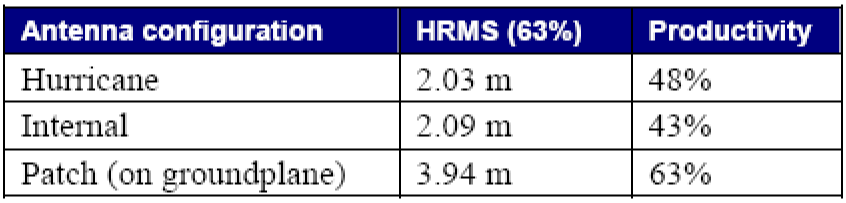
Before Trimble is able to commercially sell products to the public, testing needs to be performed, so purchasers can compare the expected accuracy of different models. Trimble also undertakes testing using the various antennas that are available for a particular GPS receiver *(Trimble 2006e)*. Testing was carried out by setting an antenna over a known mark and continually logging the position over a period of time. The receiver used during this testing was the Geo XT receiver. A variety of antennas were used with this receiver, namely the internal and the Hurricane and Patch antennas. The use of external antennas is important when testing GPS receivers as standard receivers are often used with external antennas to increase the accuracy of data collected. The increase in accuracy needs to be determined, so that is why testing is completed using external antennas. The use of the zephyr antenna with the Pro XH receiver can be used to see if there is any improvement in the accuracy by using an external antenna. This particular testing also involved static performance under canopy and dynamic performance under canopy. However, the testing of the receivers under canopy and dynamic performance is not important to this project, as the observations will be taken when the receiver is static over a particular mark.

Once the testing was concluded the Root Mean Square (RMS), and in particular Horizontal RMS (HRMS) value was calculated. The smaller the HRMS value the better the relative accuracy. RMS error is used to describe uncertainty and summarise the entire error distribution. The results of the testing undertaken by Trimble are shown in Figures 2.5 and 2.6.



Antenna configuration	HRMS (63%)
Hurricane	46 cm
Internal	51 cm
Patch (on groundplane)	78 cm

Figure 2.5: Static accuracy by antenna configuration in open sky conditions (Source: Trimble 2006e)



Antenna configuration	HRMS (63%)	Productivity
Hurricane	2.03 m	48%
Internal	2.09 m	43%
Patch (on groundplane)	3.94 m	63%

Figure 2.6: Static accuracy and productivity by antenna configuration under canopy (Source: Trimble 2006e)

Note: This testing also compared productivity of the antenna configurations

Testing conducted under trees, once again required receivers to be set up over known control marks. Even though this particular testing looked at performance under trees, this project will not look at this aspect of GPS receiver testing. These control marks were co-ordinated using a Trimble total station. Data was logged over an extended period of time and reduced. To ensure that data recorded is useful and will allow conclusions to be drawn regarding receiver accuracy, observations were taken over the marks at the same time of day. By taking observations at the same time of day this ensured that the environmental conditions are very similar and will have the same effects on observations. This is one of the strategies employed by Trimble to ensure comparable data sets. The taking of observations at the same time every day is not going to provide the same range of environmental conditions that would be encountered when undertaking normal field. Field work is normally taken at different times of the day, as personnel and resources become available for use. That is why the testing undertaken by this project will visit the various Permanent Survey Marks (PSMs) at differing times that are more likely to be a representation the actual process involved in field work. This testing undertaken by Trimble has been helpful in explaining how a testing regime is conducted, but is of limited use because of the testing done under trees and the dynamic testing that was also completed.

2.4.2 Testing by US Forest Service

Similar testing procedures were used by the US Forest Service to determine receiver performance under West Oregon forest canopies (Chamberlain 2002). Testing was carried out on 12 marks of known co-ordinates; once again these marks were co-ordinated using total station measurements. A lot of the existing testing regimes that have been found and examined have used conventional total station to co-ordinate the marks needed to test over. This will not be necessary for this project as the details of co-ordinated PSMs will be gained from the Department of Natural Resources and Water (DNRW) survey data base.

Once set up over the marks, data was logged at a rate of 1 position/second and 15° elevation mask. Testing was carried out using both internal and external antennas for the Geo XT receiver. This was completed for the same reasons as the testing regime undertaken by Trimble; to see if accuracy improves. Data used for this testing was collected over multiple days in order to obtain results under differing conditions. This would allow researchers to compare receiver performance under the expected conditions for this site. This testing method is very important in supporting the testing procedure that will be developed for this project. Trimble Pathfinder Office version 2.9 was used to post-process the data collected during the testing phase. Differential corrections obtained from the Portland State University Community Base Station (CBS) were used as the basis for the post-processing.

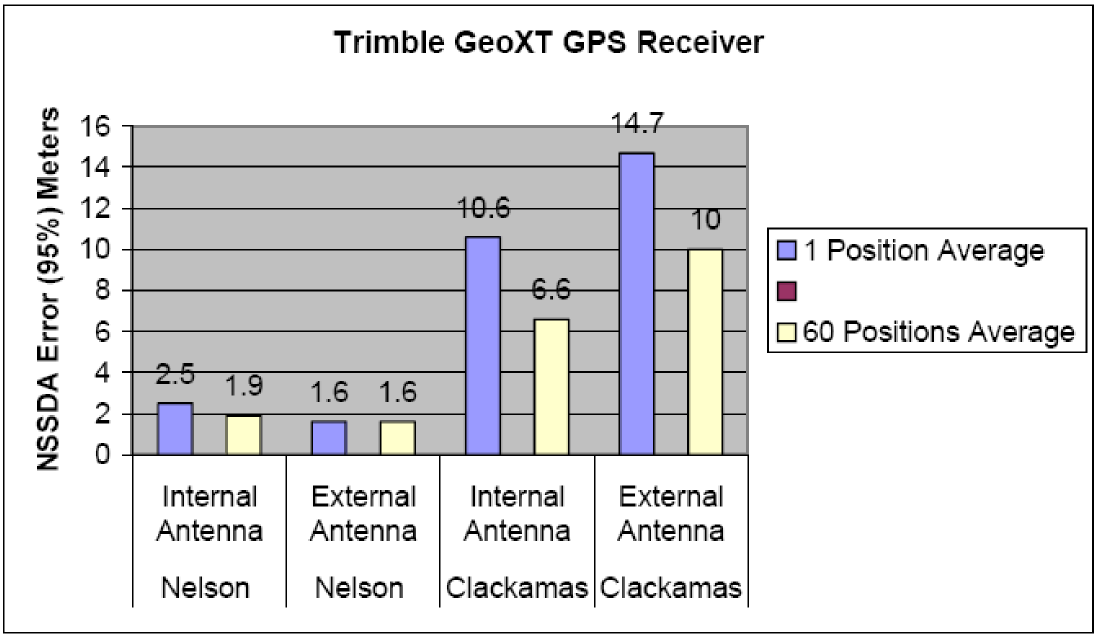


Figure 2.7: Results achieved from testing regime (Source: Chamberlain, 2002)

Nelson is an open site with no obstructions, while Clackamas is a forested site.

The results gained were unexpected when compared to other tests, as the internal antenna produced higher accuracy positions then the external antenna (Chamberlain 2002). A possible reason for these unexpected results is the differing nature of the internal and external antennas. Internal antennas are designed to optimise on accuracy, whereas external antennas are designed to optimise on efficiency (Chamberlain 2002). Both internal and external antenna use Everest multipath rejection technology, which works by examining the polarity of GPS signals. The internal antenna feeds GPS signals in a bandwidth that is designed to optimise accuracy and the external antenna feed to designed to improve efficiency (Chamberlain 2002). The testing procedure undertaken by the US Forest Service is known as characterising a GPS receiver. This type of testing determines performance capabilities in given environmental and terrain conditions. This information will allow data collectors to implement site specific procedures to ensure that client specified tolerances are reached.

2.4.3 Testing by Serr, Weber and Windholz

Serr, Weber and Windholz (2006) undertook their testing regime to study which receivers would be the most appropriate for various research, remote sensing and GIS applications. It is important to know the practical accuracy of GPS receivers because their use in GIS applications is increasing. GPS data is being used to geo-reference satellite imagery and aerial photographs. New imagery systems such as Quick bird are able to achieve a spatial resolution of 2.4 m per pixel. To ensure that the geo-referencing is performed correctly the GPS receivers must be capable to deliver results that are one half of the spatial resolution of the imagery. This makes sure the each field observation is registered to the correct image pixel. The study was conducted in and around the city of Pocatella, Idaho. The receivers used in this testing regime were:

1. Trimble Geo XT with WAAS
2. Trimble Geo XT without WAAS
3. Trimble GeoExplorer II
4. Trimble Pro XR
5. HP IPaq with Pharos Navigation software and antenna.

Once again a number of pre-existing co-ordinated marks were chosen as the basis of the testing procedure. Serr, Weber and Windholz (2006) chose control marks based on their accessibility and visibility to GPS satellites. This is partly relevant to the testing completed as part of this project, as control marks have been selected based on their accessibility. This was done to provide the best conditions under which the receiver could operate. These conditions represent the environments that targets are placed in to geo-reference aerial photography and satellite imagery. Trimble Quick Plan software was used to plan the observation periods, when the Position Dilution of Precision (PDOP) was less than 5.0.

The data was post-processed using data from the Idaho State University GIS Training and Research Centre’s GPS CBS. Points were collected using latitude/longitude World Geocentric Datum of 1984 (WGS84) datum. The receivers used averaged 120 positions each of the ten times the marks were visited.

These testing procedures emphasise the following main points which are important to GIS database managers.

1. understand the differences in horizontal accuracy obtained from various GPS receivers
2. ensure co-registration of GPS acquired features and satellite or aerial imagery
3. determine the appropriate GPS receiver to use to satisfy mapping scale requirements.

This testing procedure shows the need to undertake independent testing to ensure that the practical limitations of the receivers being used are suitable for the desired use. The original reason for this was to study which receivers would be the most appropriate for various research, remote sensing and GIS applications. The main reason why a variety of receivers are being tested as part of the testing regime for this project is because of the currently high use of mapping grade GPS receivers in the maintenance of spatial databases.

2.5 Post-processing GPS data

GPS measurements are effected by a number of different error sources. These errors affect the time for satellite signals to reach the receiver on the earths' surface, and thus the computed position is inaccurate. Many of these errors are due to the limitations of the equipment and the environment in which the receiver is being used. The types of errors in GPS measurements are satellite errors, the atmosphere, multipath, receiver error and selective availability (*Trimble 2006d*). Selective Availability was turned off on 2nd May 2000 after the announcement from the White house a day earlier (Collins, Hofmann-Wellenhof & Lichtenegger 2001, *p 17).* Satellite and receiver errors are a result of errors within the clocks used to measure the time for the signals to reach the receiver. Even though satellite clocks are very accurate, there are still inaccuracies which lead to errors in position measurements (*Trimble 2006d*).

Errors from the atmosphere and multipath are resultant of the environment where the GPS receiver is being used. Atmospheric error is caused as the satellite signals travel through the various layers of the atmosphere; this delays the signals reaching the receiver. Since the distance calculation assumes a constant speed, the delay leads to a miscalculation of the distance (*Trimble 2006d*). Multipath occurs when satellite signals bounce off reflective surfaces before reaching the receiver. This delays the signals to the receiver, and also leads to a miscalculation of the distance. Many receivers now have sophisticated multipath rejection software such as EVEREST Multipath Rejection Technology, which allows these errors to be minimised. Carrier phase waves are right hand circularly polarised, but once reflected off surfaces becomes left hand circular polarised. The software is able to reject these reflected waves and only allow the right hand polarised waves to reach the receiver.

To remove these errors a differential correction can be applied to the GPS measurements. For corrections to be made in real-time, a radio link is needed to broadcast the corrections to the roving receiver. A differential correction is calculated by setting one receiver as a base station. This receiver is able to compute the actual time signals should take to reach it, using the known position on the ground that it occupies and the satellites' position. It is assumed that since the two receivers are usually close together the signals have travelled through essentially the same atmosphere, and as a result the corrections are the same. This differential correction can be applied in real-time or be post-processed later in the office. Post-processing can only occur if the roving and base station are collecting data from the same satellites at the same time, there must be at least four satellites in common (Trimble *2006d*). Post processing uses data collected before and after the measurement was taken as well as the 'actual' position of the satellite to calculate positions on the earths' surface. Real-time positioning is based on where the satellite 'thinks' it is and therefore positions calculated contain a certain amount of error due to bias and drift within its orbit.

2.6 Statistical Concepts

Accuracy and precision are two terms that will be used throughout the discussion of the results achieved from the testing procedure; there is some confusion over the use of these terms since they are used interchangeably. Accuracy and precision do actually differ in their reference to measurements. Accuracy refers to the agreement between a measurement and the true or correct value (Bellevue Community College, 2005). The true or correct value needs to be known or able to be determined for accuracy of any measurements to be discussed and analysed. Accuracy refers only to the 'closeness' of a measured value and the expected value and makes no statement regarding the ability at which these results can be reproduced. Figure 2.8 is an example of accurate measurements.

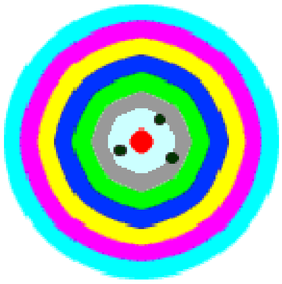


Figure 2.8: An example of accuracy (Source: Flatirons Surveying, Inc)

Precision on the other hand refers to the ability of which measurements can be repeated. Successive measurements can be 'far' from the true value but still be close together indicating low accuracy but high precision. Figure 2.9 shows how precise observations are closely grouped together. When observations are both accurate and precise, their relationship to the true value (bull's eye) is pictured in Figure 2.10

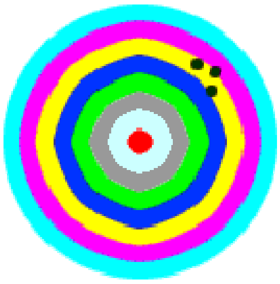


Figure 2.9: An example of precision (Source: Flatirons Surveying, Inc)

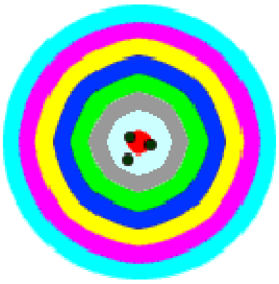


Figure 2.10: An example of accuracy and precision (Source: Flatirons Surveying, Inc)

Uncertainty is another term that will be used in the statistical analysis of the results gained from the post-processing. Uncertainty is the interval in which future measurements are expected to be contained. Uncertainty is quoted by a confidence interval, which states that a certain percentage of future measurements should be expected to lie within a set amount from the true value. A confidence interval is stated as plus/minus some value from a central value, usually the mean of the data being tested. For example if the confidence interval is stated as 0.5m ± 0.15m, means that it can be expected that results gained will be between 0.35 and 0.65m.

Confidence intervals are used to show what should be expected if repeated measurements are taken. A confidence interval is the range in which successive measurements are expected to be within, at a given percentage of confidence. An example of a confidence interval is represented in Figure 2.11.

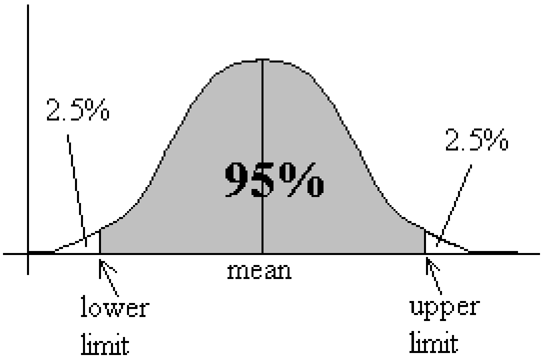


Figure 2.11: An example of a confidence interval (Source: Flatirons Surveying, Inc)

The shaded area of Figure 2.11 represents a confidence interval of ninety-five percent. A confidence interval is usually centred about the mean value and is quoted as values either side of the mean.

2.7 H-Star Technology

H-Star post-processing is a method of post-processing GPS observations. H-Star technology is a combination of advanced GPS receiver, field software with sophisticated logging capabilities, and office software with innovative post-processing capabilities (Trimble 2006a). This method uses multiple base stations to differentially correct measurements taken by the receiver while out in the field. The three essentials for the H-Star system are:

1. Quality GPS data
2. PPA-driven workflow
3. H-Star post-processing

The GPS receivers used in H-Star processing are constructed to a high standard: therefore the equipment is able to capture a better quality of GPS signals. Since the GPS data collected is of a higher quality it is less likely to contain errors such as multipath to the same magnitude as receivers that don’t have H-Star capabilities.

The PPA-driven workflow is another important feature of H-Star technology. Predicted Post-processed Accuracy (PPA) is the accuracy that can be expected once the field data is post-processed back in the office. This feature allows the operator to have confidence that results from post-processing will be able to satisfy client requirements. PPA is based on antenna type, satellite geometry, the time lock has been maintained on a minimum number of satellites and that base stations used to post-process the data will meet H-Star requirements (Trimble 2006a). The PPA value is continually calculated and displayed on the screen of the data collection device. Even though the PPA value is continually being up-dated on the data collection device, it is of little consequence what value this actually is. The testing that was completed during this project has used a variety of observation times, one of which was based on the minimum time taken by the Pro XR to collect enough data to be able to be post-processed. This time was ten minutes, to be able to compare the differences between the two receivers the observation times needed to be the same. There is no such thing as minimum observation time when using H-Star receivers, because the PPA gives an indication of the accuracy that will be achieved after post-processing. When lock on satellite signals is lost the best PPA achieved in a session, is the PPA of all post-processed points collected during that time, when lock is regained the PPA will be recalculated as duration of lock increases.

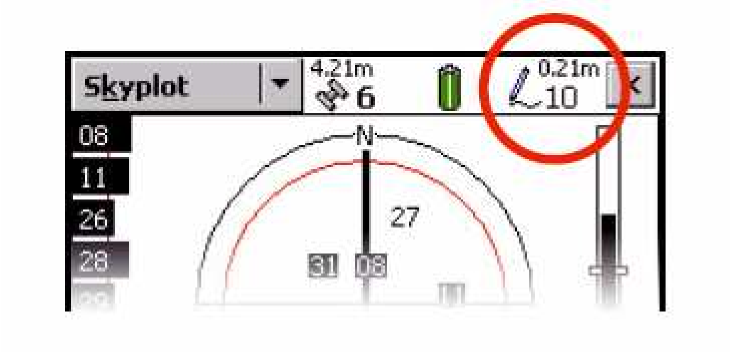


Figure 2.12: The TerraSync software showing a PPA value (Source: Trimble 2006a)

To ensure that post-processed results are of the best possible quality, the reference stations used need to be of the highest quality. The quality of a reference station is shown as a value known as an integrity index. These values range from 0 to 100, the higher the value, the more reliable the reference station is for use in post-processing observations.

H-Star technology because of its PPA-driven workflow makes data capture more efficient; the reason for this is that the PPA indicates the accuracy that can be achieved once post-processing is complete. Without the use of H-Star, lock needs to be maintained for extended periods to ensure that post-processed results will meet designated specifications. The PPA value is continually calculated and displayed on screen and the operator is able to cease data collection once the required PPA value is reached, thus saving field time.

H-Star post-processing used in project used three local base stations. These base were Ananga which is located at the USQ Toowoomba campus, the other two base stations are part of the VRS that is currently operating in SEQ. The names of the other two base stations are Caboolture and Robina. The location of the three base stations with respect to SEQ is shown in Figure 2.13.

Figure 2.13: Base stations used as part of H-Star post-processing (Adapted from RACQ website)

2.8 Conclusion

It can be seen that there are many similarities in the testing procedures examined. The main point is that a number of existing co-ordinated marks are chosen as references to determine accuracy of the receivers being tested. The number of points chosen is usually about twelve.

Another common factor is that testing is done while the receivers are static and set up over the mark for extended periods of time. The RMS values are always calculated and used as a basis for comparison against manufacturer claims and other receivers. A variety of receivers and antennas have been used by the individuals who are undertaking the testing observation regime. Data is post-processed from nearby base stations that are continually monitoring GPS satellites.

Having reviewed the relevant literature regarding existing test procedures and recognising the similarities above, the author proposes to undertake a testing procedure that will allow comparable datasets to be produced and allow statistical analysis to be performed, to allow the various receivers to be compared with each other. The next chapter will outline more specifically the extent of the procedure to be used during this project. This chapter will outline the field and office procedures and explain the observation regime that has been used to test the receivers.

Chapter 3

Testing Procedures

3.1 Introduction

This chapter explains the testing regime, field and office procedures and stipulates why these procedures were appropriate to this project. The testing will be based on existing testing methods as reviewed in Chapter 2 and other specific procedures that will ensure that the project aim is met.

The aim of this chapter is to provide enough information to the reader to allow them to understand what the testing procedure involves, how this was completed and why this was done.

The testing procedure will involve setting various receivers over control marks with known co-ordinates and logging GPS data for varying time periods. Marks to be used will be selected from the Toowoomba City and Gatton Shire regions and will consist of co-ordinated PSMs. PSMs were selected on the basis of distance from Toowoomba and accessibility. The DNRW databases were used to gain co-ordinate information for the PSMs chosen.

3.2 Data Characteristics and Testing Overview

To allow statistical analysis to be performed enough data needs to be collected for a period of time that can be considered to be a representation of the expected operating conditions. The data collected needs to be compatible with the software packages used for the processing of data. This should not be a problem as Trimble Pathfinder Office and Trimble Geomatics Office are designed to process the data files that the receivers will output. The output from the receivers is an un-corrected file in the .SSF file format.

The receivers that will be tested, namely the Trimble Pro XR and Pro XH, will be stationed at each mark and data will be logged at a rate of one position per second until the receiver indicates it has logged enough data for an adequate fix. Time taken for the receiver to record enough data for an adequate fix depends on many factors such as satellite geometry and environmental conditions surrounding the receiver whilst in use. The time taken for the Pro XR receiver to log enough data is indicted by a message shown on the screen of the data collection device, in this case a Recon. The message shown on the screen of the Recon was ten minutes. Ten minutes was therefore also used with the Pro XH receiver, even though this receiver is able to collect H-Star data and there is no such thing as minimum time required for an adequate fix.

Further testing will be carried out to test claims regarding accuracies as observation time increases. GPS data will be logged for a period of forty-five minutes at one second epochs at the same mark with the Pro XH receiver. Once data has been collected and downloaded, the data will be processed using Trimble Pathfinder Office and Trimble Geomatics Office. Data will be processed at ten, twenty and forty-five minutes and statistical analysis will be performed after the processing of each lot of data. This will allow conclusions to be drawn regarding the changes in accuracies as observation time increases. The use of observation times of twenty and forty-five minutes are based on the manufacturer claims as stated on the data sheets for the relevant receiver. For the Pro XH the manufacturer makes the following claims as shown in Table 3.1 more specific information can be found in Appendix B.

Table 3.1: Manufacturer claims for the Pro XH

Post-processing Method		Accuracy (HRMS)
H-Star processed	with internal antenna	30cm
	with optional zephyr antenna	20cm
Carrier Post-processed	with 20 minutes of satellite tracking	10cm
	with 45 minutes of satellite	1cm

Table 3.1 also shows the expected accuracy when using the zephyr antenna; this is why this project will test this antennas operation. It can be seen in Table 3.1 that as observation time increases so does the accuracy.

3.2 Observation and Post-processing Regime

This section will explain the observations taken by each receiver configuration and which software programs will be used to post-process the data collected. The observation regime used for the project is shown in Table 3.2.

Table 3.2: Observation Regime

	Bases		**Software Packages**	
	1	3	PFO	TGO
Pro XH (Internal)	🟩 **minimum**	🟩 **minimum**	✓	✓
	🟨 **minimum/ varying**	🟨 **minimum/ varying**	✓	✓
Pro XH + Zephyr	🟩	🟩		
	🟨 **minimum**	🟨 **minimum**	✓	
Pro XR (Internal)	🟩 **minimum**	🟩 **NA**	✓	
	🟨 **minimum**	🟨 **NA**	✓	

Toowoomba 🟩
Gatton 🟨

Table 3.2 shows that three different receiver configurations have been used in this project. The three receiver configurations used are the Pro XR and Pro XH with their respective internal antennas and the zephyr antenna with the Pro XH. The minimum observation time was ten minutes, which is based on the time taken by the Pro XR to ‘collect’ enough data to calculate an adequate fix. This time was also used with the other two configurations. Two other times will also be used to test the receivers, which were twenty and forty-five minutes. The twenty minute observations were gained by deleting the last twenty-five minutes of a forty-five minute data file. These extended observation times will use the Pro XH receiver only and be carried at the marks surrounding Gatton. The exact testing carried with each receiver is shown in the following subsections

3.2.1 Pro XR Testing

H-Star post-processing will not be carried out with the Pro XR receiver as this receiver is unable to collect H-Star data. The Pro XR receiver will be used to take minimum time observations on all the marks (refer to Appendix D for list of PSMs used) and no extended observations will be carried out using this receiver. These observations will be post-processed using Path Finder Office. Single base station post-processing will be carried out using base station files from Ananga only.

3.2.2 Pro XH Testing

The configurations using the Pro XH receiver will be post-processed using single base station and H-Star methods. This will allow single base and H-Star methods to be compared to see which is able to provide more consistent results. This receiver was used to take both minimum and extended time observations. Minimum time observations were conducted over PSMs, both at Toowoomba and Gatton. On the other hand extended time observations were only taken over Gatton PSMs. Observations taken using this receiver with the internal antenna will be post-processed using Trimble Path Finder Office and Trimble Geomatics Office

3.2.3 Pro XH and Zephyr Antenna Testing

The zephyr antenna will be used to compare the accuracy differences between the internal antenna of the Pro XH and the zephyr antenna. Observations taken with the zephyr antenna will only be of the minimum time of ten minutes and over the Gatton marks only. Observations taken with the zephyr antenna will be post-processed using Path Finder Office only.

3.3 Field Procedures

The first step in the field procedure was the successful location and identification of the PSMs to be used during testing. This ensured that when testing was completed, the marks can be quickly and reliably located and the right mark used. Once individual marks had been located, the receivers were setup on a stable platform in this case a tripod.

Figure 3.1: Photograph of Pro XR setup over a PSM

The receiver remained on the tripod during the entire observation period. Observations were taken over a number of days as testing could not be completed in one day. The minimum time observations were completed first using the Pro XR receiver and the remaining observations were taken over subsequent days. Table 3.3 shows the date when each receiver configuration was tested.

Table 3.3: Observation Dates

Receiver/Marks	Date
Pro XR/Toowoomba	7 July 2006
Pro XH/Toowoomba and Gatton	10 July 2006
Pro XH (extended)/Gatton	11 July 2006
Pro XR and Pro XH with Zephyr Antenna	12 July 2006

Minimum time observations will test the ability of the onboard receiver software to determine when sufficient data has been logged, to ensure that the post-processed accuracy will be within manufacturers' claims. Extended observations will determine whether there are any changes in accuracy as observation time increases. Results from this testing have been compared with claims made in the equipment specifications. The optimum observation time for efficient data collection can also be determined, but this is outside the scope of this project.

3.4 Office Procedures

Once the data had been collected in the field, it was post-processed using two different software packages: Trimble Pathfinder Office and Trimble Geomatics Offices (refer to Appendix F for Trimble Pathfinder Office post-processing settings and Appendix G for Trimble Geomatics Office project properties and processing style).

These software packages were used to apply the differential corrections used in post-processing. The differential corrections applied by the software packages came from base station files at USQ Toowoomba Campus and VRS data from Robina and Caboolture. Since data being logged by the receivers is at the rate of 1 position per second, data from the base stations was also logged at this rate. This happens to be the standard logging rate at the base stations used to post-process the data collected.

Data from the minimal time observations was post-processed from Ananga, because of the ease of access to base station files. The varying baseline lengths have allowed changes in accuracy to be seen as the baseline length changes.

Data from the extended observations of the procedure were processed using the same procedure as the minimal time observations. Data from the 45 minute block have been processed after twenty and forty-five minutes, as according to the manufacturer's specifications. A twenty minute data file was gained by removing the last twenty-five minutes of a forty-five minute file. This processing has allowed changes in accuracy to be seen and compared as the observation time increases. Since this data was logged with the Pro XH, the data was processed using both single and multiple bases. The processing for this part of the testing was undertaken using Trimble Pathfinder Office and Trimble Geomatics Offices.

Data collected with the Pro XR, and the Pro XH with zephyr antenna, was only post-processed using Pathfinder office. The data collected with the zephyr antenna was post-processed using both single and multiple bases.

3.5 Pro XR Receiver

3.5.1 Test/Data Collection

As mentioned earlier the Pro XR receiver was used to take ten minute observations on PSMs around both Toowoomba and Gatton. Observations were collected using a Recon Data collector, using the settings as outlined in Appendix E.

3.5.2 Post-processing

The observations taken by the Pro XR receiver were post-processed in Trimble Path Finder Office only. The post-processing that was undertaken with this receiver was carrier post-processing only. H-Star post-processing could not be undertaken as this receiver is unable to collect H-Star data. The single base used for this post-processing was Ananga, the base that is located on the top of Z Block of the Toowoomba USQ campus.

3.5.3 Expected Analysis

After the observation files had been post-processed using Path Finder Office, the results of these files have been analysed with a number of Pro XH post-processed results. Comparing all the minimum time observations of both receivers has allowed the differences between single and H-star post-processing methods to be discussed. This can be achieved because the same control marks were observed for the same period of time by both receivers. This comparison will show which of the two methods is able to produce more consistent results. Dividing the marks into ‘close’ and ‘central’, has provided a way to see if there are any benefits in H-Star post-processing with the Pro XH receiver

Results from ‘close’ marks have been used to determine if there is extra weight placed on any one base station in the network of the H-Star base stations used when post-processing Pro XH observations. While results from ‘central’ marks have been used to compare the differences in accuracy with the Pro XR and H-Star post-processing using the Pro XH receiver

3.6 Pro XH Receiver

3.6.1 Test/Data Collection

This receiver has used with both the internal and zephyr antennas. The use of these two different antennas allowed the differences in these to be analysed. The internal antenna has been used to take minimum time observations on all marks, just like the Pro XR. Extended observations were also taken with Pro XH receiver; these observations were completed over Gatton PSMs only. The use of the zephyr antenna was restricted to the minimum time and conducted over Gatton marks only. The settings used with this receiver are the same as those used with the Pro XR and are outlined in Appendix E.

3.6.2 Post-processing

The Pro XH receiver is able to collect H-Star data as described in section 2.7. Post-processing of Pro XH data files were therefore carried out using single and multiple base station post-processing. All data files taken using this receiver were post-processed using Ananga as the single base and the H-Star base station network as shown in section 2.7.

The minimum time observations using the internal were post-processed using both Trimble Path Finder Office and Trimble Geomatics Office. By using two software packages to correct the data files the differences between the two software packages can be analysed.

The extended observations were taken for forty-five minutes over ‘central’ PSMs only. These files were post-processed after twenty and forty-five minutes as set out in the manufacturer’s specifications as exhibited Appendix B. The twenty minute observations were obtained by removing the last twenty-five minutes of a forty-five minute data file. These data files were post-processed in Trimble Path Finder Office only.

The zephyr antenna data files were processed using single and multiple base stations. Observations for this configuration were restricted to the minimum observation time of ten minutes and taken over ‘central’ PSMs only. These files were only post-processed using Trimble Path Finder Office.

3.6.3 Expected Analysis

The minimum time observations have been analysed in the manner as described earlier in section 3.5.3. Results from Trimble Geomatics Office software have been used to compare the two packages and to see which processes data more accurately. The results extended observations have been used to see if there is any change between increased observation times and increased accuracy. By using both single and multiple base station post-processing the differences can be seen between the two methods, this will be discussed further in chapter four.

The zephyr antenna results have been compared with the minimum time observations taken with the internal antenna. The manufacturers have claimed that the zephyr antenna is able to collect data of a higher quality than the internal antenna. Comparing these two different data sets has allowed the claims by the manufacturer to be tested.

3.6 Conclusion

By using the above mentioned observation and post-processing regime, the results can be analysed in a number of ways that will allow the different characteristics of the Pro XR and Pro XH receivers to be compared with each other. The main difference between the receivers is that the Pro XH data can be post-processed using multiple base stations, while the Pro XR cannot. The observation regime has been designed to see if there is any difference in using single base station post-processing when compared to multiple base post-processing. The way in which PSMs have been chosen for use in this project has allowed the opportunity to compare post-processed results as baseline length increases.

Since not all consumers have access to the same software packages and each operates in a slightly different way, the use of the three above mentioned packages will provide additional information to consumers in this area. This information will allow consumers to make an informed decision about the capabilities of the software and the reliability of the results each individual package and receiver is able to produce.

Chapter 4

Results

4.1 Introduction

This chapter shows a number of graphs of the results from each of the software packages, Trimble Pathfinder Office and Trimble Geomatics Office. The graphs will allow the reader to picture the differences between each of the post-processing methods and observation times used.

The aim is that the reader will gain an understanding of the differences between the results from each of the receivers with respect to the post-processing methods and observation times used by viewing the graphs in this chapter.

The graphs that have been constructed have been used in chapter 5: Analysis and Discussions. Each graph will be accompanied by a short paragraph explaining what is depicted on the graph above. The graphs have been divided into two sections, Trimble Pathfinder Office Pro XR and Pro XH and Trimble Geomatics Office Pro XH.

4.2 Explanation of results shown

In the explanation of the graphs that follows reference is made to distance from the ‘true’ value. The ‘true’ value is the co-ordinate value as published in the DNRW database. The difference from the ‘true’ value was calculated in two components, as a change in easting (ΔE) and northing (ΔN). The change was calculated by subtracting the post-processed co-ordinate pair from the respective ‘true’ pair. The distance error from the ‘true’ value was calculated by $\sqrt{(\Delta E^2+\Delta N^2)}$. The reduced level error was calculated as a difference from the ‘true’ reduced level value as published in the DNRW database for a particular PSM.

The software packages, Trimble Pathfinder Office and Trimble Geomatics Office were compared using HRMS and Vertical RMS (VRMS). RMS error is used to describe uncertainty and summarise the entire error distribution. The HRMS describes the error in the distance component. HRMS is calculated by finding the square root of the average of all the distance errors squared. VRMS describes the error in the reduced level component. VRMS is calculated by finding the square root of the average of all the reduced level errors squared.

The graphs below show the 68% confidence intervals. The average is shown by the large horizontal bar in the middle, with the respective bounds shown by smaller bars at the top and bottom. The 68% confidence interval is the range between the upper and lower bounds as depicted by the blue and red bars respectively.

The graphs have been divided into their respective software packages; this has been done to give the reader some idea as to the individual results of each software package. The final section will show graphs that will be used to compare the two software packages against each other.

The graphs in this chapter refer to marks as ‘close’ and ‘central’. ‘Close’ is used to describe marks that are in close proximity to the base station Ananga as shown in Figure 2.13, ‘Central’, on the other hand, is used to describe the five marks located central to the H-Star base stations.

4.3 Analysis to be undertaken

The analysis of the results has been divided into two sections, the individual software packages that have been used to post-process the observations as outlined in section 3.2. The analysis undertaken was based on section 3.5.3 (for the Pro XR receiver) and section 3.6.3 (for the Pro XH receiver).

After completing the post-processing of the observations that were taken according to sections 3.5.2 and 3.6.2, there were a number of comparisons that could used to check the various claims made by the manufacturers of the equipment tested. The comparisons used in this analysis were:

- one base & H-Star processing methods,
- how distance from base station affects post-processed results, and
- base station network weighting

The results have been compared using these three comparisons as a basis. These three comparison areas have provided the opportunity to see the difference between single and H-Star post-processing methods and see if H-Star is significantly better than single base station post-processing. The changes in accuracy as baseline length increases can be seen by using these three areas of comparison. The final area of analysis was to see if there is extra weight placed on any base in the H-Star base network. Extra weighting in the base station network would be proved by the fact that results from marks close to Ananga using single base station post-processing would be very similar to those obtained using H-star methods.

4.4 Trimble Pathfinder Office Pro XR and Pro XH

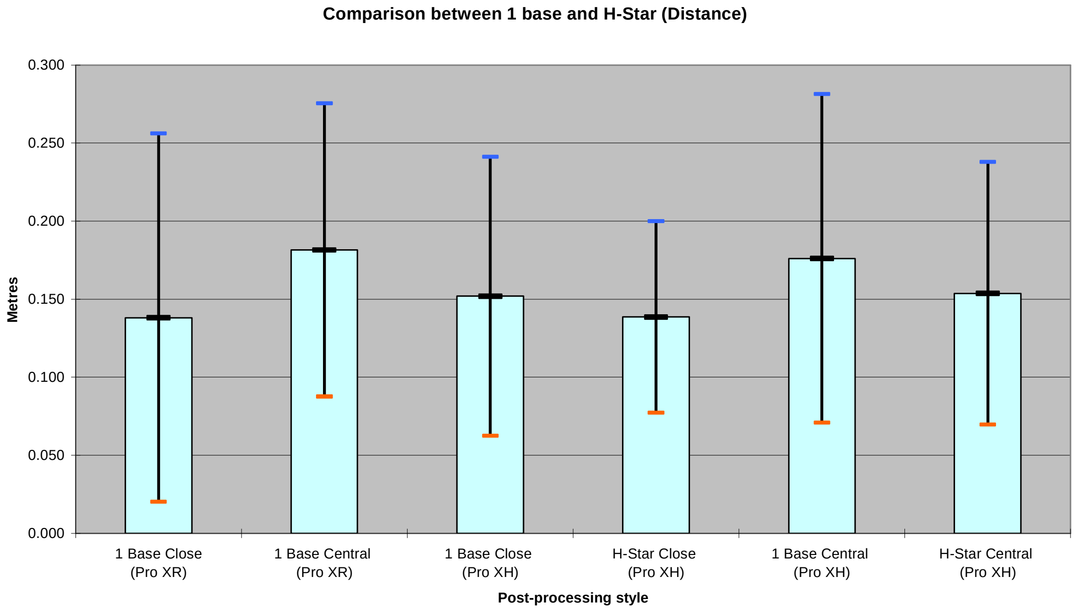


Figure 4.1: Comparison of 10 minute observations with respect to distance error

The difference between the Pro XR and Pro XH receivers is shown in Figure 4.1; the marks used in this figure have been divided into two categories 'close' and 'central' marks as described in section 4.2. The various post-processing methods used for each receiver are shown on this Figure. It can be seen that there is little difference between average distance errors of the two receivers when post-processing 'close' marks form a single base. There is quite a difference however in the confidence interval indicating that the Pro XH receiver is more reliable.

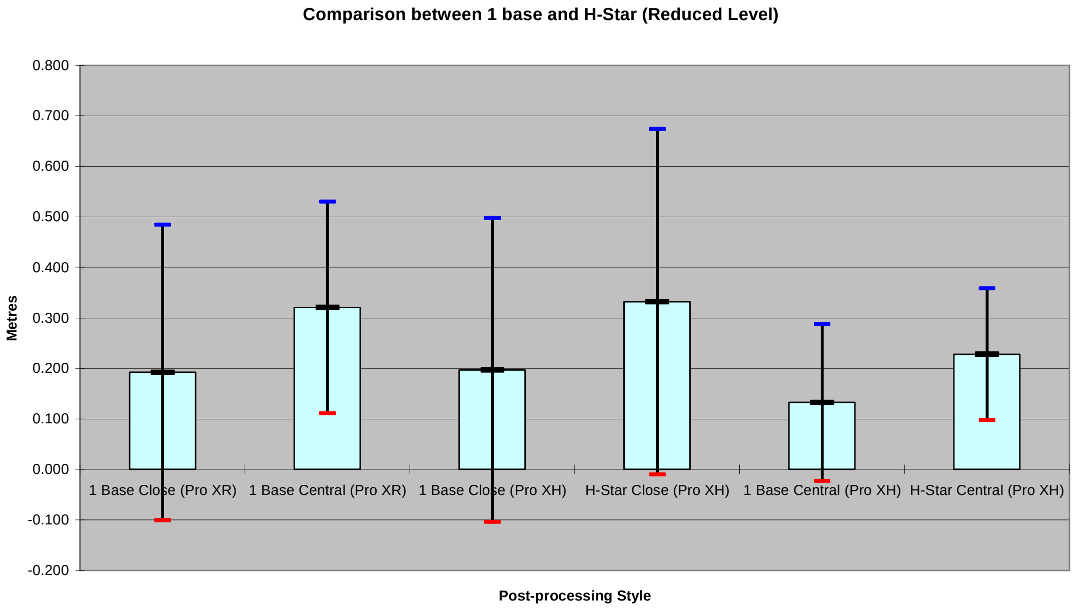


Figure 4.2: Comparison of 10 minute observations with respect to reduced level error

The differences in RL from the published value for the varying post-processing methods are shown in Figure 4.2. It can be seen that the RLs were not as accurate as their corresponding distance errors (refer to Figure 4.1). There is no significant difference in single base post-processing when using either receiver on control marks that are located around Toowoomba. To prove that there is no significant difference in single base post-processing using either receiver an F-Test was undertaken using Microsoft Excel statistical functionality. The F-Test calculated the probability of there not being any significant difference between single and H-Star post-processing with respect to reduced level error to be 93.96%.

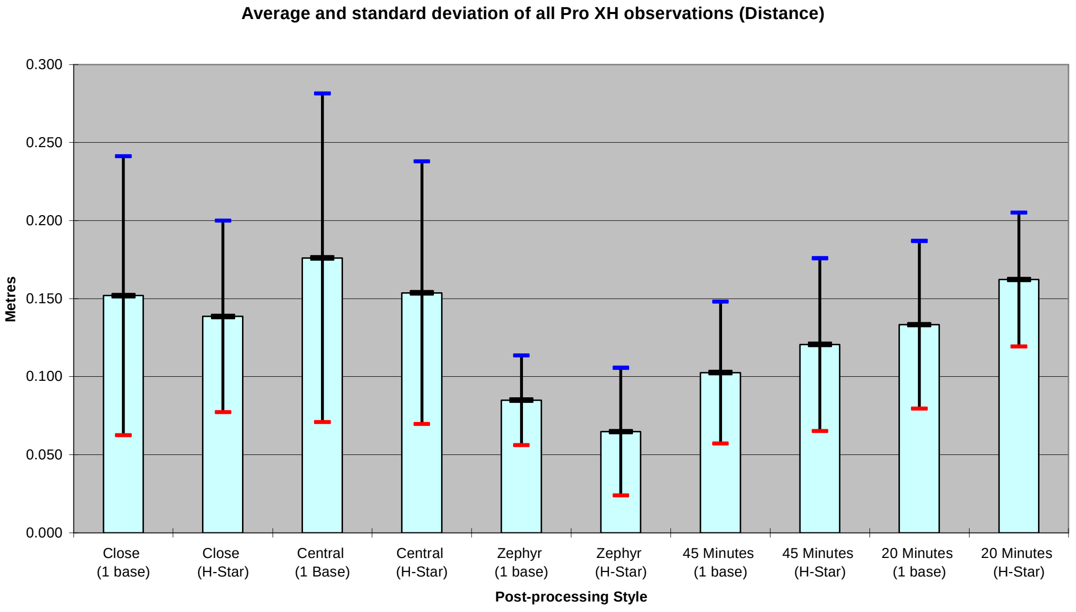


Figure 4.3: Comparison of all observations taken by the Pro XH GPS receiver with respect to distance error

Figure 4.3 shows all observations taken by the Pro XH receiver. It can be seen that the zephyr antenna is able to collect satellite signals a lot better than the internal antenna of the Pro XH receiver. Also as observation time increases, so does accuracy. H-Star results for the twenty and forty-five minute observations were not as accurate as the single base station results. This difference may be the result of conditions at the Caboolture and Robina base stations not being representative of those at the testing sites.

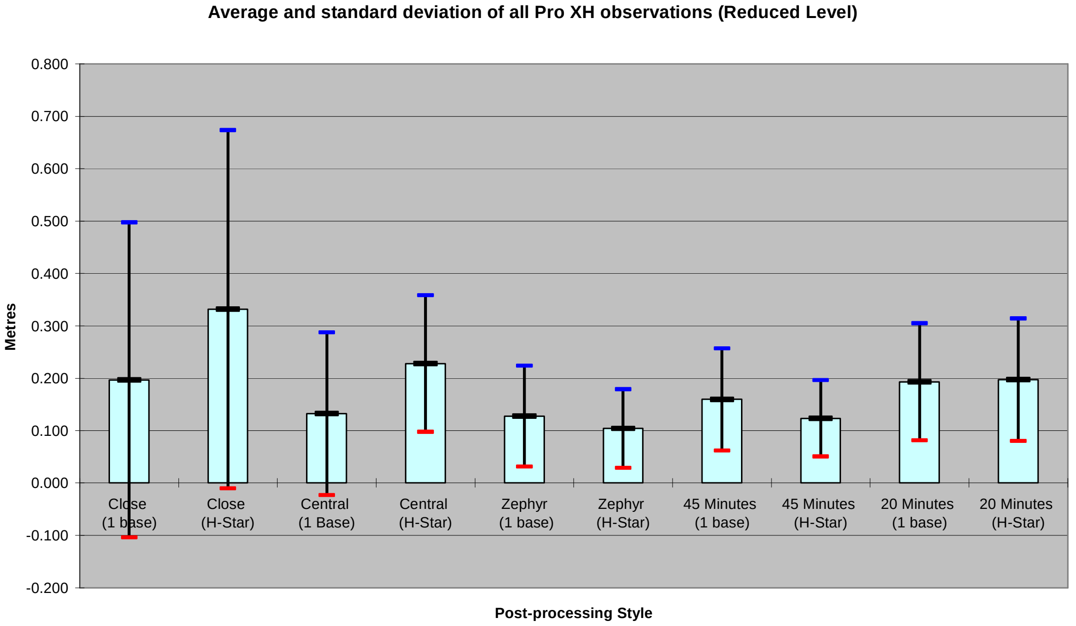


Figure 4.4: Comparison of all observations taken by the Pro XH GPS receiver with respect to reduced level error

Shown in Figure 4.4 are the average and confidence interval of the difference from the ‘true’ value in RLs for all observations taken by the Pro XH receiver. The observation times in this graph vary between ten, twenty and forty-five minutes. In some instances the results of H-Star post-processing were worse than post-processing from a single base, for example observations taken by the internal antenna of the Pro XH receiver were not as accurate as observations post-processed using a single base station.

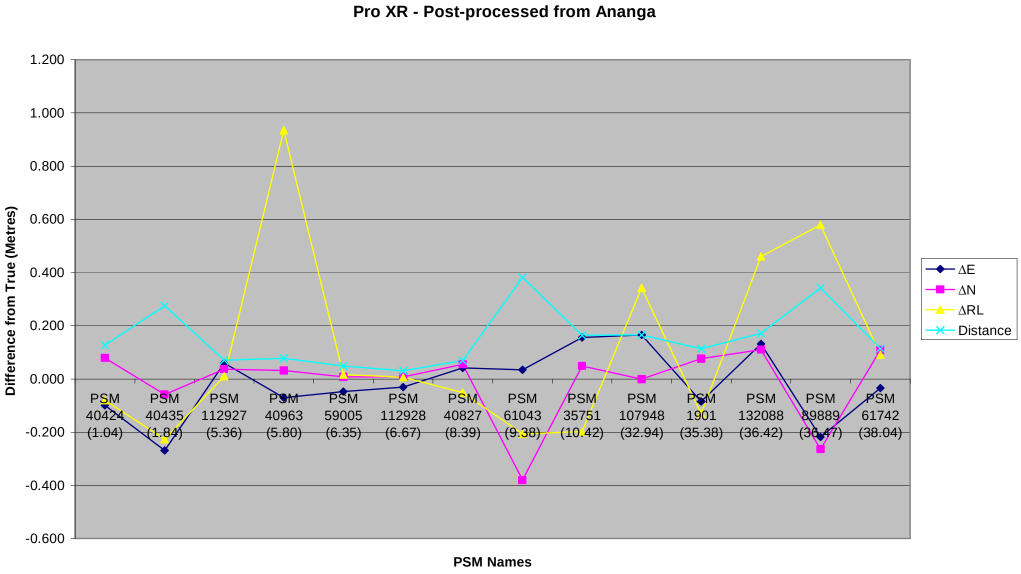


Figure 4.5: Difference from the ‘true’ in Easting, Northing, Reduced Level and Distance from the ‘true’ as baseline increases from Ananga using the Pro XR receiver

Figure 4.5 depicts the difference from the ‘true’ value for the individual components of the marks’ co-ordinates. The baseline length to the nearest ten metres is shown in brackets under the PSM name. This Figure shows if there is any decrease in accuracy as baseline length increases. There is minimal indication of this occurring, if this was occurring marks close to the base station would be closer to the ‘true’ value than marks that are further away. From Figure 4.5 it can be seen that there is large difference between the ‘true’ reduced level value and the post-processed result for PSM 40963, which indicates the possibly of a incorrect height for PSM 40963.

4.5 Trimble Geomatics Office Pro XH

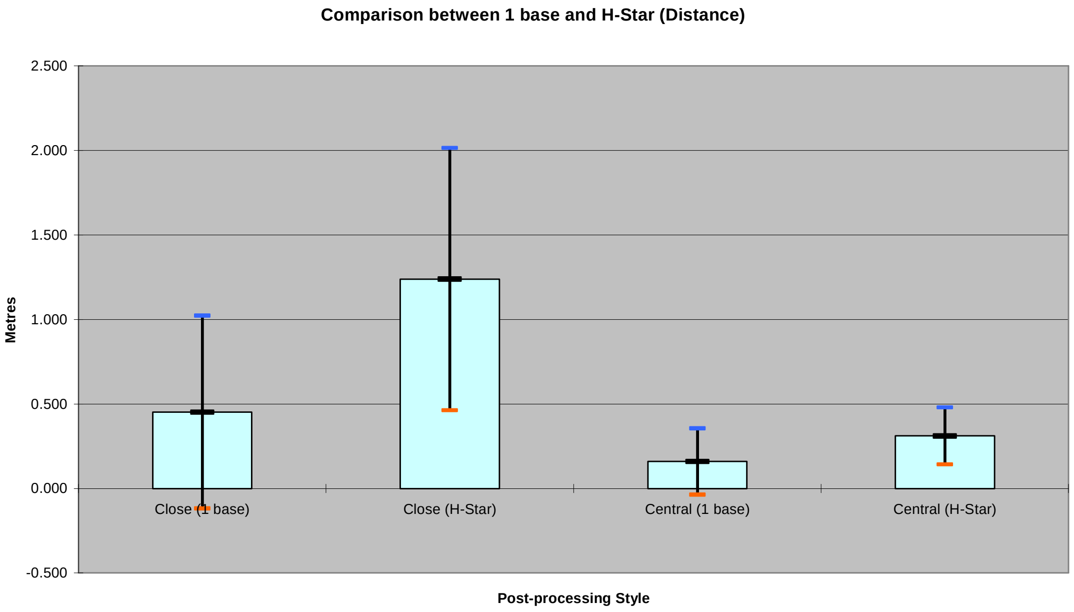


Figure 4.6: Average and standard deviation for ten minute observations with respect to distance error

Figure 4.6 includes both fixed and float baseline solutions, which is why the averages and standard deviations are large. Appendix H shows the average and standard deviations for fixed and float solution baselines separately. It can be seen that single base post-processing is better than using H-Star. The reason for this is that the baseline Caboolture to PSM 107948 was fixed, with all others from Caboolture and Robina not fixed.

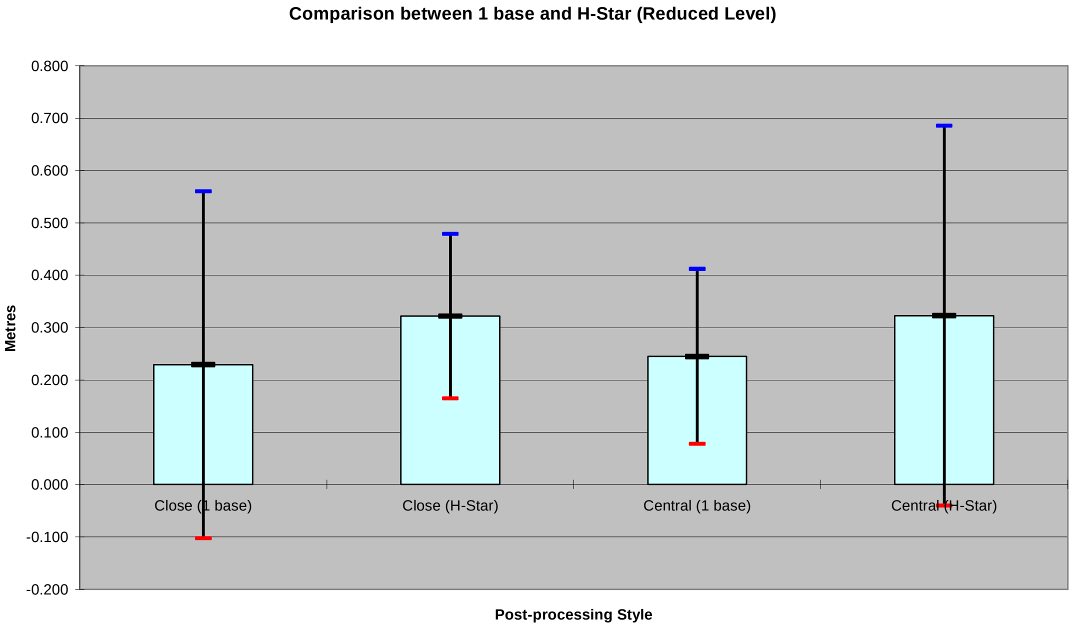


Figure 4.7: Average and standard deviation for ten minute observations with respect to reduced level error.

Both fixed and float baselines are shown in Figure 4.7. It can be seen that the RLs of the corrected points are closer to the ‘true’ value when compared with their corresponding distance errors in Figure 4.6. Appendix I shows the average and standard deviations for fixed and float baselines individually. Single base post-processing outperformed H-Star because of the large number of float baseline solutions present in H-Star processing.

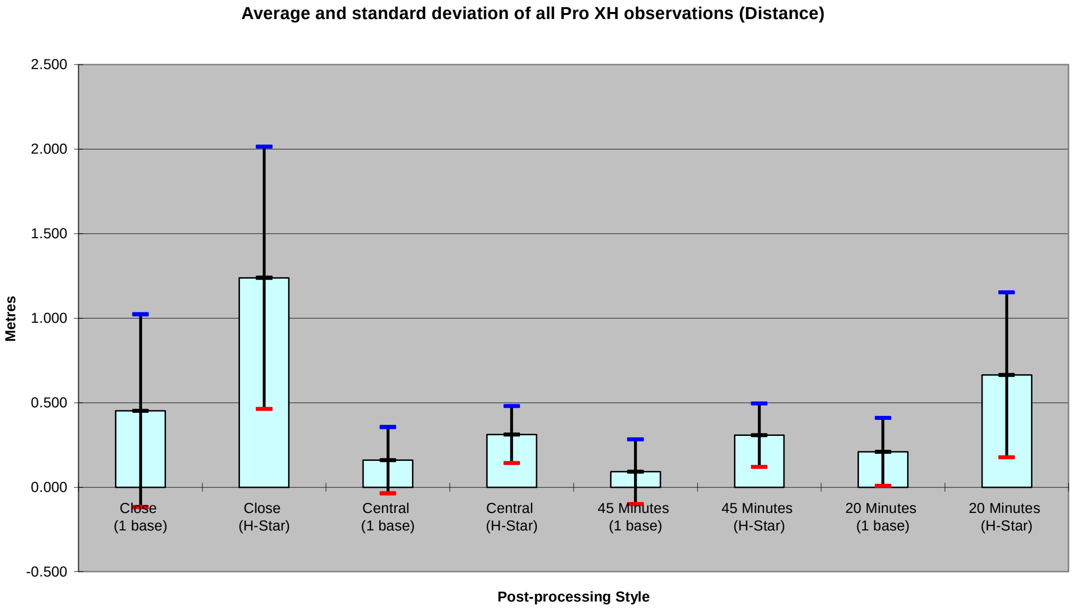


Figure 4.8: Comparison of all observations taken by the Pro XH GPS receiver with respect to distance error

Figure 4.8 shows how varying observation times and post-processing methods affect the average and standard deviations of distance errors. This graph clearly shows that the H-Star post-processing method did not perform as well as expected. The reason for this is that baselines from Caboolture and Robina were not fixed.

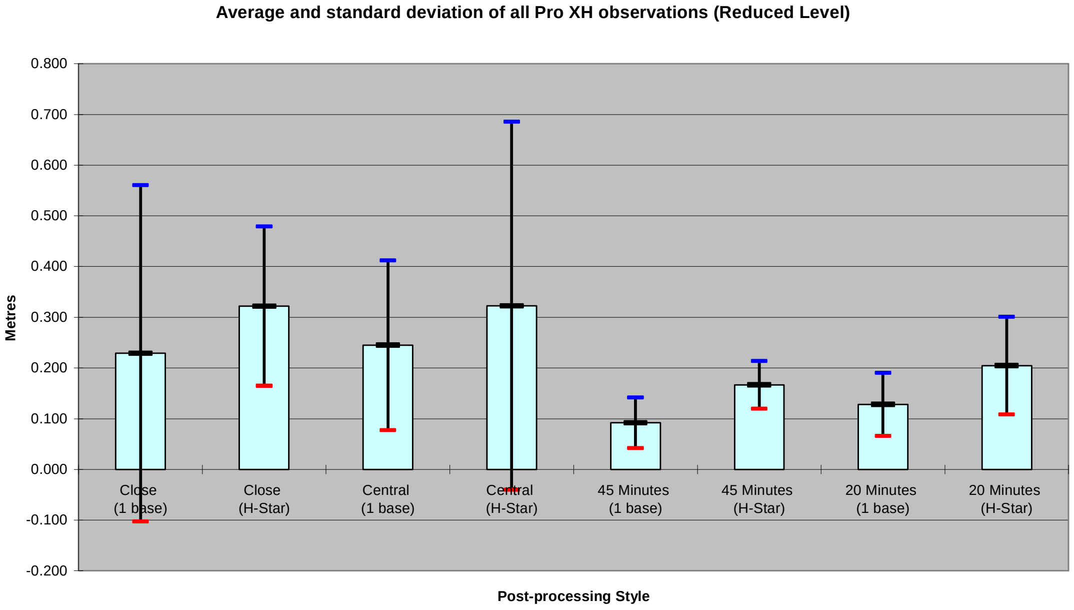


Figure 4.9: Comparison of all observation taken by the Pro XH GPS receiver with respect to reduced level error

It can be seen in Figure 4.9 how the average and standard deviations of reduced levels at varying observation times change. The results for the RLs are closer to the 'true' values than their corresponding distance errors shown in Figure 4.8.

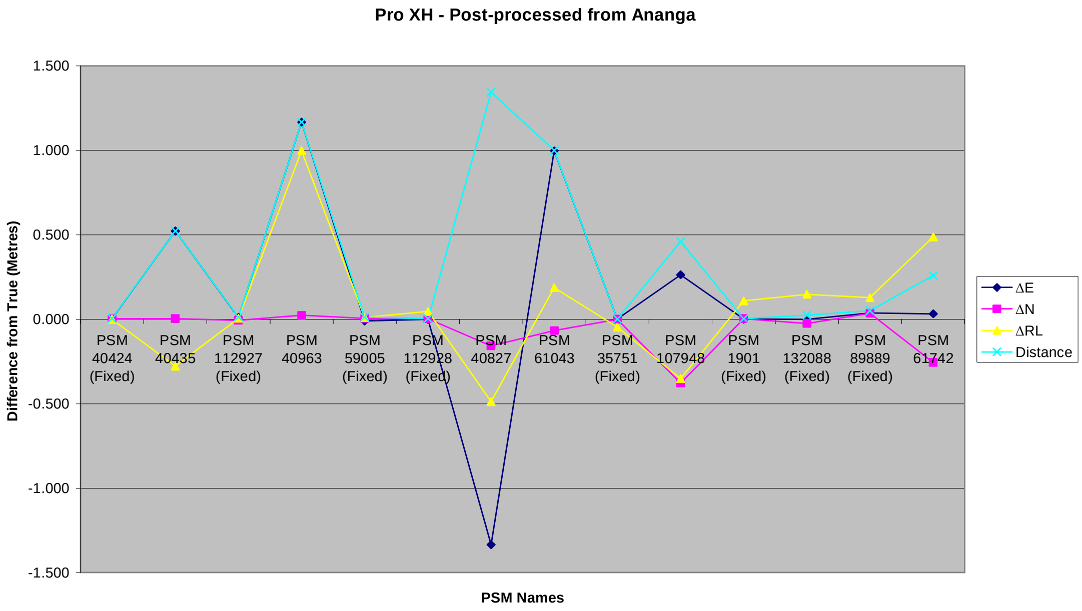


Figure 4. 10: Difference from the 'true' in Easting, Northing, Reduced Level and Distance from the 'true' as baseline increases from Ananga using the Pro XH receiver

Figure 4.10 shows how the co-ordinates vary with increasing baseline length from Ananga. It can be clearly seen that the magnitude of errors associated with baselines that are fixed are smaller than those of non-fixed or float solutions. Errors associated float baseline solutions are random and are a result of environmental and systematic errors.

4.6 Comparing Trimble Pathfinder Office and Trimble Geomatics Office

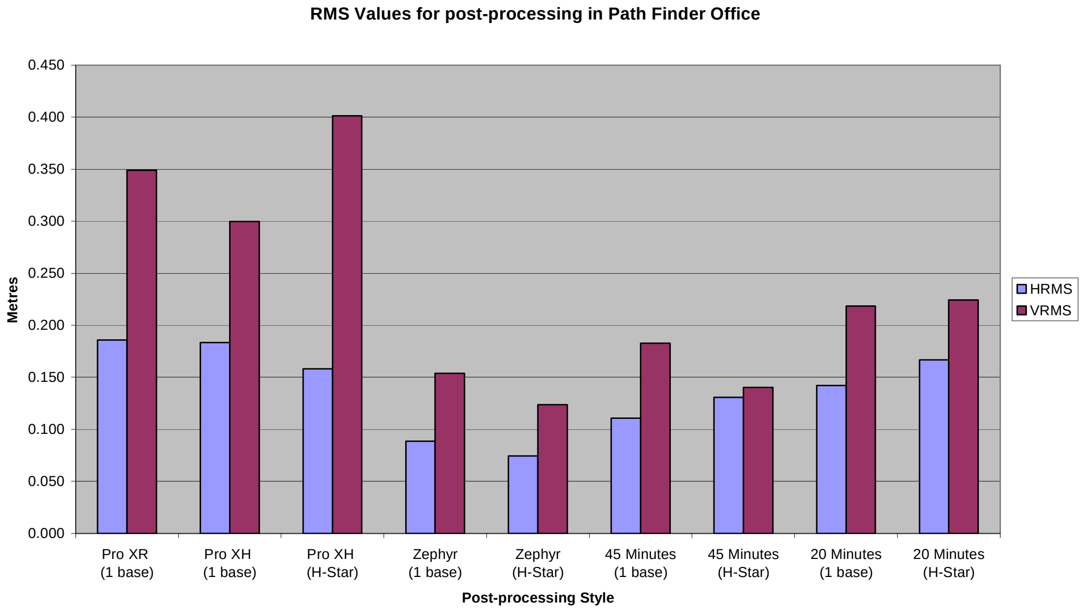


Figure 4.11: Horizontal and Vertical Root Mean Square for observations post-processed in Trimble Pathfinder Office

The HRMS and VRMS values for all observations post-processed in Trimble Pathfinder Office are shown in Figure 4.11. Figure 4.11 shows that similar results can be gained by using either the Pro XR or Pro XH receivers with single base station post-processing and achieve the same HRMS value. Figure 4.11 depicts that the corresponding VRMS value is larger than the HRMS value, indicating that horizontal results have a better relative accuracy.

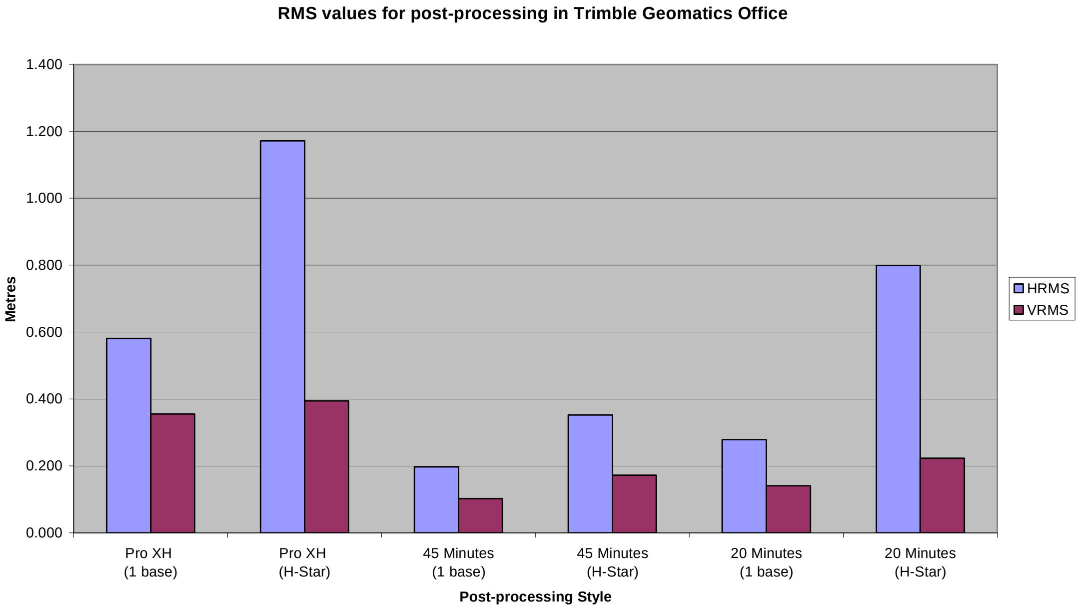


Figure 4.12: Horizontal and Vertical Root Mean Square for observations post-processed in Trimble Geomatics Office

Figure 4.12 shows the HRMS and VRMS values for all observations post-processed with Trimble Geomatics Office. Figure 4.12 portrays that HRMS and VRMS values are larger for multiple base station post-processing than single base post-processing; the reason for this is that baselines from Caboolture and Robina were float solutions. HRMS value is larger than the VRMS value, indicating that vertical results have a better relative accuracy.

4.7 Conclusion

The Figures shown in this chapter were been used in the discussions presented in the following chapter. The discussions that will be presented in chapter 5 have been based on section 4.3. The discussions in the next chapter will give a detailed explanation of what the Figures in this chapter represent. The next chapter will make continual references to Figures presented in this chapter.

The results presented in this chapter can be summarised as follows; the Pro XR and Pro XH receivers have similar accuracies when ten minute observations are post-processed from a single base station. As observation time increases, so does accuracy and the zephyr antenna, because of its ability to track both L1 and L2 wave lengths, is able to produce the most accurate results. It has also been found that H-Star post-processing is advantageous when the work site is located in the centre of the multiple base station network.

Chapter 5

Analysis and Discussion

5.1 Introduction

This chapter links to the previous chapter in which the results were shown by a series of graphs. The discussions presented in this chapter are based on the areas identified in section 4.3. The main areas of analysis discussed in section 4.3, and presented in sections 3.5.2 and 3.6.2, were:

- single base compared against H-Star processing methods,
- how distance from base station affects post-processed results, and
- base station network weighting

The discussions in this chapter revolve around these key issues.

The aim of this chapter is to explain and interpret more thoroughly the results of the project to facilitate an understanding of the findings. The reader should understand the differences in accuracy between the Pro XR and Pro XH receivers and the use of the zephyr antenna with the Pro XH receiver after reading this chapter. Upon reading this chapter the accuracy differences between single and H-Star post-processing methods will be understood.

The analysis in this chapter has been divided into a number of sections, one each for Trimble Pathfinder Office, Trimble Geomatics Office, Comparing Pathfinder Office and Geomatics Office and Manufacturer Claims.

5.2 Post-processing with Pathfinder Office

5.2.1 One base and H-Star Processing Methods

5.2.1.1 Pro XR and Pro XH Internal Antennas

GPS data can be post-processed using a single base station or multiple base stations. The advantage of a multiple base station processing method is the ability to correct for atmospheric errors that surround the work site (refer to Figure 2.13). Results show that there is minimal difference between post-processing with one base or using multiple bases with H-Star processing if the marks are close to one physical base (refer to Figure 4.1). The average distance error from the true value was very similar for both post-processing methods (0.1382m for one base using the Pro XR and 0.1386m for H-Star using the Pro XH). This means if the marks are close to one of the physical base stations there is no real advantage in using H-Star post-processing.

It should be noted that the H-Star post-processing does however, produce smaller standard deviation values (0.1180 m for single base with the Pro XR and 0.0614 m for H-Star with the Pro XH). This means that even though both post-processing methods will achieve similar accuracies, the H-Star method gives results that are more precise and consistently closer to the average result. The use of H-Star data has minimised the magnitude of multipath and atmospheric errors (refer to section 2.7) which are associated with GPS observations. The use of multiple base stations to model the changes in atmospheric conditions becomes increasingly important, as the baseline length from the single base increases. The ability of a single base to be representative of conditions at the rover diminishes as the baseline distances increase, so using multiple base stations to monitor changes in atmospheric conditions helps to minimise atmospheric error sources.

H-Star post-processing methods are advantageous when the work site is central to the base station network being used to correct the observations (refer to Figure 4.1). Table 5.1 shows the average distance error and standard deviation for ten minute observations taken on control marks located central to the H-Star base network by the Pro XR and Pro XH receivers. The Pro XR observations have been post-processed from a single base station, while the Pro XH observations have been processed using H-Star.

Depicted in Table 5.1 is the average distance error and standard deviation for ten minute observations taken on control marks located central to the H-Star base network by the Pro XH receiver.

Table 5.1: (One base vs. H-Star)

Processing method	Average distance error (m)	Standard deviation (m)
Pro XH (1 base – Ananga)	0.1762	0.1053
Pro XH (H-Star)	0.1538	0.0842

Table 5.1 shows that H-Star post-processing methods are better able to correct for atmospheric errors. The standard deviations are 0.1053m for one base using the Pro XH receiver and 0.0842m for H-Star post-processing. The above results are based on ten minutes of data as depicted by Figure 4.1.

Table 5.2 shows the expected accuracy of all ten minute observations (‘close’ and ‘central’) taken by the Pro XH receiver. The full set of data, from which values in Table 5.2 have been extracted, is presented in Appendix J.

Table 5.2: Comparing all minimum time observations taken by the Pro XH receiver

Processing method	Average distance error (m)	Standard deviation (m)
Pro XH (1 base – Ananga)	0.1605	0.0920
Pro XH (H-Star)	0.1440	0.0675

The average distance error for all minimum time observations taken by the Pro XH receiver using H-Star post-processing is 0.1440m and standard deviation of 0.0675m while using a single base with the Pro XH; the two values are 0.1605m and 0.0920m respectively. This shows that H-Star is able to post-process GPS observations more consistently which is evident by the lower average distance error and standard deviation. Comparison with the manufacturer's claimed accuracy will be discussed in section 5.5.

5.2.1.2 Comparison of Internal and Zephyr Antennas with Pro XH

To test if there is any advantage in using an external antenna, a zephyr antenna was used with the Pro XH receiver. Table 5.3 shows the differences between the internal and zephyr antennas when used with the Pro XH receiver and the differences between single and H-Star post-processing. The values in Table 5.3 have been adapted from Figure 4.3. Average distance error refers to the average of all the horizontal distance errors from the 'true' co-ordinate value. The 'true' co-ordinate value is the value as published in the DNRW database. The horizontal distance error is calculated by the method as stated in section 4.2.

Table 5.3: Comparison between Pro XH internal and zephyr antennas

Processing method	Average distance error (m)	Standard deviation (m)
Pro XH Internal (1 Base - Ananga)	0.1386	0.0614
Pro XH Zephyr (1 Base - Ananga)	0.0849	0.0287
Pro XH Internal (H-Star)	0.1538	0.0842
Pro XH Zephyr (H-Star)	0.0648	0.0408

Data logged using these configurations were for ten minutes at the control marks located at Gatton. These control marks are central to the multiple base stations that are used for H-Star post-processing methods (refer to Figure 2.13). These data files were post-processed using single base and H-Star methods. Values for Table 5.3 show when using a single base to correct the zephyr antenna data files the average distance error from the 'true' value is 0.0849m with a standard deviation of 0.0287m.When the results of the Pro XH internal antenna are compared with those achieved when using the zephyr antenna; proves that the zephyr antenna improves the accuracy of the results achieved by the Pro XH. This improvement when using the zephyr antenna is evident in both single base and H-Star post-processing. Comparison of results obtained and the manufacturer's claims will be discussed in section 5.5.

5.2.1.3 Pro XH Extended Observations

Table 5.4 shows the differences between twenty and forty-five minute observations and single and H-Star post-processing methods. It should be noted that the Pro XH receiver only, was used to take extended observations on PSMs located around Gatton (refer to Figure 2.13). Values for Table 5.4 from been adapted from Figure 4.3 in chapter four. As observation time increases, it is claimed (refer to Appendix B) that the accuracy of the post-processed results obtained will also increase.

Table 5.4: Comparison between 20 and 45 minute data logging times with respect to distance

Processing method	Average distance error (m)	Standard deviation (m)
Pro XH (20 minutes – Ananga)	0.1333	0.0537
Pro XH (45 minutes – Ananga)	0.1026	0.0455
Pro XH (20 minutes – H-Star)	0.1622	0.0430
Pro XH (45 minutes – H-Star)	0.1206	0.0553

Values in Table 5.4 prove that as observation time increases so does accuracy. Observations shown in Table 5.4 were taken at control marks central to the H-Star base stations for a period of forty-five minutes with the Pro XH receiver. To determine if there is any change as observation time increases, twenty minute observations were post-processed. Twenty minute observation files were forty-five minute data files with the last twenty-five minutes removed. Post-processing was carried out using one base station (Ananga) and H-Star methods. The observations in Table 5.4 prove that logging data forty-five minutes gives more accurate results than logging data for twenty minutes. The results of these extended logging times were not what was expected because processing from one base gave results of a higher accuracy than H-Star post-processing. The average distance error for forty-five minutes from one base is 0.1026m and a standard deviation of 0.0455m, while H-Star gives an average distance error of 0.1206m and a standard deviation of 0.0553m as shown in Table 5.4. The results for twenty minutes are not as accurate as logging data for forty-five minutes. One base station gives an average distance error of

0.1333m and a standard deviation of 0.0537m; however H-Star results in an average distance error 0.1622m and a standard of 0.0430m.

Calculating the 95% confidence interval of the mean for the twenty and forty-five minute observations involved the standard deviation of the mean to be calculated. The standard deviation of the mean is the standard deviation of the population divided by the square root of the number of observations. For twenty minutes single base post-processed the standard deviation of the mean is 0.0219 m (0.0537/√6). H-Star post-processed the standard deviation of the mean is 0.0176 m (0.0430/√6).

The standard deviation of the mean for forty-five minute observation post-processed from a single base is 0.0186 m (0.0455/√6), while for H-Star the standard deviation of the mean is 0.0026 m (0.0553/√6). The upper and lower bounds of the confidence interval are calculated using the process described in section 2.6.

Table 5.5 shows the upper and lower bounds of the twenty and forty-five minute observations with respect to distance error. The student-t distribution was used calculate the number of standard deviations the results should lie from the mean for a given confidence interval. The confidence interval used was 95%, from Eton p49 the number of standard deviations from the mean with five degrees of freedom is 2.571.

Table 5.5: Upper and lower confidence interval bounds at 95% confidence

Post-processing Style	Upper bound (m)	Lower Bound (m)	Range (m)
20 minute (1 base)	0.1897	0.0769	0.1128
20 minute (H-Star)	0.2073	0.1171	0.0902
45 minute (1 base)	0.1504	0.0548	0.0956
45 (H-Star)	0.1786	0.0626	0.1160

To see if there was any significant difference between single base and H-Star processing methods, an F-Test was conducted using the statistical functionality of Microsoft Excel.

Using the F-Test functionality in Microsoft Excel to test between the two twenty minute observation data sets, it was found that the one tail probability of the two data sets being not significantly different was 63.55%. This indicates that there is a significant difference between single and H-Star post-processing of twenty minute observation files.

When forty-five minute files are tested the probability of single and H-Star being not significantly different is 67.65%. There is still a 32.35% chance that there are significant differences between single and H-Star processing of forty-five minute files indicating that the two data sets are not alike.

Figure 4.3 shows all observations that where taken by the Pro XH receiver. It can be seen in Figure 4.3, as observation times increases, so does the accuracy of the results given. Figure 4.3 shows that H-Star post-processing methods are better than processing from a single base especially if the observations are being taken in the centre of the multiple bases used in H-Star post-processing. However, this is not true for observation times of twenty and forty-five minutes. A possible reason for this difference is that the atmospheric conditions at Caboolture and Robina were not representative of those at the testing sites when observations were taken. The use of multiple base stations to model the changes in atmospheric conditions becomes increasingly important, as the baseline length from the single base increases. However if the conditions are significantly different at the base station to those at the test site, the ability remove errors will diminish. The difference in atmospheric conditions is highlighted when H-Star post-processing is used, because of the multiple base stations used to correct the observations taken.

5.2.1.4 Reduced Level Results

Average reduced error refers the average of all the reduced level errors from a particular receiver configuration and observation time. The ‘true’ co-ordinate value is the value as published in the DNRW database. The reduced level error is calculated by the method as stated in section 4.2.

The results given for the corrected reduced level value for a control mark were not as accurate as the corrected Eastings and Northings. There is quite a difference between reduced level results using one base and H-Star to differentially correct the files as Figure 4.4 depicts. The most accurate results were obtained using the zephyr antenna with the Pro XH logging data for ten minutes. The post-processing method made little difference when using the zephyr antenna. From Figure 4.4 it can be seen that post-processing the zephyr antenna observations with H-Star methods was slightly better with an average reduced level error of 0.1040m and a standard deviation of 0.0749m. Single base station processing with the zephyr antenna yielded: an average reduced level error of 0.1276m and standard deviation of 0.0963m. This antenna is capable of monitoring both L1 and L2 frequencies and the ability to track low elevation satellite signals which is why this receiver outperforms the internal antenna of the Pro XH receiver.

The data logged for forty-five minutes gave accurate results (refer to Figure 4.4); this is due to the shear amount of data that was recorded during this time. Logging data for this period of time allows the receiver to collect a large amount of data free from cycle slips and other errors associated with GPS usage. Extended observations were only taken at control marks central to the H-Star base station network, and as a result, data files corrected using H-Star methods was more accurate than single base station processing.

When extended observation times (twenty and forty-five minutes) are used, there is some decrease in accuracy as baseline length increases from Ananga. This trend can be seen with both single and H-Star post-processing methods. Values for Table 5.6 have been sourced from Figure 4.4.

Table 5.6: Comparison between 20 and 45 minutes data logging times with respect to reduced level

Processing method	Average RL error (m)	Standard deviation (m)
Pro XH (20 minutes – Ananga)	0.1932	0.1116
Pro XH (45 minutes – Ananga)	0.1597	0.0975
Pro XH (20 minutes – H-Star)	0.1973	0.1169
Pro XH (45 minutes – H-Star)	0.1235	0.0730

The F-test was used to test the twenty minute observation files with respect to reduced level error, the probability of there not being any significant difference between single and H-Star post-processing is 92.26%. This proves that single and H-Star post-processing are the almost identical when post-processing twenty minute observation files with respect to reduced level error.

As observation time increased the accuracy of reduced level values also increased. This was seen with forty-five minutes of observation giving more accurate results than twenty minutes of observation. H-Star gave more accurate results than processing from a single base station when post-processing forty-five minute observations; this is because the control marks used for these extended observations were located in Gatton, which is central to the H-Star network.

5.2.2 How distance from base station affects post-processed results

It can be assumed that as distance from a base station increases the accuracy of the results should decrease, this is because the conditions at the base are not the same as those at the rover. Testing this fact involved using a number of co-ordinated marks that were located at increasing baseline distances from Ananga, the single base station located at USQ Toowoomba Campus.

5.2.1.1 Pro XR and Pro XH Internal Antenna

Results obtained using the Pro XR (Figure 4.5) and processing from a single base station reveal that as baseline length increases, the accuracy decreases; this trend can be seen for baseline lengths from 5.8 km to 32.9km. Results either side of this range don’t exhibit the characteristics expected with increasing baseline length. Results using the Pro XH from both single and H-Star post-processing exhibit no uniform change in accuracy as marks increase in distance from Ananga (refer to Appendices K and L respectively).

5.2.2.2 Pro XH Extended Observations

When twenty and forty-five minute observations are post-processed from a single base station it can be seen that as baseline length increases accuracy decreases (refer to Appendices M and N). Table 5.7 depicts the changes in distance from the ‘true’ co-ordinate values using twenty and forty-five observation files post-processed from a single base.

Table 5.7: Distance from 'true' co-ordinate value as baseline length increases

Control mark name	Baseline length (m)	20 minutes (m)	45 minutes (m)
PSM 107948	32943	0.0750	0.0883
PSM 1901	35376	0.0930	0.0906
PSM 132088	36417	0.1846	0.0721
PSM 89889	36472	0.1271	0.0678
PSM 61742	38038	0.2115	0.1911

Results portrayed by Table 5.7 are consistent with the expected results from baselines of increasing length.

5.2.2.3 Reduced Level Results

As baseline length increases there is no evidence to support the fact that accuracy of reduced level values decreases (refer to Appendices K, L, M and N). This characteristic was present in both receivers and post-processing methods. One point in particular may have what appears to be an 'incorrect' published value for its reduced level, this point is PSM 40963. The RL of this PSM has been spirit levelled to class D and to order 4. The difference seems to be about 0.900m as Figure 4.5 depicts, but before any absolute conclusion can be made regarding the reduced level value for this point, checks need to be made. This difference was evident in results from the Pro XR and Pro XH receivers and using either single or H-Star post-processing techniques in Trimble Pathfinder Office (refer to Appendices K and L). It should be noted that data was logged for ten minutes only and no further visits have been made to verify this fact. Checking would involve using Real Time Kinematic (RTK) or Fast Static GPS techniques or levelling from another mark to verify the reduced level of PSM 40963.

5.2.3 Base station network weighting

Weighting in the base station network would be proved by the fact that results from marks ‘close’ to Ananga using single base station post-processing would be very similar to those obtained using H-star methods.

This can be seen when comparing observations taken by the Pro XR and Pro XH receivers close to Ananga. There is no difference in the average distance from the ‘true’ position using single base station processing with Pro XR data or H-Star with the Pro XH data as Figure 4.1 portrays. The average distances for the Pro XR and Pro XH both post-processed using a single base station are 0.1382m and 0.1386m respectively (values from Figure 4.1). This shows that the other base stations; Caboolture and Robina make little difference in affecting results this is because they are far from the worksite. Corrections provided by Caboolture and Robina base stations have minimal affect on the results obtained. This shows that there is more weight placed on corrections provided by the close base station Ananga, when the worksite is close to this base station. However H-Star does produce more consistent results because of the smaller standard deviation that is evident in the results from this post-processing method. The standard deviation for the Pro XR is 0.1180m and for the Pro XH is 0.0614m (H-Star post-processed).

Base station weighting is also evident in the reduced levels of the corrected points. Reduced levels of corrected points have an average reduced level error of 0.1922m from the ‘true’ value using Pro XR data processed from one station and 0.3319m for Pro XH data processed using H-Star as Figure 4.2 shows. The standard deviations are 0.2925m and 0.3419m respectively. This shows that the results tend to be more accurate when post-processed using a single base station.

5.3 Post-processing with Trimble Geomatics Office

5.3.1 One base and H-Star Processing Methods

Figure 4.10 shows one interesting fact; when post-processing in Trimble Geomatics Office not all of the baselines solutions were fixed. This even occurred when using observation times of twenty and forty-five minutes. Reasons for this are unknown. Results from those baselines that are fixed are more accurate when compared to those that are not fixed as portrayed in Table 5.8. The standard deviations for the observations are pictured in Table 5.9.

Table 5.8: Average of minimum time observations with respect to calculated errors

Solution type	Distance (m)	ΔE (m)	ΔN (m)	ΔRL (m)
Fixed	0.0142	0.0081	0.0104	0.0618
Float	0.7917	0.7193	0.1473	0.4650

Table 5.9: Standard deviation of minimum time observations with respect to calculated errors

Solution type	Distance (m)	ΔE (m)	ΔN (m)	ΔRL (m)
Fixed	0.0166	0.0125	0.0123	0.0586
Float	0.4375	0.5246	0.1464	0.2865

Only observations taken using the Pro XH with internal antenna were post-processed using Trimble Geomatics Office. Processing from one base station gave better results than using H-Star post-processing. A possible reason for this is that only one of the baselines from either Caboolture or Robina was fixed. Caboolture to PSM 107948 was the only fixed baseline. The unknown whole number of wavelengths counted by the GPS receiver is known as an ambiguity term. A fixed baseline solution means that all ambiguity terms have been solved. If a baseline solution is not fixed the ambiguity terms have not been solved. If the ambiguity terms are not solved for, there are errors in the resultant co-ordinate value. This affected H-Star post-processed results. This can be seen from the average distance error from the ‘true’ value is always better using single base post-processing in Trimble Geomatics Office as depicted in Table 5.10.

Table 5.10: Average and standard deviation of observations post-processed in Trimble Geomatics Office

Observation Time (mins)	Post-processing style	Distance		Reduced Level	
		Average (m)	Standard deviation (m)	Average (m)	Standard deviation (m)
10	Single	0.3474	0.4829	0.2346	0.2762
	H-Star	0.9074	0.7692	0.3221	0.2360
20	Single	0.2090	0.2010	0.1283	0.0624
	H-Star	0.6637	0.4880	0.2045	0.0964
45	Single	0.0917	0.1912	0.0917	0.0497
	H-Star	0.3077	0.1881	0.1667	0.0469

Processing all minimal time observations from Ananga alone produces an average distance error of 0.3474m and a standard deviation of 0.4829m. As Appendix O shows, dividing this into ‘close’ marks and ‘central’ marks the following results are achieved as Table 5.11 portrays.

Table 5.11: Comparison between ‘close’ and ‘central’ marks using single base post-processing

Processing method	Average distance error (m)	Standard deviation (m)
Pro XH (1 base – close)	0.4519	0.5704
Pro XH (1 base – central)	0.1593	0.1963

When processing the same data files by H-Star methods the average distance error from the ‘true’ value for all points processed this way is 0.9074m and a standard deviation of 0.7692m as shown in Appendix O, breaking this down into ‘close’ marks and ‘central’ marks the following results are achieved as shown in Table 5.12.

Table 5.12: Comparison between ‘close’ and ‘central’ marks using H-Star post-processing

Processing method	Average distance error (m)	Standard deviation (m)
Pro XH (H-Star – close)	1.2385	0.7759
Pro XH (H-Star – central)	0.3113	0.1684

The distance error from the ‘true’ value showed that there is more error in the Easting component of the co-ordinate pair then the Northing component as can be seen in Figure 4.10. This is true for all files post-processed using Trimble Geomatics Office. The average reduced level error given is better than their corresponding distance errors.

5.3.2 How distance from base station affects post-processed results

When processing from a single base station, a similar percentage of baselines were fixed for both Toowoomba and Gatton marks. For Toowoomba five of the nine control marks (55.55%) had fixed baselines, while three of the five (60%) of the Gatton control marks had fixed base lines. This shows that distance had little effect on whether a baseline was fixed or not. Only one of the baselines from either Caboolture or Robina is fixed; which was Caboolture to PSM 107948 using forty-five minutes of observations.

Processing minimal time observations from Ananga it can be seen that for those PSMs where the baselines are fixed, there is a trend that as baseline length increases, accuracy decreases as Table 5.13 depicts (refer to Appendix P for graphical representation).

Table 5.13: Distance from ‘true’ co-ordinate value as baseline length increases for baselines with fixed solutions

Control mark name	Baseline length (m)	Distance (m)	Reduced Level (m)
PSM 40424	1038	0.0042	0.001
PSM 112927	5355	0.0130	0.006
PSM 59005	6345	0.0125	0.010
PSM 112928	6670	0.0032	0.046
PSM 35751	10428	0.0014	0.046
PSM 1901	35376	0.0041	0.109
PSM 132088	36417	0.0240	0.148
PSM 89889	36472	0.0509	0.128

Reduced levels of baselines with fixed solutions however are worse than their corresponding distance results as Table 5.13 portrays. A fixed baseline solution is when all the ambiguity terms are solved. Those marks with float baselines exhibit no characteristics of decreasing accuracy as baseline increases as portrayed in Table 5.14 (refer to Appendix Q for graphical representation).

Table 5.14: Distance from 'true' co-ordinate value as baseline length increase for baselines with float solutions

Control mark name	Baseline length (m)	Distance (m)	Reduced Level (m)
PSM 40435	1840	0.5220	0.278
PSM 40963	5802	1.1672	0.998
PSM 40827	8389	1.3442	0.488
PSM 61043	9383	0.9992	0.187
PSM 107948	32943	0.4597	0.351
PSM 61742	38038	0.2580	0.488

The differences from the 'true' value are random and are a result of environmental and system errors as can be seen in Table 5.14.

5.3.3 Base station network weighting

There is no evidence of weighting of in the base station network when post-processing in Trimble Geomatics Office. The multiple base method was worse than the single base station method because the Caboolture and Robina baselines are not fixed, except Caboolture to PSM 107948 using forty-five minutes of observation. The average distance error from the 'true' for single base station processing of minimum time observations is 0.4519m and multiple base station processing is 1.2385m (taken from Figure 4.6). If Ananga had an increased effect on the results, the two averages would be close reflecting the dominance of the corrections provided by the Ananga base station files when post-processed.

The characteristic of base station weighting in the multiple base station network is evident in the reduced level error for the control marks used in this testing. Once again the multiple base method was not as accurate as correcting from a single base station. Figure 4.7 shows that the average reduced level error from the ‘true’ reduced level for ten minute observations is 0.2289m for single base processing and 0.3218m for multiple base station post-processing. If extra weight was placed on the corrections from Ananga base station files, the two averages would be similar.

5.4 Comparing Trimble Pathfinder Office and Trimble Geomatics Office

The software packages, Trimble Pathfinder Office and Trimble Geomatics Office were compared using HRMS and VRMS. RMS error is used to describe uncertainty and summarise the entire error distribution. The HRMS describes the error in the horizontal distance component. HRMS is calculated by finding the square root of the average of all the distance errors squared. VRMS describes the error in the reduced level component. VRMS is calculated by finding the square root of the average of all the reduced level errors squared.

Figure 4.11 shows that the HRMS values are smaller than the VRMS values for data files post-processed using Pathfinder Office, indicating that horizontal results have a better relative accuracy, as explained earlier in section 2.4.1. Figure 4.11 also confirms the fact that the zephyr antenna is able to produce results of a higher accuracy than the internal antenna of the Pro XH receiver, even when using extended observation times. Figure 4.11 depicts the fact that the observations taken by both the Pro XR and Pro XH receivers are able to be post-processed to the same HRMS when using a single base station to post-process as depicted in Table 5.15.

Table 5.15: RMS values for post-processing in Trimble Pathfinder Office

Processing method	HRMS (m)	VRMS (m)
Pro XR (1 base – Ananga)	0.186	0.349
Pro XH internal (1 base – Ananga)	0.183	0.300

The HRMS value for the Pro XR post-processed from one base station is 0.186m and for the Pro XH the HRMS value is 0.183m as Table 5.15 states.

Figure 4.12 shows the RMS values for both horizontal and vertical for files post-processed using Trimble Geomatics Office. It can be seen that in Figure 4.12 the

VRMS values are smaller than the corresponding HRMS values. The HRMS and VRMS values also confirm that as observation time increase, the accuracy also increases. Values for Table 5.16 have been adapted from Figure 4.12.

Table 5.16: RMS values for post-processing in Trimble Geomatics Office

Processing method	HRMS (m)	VRMS (m)
Pro XH (10 minutes - Ananga)	0.581	0.355
Pro XH (10 minutes - H-Star)	1.172	0.394
Pro XH (20 minutes – Ananga)	0.278	0.140
Pro XH (20 minutes – H-Star)	0.799	0.223
Pro XH (45 minutes – Ananga)	0.197	0.102
Pro XH (45 minutes – H-Star)	0.352	0.172

The HRMS and VRMS values as depicted by Table 5.16 show that the values for multiple base post-processing are larger than the corresponding single base station values. The reason for this is that baselines for Caboolture and Robina were not fixed and as a result had a large number of float baseline solutions.

When comparing just the HRMS values for observations post-processed in both Trimble Pathfinder Office and Trimble Geomatics Office, the Pathfinder Office HRMS values are consistently better than the corresponding Trimble Geomatics Office values (refer to Appendix R). The reason for this is due to the fact that a large proportion of baselines in Trimble Geomatics Office were not fixed. The VRMS values on the other hand portray that both Pathfinder Office and Geomatics office are able to post-process data files to a similar accuracy (refer to Appendix S).

When taking into account both HRMS and VRMS values, Trimble Pathfinder Office is able to consistently post-process GPS observations with a higher degree of accuracy and consistency than Trimble Geomatics Office. This fact is consistent with either single base station or H-Star post-processing and using extended observations. For this reason Trimble Pathfinder Office should be the software package of choice when post-processing mapping grade GPS receiver observations.

5.5 Manufacturer Claims

An interesting observation was made when perusing the manufacturer claims; no reference was made to the confidence interval for which the quoted HRMS value is valid for. It has been assumed to be one standard deviation from the mean. Claims regarding VRMS have not been made by the manufacturer and as a result can't be compared with results from this project.

5.5.1 Trimble Pathfinder Office

5.5.1.1 Minimum Time Observations

The claims made by the manufacturer's for the Pro XR and Pro XH receiver can be can seen in Appendices C and B respectively. Table 5.17 shows the claims for the Pro XR and Pro XH receivers that have been tested as part of this project.

Table 5.17: Manufacturer claims (HRMS) for Pro XR and Pro XH mapping grade GPS receivers

Post-processing Method	Observation time	Pro XR	Pro XH
Carrier Post-processed (1 base)	10 minutes	20 cm	not given
	20 minutes	N/A	10 cm
	45 minutes	N/A	1 cm
H-Star Post-processed	Internal	N/A	30 cm
	Zephyr	N/A	20 cm

Table 5.18: Comparison between Manufacturers' claims HRMS and obtained HRMS with Pro XR receiver post-processed in Trimble Pathfinder Office

Observation time	Manufacturer's Claim	Obtained Results
10 minutes	0.200 m	0.186 m

HRMS values for Trimble Pathfinder Office can be seen in Figure 4.11. The claims made by Trimble regarding the Pro XR using carrier post-processing using ten minutes can be justified by work undertaken in this project. The HRMS value for work conducted during this project for the Pro XR using ten minutes of data is 0.186 m (refer to Table 5.18) when post-processed in Pathfinder Office. This value is less than the manufacturer’s claim of 0.200 m therefore; the HRMS values given by the manufacturer have been confirmed.

Table 5.19 as been adapted from Figure 4.11 and Table 5.17.

Table 5.19: Comparison between Manufacturer’s claimed HRMS and obtained HRMS with Pro XH receiver post-processed in Trimble Pathfinder Office

Post-processing Method	Observation time	Manufacturer’s Claim (m)	Obtained Results (m)
Carrier Post-processed (1 base)	20 minutes	0.100	0.142
	45 minutes	0.010	0.111
H-Star (Internal – Antenna)	10 minutes	0.300	0.158
	20 minutes		0.167
	45 minutes		0.131
H-Star (Zephyr – Antenna)	10 minutes	0.200	0.074

The manufacturer claims that post-processing Pro XH internal antenna observations using H-Star methods gives a HRMS value of 0.300 m; this project has found the value to be 0.158 m as shown in Table 5.19 when using Pathfinder Office to post-process ten minute observations, which is less than the manufacturer’s claims. Results from observations with the zephyr antenna produced an HRMS of 0.074 m when ten minute observations were H-Star post-processed in Trimble Pathfinder Office. The corresponding manufacturer’s claim is 0.200 m. This means that the manufacturer’s claims when using H-Star post-processing of either the internal antenna of the Pro XH receiver or zephyr antenna have been verified.

5.5.1.2 Extended Time Observations

Claims made by the manufacturer regarding the twenty and forty-five minute observations when using the Pro XH internal antenna weren’t verified in this project. Results from this project are contrary to the values given by the manufacturer. The manufacturer claims a HRMS value of 0.100m for twenty minute observations carrier post-processed. This project has found the value to be 0.142 m as can be seen in Table 5.19 when using Pathfinder Office. The manufacturer claims the HRMS value for forty-five minute observations when post-processed from one base to be 0.010 m. Results form this project found the value to be 0.111 m as shown in Table 5.19. The manufacturer's claims for the extended observation times are were not verified and may need revising when post-processed using a single base station.

This project has calculated the HRMS values for twenty and forty-five minute observations when H-Star post-processed to be 0.167 m and 0.131 m respectively, these values are shown in Table 5.19. Both HRMS values are within the manufacturer's claim of 0.300 m. The claims made by the manufacturer with regards to H-Star post-processing have been justified by the testing that this project has completed.

5.5.1 Trimble Geomatics Office

5.5.1.1 Minimum Time Observations

Table 5.20: Comparison between Manufacturer's claimed HRMS and obtained HRMS with Pro XH receiver post-processed in Trimble Geomatics Office

Post-processing Method	Observation time	Manufacturer's Claim (m)	Obtained Results (m)
Carrier Post-processed (1 base)	20 minutes	0.100	0.278
	45 minutes	0.010	0.197
H-Star (Internal – Antenna)	10 minutes	0.300	1.172
	20 minutes		0.799
	45 minutes		0.352

Trimble Geomatics Office was used to post-process all Pro XH internal antenna observations. The HRMS values for ten minute observations didn't meet the manufacturer's claims when post-processed using multiple base stations in this software package. The manufacturer claims that HRMS should be 0.300 m, while Table 5.20 shows the HRMS value calculated from observations taken during this project was 1.172 m when post-processed in Trimble Geomatics Office. The differences between the HRMS values are due to the large number of float baseline solutions when post-processing Trimble Geomatics Office.

5.5.2.2 Extended Time Observations

Single base station HRMS values claimed by the manufacturer are 0.100 m and 0.010 m for twenty and forty-five minutes respectively. Table 5.20 shows when the observations taken during this project were post-processed using a single base station the HRMS values were 0.278 m for twenty minutes and 0.197 m for forty-five minutes. Neither HRMS values met the manufacturer’s claims of 0.100 m for twenty minutes of satellite tracking and 0.010 m for forty-five minutes of satellite tracking. The difference between the HRMS values is due to the large number of float baseline solutions when post-processing Trimble Geomatics Office.

The twenty and forty-five minute observation times didn’t meet the manufacturer’s claims for H-Star post-processing either. The manufacturer claims that Pro XH internal antenna observations should have a HRMS of 0.300 m; the values found in this project are shown in Table 5.20, for twenty minutes the average distance error is 0.799 m and for forty-five minutes 0.352 m. The reason for these higher HRMS values is that when the data files were post-processed baselines from Caboolture and Robina were not fixed when post-processing in Trimble Geomatics Office.

It is evident that there are problems with the twenty and forty-five minute observations. This fact is portrayed by the failure of the twenty and forty-five minute observations to meet the manufacturers claimed accuracy. The manufacturer’s claims are not reached when observation files are post-processed in either Trimble Pathfinder Office or Trimble Geomatics Office. This indicates that the problem does not lie within the software package but in the observations taken. To ascertain where the problem exists the recording of data for forty-five minutes should be completed again.

5.6 Conclusion

The Pro XR and Pro XH receivers are able to achieve similar accuracies when minimum time observations are post-processed using a single base station in Trimble Pathfinder Office especially if the work site is located close to a single base. This proves that H-Star methods uses a weighted approach when post-processing data files.

H-Star post-processing methods is a better choice when the work site is central to the base stations being used to correct the minimum observations taken; this is because the H-Star methods use multiple base stations to correct for atmospheric errors. As the observation time increases, so does accuracy. The zephyr antenna, because of the ability to track both L1 and L2 wave lengths, is able to out perform both twenty and forty-five minute observations taken by the internal antenna of the Pro XH receiver.

Pro XR observations and twenty and forty-five observations taken by the Pro XH exhibit the characteristic: that as baseline length increases accuracy decreases. This occurs when observation files are post-processed from a single base station.

It has been found that Trimble Pathfinder Office is able to consistently post-process data files using both single and H-Star methods more reliably then Trimble Geomatics Office. This fact makes Pathfinder Office a better choice of software package to post-process mapping grade GPS observations.

Chapter 6

Conclusions & Recommendations

6.1 Introduction

This chapter will be used to conclude the results found during this project. These results will relate to the differences in the receivers, post-processing methods and software packages. The results will be referenced to the manufacturer’s claim, which relates to the aim of the project: “to compare the accuracy of Trimble’s Mapping Grade GPS Receivers against the manufacturer’s claims using static carrier phase observations”.

The aim of this chapter is to provide the reader with a summary of the results found during this project. It is anticipated that once reading this chapter, the reader would have gained an understanding of all project work completed and the results from the consequent observations and post-processing as described in earlier chapters.

An understanding of the results of the project work completed will be provided by dividing this chapter into two sections; conclusions and recommendations. The conclusions section will summaries the main facts discussed in chapter 5, while the recommendations section will be used to give some examples of areas where future testing and studying can occur.

6.2 Conclusions

6.2.1 Differences in Receivers

This project has found that ten minute observations taken by both the Pro XR and Pro XH receivers are capable of being post-processed to the same accuracy when post-processed in Trimble Pathfinder Office. The same accuracy is achieved by the Pro XR and Pro XH receivers, when the Pro XR receiver is post-processed using a single base station and the Pro XH receiver is post-processed using H-Star technology when control marks are located close to the single base.

It has also been found that the zephyr antenna is able to increase the accuracy of post-processed results gained by using the Pro XH receiver. The reader should be reminded that the Pro XR did not use the zephyr antenna. The use of this external antenna has produced results that are more accurate than the internal antenna of the Pro XH receiver because of the ability to track L1 and L2 carrier wave lengths. By monitoring these two wave lengths the distortions caused by the ionosphere can be modelled and corrected better than monitoring only one wave length.

6.2.2 Differences in Post-processing methods

The two processing methods used for this project have been single base station and H-Star post-processing. H-Star post-processing is based on using base station files from a number of base stations during post-processing.

When marks are located close to the middle of the multiple base stations, H-Star is a more accurate post-processing method. The reason for choosing H-Star post-processing when the work site is central to the multiple base stations, is that by surrounding the work site the base stations are better able to monitor the changes in atmospheric conditions that affect the work site and correct for these errors.

However if the work site is located close to a single base station, both single station and H-Star post-processing give results of the same accuracy. This is because the single base is able to monitor the atmospheric changes as well as the multiple base stations can.

6.2.3 Differences in software packages

The two software packages used to post-process the observations taken as part of this project were Trimble Pathfinder Office and Trimble Geomatics Office. The software packages, Trimble Pathfinder Office and Trimble Geomatics Office were compared using HRMS and VRMS. RMS error is used to describe uncertainty and summarise the entire error distribution. The smaller HRMS values as shown in Appendix N for observations post-processed in Pathfinder Office and the more consistent VRMS values make Trimble Pathfinder Office a more reliable software package to use when post-processing mapping grade GPS receiver observations.

6.2.4 Manufacturer’s Claims

It has been found that some of the manufacturer’s claims are not justified. The claims that need revising are for the Pro XH receiver when post-processing twenty and forty-five minute observations from a single base station. The HRMS values calculated as a result of observations taken as part of this project have been found to be larger than those figures claimed by the manufacturer.

Data files post-processed in Trimble Geomatics Office didn’t pass because of the high number of baselines that where not fixed solutions especially with multiple base station processing.

One point to note is that the manufacturers have made no claims in regard to vertical accuracy.

6.3 Recommendations

It is recommended that further testing be completed to verify the RL of PSM 40963. When observations taken at this PSM were post-processed in Trimble Pathfinder Office, there was a large difference between the published RL value and the value from the corrected files. The other recommendation is to undertake further testing to verify the fact that the manufacturer’s claims are incorrect for the twenty and forty-five minute observations taken by the Pro XH receivers when post-processed from a single base station.

This project has only looked at static observations as mentioned in section 1.2.2. Recommendations for future research come from areas that have not been completed as part of this project. Two main areas of future study have been recognised, these are:

- Dynamic tracking, and
- The use of real time corrections

Dynamic tracking refers to taking measurements as the receiver is moving. Dynamic observations can be used for a number of applications such as taking measurements while the user walks around the perimeter of an area or along a kerb or gutter line. Measurements taken while the receiver is moving will be affected by latency. Latency is the time delay between when a task is initiated and when the action actually takes place.

The second area of future study is using real time corrections to correct positions collected in the field. Both the Pro XR and Pro XH receivers are capable of using real time corrections to correct observations taken in the field. A real time correction means that corrections applied by the software packages Trimble Pathfinder and Geomatics Offices can be applied in the field while the person collecting the data is still out at the work site.

6.4 Close

The project has been successful in achieving the project aim, which was “to compare the accuracy of Trimble’s Mapping Grade GPS Receivers against the manufacturer’s claims using static carrier phase observations”. The aim was completed by accomplishing the project objectives as stated in section 1.2.2. The objectives were to use the Pro XR and Pro XH receivers to take static carrier phase observations of varying baseline length and to post-process these observations using single and multiple base station post-processing

It is hoped that after reading this chapter, ideas for further research can be devised, and students and others commencing studies will be able to use this project as a basis for their own studies.

Appendix A: Project Specification

University of Southern Queensland

FACULTY OF ENGINEERING AND SURVEYING

ENG 4111/4112 Research Project

PROJECT SPECIFICATION

FOR:	**NELSON HARCH**
TOPIC:	Testing Mapping Grade GPS Carrier Phase Accuracy
SUPERVISOR:	Mr Peter Gibbings
SPONSORSHIP:	Faculty of Engineering and Surveying, USQ
PROJECT AIM:	To compare the accuracy of Trimble's Mapping Grade receivers against the manufacturer's claims using static carrier phase observations.

Programme: Issue C, 20 October 2006

1. Undertake a review of current literature regarding manufacturer's testing procedures and results.

2. Establish and/or verify control points to be used during the testing phase.

3. Undertake an observation regime with the Pro XR and Pro XH receivers. Internal antennas will be used as well as the Zephyr Antenna with the Pro XH receiver.

4. Process the data using a variety of software packages. Packages to be used are Pathfinder Office and Trimble Geomatics Office. Only Pro XH internal antenna observations will be post-processed using Trimble Geomatics Office.

5. Data will be processed from one base for both receivers, the one station being Ananga. H-Star processing will be carried out with the Pro XH.

6. Analyse the data and draw conclusions with regard to manufacturer's claims

Agreed.

Student: Nelson Harch
Date: 24/10/06

Supervisor: Peter Gibbings
Date: 24/10/06

Appendix B: Pro XR Specifications

Physical

GPS receiver
Size . . . . .11.1 cm × 5.1 cm × 19.5 cm (4.4 in × 2.0 in × 7.7 in)
Weight . . . . .0.76 kg (1.68 lb)
Antenna
Size . . . . 15.5 cm diameter × 10.8 cm high (6.1 in × 4.2 in)
Weight . . . . 0.49 kg (1.08 lbs)
Power . . . . 6 Watts (maximum), 10 to 32 VDC

Environmental

Temperature
Operating . . . .–20 °C to +65 °C (–4 °F to +149 °F)
Storage . . . .–30 °C to +85 °C (–22 °F to +185 °F)
Humidity . . . . 100% fully sealed
Receiver casing . . . . Dustproof, splash proof, shock-resistant; sealed to 5 psi
Antenna casing . . . . Dustproof, waterproof, shock-resistant

GPS

General . . . . 12 channel, L1/CA code tracking
carrier phase filtered measurements, multibit digitizer
Antenna . . . . Right-hand, circular polarized;
Omni directional; hemispherical coverage
Integrated real-time . . . . WAAS or EGNOS
Update rate . . . . 1 Hz
Time to first fix . . . . 30 seconds (typical)

Accuracy (RMS) after differential correction

Post-processed . . . . 50 cm
Carrier post-processed
With 5 minutes tracking satellites . . . . 30 cm
With 10 minutes tracking satellites . . . . 20 cm
With 20 minutes tracking satellites . . . . 10 cm
With 45 minutes tracking satellites . . . . 1 cm
Real-time . . . . Sub metre

Source: Trimble 2006l

Appendix C: Pro XH Specifications

Physical

Integrated GPS receiver, antenna, and battery
Size . . . . 10.6 cm × 4.0 cm × 14.6 cm (4.2 in × 1.6 in × 5.75 in)
Weight . . . . 0.53 kg (1.16 lb)
Power
Low (GPS only) . . . . 0.8 Watts
Normal (GPS and Bluetooth) . . . . 1.0 Watt
High (optional Zephyr antenna, GPS, and Bluetooth) . . . . 1.6 Watts
Battery . .User replaceable lithium-ion, chargeable in unit,12.6 Watt hours

Environmental

Temperature
Operating . . . .–20 °C to +60 °C (–4 °F to +140 °F)
Storage . . . .–30 °C to +85 °C (–22 °F to +185 °F)
Humidity . . . . .99% non-condensing
Casing . . . . Wind-driven rain and dust-resistant per IP 54 standard
Drop . . . . 1.22 m (4 ft), MIL-STD-810F, Method 516.5, Procedure IV
Vibration . . Vibration resistant, MIL-STD-810F, Method 514.5, Procedure I
Shock . . . . Shock resistant, MIL-STD-810F, Method 516.5, Procedure I

Input/output

Serial . . . . Dual port in single DE9
Bluetooth . . . . 2 NMEA/TSIP Serial Port (SPP) services
Interface . . . . Power button, 3 status LEDs

GPS

Channels . . . . 12 (L1 code and carrier/L2 carrier)
Integrated real-time . . . . .SBAS
Update rate . . . . 1 Hz
Time to first fix . . . . 30 seconds (typical)
Protocols . . . . TSIP, NMEA (GGA, VTG, GLL, GSA, ZDA, GSV, RMC)

Accuracy (HRMS) after differential correction

H-Star post-processed
With internal antenna . . . . 30 cm
With optional Zephyr antenna . . . . 20 cm
Code post-processed . . . . Sub metre
Carrier post-processed
With 20 minutes tracking satellites . . . . 10 cm
With 45 minutes tracking satellites . . . . 1 cm
Real-time (SBAS or external RTCM source) . . . . Sub metre

Source: Trimble 2006k

Appendix D: Permanent Survey Mark Information

Permanent Survey Mark Information					Horizontal				Vertical				
Mark	Easting	Northing	RL	Zone	Datum	Order	Class	Fixed by	Datum	Order	Class	Fixed by	Locality
PSM 1901	429520.527	6952001.654	100.750	56	GDA94	1	A	GPS	AHD D	4			Gatton
PSM 35751	369799.842	6956678.574	708.203	56	GDA94	1	A	GPS	AHD D	4	D	GPS	Toowoomba
PSM 40424	394860.175	6945489.266	683.293	56	GDA94	1	A	GPS	AHD	4	D	Spirit Levelling	Toowoomba
PSM 40435	394349.531	6948315.224	682.050	56	GDA94	1	A	TRIG	AHD	4	D		Toowoomba
PSM 40827	400593.839	6952343.303	614.622	56	GDA94	1	A	GPS	AHD	4	D	TRIG	Toowoomba
PSM 40963	398848.830	6950425.672	665.198	56	GDA94	1	A	GPS	AHD D	4	D	Spirit Levelling	Toowoomba
PSM 59005	391674.488	6952126.284	615.218	56	GDA94	1	A	GPS	AHD D	4	D		Toowoomba
PSM 61403	389641.400	6954461.975	583.097	56	GDA94	1	A	GPS	AHD	4	D		Toowoomba
PSM 61742	432244.688	6951779.551	93.950	56	GDA94	1	A	GPS	AHD D	4	D	GPS	Gatton
PSM 89889	430278.473	6953943.686	114.052	56	GDA94	1	A	GPS	AHD D	4		GPS	Gatton
PSM 107948	426531.436	6954501.309	129.513	56	GDA94	1	A	GPS	AHD D	4	D	GPS	Gatton
PSM 112927	391446.340	6950826.861	607.311	56	GDA94	1	A	GPS	AHD	4	D		Toowoomba
PSM 112928	389728.340	6951057.972	542.529	56	GDA94	1	A	GPS	AHD	4	D		Toowoomba
PSM 132088	431357.061	6948121.418	124.070	56	GDA94	1	A	GPS	AHD D	4	D	GPS	Gatton

Appendix E: Settings used with the Recon data collection device

Logging Settings

Log Velocity Data	no
Log H-Star Data	Auto
Log Super Correct Data	yes
Antenna Height	
Allow position update	Confirm
Confirm end feature	No
File name prefix	R
Between Feature	off

GPS Settings

GPS receiver port	COM 3
DOP Type	PDOP
Max DOP	6
SNR	39
Min elevation	15°
Velocity filter	off
NMEA	off
RTK Precisions	N/A

Co-ordinate Settings

System	Map Grid of Aust
Zone	56
Altitude Reference	Mean Sea Level
Altitude Units	m
Geoid Model	other
Geoid	DMA 10*10 Global
Co-ordinate Unit	m
Display USNG	off

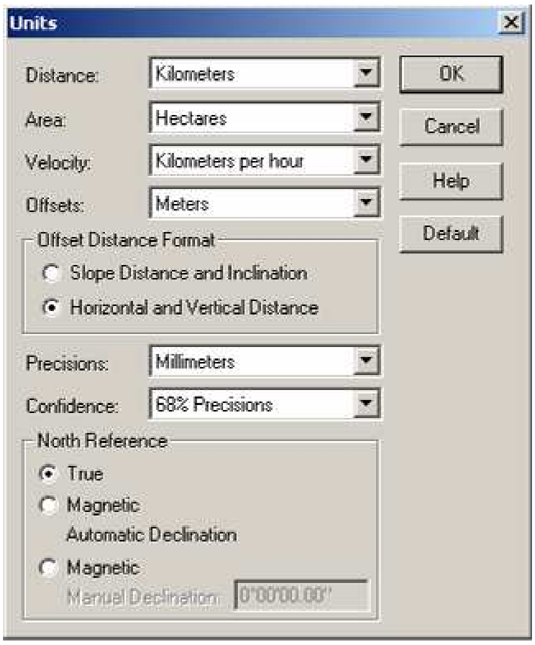
Units

Distance units	m
Area units	m²
Velocity units	km/h
Angle units	degrees
Lat/Long Format	DD°MM'SS.SS"
Offset format	Horizontal/ Vertical
North reference	TRUE
Magnetic declination	auto

Appendix F: Trimble Pathfinder Office Post-processing settings

Version 3.10 of Trimble Pathfinder Office was used for post-processing completed during this project

These can be found under the options tab



Distance: Kilometers

Area: Hectares

Velocity: Kilometers per hour

Offsets: Meters

Offset Distance Format

○ Slope Distance and Inclination

● Horizontal and Vertical Distance

Precisions: Millimeters

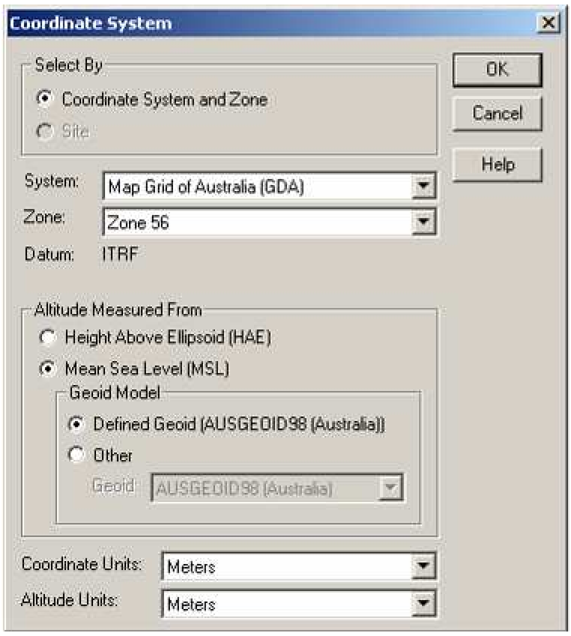
Confidence: 68% Precisions

North Reference

● True

○ Magnetic
Automatic Declination

○ Magnetic
Manual Declination: 0°00'00.00"



Select By

● Coordinate System and Zone

○ Site

System: Map Grid of Australia (GDA)

Zone: Zone 56

Datum: ITRF

Altitude Measured From

○ Height Above Ellipsoid (HAE)

● Mean Sea Level (MSL)

Geoid Model

● Defined Geoid (AUSGEOID98 (Australia))

○ Other
Geoid: AUSGEOID98 (Australia)

Coordinate Units: Meters

Altitude Units: Meters

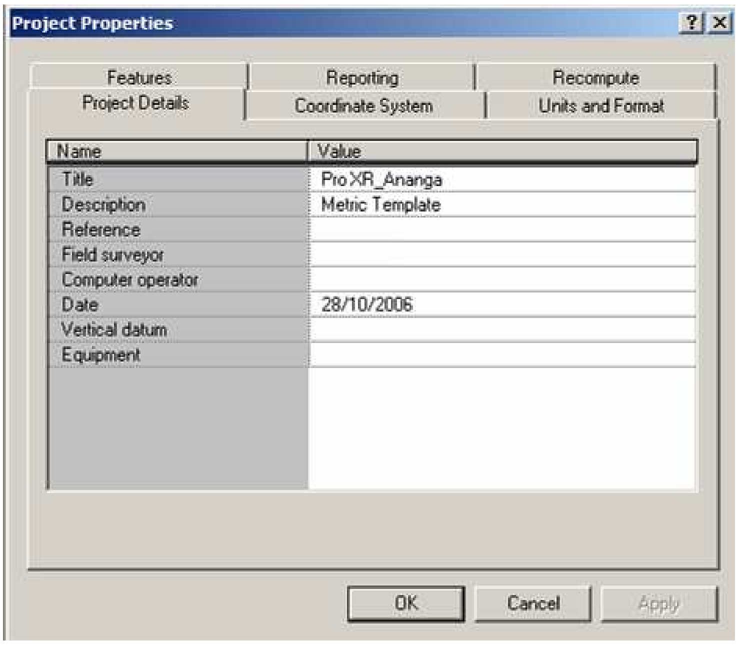
When data files were post-processed using one base, Standard Carrier Processing Only was selected in the Differential Correction Wizard

When data files were post-processed using H-Star methods, H-Star Carrier Processing Only was selected in the Differential Correction wizard.

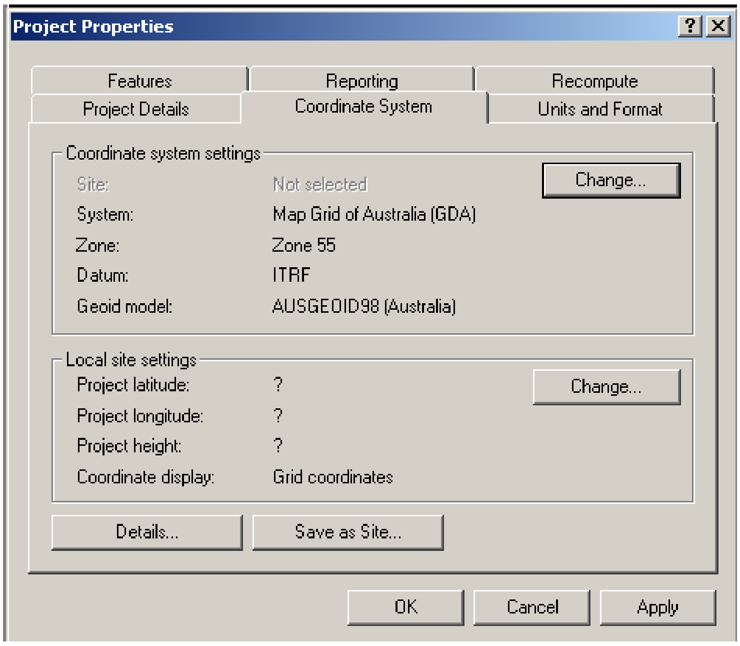
Appendix G: Trimble Geomatics Office Post-processing settings

Trimble Geomatics Office version 1.63 was used for the post-processing of Pro XH internal antenna observation files.

Project Properties



Name	Value
Title	Pro XR_Ananga
Description	Metric Template
Reference	
Field surveyor	
Computer operator	
Date	28/10/2006
Vertical datum	
Equipment	

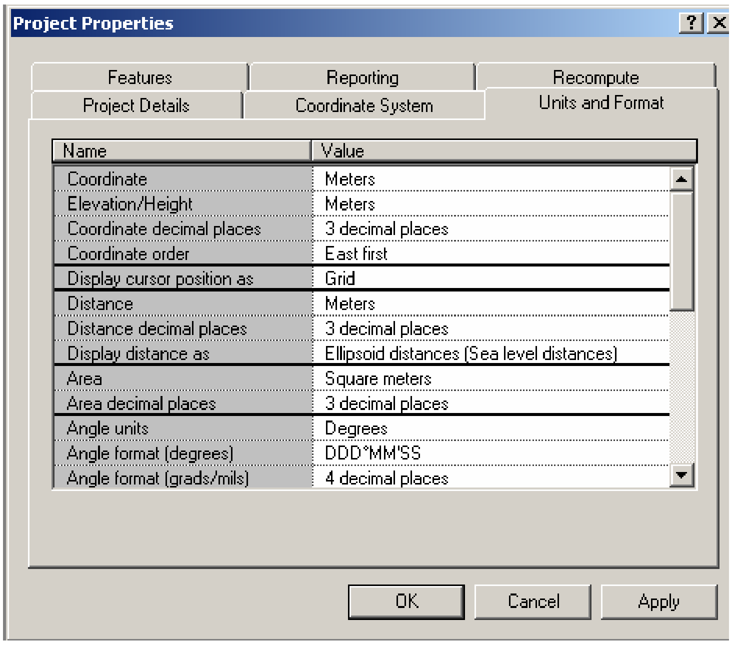


Coordinate system settings

Site:	Not selected
System:	Map Grid of Australia (GDA)
Zone:	Zone 55
Datum:	ITRF
Geoid model:	AUSGEOID98 (Australia)

Local site settings

Project latitude:	?
Project longitude:	?
Project height:	?
Coordinate display:	Grid coordinates



Name	Value
Coordinate	Meters
Elevation/Height	Meters
Coordinate decimal places	3 decimal places
Coordinate order	East first
Display cursor position as	Grid
Distance	Meters
Distance decimal places	3 decimal places
Display distance as	Ellipsoid distances (Sea level distances)
Area	Square meters
Area decimal places	3 decimal places
Angle units	Degrees
Angle format (degrees)	DDD°MM'SS
Angle format (grads/mils)	4 decimal places

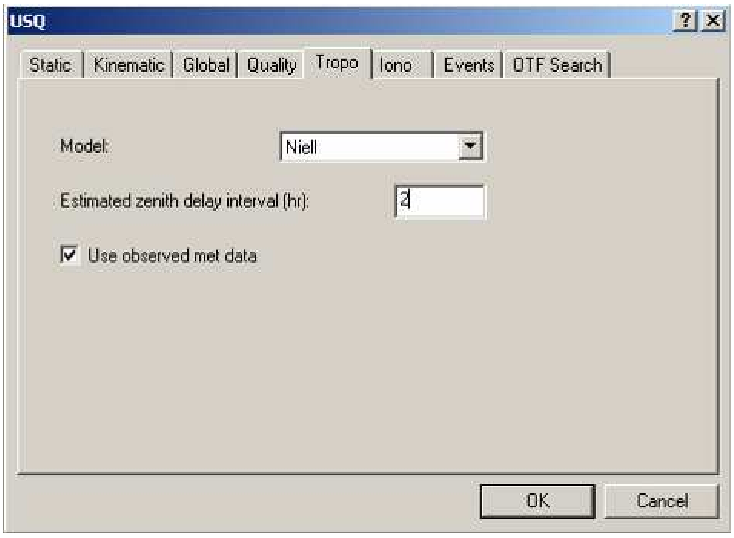
Under the Survey tab, GPS Processing Styles, a new post-processing style was made. This processing style was called USQ. USQ was a copy of the default Trimble Post-processing style with the following changes

Elevation mask (deg): 15

Ephemeris: Broadcast

Solution type: Fixed

Under the Advanced button the following changes were made



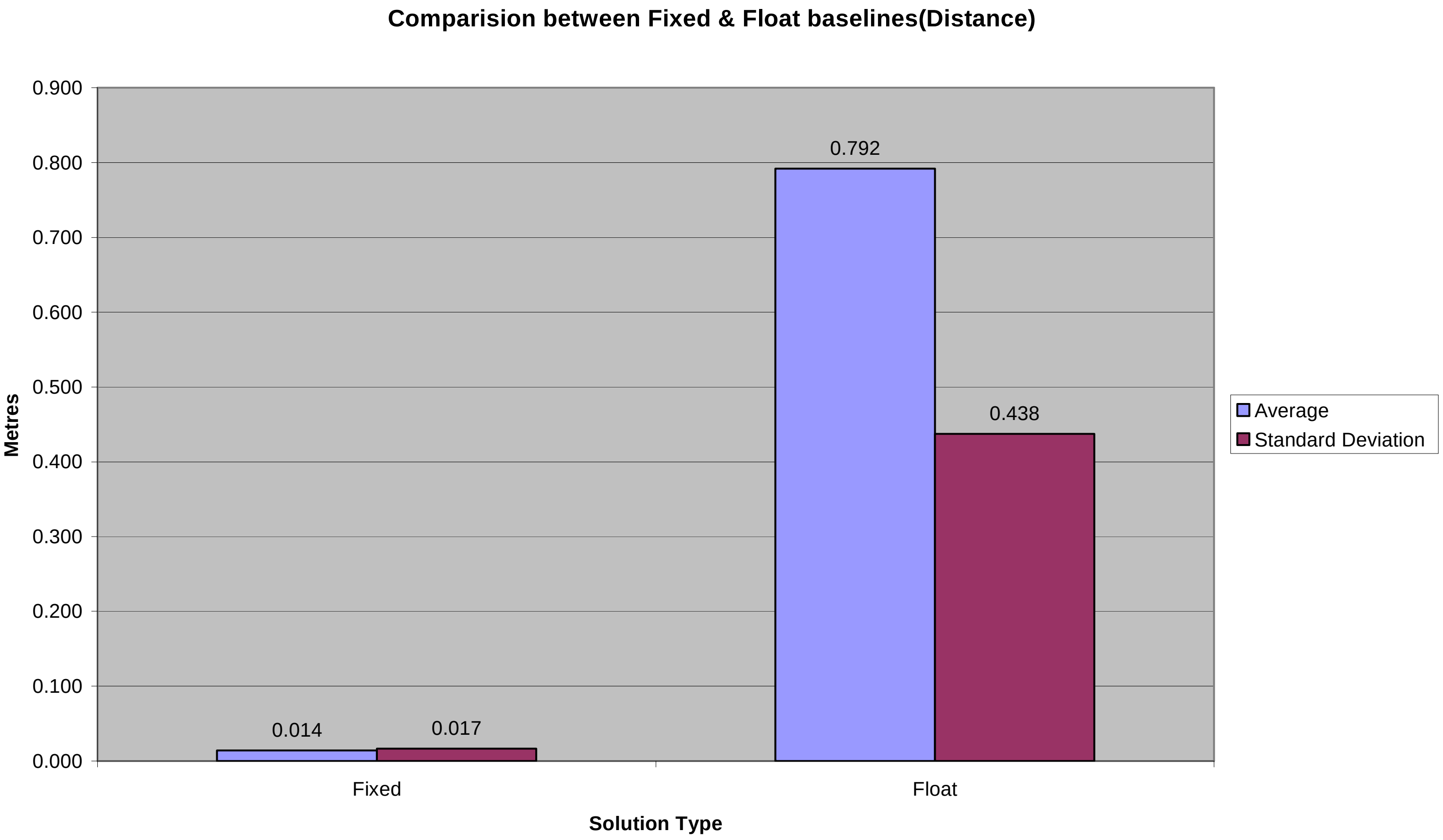
Model: Niell

Estimated zenith delay interval (hr): 2

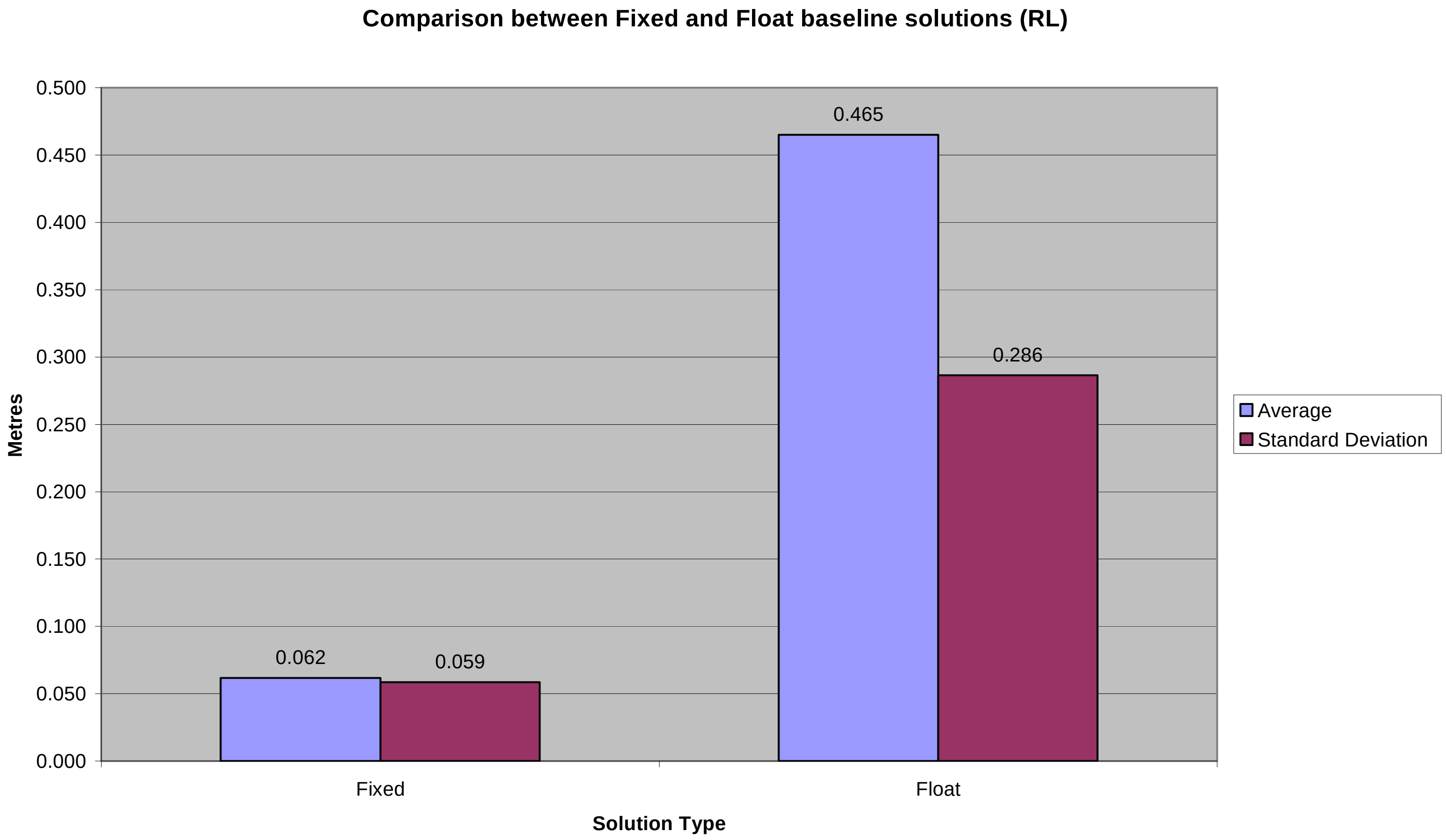
☑ Use observed met data

.

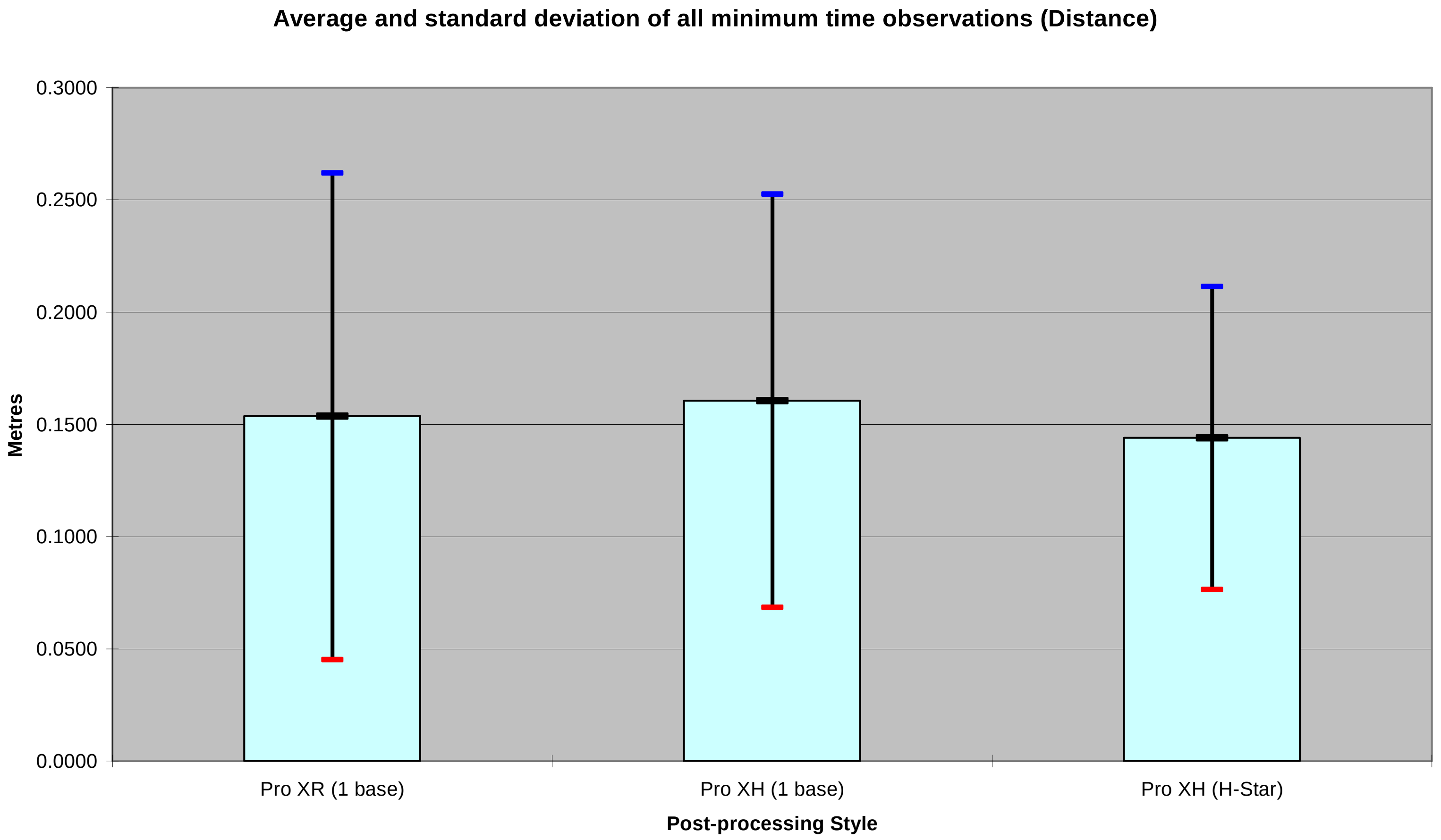
Appendix H: Comparing the average and standard deviation of Fixed and Float baselines



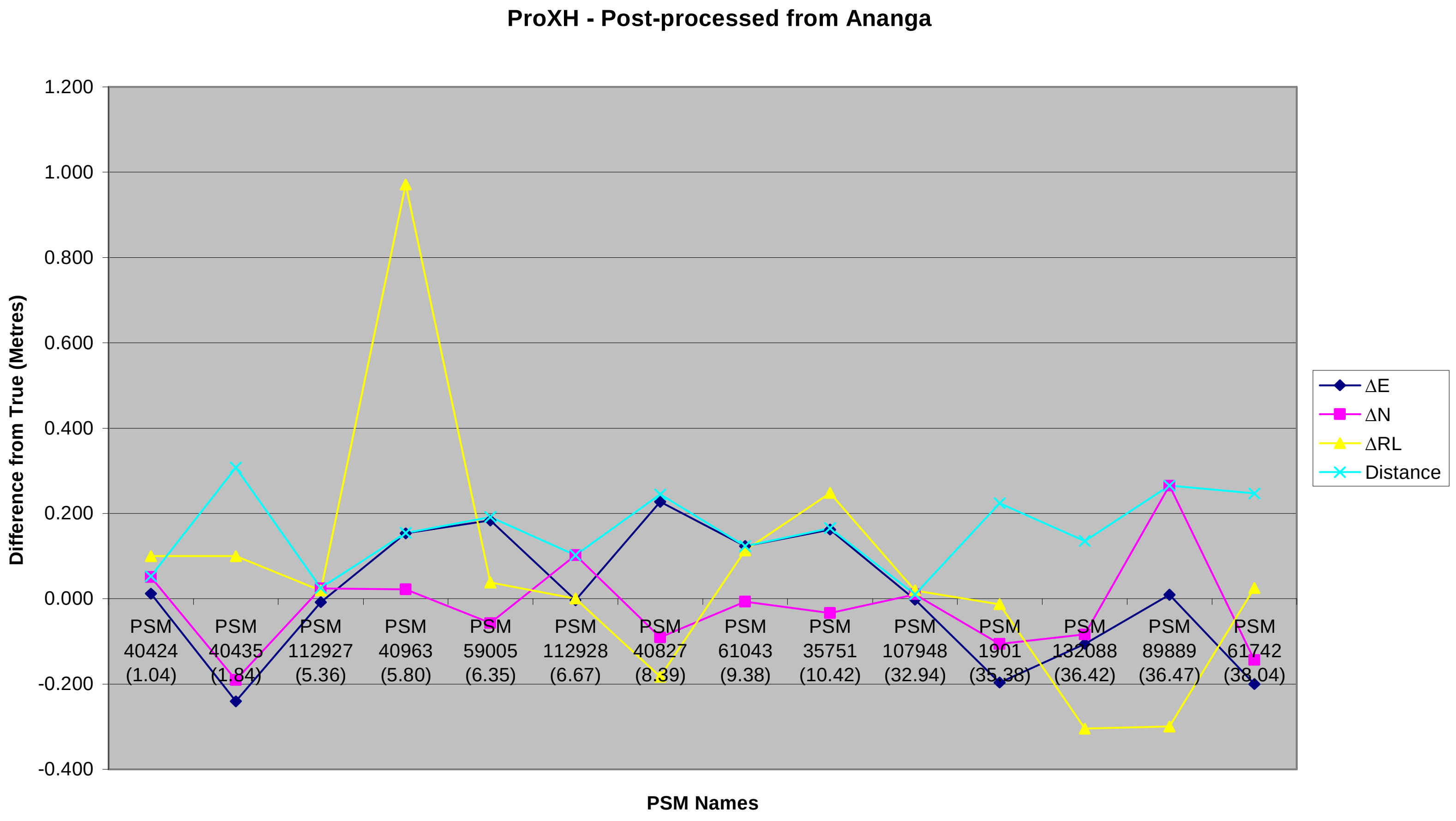
Appendix I: Comparing the average and standard deviation of Fixed and Float baselines



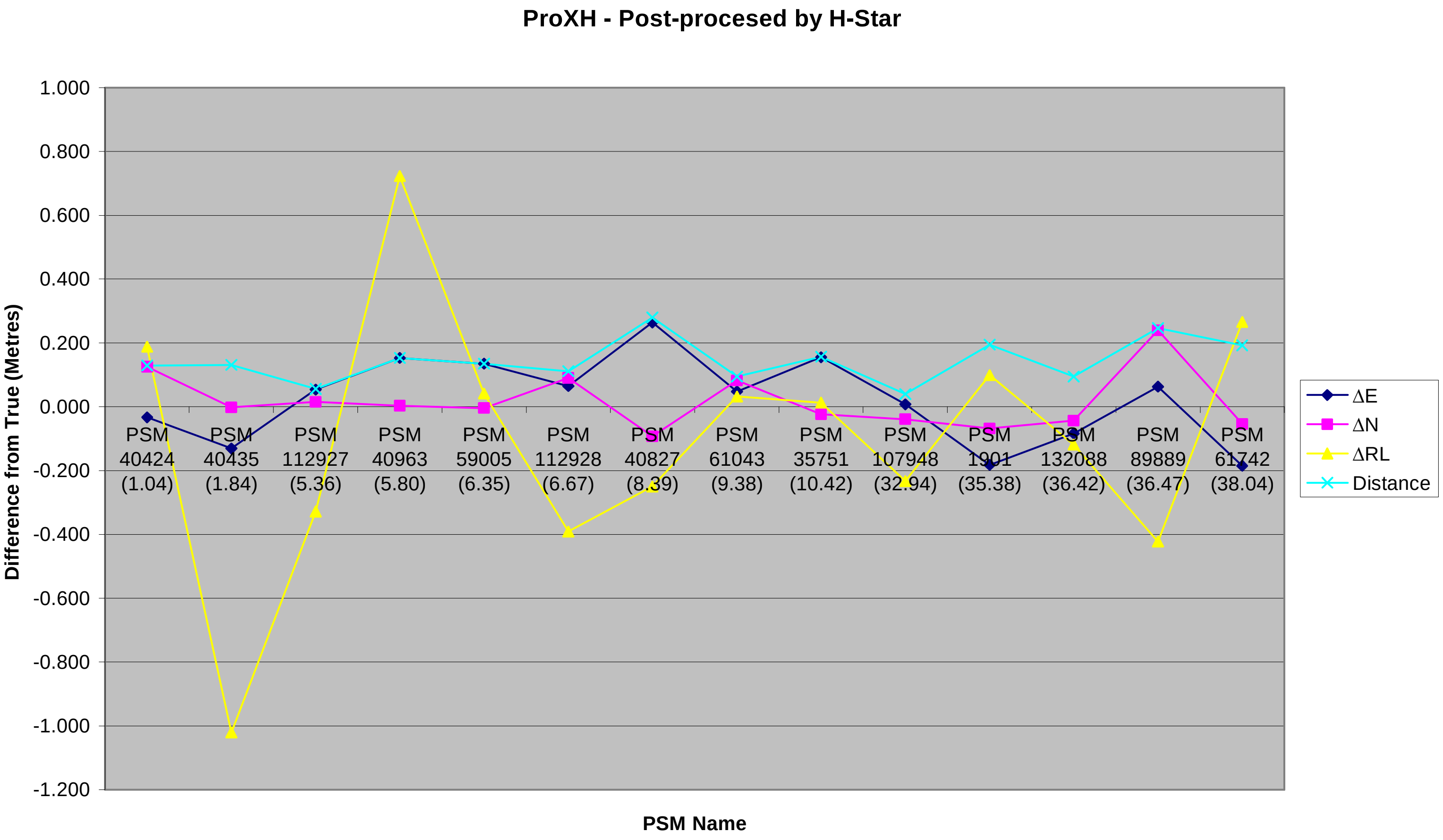
Appendix J: Average and standard deviation of minimum time observations post-processed with Trimble Pathfinder Office



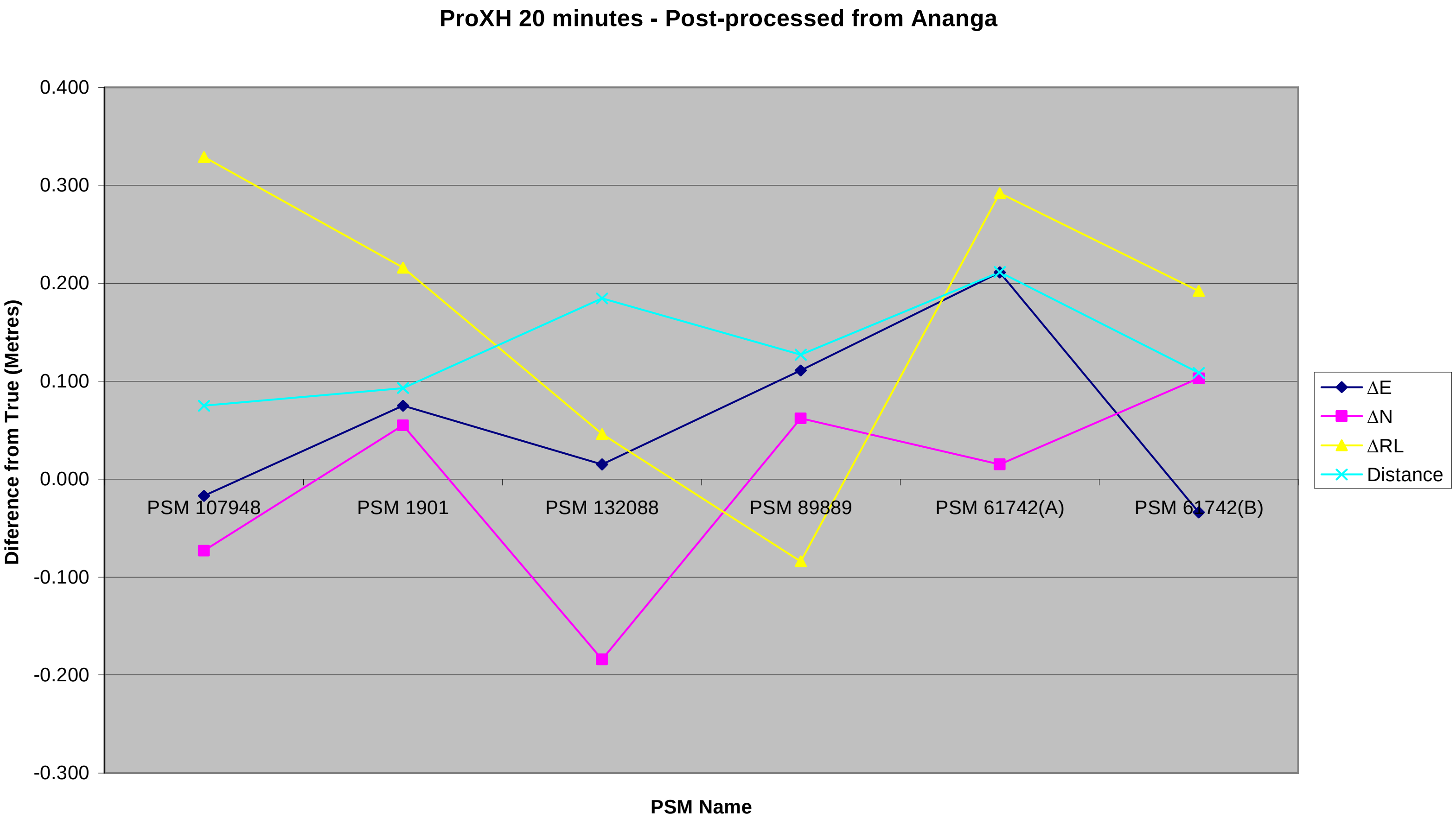
Appendix K: Pro XH – Post-processed from Ananga



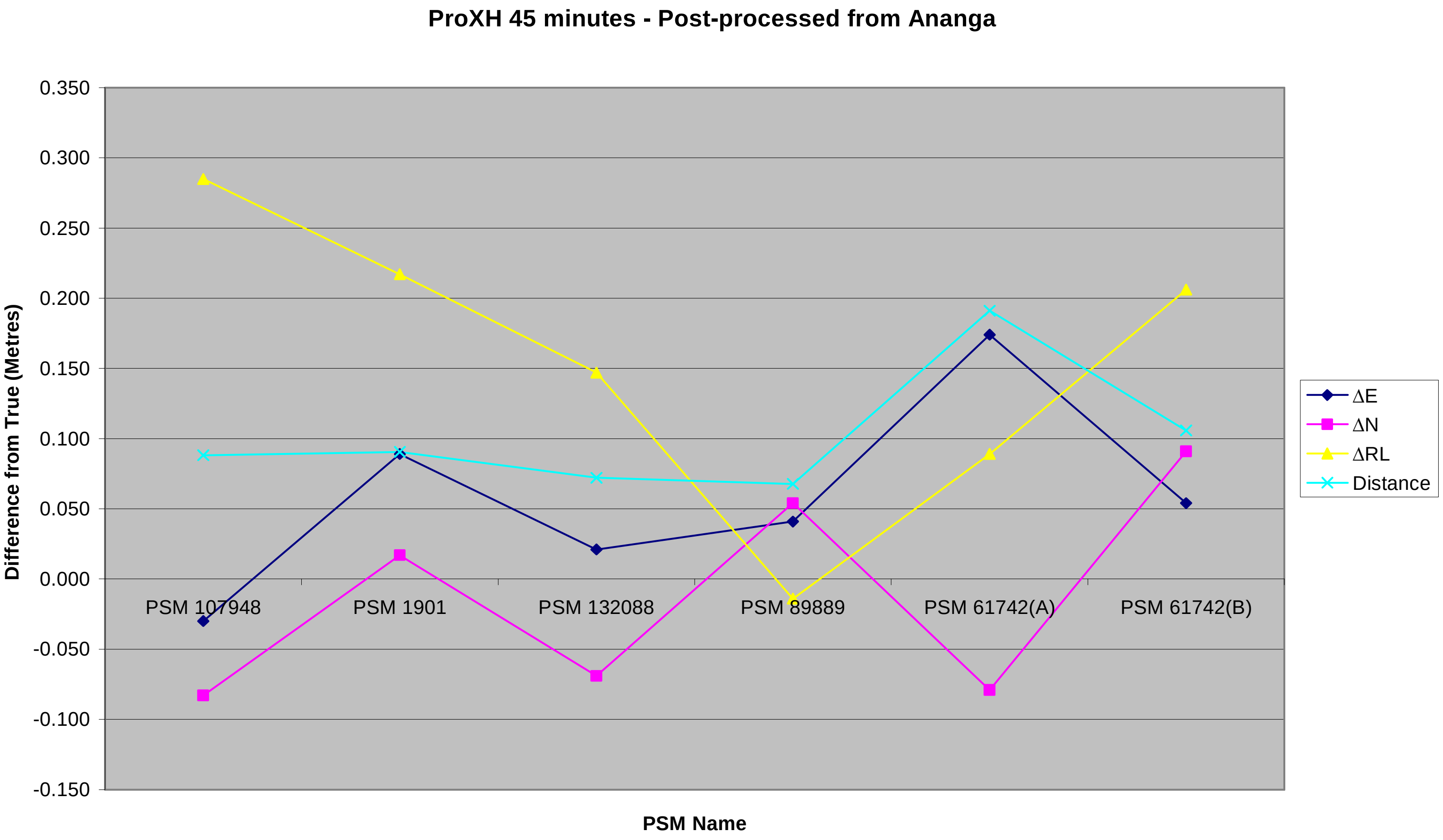
Appendix L: Pro XH – Post-processed by H-Star



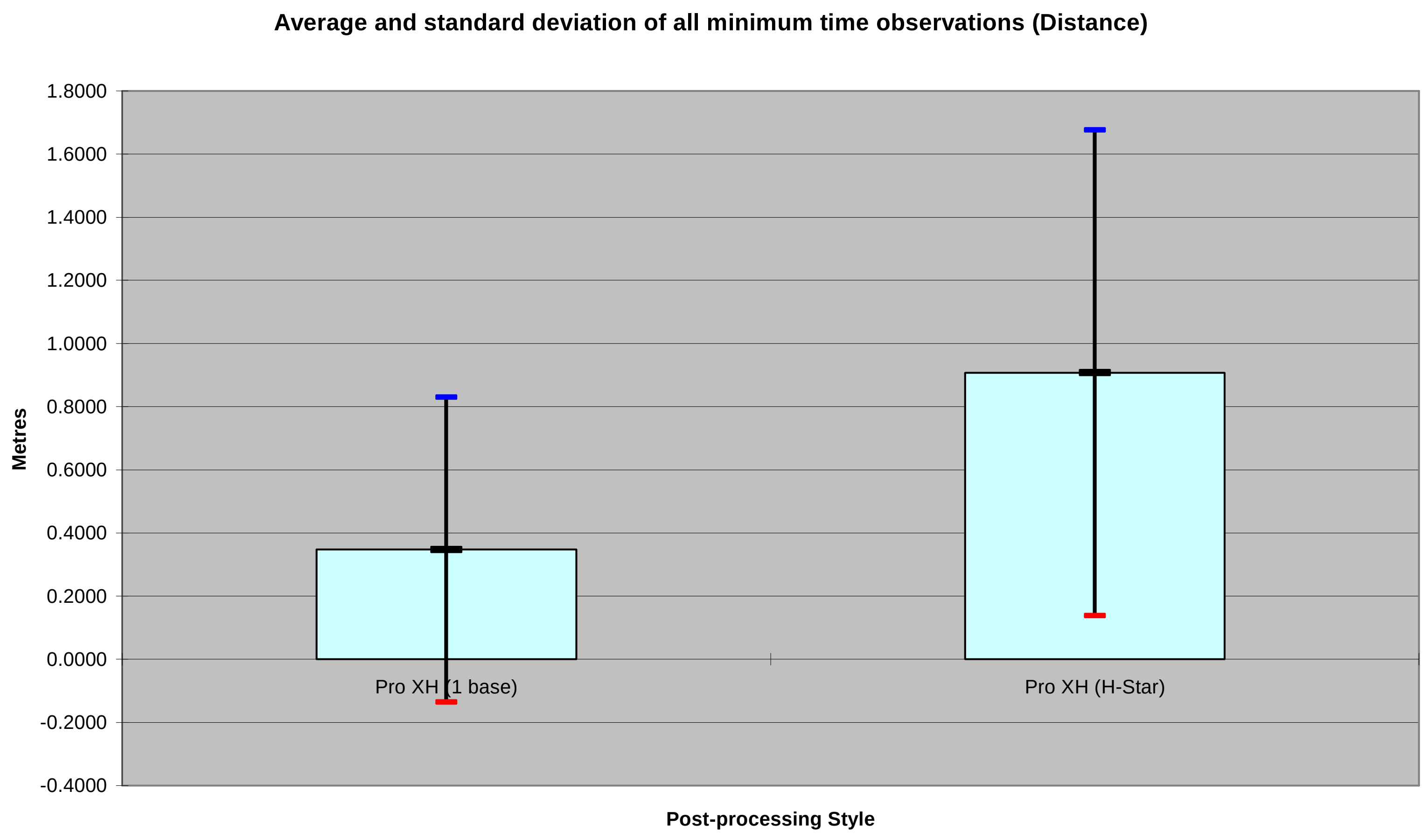
Appendix M: Pro XH 20 minutes – Post-processed from Ananga



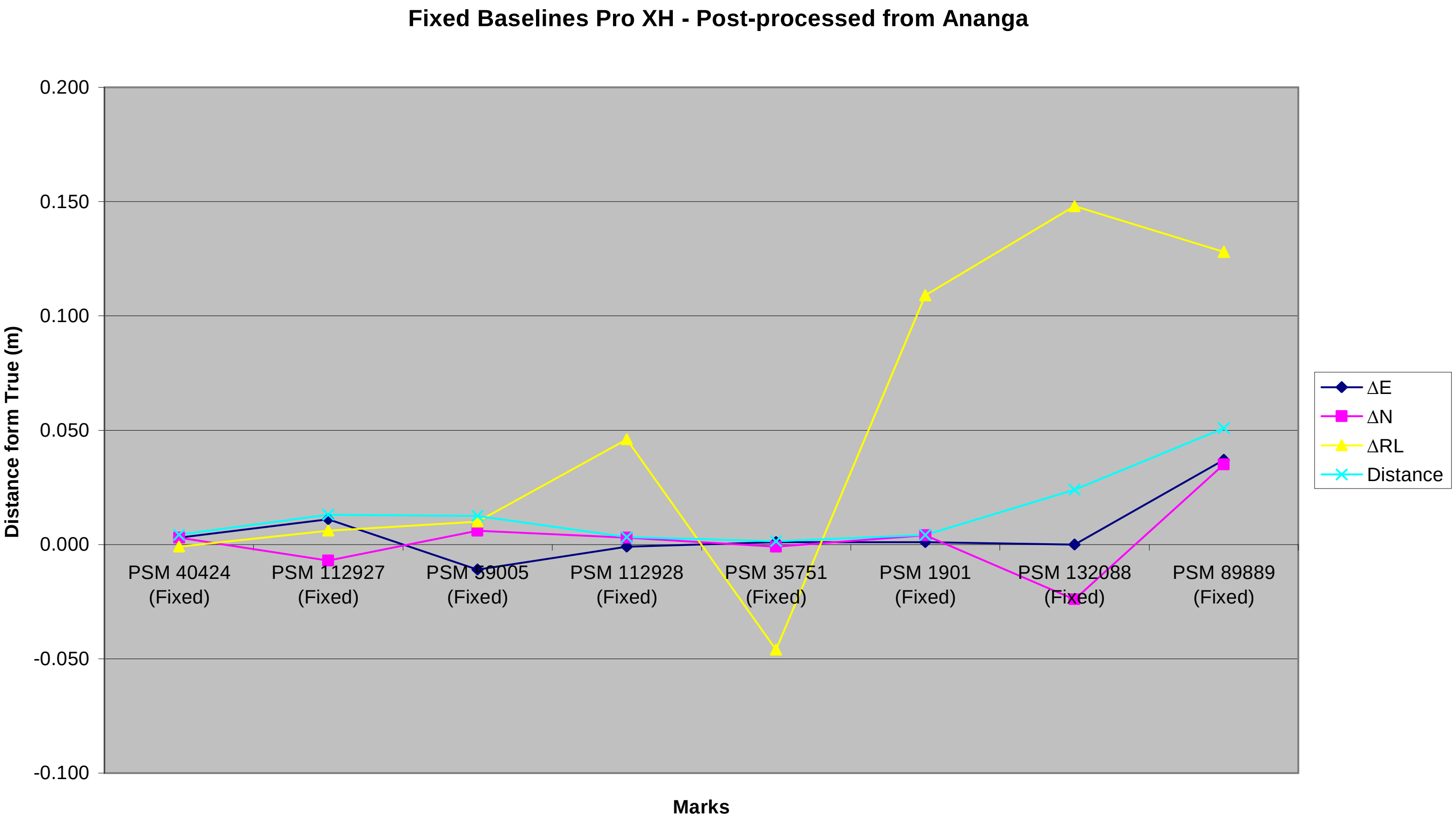
Appendix N: Pro XH – Post-processed from Ananga



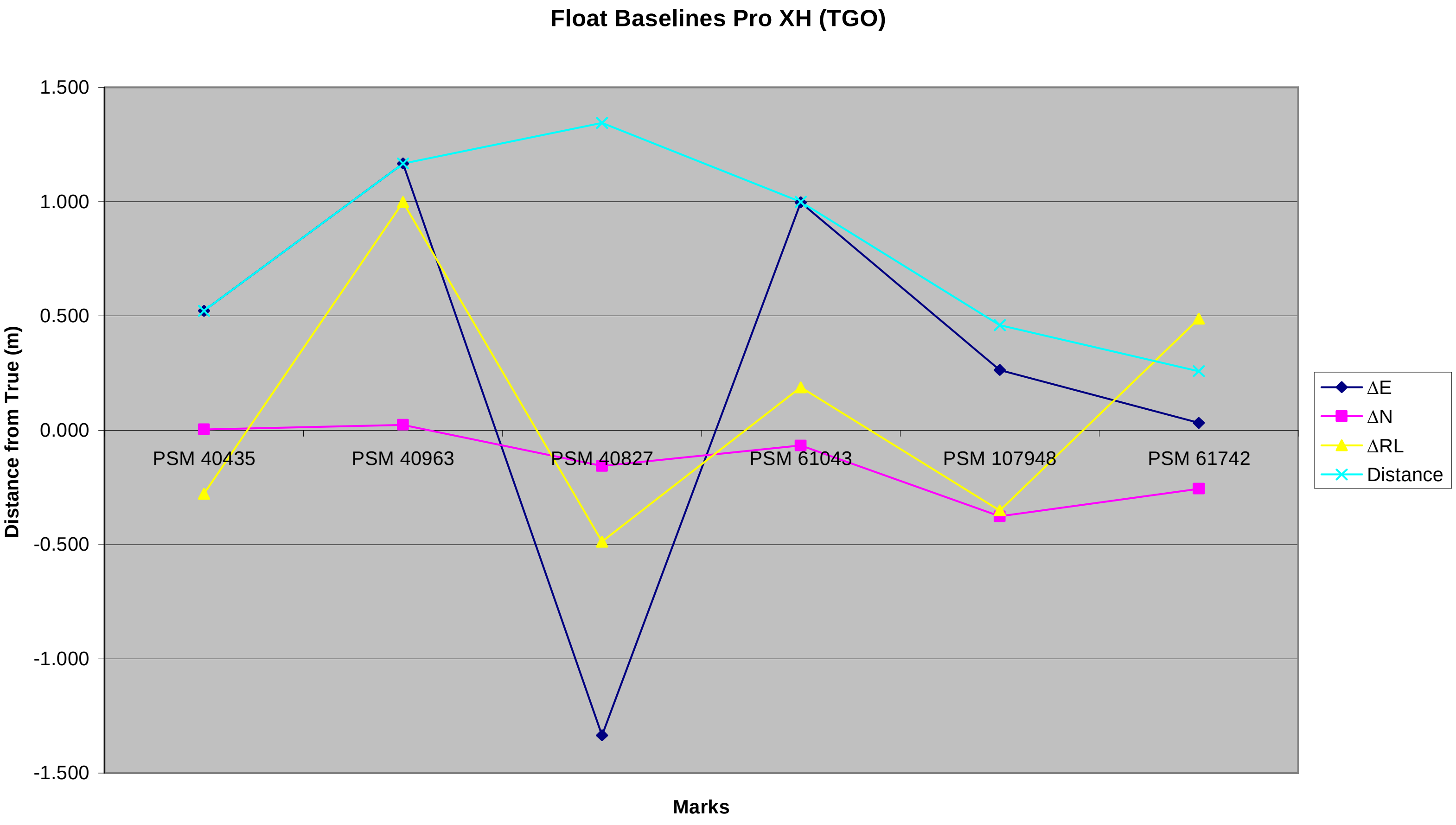
Appendix O: Average and standard deviation of minimum time observations post-processed with Trimble Geomatics Office



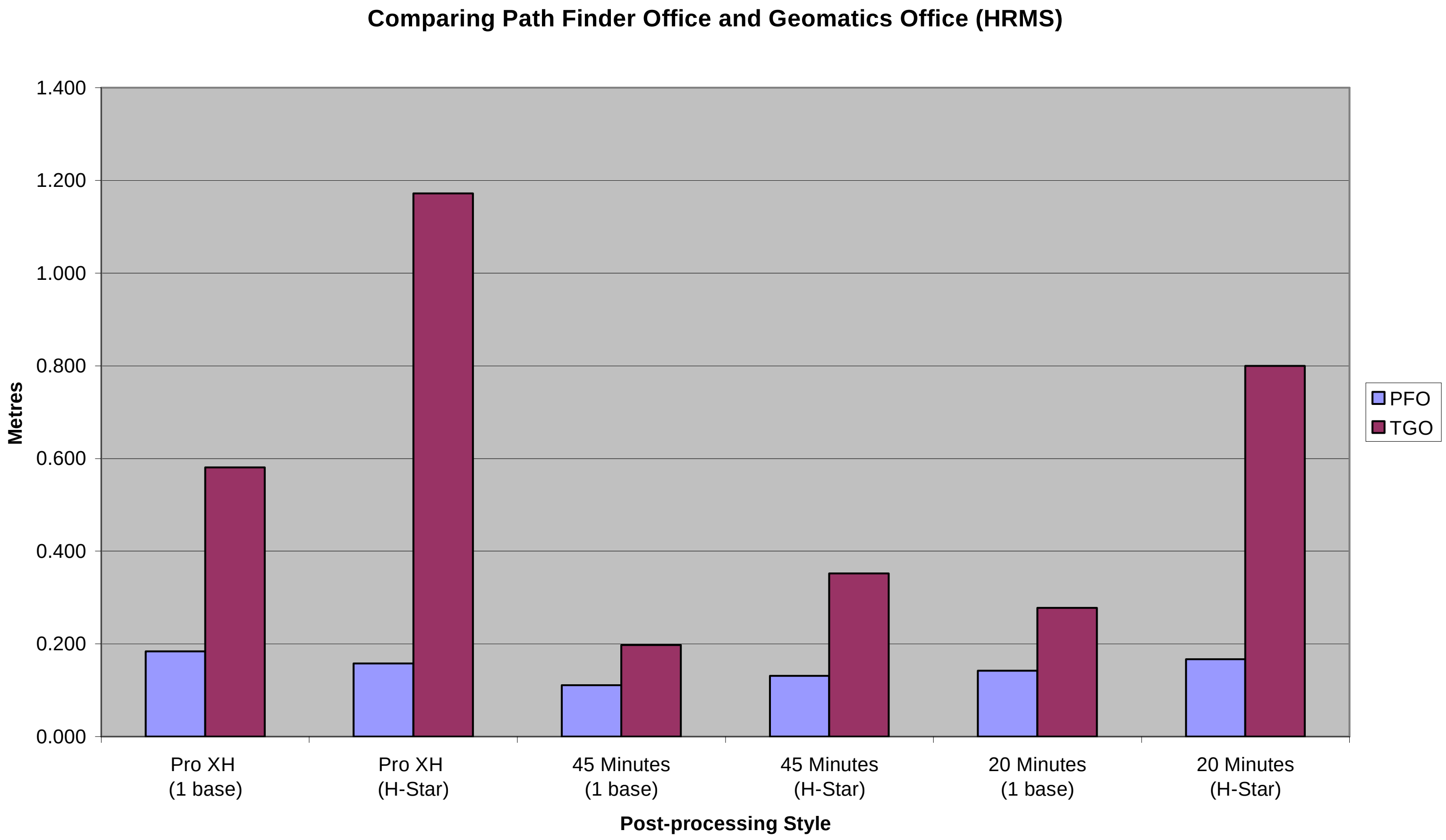
Appendix P: Co-ordinate errors for fixed baselines



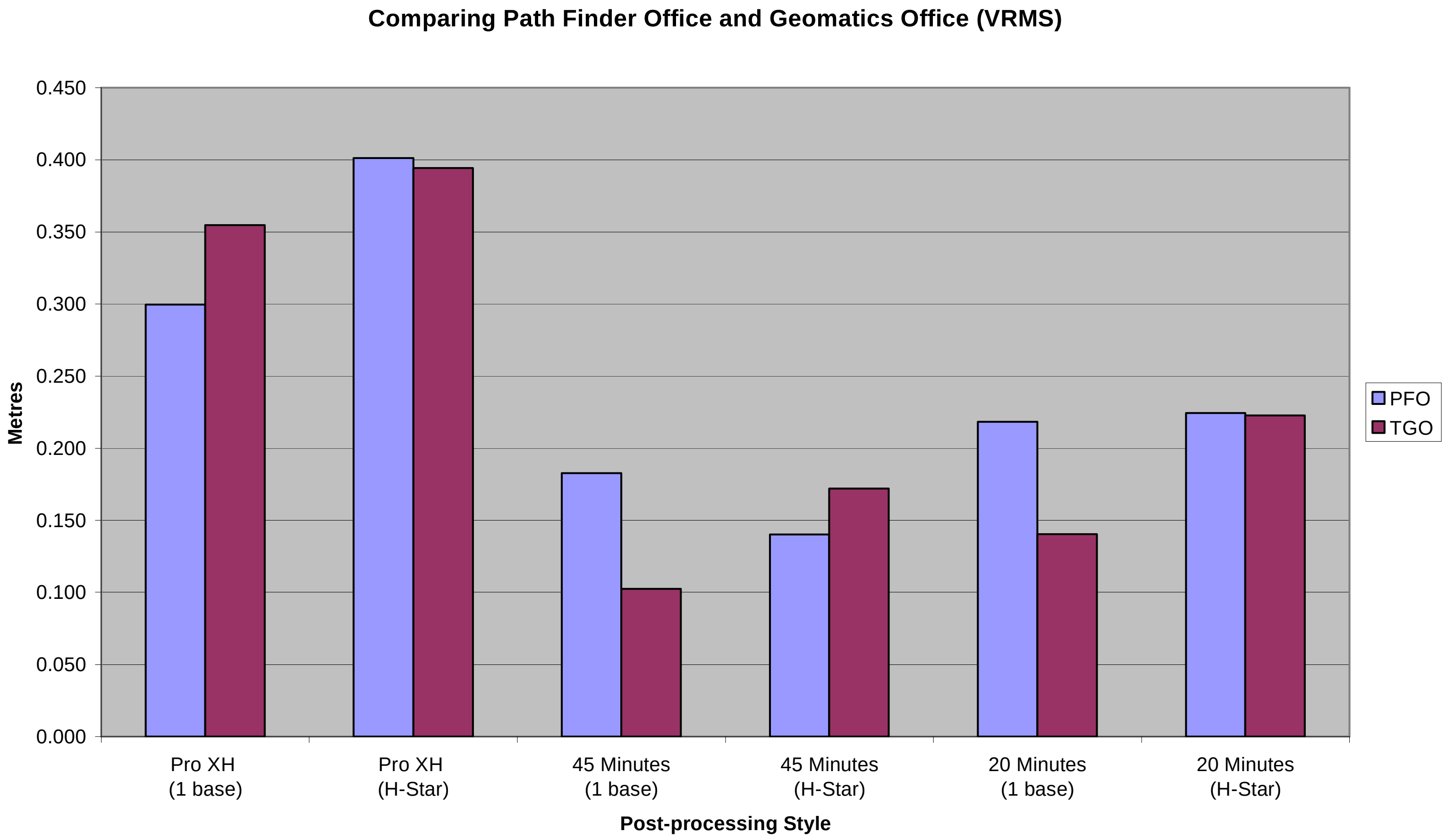
Appendix Q: Co-ordinate errors for fixed baselines



Appendix R: Comparing HRMS values in Trimble Pathfinder Office and Trimble Geomatics Office



Appendix S: Comparing VRMS values in Trimble Pathfinder Office and Trimble Geomatics Office



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