University of Southern Queensland
Faculty of Engineering and Surveying

SCADA and RFI Interference on RTK Surveys

A dissertation submitted by

Mr Matthew Hopson
Associate Diploma - Surveying

In fulfilment of the requirements of

Degree of Spatial Science (Surveying)

October 2009

ABSTRACT

This thesis investigated interference between SCADA radio transmissions and RTK radio transmissions. The research primarily focused on the SCADA network controlled by State Water Corporation

Previous research conducted by USQ students has indicated the validity of interference to GNSS from outside RF (radio frequencies).

Anecdotally, it has been observed that SCADA (Supervisory Control and Data Acquisition) has detrimentally affected RTK surveying when in the vicinity of such transmitters

The objective of the study was to quantify the extent and severity of any such interference, and from this information, produce a map specific to State Water's SCADA network showing all potential areas where RTK Surveying might be compromised by the SCADA network.

The field survey examined 4 State Water operated SCADA sites at two different locations. A third site, minimally affected by RFI was used as a reference site.

At each site a series of coordinated points was measured using conventional traversing techniques and static GNSS, thereby eliminating RF interference.

Leica 500 and 1200 RTK receivers were used to measure the test points with the result being compared to the control coordinates.

It was found that accuracy and precision of the RTK results was negatively affected when operated in the vicinity of SCADA and other RF interference. This dissertation will show the extent of the effect and comment upon potential 'zone of influence' that surrounds the SCADA sites tested.

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ENG4111 Research Project Part 1 &
ENG4112 Research Project Part 2

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CERTIFICATION

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

Matthew Hopson

Student Number: 0050010291

(Signature)

(Date)

ACKNOWLEDGEMENTS

This research was carried out under the principal supervision of Dr Armando A Apan, Associate Professor, BSF UP, MSc AIT, PhD Monash.

Appreciation is also due to Neil Porter and Jim Salmon of State Water Corporation Survey Section without whose assistance this study would have been much the lesser a document.

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NOMENCLATURE AND ACRONYMS
(OR ABBREVIATIONS)

The following abbreviations have been used throughout the text and bibliography:-

EM	Electro-Magnetic.
EMI	Electro-Magnetic Interference.
GNSS	Global Navigation Satellite System.
GPS	Global Positioning System.
LGO	Leica Geo Office.
RF	Radio Frequency.
RFI	Radio Frequency Interference.
RTK	Real Time Kinematic.
SCADA	Supervisory Control and Data Acquisition.
SWC	State Water Corporation.

CHAPTER 1

INTRODUCTION

1.1 Outline of the study.

EMI (Electro-Magnetic Interference) and more specifically, RFI (Radio Frequency Interference) are well documented phenomenon. RFI (caused when a radio frequency is altered in some way by another radio frequency source) is a well known issue in modern civilisation and despite measures taken to limit the problem will continue to grow as an issue.

RTK GNSS relies on radio spectrum to operate in the form of received satellite signals and frequently via data radios used to communicate corrections from a base to a receiver. As a direct result RTK GNSS is therefore susceptible to RFI.

Previous studies performed by Mr Rafe Samuel Penington (2001) and Mr Stuart O'Leary (2003) have successfully identified degrading of RTK GNSS results and that EMI is a likely cause of incorrect initialisation, slower initialisation and point precision accuracy results.

Anecdotal evidence has also shown that RTK GNSS has been affected whilst in the vicinity of RF emitting SCADA (Supervisory Control And Data Acquisition) equipment, as well as other RF emitters.

These anecdotal experiences coupled with the formal examination of the potential issue, allowed a specific study aimed at quantifying the effect a radio network linked SCADA might have upon RTK equipment and observations. The Survey Section within SWC (State Water Corporation) has a frequent requirement to use RTK systems on sites that operate radio network linked SCADA systems so the relevance of this study to SWC was high.

RTK measurement consists of two GNSS receivers and some method of communicating data between the two. Data communication between RTK receivers is carried out using radio equipment or mobile phone networks.

Radio communications between two GNSS receivers is critical in obtaining an RTK solution. Radio communication is also vulnerable to interference which can reduce communication range and/or corrupt the RF (radio frequency) communication. A common source of RF interference is foreign RF emitters such as other radios.

SCADA refers to a remote site monitoring and control system. It's relevance to RTK GPS surveys is through the use of RF communications links within some SCADA systems. RF reliant SCADA systems can interfere with other RF reliant systems such as RTK GPS. RF SCADA systems are in widespread use with various water authorities across the country and this use is expected to increase in the future as these authorities utilise SCADA to further automate their operations. Within NSW, SWC makes extensive use of SCADA across most of its storages. This use is expected to increase.

It can therefore be seen that RF SCADA systems have the potential to interfere with data radio reliant RTK GNSS. There has also been direct anecdotal experience with data radio problems in the vicinity of such SCADA sites.

Since a component of the study is RF based it follows that some understanding of RF behaviour should be gained. However this study will be orientated towards the practical behaviour of RF interference between SCADA and GNSS RTK radios. This study direction is necessary as I have no training or previous understanding of RF science. A thorough understanding of RF science is beyond the scope of the project. This project therefore intends to be a practical experiment designed to quantify SCADA RFI effect upon RTK observations and find approximate zones of influence around a SCADA site. These results will then be extrapolated into a map containing SWC NSW SCADA sites with potential zones of influence marked upon it.

It is intended that the result will be a useful tool for any RTK GNSS operators planning to do work in proximity to SCADA sites, enabling users to predict areas of potential interference.

1.2 Research Objectives.

1.2.1 Objective 1

Conduct review of literature pertaining to SCADA radio frequencies and RTK radio frequencies. Research any existing studies related to RTK interference from SCADA and other radio frequencies. Acquiring an initial listing of radio frequencies used by SWC SCADA sites. The literature review will also allow the study to develop on existing ideas.

1.2.2 Objective 2

Building upon the results from the review conducted in stage 1, field work will be carried out using two different RTK systems operating on two different radio frequencies. This field work can be conducted at any of the various SWC storages across NSW that utilise a SCADA system
SWC survey section has two RTK systems using different data radios. Both these systems will be involved in a systematically organised field work trial to determine level of interference at different proximities to a SCADA emitter.

1.2.3 Objective 3

The gathered field data will be analysed and arranged into a preliminary results document. In accordance with the systematic approach laid down in the previous stage, results will be organised, tabulated and analysed. The interference behaviour will be extrapolated out to other SCADA sites. The results will enable conclusions to be drawn that will lead to the next objective.

1.2.4 Objective 4

Create a methodology or series of operating restraints designed to minimise interference issues. The results from field trials and experimentation will allow the production of a set of guidelines to minimise the effects of SCADA emitter interference on RTK surveys.

1.2.5 Objective 5 & 6

The creation of a map showing the current and proposed State Water SCADA sites. A GIS map or CAD drawing will be produced with all known SWC SCADA emitter sites displayed across NSW with attendant zones of influence also shown on the map.

1.3 RFI and its Influence on RTK GNSS Survey.

It has become anecdotally apparent that RFI can degrade RTK GNSS results and certainly eliminate radio links altogether. In 2001 and 2003 respectively, Penington and then O'Leary, demonstrated a clear detrimental effect on RTK results as caused by power line generated EMI in the first case and then laboratory generated low frequency EMI in the second instance.

Coupled with the known issues EMI and RFI can potentially have on RTK GNSS was the specific SWC situation in which extensive use of RTK was made at SWC operated sites in which extensive SCADA radio networks also operated. Clearly there was then the knowledge that some effect could be expected but no knowledge as to the magnitude of that effect or the level of proximity to SCADA radio emitters required to begin impacting on RTK results.

This combination of factors that culminated in the uncertainty of RTK GNSS results when utilised on SWC sites was the driving impetus behind this projects aims, goals and expected results.

1.4 Practical Limitations Associated with the RFI and SCADA components of the Study.

This study involves two distinct technologies, being radio communications networks and RTK GNSS. It is immediately obvious that a comprehensive understanding of both technologies is required in order to gain maximum understanding of the behaviour of the RTK system operating in a RFI environment. Unfortunately this study has no input from professionals or experts involved in RF manipulation. As such it must be understood that the project was from the beginning set up as a practical, field based study. Put simply, RTK GNSS was observed, recorded and compared to ascertain probable SCADA RFI influence. Sites were chosen that minimised alternative RFI (to the SCADA network), several sites were used to provide some ability to compare results and achieve consistency, and finally a reference site, judged to minimise all forms of RFI, to which all other sites were compared.

Detailed methodologies concerning RTK test point observations will follow in chapter 3.

1.5 Employer as a Stakeholder.

1.5.1 Employer Outcomes

In conjunction with formulating a topic and direction of study for this thesis, I sought to perform my research within the operating environment of my employer, SWC.
As such a business case was put together detailing the aims, expected results and beneficial outcomes for SWC. The case included expected timeframes and costs associated with the project. Following submission of the case to SWC management, the plan was met with approval and the go ahead was given. It is expected that these results will be a tool that SWC survey teams can utilise during the planning phase of a job, enabling decisions to be made as to the viability of RTK GNSS survey techniques in affected areas. Indeed these results will allow RTK operators to make informed judgements in any area in which high RFI is suspected.

1.5.2 Employer Operational Constraints

The priorities and demands of this project took a secondary place to the operational requirements of SWC Survey Services. As such use of the total station and GNSS sets was scheduled to fit in around the other users of the equipment. This constraint also applied to the use of software processing authentication keys (USB dongles). Finally it was necessary to adhere to the time limits as set out in the business case approved by SWC management. Field work especially was strongly constrained with no scope for returning to sites to perform additional survey. The tight time frames resulted in long days (and nights). A positive side effect of this schedule was a broader GNSS satellite configuration exposure than what would normally be experienced in daylight hours alone.

1.4 Conclusions: Chapter 1.

It was expected that information gathered during the field work stage would concur with the previous work on the issue. As such it was expected to see a detrimental effect on the accuracy and precision of RTK derived coordinates when measured in proximity to SCADA emitters. Unknowns included the magnitude of influence and the proximity to a SCADA emitter at which the first signs of interference would begin.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction.

The previous work of two USQ students, namely Mr Rafe Samuel Penington and Mr Stuart O'Leary provided the foundation work for this project. The dissertations from these two students directly impacts upon this projects focus. Both deal with electromagnetic interference with GPS and RTK GPS. The interference caused by SCADA sites upon RTK radio communications is based upon the radio frequency (part of the electromagnetic spectrum) emissions that SCADA sites create.

The remaining aspect of background research stems from knowledge held by State Water officers, specifically the SCADA systems project manager Stuart Cariss and his staff. Information such as SCADA site location, type of RF emission, strength of RF emission and frequency of emission were all obtained through this source.

2.2 Background Information

2.2.1 Determining the Effects of Transmission Lines on RTK GPS Initialisation, Penington, 2001

The study performed by Penington (2001) attempted to identify, amongst other goals, the effects of EMI produced by transmission lines on a specific RTK GPS system (Trimble 4700). Penington already had evidence that power lines caused EMI capable of degrading RTK GPS initialisation and coordinate accuracy success so his methodology used in this research attempted to isolate the effects of EMI, the conductor cables, and the transmission line towers. Some success was achieved however Penington suggests further research is required to eliminate extraneous causes of interference. Despite the suspicion of extraneous interference, the evidence from the six test sites indicated that EMI is a likely cause of incorrect initialisation, slower initialisation and point precision accuracy results.

2.2.2 Testing GPS Components for Effects of Electromagnetic and Other Interference, O'Leary, 2003

O'Leary (2003) extrapolated from Penington's (2001) work, specifically on the EMI (electro-magnetic interference) to GPS RTK receivers. This work went some way to confirming that EMI was probably an influence on reduced precision and initialisation times. Of further relevance to this project was O'Leary's decision to split his research into two components, these being a replication of an element of power line EM radiation, and a replication of EM radiation used by some mobile phone equipment. The former EM radiation was a magnetic field operating at 50Hz and the latter EM radiation was produced at 800MHz. The testing of the lower frequency EMI successfully identified degrading of RTK GPS results however the higher frequency EMI testing was flawed, resulting in unreliable results.

In addition to the unreliable results, possible faults within the GPS hardware were identified further reducing the validity of the testing results.

The net effect on the current project is to indicate that at least low frequency EMI compromises accuracy and initialisation.

2.3 Conclusions: Chapter 2

Literature directly concerning the subject of RTK interference caused by EMI was difficult to find. The most readily available option was found within the USQ library. Even this source required some effort in order to obtain copies of the work in its entirety. However once this source of information had been obtained it became apparent that they provided an excellent background of work that lead directly into the projects desired goals.

The previous research showed that RFI such as caused by SCADA radio networks had a high likelihood of detrimentally affecting RTK GNSS results. This provided the formal background study to support existing anecdotal evidence upon which the basis of the study was founded.

CHAPTER 3

METHODOLOGY

3.1 Introduction.

Proceeding on the basis of this project being practically orientated in its nature, planning the methodology began with finding several different SCADA sites operated by SWC. From this listing I chose sites based on the following criteria:

- Have a SCADA radio frequency as close to possible to that used by the RTK system data radios.
- Be as close to possible to Sydney.
- Be suitable for observing a network of stations that have LOS between each other but are long distances apart.
- Have a currently operating SCADA system.

Once several sites meeting these criteria had been decided upon, field work scheduling and planning began. Initially a flexible plan was required as none of the chosen sites had been visited before.

Once a suitable opportunity had arisen field work would commence and proceed as much as possible along the lines of the flexible plan. Consistency across the three sites was a major goal so that comparisons made between them were valid.

Another important consideration when operating within the working environment were the OH&S (Occupational Health and Safety) considerations. Whilst in the field the established OH&S procedures for survey field work within SWC were adhered to.

Upon completion of the field work it was intended that a combination of software would be used to firstly process each of the sites, and then secondly to analyse the body of data and thus to make comparisons between the reference site and the individual SCADA affected sites.

3.2 Method – Field Work Planning.

3.2.1 SCADA site selection

Initially, Stuart Cariss, the SCADA Systems Project Manager for SWC provided a complete listing of radio frequency licences owned by SWC. The listing came with approximate locations for each SCADA site. Unfortunately Mr Cariss was unable to guarantee weather or not a SCADA radio existed at each of these sites as an unknown number were proposed locations rather than actual antennas. At the time of the research project being conducted SWC was involved in a major audit of its SCADA network and confirmed data would not be available until around the projects prescribed completion date.

At the time Mr Cariss provided me with what information he could and so 'best estimates' were made as to the sites most likely to be operating active SCADA equipment.

The list of possible SCADA sites was narrowed down based on the radio frequency assigned to each site and it's proximity to the RTK systems own radio frequency, these being 152.375 MHz for the system 500 and 469.95 MHz for the system 1200. It was felt that RFI might be at its greatest level when the two opposing frequencies were similar. This was desirable as the project aimed to quantify the worst case affect on RTK GNSS.

Once a list of sites was narrowed down the exact locations were found either via topographic maps as in the case of the Mt Lambie site, or simply by contacting the SWC staff on site for confirmation such as in the case of Burrendong Dam and Windamere Dam. The initial listing of sites is as follows:

- Mt Lambie SWC SCADA site – 158.875 MHz.
- Burrendong Dam SWC SCADA site – 164.396 MHz, 148.6875 MHz, 172.185 MHz, 451.525 MHz, 452.275 MHz, 452.375 MHz, 455.375 MHz, 461.025 MHz, 464.875 MHz.
- Windamere Dam SWC SCADA site – 466.625 MHz.

3.2.2 Reference site selection

The reference site selected had some similar criteria to those that governed the SCADA sites:

- Be as close to possible to Sydney.
- Be suitable for observing a network of stations that have LOS between each other but are long distances apart.
- Have a minimum of RFI of any kind

An ideal location might only be found in extremely remote locations such as central Australia but an area such as this was clearly impractical within the scope of this study. Subsequently a location was required that was close to Sydney or one of the other sites that I would visit. Tools for determining such a site were limited. There was no access to RF meters that might allow me to determine the absence of RFI nor was professional advice at hand to consult over such matters. Without such equipment or professional advice it was determined to find a location that was as geographically isolated from human settlements as possible. The only such site that local knowledge suggested was within the Newnes State Forest, adjacent to the Wollemi Wilderness area. This site was accessible, had deep valleys and clear felled areas due to logging, and from previous experience, was known to have no mobile phone reception, an indicator of a reduced level of RFI.

3.2.3 Resource Analysis

Equipment utilised on the project was entirely sourced from within SWC survey section. This included two RTK systems, a total station and various software applications used for processing. Access to these resources was constrained by the needs of the survey section which had priority over the projects operational needs. Since the proposed sites were some distance from Sydney with unknown quality of access, a four wheel drive survey vehicle with all its attendant paraphernalia was also used.

3.2.4 Itemised equipment list:

- Leica 1200 RTK base receiver and UHF radio.
- Leica 1200 RTK rover 1 receiver and UHF radio.
- Leica 1200 RTK rover 2 receiver and UHF radio.
- Leica 500 RTK base receiver and VHF radio.
- Leica 500 RTK rover receiver and VHF radio.
- Trimble S6 Total Station.
- Traversing kit (prisms, tribrachs, stalks).
- Various survey equipment (legs, marks, etc).
- Nissan Navara Four Wheel Drive Utility.

3.2.5 RTK Data Radio technical information:

During this trial two different types of data radios were used. The older 500 series equipment uses a 50W radio operating on the 152.375 MHz frequency. The later model 1200 series utilises a 35W radio operating on the 469.95 MHz frequency. In practice these radios allow an RTK operating range up to approximately 10km although ranges of up to16km have been achieved with the 500 series radios and in difficult geographic conditions the range decreases from the usual maximums. Throughout this project the distance between base stations and rover receivers never exceeded 4.2km.

3.2.6 Initial Planning

The initial flexible plan had to cater for some unknowns, specifically

- Site Geography;
- Site Access;
- Equipment availability.

Subsequently it was accepted that upon arrival at any particular site it would prove to be unsuitable for the proposed field work. It was expected that should one site prove unsuitable a subsequent location would meet the necessary criteria. With these unknowns in mind the initial plan was as follows:

- A surround network would be established with major control points adjacent to each SCADA emitter and remote control points placed at a maximum practical distance from any SCADA emitter.
- From each adjacent control point a line of test points would be placed extending away from the SCADA emitter at regular intervals.
- Marks with MGA coordinates would be included where possible in the network.
- The first stage of the measurement process would involve traditional traversing techniques and Static GNSS measurement of the control network.
- It is expected that the RFI environment would have no influence over the total station measurements.
- It is expected although not certain the RFI environment would have a zero to minimum effect on static GNSS observations.
- When using the total station, 6 arcs would be read in both faces from each control point.
- When using performing static observations a minimum of 20 minutes would be observed at each control point.
- The second stage would coordinate the test marks via total station radiations. Each test mark would be radiated in both faces using 3 rounds of arc.

- The third stage would use the remote control points as RTK base’s whilst the RTK measurement of the adjacent control points and the test points occurred.
- During the third stage, the two different RTK receiver systems would be used simultaneously to maximise efficiency.
- This phase of the testing is designed to quantify the effect of RFI on the rover receivers only.
- The forth stage relocated one of the RTK base receivers to a control point adjacent to a SCADA emitter. Then RTK measurements would be taken at a remote control station and where possible one of the other adjacent control stations.
- This forth stage testing procedure is designed to observe potential effects on the base receiver individually. In addition it was hoped that opportunities would arise to test the impact of RFI when both the rover and base receivers would be influenced by a SCADA emitter.
- It was found that the AUTO function available to both Leica RTK systems was the most useful for gathering measured data. A regime of measuring every 5 seconds with a minimum number of 500 points per setup was adopted. This gathered a statistically representative amount of data whilst fitting in with the over all time constraints acting on the field work stage of the project.

The body of data collected at each test point will enable comparisons between the observed RTK coordinates and the control coordinate applied to the mark in question.
This comparison will allow an analysis of accuracy and precision of the group of observations.
Accuracy in this case will be defined as the mean coordinate for each group of observations, compared to the control coordinate.
Precision of the group of observations will be defined by the size of the point cloud created by the total number of RTK observations. Precision will be quantified by the percentage of observations within 10mm increments of the control value

3.2.7 Project Specific Survey Mark Identification

It is appropriate to make note on the method of identifying the multitude of survey points used at the various sites on this project so as to clarify what is being discussed in subsequent sections of this Dissertation,
When discussing each site there are four types of marks:

- Remote control stations. These are part of the survey control network and are placed a maximum practical distance from the source/s of RFI with the goal of minimising the influence of RFI on a GNSS receiver located there, hence they are remote from the test area.
- Adjacent control stations. These are also part of the survey control network but are placed immediately adjacent to the test site and source of RFI influence being studied. The primary function of these control points is to allow the RFI emitter test points to be radiated using the S6 total station. The secondary function is to act as an additional test point.
- Test points. These do not form part of the network. They are coordinated by radiations from the adjacent control stations. Radiations to these points should demonstrate a high level of repeatability as backsights will be proportionally very long (1 to 3 km), to the radiations maximum length of approximately 120m.
- Coordinated marks. These are simply survey marks included in the network primarily for the purpose of introducing MGA coordinates and AHD heights to the project. They are generally not used beyond that point.

Point identification is done through two methods. Control points start at 9001 for the project and increment to the next available multiple of ten for each testing area. Test points started at 100 and incremented to the next even hundred for each test site.
Some alternative numbers were used for the coordinated marks, for example, the single SSM used during the project was given the same number as the SSM number; 27107. Similarly the crest pillars at Burrendong Dam were identified as P11 and P12.
At each test point surveyed during the RTK phase of the survey, over 500 points were measured by each receiver set up there.

To individually identify each measurement, a point numbering mask was created that incremented by 1 for each measurement but also used alpha-numeric characters to identify which instrument had recorded the measurement. The result looked like this:

- Leica 500 series rover receiver:
    - ROV00001 – ROV01525 etc
- Leica 1200 ‘back pack’ rover receiver:
    - 12BP000001 – 12BP019599 etc
- Leica 1200 ‘smart’ rover receiver:
    - 12SR0001 – 12SR5504 etc

In this style of point numbering the initial alpha-numeric section stayed constant whilst the last 4, 5 or 6 numeric characters automatically incremented. The point numbering mask might look like:

- 12BP######

In this example the hash symbols are incrementing numbers.
The older 500 series instrument does not allow for on-the-fly editing of the point numbers when using the auto-store function. Point number modifications had to be done via altering the mask. The 1200 receiver did allow on the fly point number modification.
Generally the point numbers would be incremented at each test point, or in the case of the 500 series rover at each SCADA site. In addition these numbers would be incremented by a large amount when moving to a different site so as to make separate locations easily identifiable.

3.3 Detailed Survey by Site

The project field work was completed within two separate field trips. The first trip became one of site reconnaissance, site choice and then control and test point establishment. During this first trip I had the use of the Trimble S6 total station for traversing and the Leica system 500 for GPS work. Unfortunately some time was lost due to a firmware failure concerning the system 500. The firmware failure affected this particular piece of Leica equipment globally, and was not isolated until a full days worth of in-field testing and fault finding had been used. Fortunately this wasn't a significant issue in the scheme of the project as all the remaining time was used completing the reconnaissance, site selection and traversing component of the proposed field work.

The second field trip provided the opportunity to use all the available GPS/GNSS equipment in a single outing. In this trip all control networks were surveyed using static methods and all five receivers simultaneously. Following the static observations, the RTK survey was completed as per the original planned methodology. The exception was due to operating two 1200 rovers as opposed to a single 500 rover. Time constraints occasionally forced some points to be measured with a 1200 receiver only. Obviously with two 1200 receiver rovers, twice the number of points was able to be measured in the same time frame as the single 500 receiver was capable of.

For the purposes of conciseness each site will be described individually without reference to the breaks in field survey.

3.3.1 Mt Lambie SCADA/RFI site

The first site visited was Mt Lambie purely due to it being the first location arrived at upon leaving Sydney. Once access to the site was gained it was found to be a major telecommunications relay hub, with SWC SCADA relay tower being just one of five towers mounting an array of antennas including microwave, mobile phone and traditional UHF/radio antennas. This site was geographically suitable with surrounding hilltops being accessible and providing a clear line of site between control stations as well as a geometrically acceptable network shape. Importantly, the Mt Lambie site and the proposed control stations had a good sky views which ensured maximum continuous satellite observations.

With the knowledge that Mt Lambie would present a multitude of RFI sources to any RTK survey rather than the single influence of a SWC owned and operated SCADA site, it was decided to persevere as a useful indication of RTK performance in the worst type of RFI operational environment. This decision was taken with the knowledge that ample and ideal SCADA testing environments were to be found at the Burrendong Dam site.

The SWC owned SCADA equipment located on Mt Lambie operates at a frequency of 158.875 MHz. No further information was available for this transmitter.

The Mt Lambie Control network consisted of four control stations. Two stations (9003 and 9005) were remote from the site being approximately 3.1km and 3.2km away from the SCADA antenna. 9006 was adjacent to the SCADA antenna, whilst 9007 was the Mt Lambie Trig station (TS 2788), a short distance from the SCADA antenna. Other Control points were placed during reconnaissance but found to be redundant or unsuitable. Once the network was in place six test points were placed extending away from the SCADA antenna at 20m intervals. It was expected to see a diminishing affect on the RTK system by the SCADA antenna and other unknown antenna's located on Mt Lambie.

The network was initially measured with the S6 total station, which was then used to radiate the test points. Six and three arcs were used respectively and as per the initial field work plan.

Stage one was completed using the five available GPS and GNSS receivers to measure all of the control stations and the coordinated mark, SSM 27107.

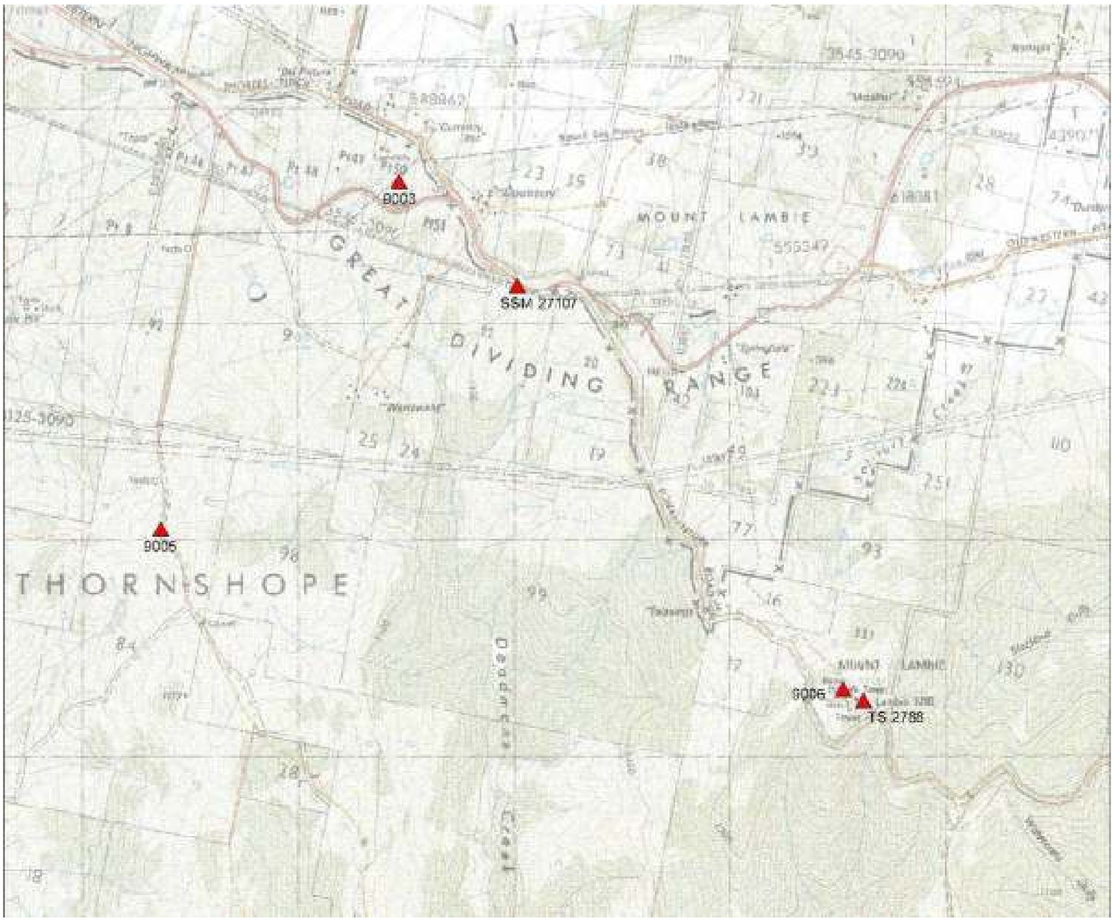

Figure 3.1 – Mt Lambie control network over topographic image

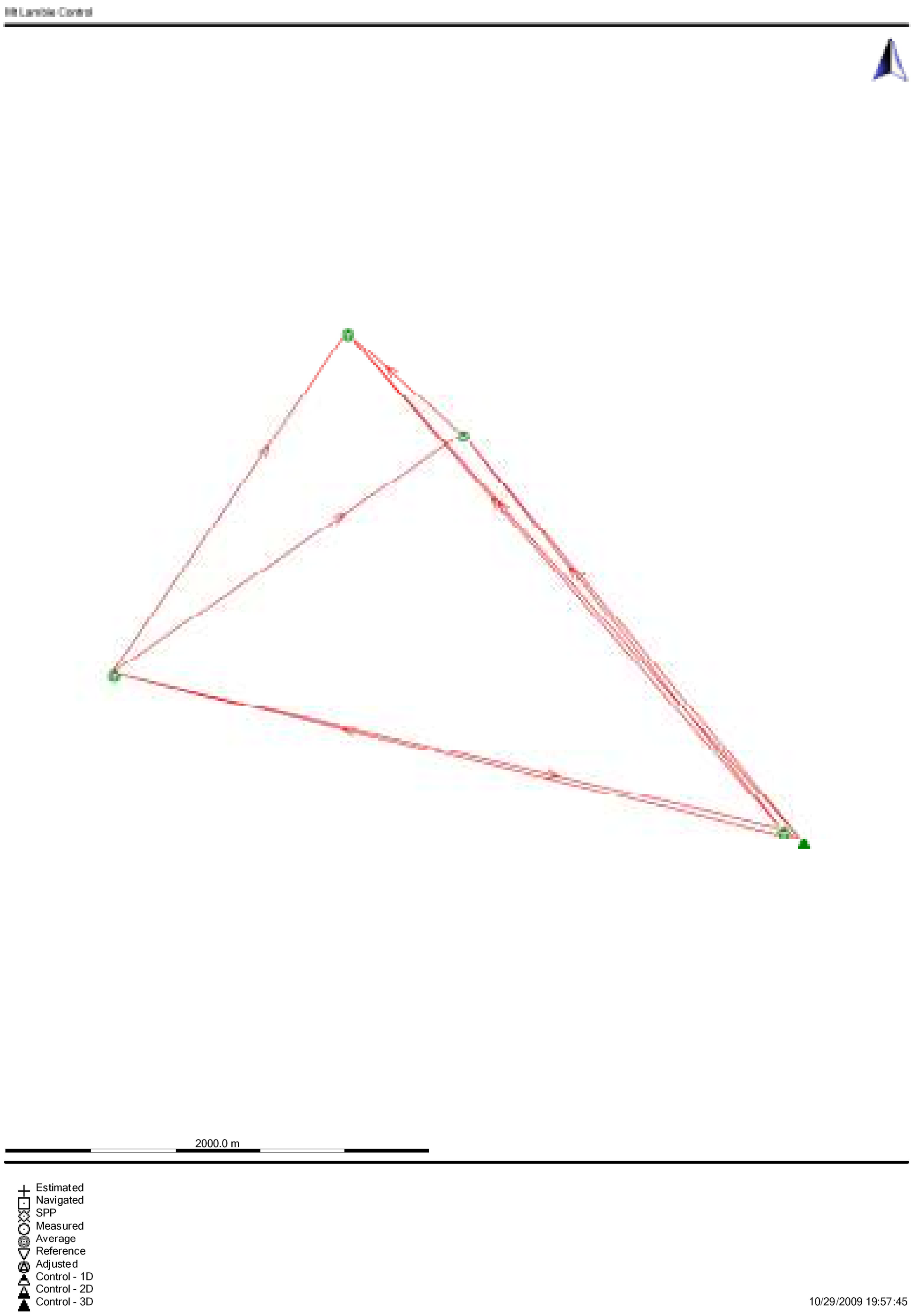

Figure 3.2 – Mt Lambie GNSS static observations

The third stage was duly embarked upon with the 1200 base being established on 9003 and the 500 base on 9005. Both of these sites were judged remote enough to be outside the appreciable zone of influence of the various radio antennas on Mt Lambie. Both adjacent control points were surveyed with a 1200 whilst only the immediately adjacent control point (9006) was surveyed with the 500 receiver. All the test points were surveyed with a 1200 receiver and a 500 receiver.

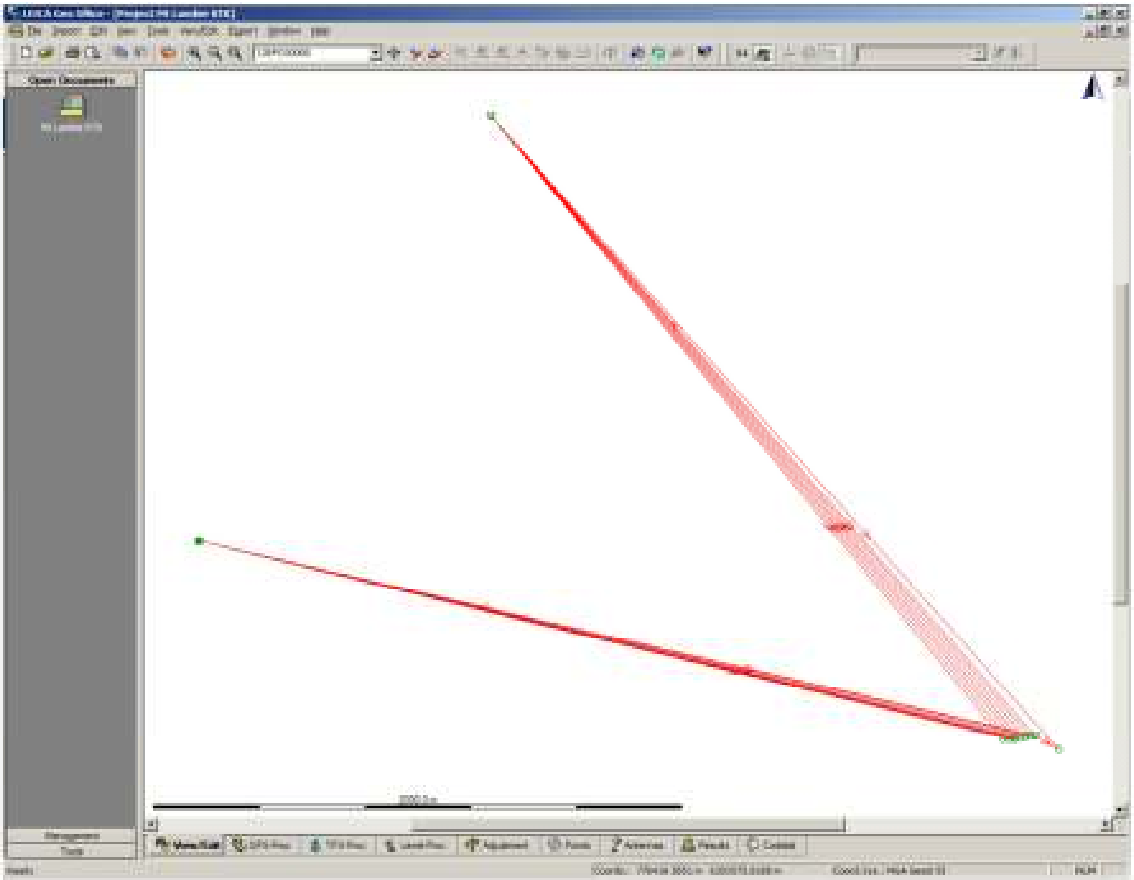

Figure 3.3 – Mt Lambie RTK observations

The forth and final stage was limited to relocating the 1200 base to the adjacent control point (9006). From here RTK measurements were made to the Trig pillar (9007), and the remote control points; 9003 and 9005. This final series of measurements demonstrated the effect of RFI impacting on just the base and both the base and rover simultaneously.

3.3.2 Burrendong Dam SCADA sites

Initial investigation of SCADA potential at Burrendong dam seemed to indicate that several licences for radio frequencies were being held for use in this area. The SWC staff at Burrendong was able to show me 5 radio antennas spread across the site. Unfortunately detailed information as to how the network was set up and what frequencies were being used was not initially available. However, later by chance, a series of schematics was discovered in one of the radio antenna huts. In conjunction with radio frequencies written on some of the radio hardware at some of the sites, a reasonable understanding of what was being transmitted at each antenna was able to be derived.

After a period of reconnaissance it was determined that Burrendong dam would provide several testing opportunities over several radio frequencies and at different power levels. In addition, the Burrendong Dam site was some distance from other sources of RFI. No mobile phone reception was available on site and the geography was reasonably hilly promoting good isolation from spurious and distant sources of RFI.

Finally it is immediately obvious that efficiency gains are possible if a single control network can be utilised for surveying multiple test sites. Aside from the reduction in control points and associated measurement time, the cut down in travel between sites was a major consideration.

As such it was deemed that there was no longer a requirement to visit the SCADA network at Windamere Dam.

Three SCADA test sites were chosen at Burrendong, all reasonably accessible between one another and all having open space surrounding them with room to install test points that would also have clear sky views.

Test site A was on the southern hill top in relation to the dam and is the Burrendong SCADA repeater site. It is used to receive and re-transmit data further along the network. Adjacent control point 9012 was placed here for setting out the test points; 200 to 205. This SCADA site transmits at two frequencies:

- 461.025 MHz and
- 452.275 MHz.

No further information was available on this SCADA system.

Test site B was on a hilltop to the north of the dam wall. This is the location for adjacent control point 9014 and the test points 300 to 305. This SCADA site was locked and unable to be opened. No further information is available on this SCADA site.

Test site C at Burrendong Dam was located on the intake tower for the dam. This tower is approximately 100m out from the northern end of the dam and connected to it via a steel and concrete bridge. The adjacent control point placed on the tower was 9013 and the test points 400 to 406 were placed at regular 10m intervals along the bridge. Information on this SCADA site is unreliable but best indications are:

- 452.375 MHz at 5W power output.

Two remote control stations were chosen in the next valley over from the dam site so as affording some separation from the SCADA signals emanating from the dam network. These stations (9010 and 9011) were also distant being 2.6km and 2.5km away from 9012, the nearest adjacent control point and SCADA antenna.

The three adjacent control points were 9012, 9013 and 9014. In addition, part of the dam's surveillance network was occupied so as to obtain MGA coordinates for the project. These were the crest pillars P11 and P12, and the axial pillar at 9015 (also known as CL Left).

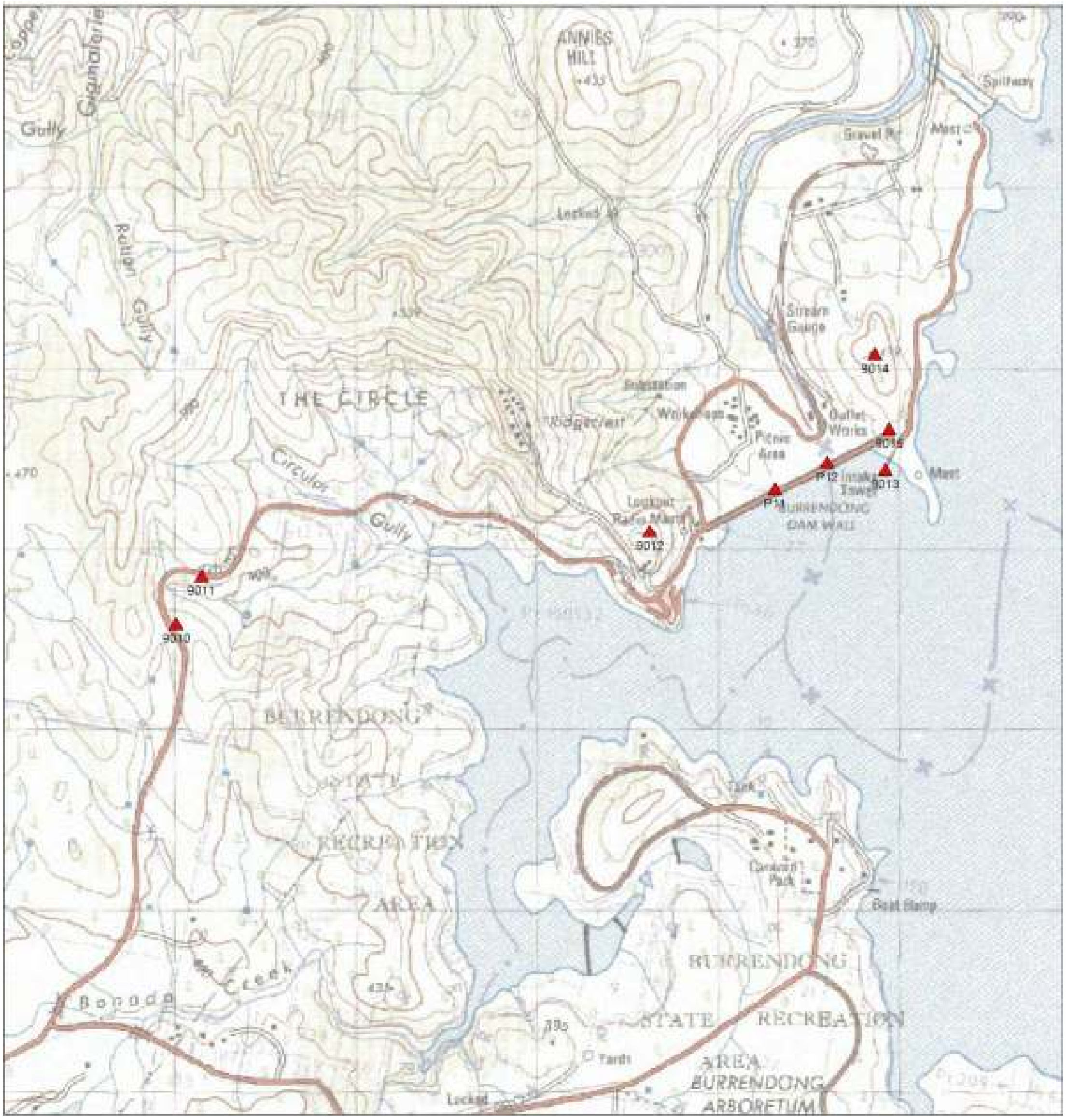

Figure 3.4 – Burrendong Dam network over topographic image

Adjacent to each of the three SCADA emitters was placed 6 or more test points at regular 10m intervals spaced in a line extending away from the Antenna.

As per the initial field work plan the network was first surveyed with the S6 total station using six rounds of arc to all visible stations from each control point. This was followed by radiations from each test point using three rounds of arc.

All five GPS/GNSS receivers were then employed to measure a series of lines between the various control stations. Each control station had several lines of measurement connecting it to maximise the level of redundancies available when the time for post processing adjustment arrived.

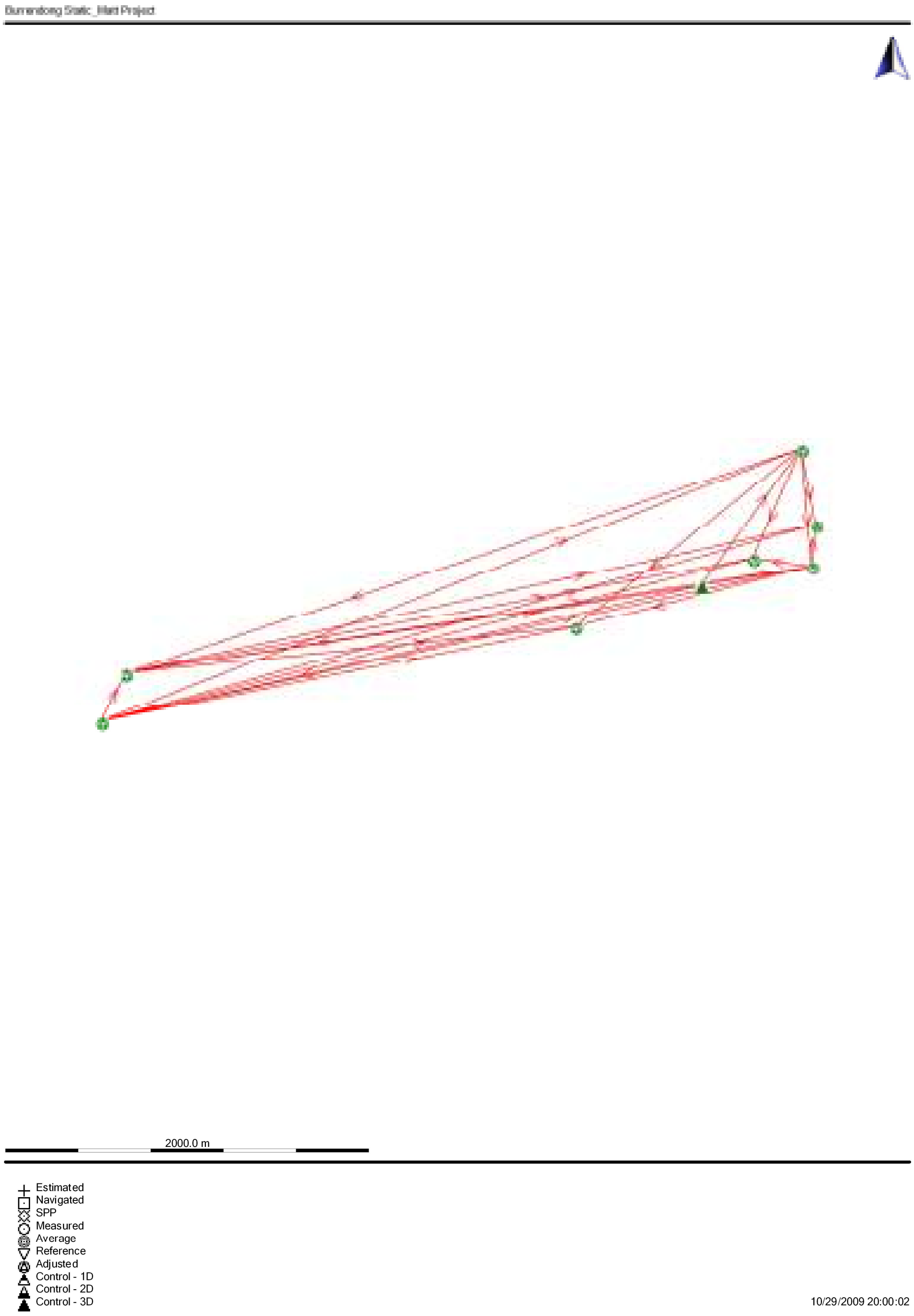

Figure 3.5 – Burrendong Dam GNSS static observations

The third stage and lengthiest step was the series of RTK measurements to adjacent control points and test points. All adjacent control points and all of the test points at Burrendong were measured using the 1200 GNSS receivers. All of the adjacent control points were also measured with the 500 GPS receiver whilst a selection of the test points were surveyed using the 500 receiver, usually every alternate test point.

In addition to the test points and control points being RTK surveyed, it was noted that the crest pillar P11 was situated quite close to the line of sight between the inlet tower SCADA antenna at 9013, and the relay antenna at 9012. Since it was clear that the 1200 RTK survey would be completed ahead of the 500 survey, the opportunity was taken to observe points at P11. This pillar was situated approximately half way between the SCADA emitter and its intended receiver and so might add to the body of data being collected.

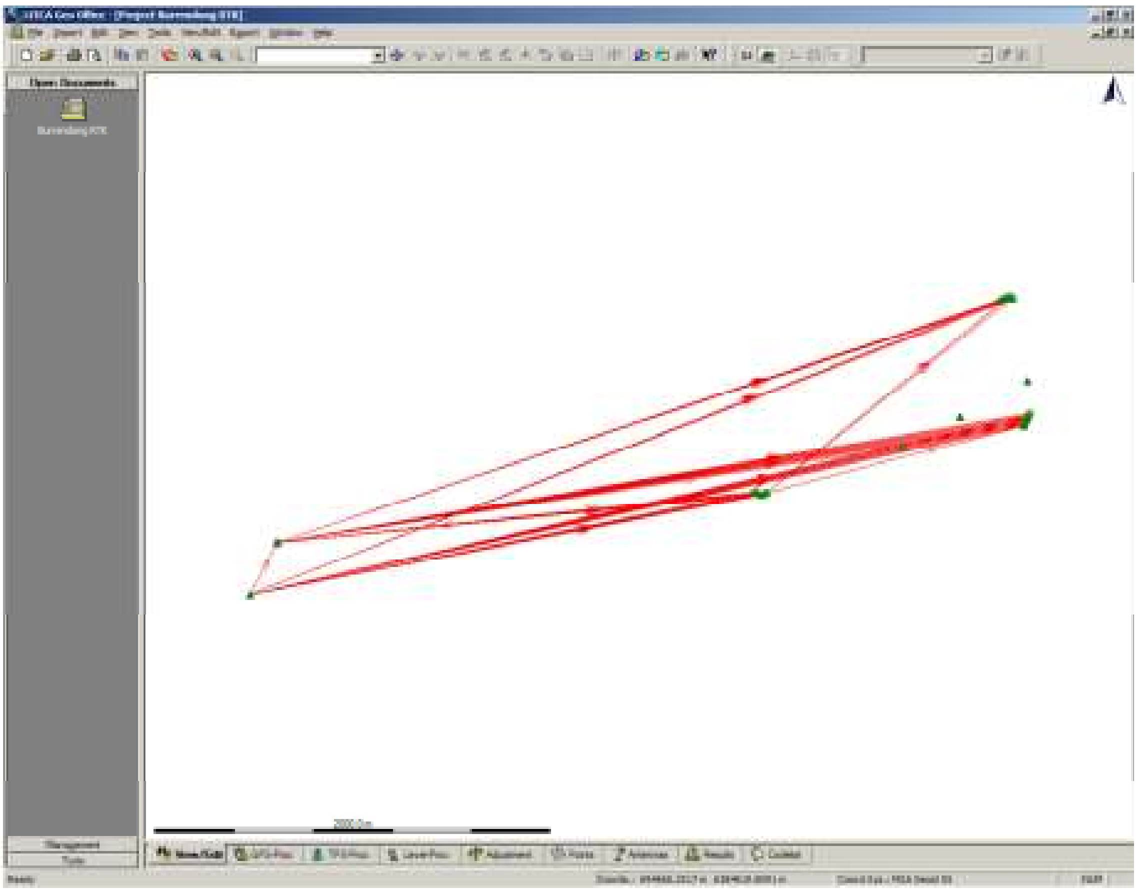

Figure 3.6 – Burrendong Dam RTK observations

In a final stage, the 1200 base receiver was set up on the adjacent control point, 9012. From here, RTK measurements were taken to the remote control point at 9011 and the adjacent control points, 9013 and 9014.

3.3.3 Newnes Reference Site

The reference site used within Newnes State Forest proved to satisfy the requirements of a reference site as well as was practically possible within the various constraints of this project. A large, recently clear felled area of plantation pine forest was found in which four corners of a braced quad network were set up with all stations visible from each other. The braced quad was adopted to give the traversed network the strongest possible geometrically arranged configuration. It was expected that this would maximise the control point coordination accuracy for the best possible comparison to the RTK observations.

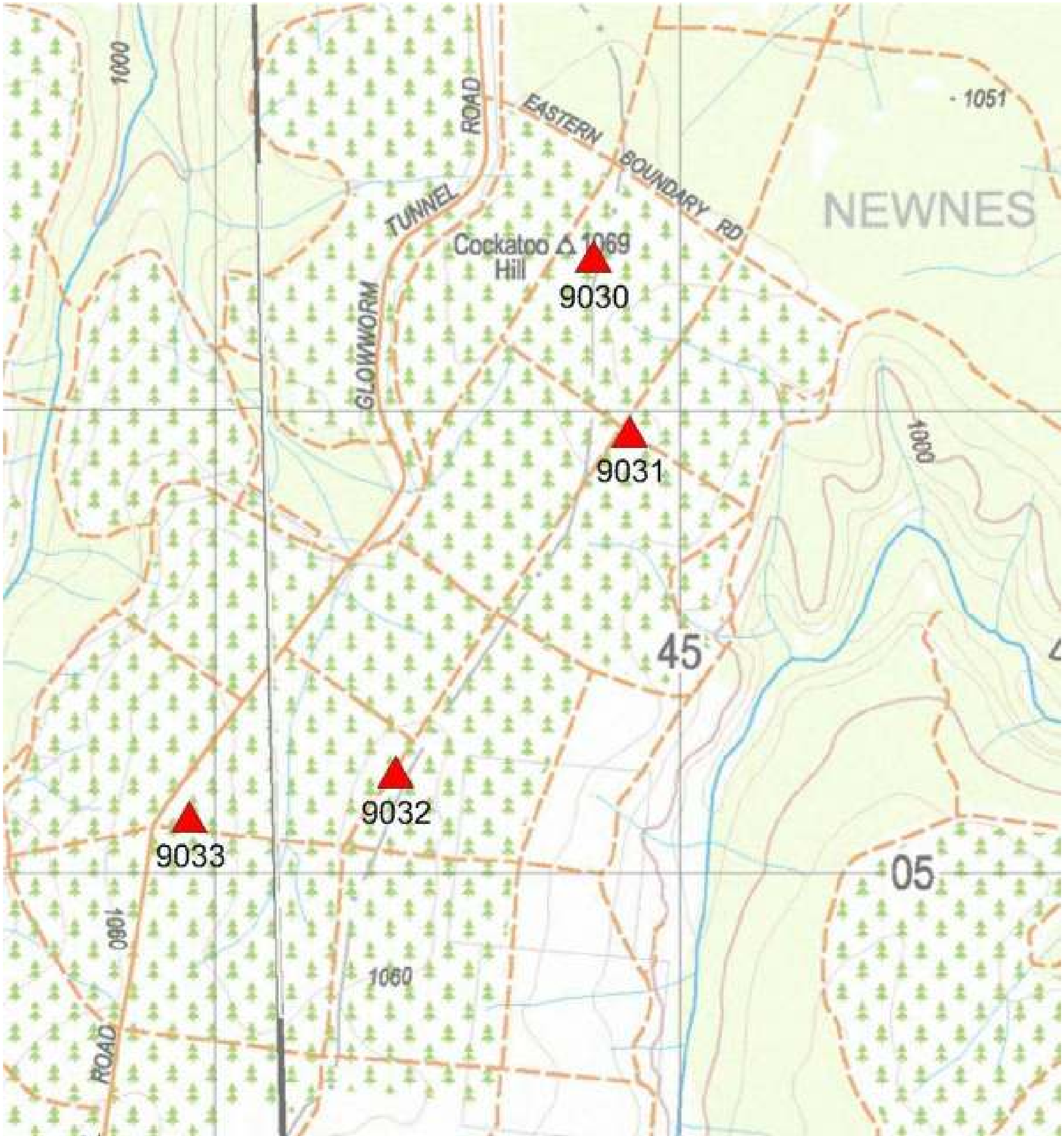

Figure 3.7 – Newnes network over topographic image

One minor issue with this site was the lack of coordinated marks available to link to the control network. As an alternative, one station (9031) was set to record five minutes of data to maximise that accuracy of its assumed starting coordinates.
Ultimately the lack of established coordinates is of minor concern. The coordinates are principally for deriving the scale factor for application to the traverse lines. The close approximate position derived for these coordinates will be more than adequate for determining scale factor.
The Newnes reference site consisted of the four control station marks with no test points. This network was measured in a similar manner as the two RFI/SCADA test locations. The network was initially traversed with the S6 total station, then all four marks were simultaneously measured using static observations (three 1200 receivers and a single 500 receiver). Finally, two control points were measured with the 500 RTK receiver and another two were measured with a 1200 RTK receiver.

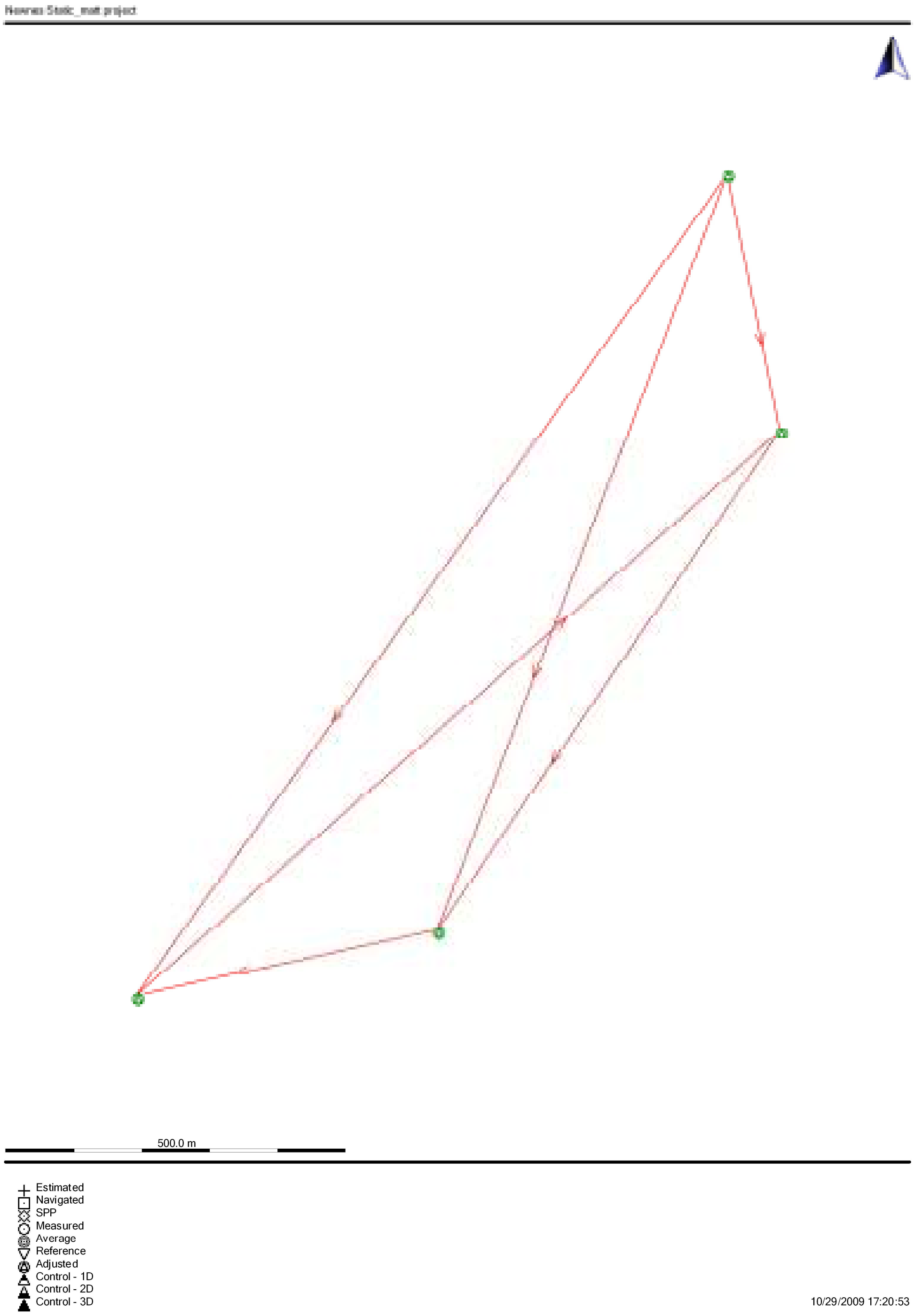

Figure 3.8 – Newnes GNSS static observations

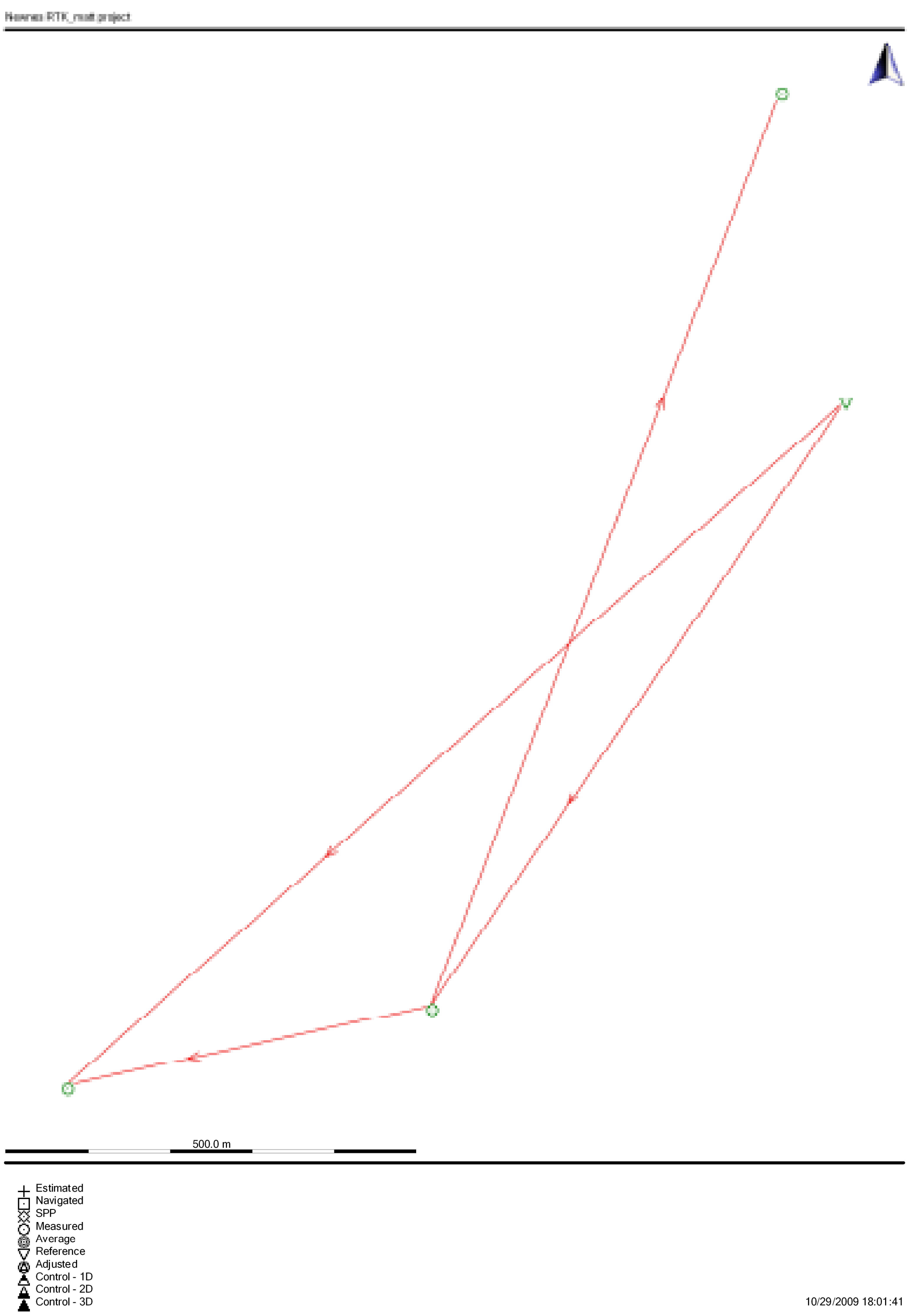

Figure 3.9 – Newnes RTK observations

3.4 Methodology Conclusions

The methodology planning discussed during this chapter ultimately set out to identify and utilise a number of SCADA radio networks and then record RTK data at known, coordinated points adjacent to the SCADA emitters. The points would radiate away from the emitter thereby determining how proximity to the emitter might affect the accuracy and precision of RTK coordinates gathered in this environment.

Various steps were taken to attempt to isolate which components of the RTK system were affected by RFI. Initially attempts were made to find test sites with limited spurious or unknown RFI, however although this is most likely the case at the Burrendong Dam location, the Mt Lambie test site represents what is most likely a very high incidence of RFI. This high incidence test site was adopted as a useful comparison site to be used against the SCADA only site.

These various test sites behaviour would finally be compared to a test site that would have a minimum of RFI apparent, as was practically possible.

Ultimately four SCADA test sites were established at two different locations and a third site was used for referencing.

A minimum of 500 RTK points were recorded at 57 test points resulting in at least 30,000 observations that were affected by SCADA RFI and in certain cases, by a variety of RFI.

This body of collected data provided an excellent basis upon which to begin statistical analysis, and begin to quantify just how much of an impact SCADA RFI or a high RFI incidence generally, might have upon an RTK survey.

CHAPTER 4

RESULTS

4.1 Introduction

This chapter will set out the results garnered from the series of observations at each of the test sites mentioned in the previous chapter, and how they were derived.

Once field work had been completed the first processing activity was the Trimble S6 total station observations. The expectation was to export the Trimble JOB file which is the Trimble raw data format and begin processing in the Compnet adjustment package. JOB file processing is supported by Compnet but for reasons unknown the JOB files were unable to be imported successfully. The Compnet package used by SWC survey section includes support for Geodimeter JOB files however these may not be the same as the later Trimble branded JOB files. Since the traverse survey had been completed using a scale factor of 1, it was important that the distances measured be adjusted to MGA grid distances as supported by Compnet. The inability to use Compnet invalidates the long distance measurements performed in the field as a method for deriving accurate network coordinates. As a result the total station data was used exclusively for deriving the short range test point coordinates only.

With the rise of the unreliable traverse information the static GNSS observations became the critical method for deriving adjusted network coordinates. In the first instance the GNSS data was entered into LGO (Leica Geo Office) for processing. Two jobs (known as projects within LGO) were created for each of the three locations visited (Mt Lambie, Burrendong Dam and Newnes State Forest), the first job being the static observations on the control network, the second being the RTK observations. After processing the results were exported as CSV (comma delimited) files for further analysis within Microsoft Excel. All points were exported with a maximum amount of ancillary information to aid analysis.

A final result file was created for each group of measurements made to a particular point by an individual receiver. This file would contain a minimum of 500 coordinated points and often many more. Functions were used to compare the easting, northing and height of the RTK coordinate with the control value. This newly created value being known as "Misclose from CTRL".

These values formed the principal variable used in the subsequent analysis of the RTK survey as affected by SCADA and other RFI. This analysis was the method by which potential accuracy and precision of RTK measurements could be quantified and was used to develop the final guidelines on what to expect and how to control, SCADA influence on RTK surveys.

4.2 Initial Processing Procedures

4.2.1 Traverse data

As mentioned in the introduction, the raw JOB file was unable to be imported into Compnet, the principle adjustment package available to SWC survey section. Instead, simple CSV coordinate files were exported from the S6 total station.

It had originally been expected to be able to compare the traverse network with the static GNSS network results to determine the effect or lack of, upon the static observations.

This was no longer an option and the static results became the only source of control coordinates for the project.

The S6 total station had also been used to radiate the control points and this was the only method in which these coordinates had been independently measured from the RTK survey.

In order to adjust the assumed coordinates adopted during the survey, the coordinate CSV file for each area was imported into the survey calculations package Foresight. Next the adjusted coordinate network derived by the static GNSS observations was also imported into Foresight. Finally a similarity transformation was used to rectify the assumed traverse network with the adjusted static observations.

This method has in effect, rectified the unadjusted coordinates onto MGA grid coordinates or in other words it has achieved the application of a scale factor which was initially planned to be applied through Compnet processing.

Obviously this removes any independence from the traverse network in relation to the static network, however as will be explained in later sections, the static network achieved excellent statistical results with loop closures showing very low PPM (typically less than 1) and misclose ratios in the vicinity of 1:1,000,000.

The loss of independence was immaterial next to the need to obtain a form of correction applied to the radiated test points. The similarity transformation achieved this. Any errors picked up through the transformation process will be significantly minimised when applied to the relatively short radiation lines compared to the long control station lines as used for the similar point transformation.

After completion of the similarity transformation, the adjusted test points were exported as CSV files and the newly adjusted coordinates were compared to the static derived coordinates as a check against the transformation parameters used by Foresight.

Typically the mean of the misclose between transformed and control points was less than 5mm with the exception being Mt Lambie where the mean of the easting misclose was 16mm which was introduced by a larger than average misclose in the easting at one of the most distant stations from the test points. As such its net effect upon the short test point radiations was minimal and could be ignored.

Finally the transformed test point coordinates were classified as control coordinates and were now suitable for direct comparison with the RTK observations.

4.2.2 Static GNSS data

Static GNSS observations were gathered with both the Leica 500 GPS series receivers and the three Leica 1200 GNSS receivers. Having a total of five receivers yielded efficiency benefits resulting in short time frames to survey large networks. Indeed at the Mt Lambie and Newnes study areas, the entire control network could be occupied simultaneously.

Since the newer model 1200 receivers observe both GPS satellites and the Russian GLONASS satellites, as opposed to the older model 500 series observing only GPS satellites, some control points did not have as many observed satellites as others (less redundancies available for a positional solution), however this presented no practical issue as this difference is automatically rectified by the LGO processing software.

All control stations were observed to for a minimum of one hour, the exception was the coordinated marks at Burrendong Dam which were truncated to a minimum due to time constraints.

All baselines resolved their ambiguities successfully, which was expected when using long observation times and having excellent sky view windows available at all control stations. Position and height quality of processed baselines was generally better than 1mm as estimated by LGO.

Once baseline processing was complete the coordinated marks had their coordinates modified to match their listed MGA values.

From here adjustment began. In all cases LGO used a minimally constrained least squares adjustment meaning that the network was adjusted around a single fixed point. At Burrendong and Mt Lambie, the adjusted control points could then be compared against a second coordinated point as a check.

The LGO default values were retained for each of the least squares processing operations.

Inspection of each report revealed some potential outliers as indicated by failures of the T-test and W-test, however the estimated errors for these failed points was always less than 5mm and so manipulation of the least squares parameters was deemed unnecessary.

After successful adjustment, the loop misclosure function was used to obtain an understanding of how the various baselines agreed with one another. This function automatically creates traverses between various points using the adjusted baselines. It reports on the absolute misclose and then converts this into a ppm based on total traverse length, and a misclose ratio for compliance testing against survey regulations.

Loop misclosures were generally better than 1ppm and misclose ratios better than 1:1,000,000. The worst loop misclose was at Burrendong dam and was 2.1 ppm with a misclose ratio of 1:466,556. These results are still far in excess of first order traversing minimums which is the norm when successfully using static GNSS over longer base lines.

In each case, once successful baselines had been processed and adjusted, the final coordinates were exported as a CSV file. Along with the basic adjusted coordinates a full quota of accuracy reporting information was exported. This includes:

- Error ellipse information.
- Reliability estimates
- Code and attribute information where applicable
- Time code information
- Standard deviation (E,N,H)
- Scale factor information

Some of this information was redundant however some of it was useful for cross checking against points that appeared as outliers in terms of absolute precision and/or accuracy, when compared against the control point.

4.2.3 RTK Observations

For RTK processing a new job within LGO was created for each study area (Mt Lambie, Burrendong Dam, and Newnes State Forest). Into each of these projects was imported the rover receiver RTK raw data.

Initially the data is checked for errors of which there were several, these being incorrect antenna heights, incorrect antenna types and some coding errors (the latter were more effectively corrected at the later Excel processing stage).

After the errors had been corrected, the control points were edited to assign them their corrected control coordinates as derived from the static survey.

A visual inspection of each point cluster was performed and outliers were identified and deleted when they proved to be caused by issues other than RFI related (One of the base stations was blown over at Mt Lambie and several times base station batteries failed at both Mt Lambie and Burrendong).

At this point the RTK points were then exported as CSV files with the same formatting and ancillary information as the static data.

4.3 Excel CSV Processing Procedures

For comparison between each test point, the large area specific CSV file was split into blocks of data pertaining to each instruments measured points at each individual setup. For instance one of these new blocks of data would refer to the 500 points gathered by a single 1200 receiver at a single test point.

For formatting purposes each of these CSV files was saved as an XLS file, Excels proprietary base format file type.

The method used to examine these new coordinate files was to compare each easting, northing and height to the control values for the point in question. This would demonstrate a positive or negative distance from true for each of the 500+ RTK measurements and occupied their own new column within the XLS spreadsheet.

These new columns were labelled E/N/AHD_misclose from CTRL. It was these new columns that formed the principle data for further analysis.
For these misclose columns the following information was derived:

- Mean;
- Standard Deviation;
- Range_Highest;
- Range_Lowest and;
- Total (number) Observations

In addition these miscloses were further split into groupings a set distance from the control value. They were grouped by each increment of 10mm away from true i.e.:

- 10mm or less;
- 11mm to 20mm;
- 21mm to 30mm;
- 31mm to 40mm;
- 41mm to 50mm and;
- Greater than 50mm.

This set of results was able to show for the precision of each group of observations via the 100mm increments and the accuracy of each grouping via the means. The standard deviation was also a good indicator of the quality of the group.
In addition to the analysis of the RTK observations misclose from true, the first batch of data as listed above (mean, SD and range) was also garnered from the recorded coordinate quality of each point. This is the estimated coordinate quality as displayed upon the instrument in the field and is relied upon by the operator to determine if the RTK position being measured will meet the survey standards required for each particular job. It was deemed another useful analysis tool in this project to determine wether the accuracy estimated by the receiver correlated with the actual coordinate accuracy.

4.3.1 Newnes State Forest – Reference Site

Due to the aforementioned issues with the traverse data it was disregarded for the Newnes reference site.

The static data returned excellent results and was accepted for use as control coordinates for the four stations at this site (See Appendix H).

The RTK data also returned consistent results. The 500 RTK data typically exhibited a precision of:

- Eastings: less than ±10mm for 98% or more with the remainder being less than ±20mm.
- Northings: less than ±10mm for 80% or more with the remainder being less than ±20mm.
- AHD heights: 50% or more being less than ±10mm, approximately 30% being between 11mm and 20mm, approximately 10% being between 21mm and 30mm with a minor percentage being between 31mm and 40mm.

Whilst the 1200 data was significantly improved over the 500 results:

- Eastings: less than ±10mm for almost 100%.
- Northings: less than ±10mm for 98% or more with the remainder being less than ±20mm.
- AHD heights: 80% being less than ±10mm, approximately 20% being between 11mm and 20mm more with the remainder being less than ±30mm.

The mean of the RTK misclosures offered a method of assessing the accuracy of the RTK observations.

The 500 horizontal coordinate means were less than 5mm from true and the heights were 10mm or less from true.

The 1200 means were again significantly better with a maximum of 5mm from true for both horizontal and vertical.

These results are within expected precision and accuracy for RTK measurements which are usually less than ±30mm for the 500 equipment and less than ±20mm (often ±10mm) for the 1200, as offered by the receivers displayed accuracy.

The excellent RTK results reinforced the expectation that the Newnes test site was suitable as a reference site for the remaining test locations.

For complete listings of the analysis summaries at Newnes State Forest refer to Appendix B.

4.3.2 Mt Lambie SCADA/RFI site

In this instance the traverse data was adjusted to best fit the static control network with the resulting test point coordinates being used to compare to the RTK measurements. In this case horizontal coordinates compared well after the similarity transformation with the exception of a 65mm difference in the easting for the remote control point 9003 (see appendix G). This had no effect on the radiated test points as it was not used as a back sight during the radiations.

Unfortunately significant errors were apparent when comparing the traverse heights with the static GNSS derived results being up to ± 500mm in error (see appendix G). In this case despite extensive examination of results and raw data no apparent reason could be garnered for this gross error. All instrument and target heights had been double checked in the field and then checked again when processed.

Examination of the static processing results revealed some errors but these were all in the vicinity of ±5mm, not enough to explain the 500mm differences from the mean found.

Examination of the traverse data showed approximately a meter difference in heights between the control points adjacent to the test site and the remote control points. This kind of error might be demonstrated by the inability to process the reciprocal trig heighting observations in the Compnet adjustment package, however the Trimble S6 averages multiple measurements to the same point automatically and this should have accounted for the refraction errors.

Since the two stations used to radiate the test points were in somewhat agreement in height (16mm difference), the radiated test points were deemed to be relatively unaffected by the error and were accordingly adopted in the expectation that the subsequent comparison with RTK measurements might still hold some validity.

Unfortunately this assumption did not stand up to the actual comparison. Whilst all the RTK measurements exhibited expected accuracy and precision in the horizontal coordinates, the heights showed gross errors and displayed inconsistency as to the magnitude of that error. The table below shows the various mean errors observed at each test point by the 500 receiver:

Test point	Mean height misclose
100	-0.010
101	-0.500
102	-0.008
103	-0.325
104	0.423

Table 4.1: Mt Lambie 500 RTK height misclose by test point

This range of errors repeated themselves with the 1200 GNSS results however again the horizontal coordinates were unaffected:

Test point	Mean height misclose
100	0.182
101	-0.313
102	0.191
103	-0.152
104	0.654

Table 4.2: Mt Lambie 1200 RTK height misclose by test point

Further speculation as to the source of these height errors will be found in chapter 5. However there is a constant difference in heights between the 1200 and 500 results. The 1200 results are approximately 0.200m higher than the 500 observations. For the purposes of this project further analysis will predominantly concentrate on the apparently unaffected horizontal comparisons exclusively.

The 500 series of horizontal observations showed the following trends:

- Eastings: less than ±10mm for between 68% and 97%, with the majority of the remainder being less than ±20mm.
- Northings: less than ±10mm for between 65% and 94%, with the remainder being less than ±20mm. The exception was test point 104, one of the furthest points from the SCADA and other telecommunications antennas. The northings at this point showed approximately 6% between 21mm and 30mm and another 1% between 31mm and 40mm.
- AHD heights: Not valid/reliable.

The 1200 series of horizontal observations showed similar trends of precision to the 500 observations:

- Eastings: less than ±10mm for between 60% and 93%, with the majority of the remainder being less than ±20mm. The exceptions were the measurements to test point 104. These showed 26% of observations were less than 10mm, 56% between 11mm and 20mm, and 17% between 21mm and 30mm.
- Northings: less than ±10mm for between 85% and 99%, with the remainder being less than ±20mm. Again the exception was test point 104. The northings at this point showed 60% of observations were less than 10mm, 31% between 11mm and 20mm, and 9% between 21mm and 30mm.
- AHD heights: Not valid/reliable.

Accuracy of the various point groupings was within 10mm of true for the horizontal values of both the 500 and 1200 observations except the 1200 observations to test point 104. The mean eastings of these observations were 14mm from true. This correlates with the poor precision exhibited by the same set of observations.
Correlation was evident between high precision and high accuracy for all the observations.

Separate from the RTK coordinate comparisons involving the traverse data were the RTK observations to the adjacent control stations that were fixed via the static control network.
These observations also showed an error in the heights but none in the horizontal coordinates.
The error in this case however appeared different to the test point errors, and possibly restricted to the observations emanating from the 1200 base at remote control point 9003. There were two sets of observations by the 1200 receivers, to 9007 and 9006. In both cases the error was approximately 0.200m which agreed with the error difference already seen between the 500 and 1200 test point observations. Further discussion will be made in Chapter 5. The observations using the 500 instruments were to adjacent control point 9006.

These appeared to have valid heights with a mean of the RTK observations being different to the control by 10mm. The precision of these points is as follows:

- Eastings: less than ±10mm for between 90% and 99%, with the remainder being less than ±20mm.
- Northings: less than ±10mm for between 53% and 92%, with the remainder being less than ±20mm. Point 9006 as measured to by the 500 system also had 3% between 21mm and 30mm.
- AHD heights: The observations by the 500 receiver from remote control point 9005 to adjacent control point 9006 appear valid. Precision was low however with significant percentage of observations being no better than ±40mm. A minor percentage were greater than ±50mm different to true.

Accuracy for these three sets of observations was typically better than 5mm. The observations by the 1200 receiver to point 9007 were slightly worse being on average 10mm off true. These series of northings also had the worst precision of the three sets (45% between 11mm and 20mm), again, following a distinct correlation between accuracy and precision as exhibited by the horizontal observations to the test points. The heights measured to 9006 by the 500 receiver displayed an acceptable accuracy with the mean differing from true by 10mm. In this case accuracy did not correlate with precision.

Finally at the Mt Lambie site, base receiver observations were taken from an adjacent control point (9006) to the two remote control points, 9003 and 9005 and also to 9007. Heights were as before, suspect. The observations from 9006 to 9003 again showed the approximate 0.200m error which agreed with the earlier observation from 9003 to 9006 and 9007. This further supports a possible height error in the 9003 remote control point. The mean heights measured from 9006 to 9007 and 9005 showed a reasonable level of accuracy, being 20mm and 10mm off of true respectively. Horizontal coordinates were within expected accuracy and precision ranges.
Horizontal precision of these three point groupings were as follows:

- Eastings: less than ±10mm for between 82% and 99%, with the majority of the remainder being less than ±20mm.

- Northings: less than ±10mm for between 77% and 99%, with the remainder being less than ±20mm.
- AHD heights: despite appearing valid precision was low for the observations to 9005 and 9007. Significant percentages of observations were no better than ±40mm from true whilst both sets of observations showed outliers greater than 50mm from true.

Mean accuracy was less than 7mm from true in all three sets of horizontal coordinates. Again, as precision lessened the mean accuracy also fell. The two valid observation sets, 9005 and 9007, saw mean heights of 10mm and 20mm different from true. This correlated with the poor precision also seen here.

The differences in height errors between GNSS measured points and total station measured points is indicative of more than one source of error. The GNSS only comparisons appear to have an error constant with the possible source being station 9003. The traverse data errors appear almost random. Further discussion will follow in Chapter 5.
For complete listings of the analysis summaries at Mt Lambie refer to Appendix C.

4.3.3 Burrendong Dam SCADA sites

Burrendong Dam contained three SCADA test sites. As was the case at Mt Lambie the traverse data passed through a similarity adjustment to best fit the static derived coordinates.
Unlike the Mt Lambie observations, heights at Burrendong fitted with expected accuracy and precision ranges. For all three test sites at Burrendong Dam, RTK coordinates of the 500 system and the 1200 system were compared to control values either derived from the static GNSS network or a combination of the static network and total station radiated test points.

4.3.3.1 Burrendong – Test Site A

The first site in question was the SCADA repeater antenna above the southern end of the dam. RTK observations were taken to the adjacent control point 9012 and the test points 200 to 205.

Precision and accuracy for the 500 series of observations was as follows:

- Eastings: less than ±10mm for 73% to 100% or more with the remainder being less than ±20mm.
- Northings: Except for the observations to test point 204 the northings were less than ±10mm for 90% or more with the remainder being less than ±20mm. 204 showed 49% less than ±10mm, 43% between 11mm and 20mm and 8% between 21mm and 30mm.
- AHD heights: between 53% and 79% were less than ±10mm, between 20% and 33% were in the 11mm and 20mm bracket and up to 8% being between 21mm and 30mm with a minor percentage being between 31mm and 40mm.

Accuracy was proportional to precision and was less than ±11mm for all horizontal measurements. The worst accuracy was found in the northings of 204 which correlated with the low percentage (49%) of northing coordinates within 10mm of true. Accuracy of heights was actually better than horizontal coordinates being better than 7mm from true.

Precision and accuracy for the same points as measured by the 1200 receivers is as follows:

- Eastings: less than ±10mm for 58% to 97% with the majority of the remainder being less than ±20mm.
- Northings: less than ±10mm for 53% to 90% with the remainder being less than ±20mm.
- AHD heights: between 37% and 57% were less than ±10mm, between 26% and 52% were in the 11mm and 20mm bracket, between 4% and 18%

being between 21mm and 30mm and up to 7% being between 31mm and 40mm.

As expected accuracy was proportional to the precision of a group of observations. The maximum difference between the mean of the observations and the true coordinate was 11mm in the horizontal and 13mm in vertical.
The results from this test indicated that as opposed to the reference site the 1200 receiver results experienced a reduction in precision and accuracy compared to the 500 receiver. This indicates that the 1200 equipment was more affected by the SCADA equipment than the 500. This would agree with the adjacent SCADA radios frequencies being closer to the 1200 operating frequency than the 500. No correlation between degraded accuracy or precision was found with distance from the antenna however.

4.3.3.2 Burrendong – Test Site B

The second site observed was the antenna found to the north of the dam wall. As per the other test sites at Burrendong Dam, it consisted of an adjacent control point called 9014 and 6 test points radiating away from the antenna at 10m intervals.
Precision and accuracy for the 500 series of observations was as follows:

- Eastings: less than ±10mm for 74% to 100% with the remainder being less than ±20mm.
- Northings: less than ±10mm for between 29% and 99%, up to 65% between 11mm and 20mm and up to 22% between 21mm and 30mm. Test point 302 also saw a further 4% of observations fall into the 31mm to 40mm bracket.
- AHD heights: between 42% and 80% were less than ±10mm, between 18% and 30% were in the 11mm and 20mm bracket and between 1% and 18% being between 21mm and 30mm. Test point 302 also stood out as exhibiting particularly poor precision with a further 7% being between 31mm and 40mm and 3% being between 41mm and 50mm.

This set of observations was characterised by a wide range of precision in the northings for the RTK measured test points. The adjacent control point 9014 displayed better than 92% of its horizontal observations within the sub 10mm precision range, while the northing observations of all the test points was generally in the higher 11mm to 20mm range and the 21mm to 30mm range

Accuracy was proportional to precision and was less than ±11mm for all horizontal measurements. Although height accuracy was less than 8mm for all the observation groupings, it was not in proportion to the precision of the height observations. Test point 302 and 304 both exhibited a fairly broad spread of precision with significant percentages in the 31mm to 40mm bracket, whilst the over all mean accuracy for these two points was within 6mm and 8mm respectively.

Precision and accuracy for the 1200 series of observations was as follows:

- Eastings: Except 301 all points had 87% to 100% less than ±10mm with the remainder being less than ±20mm. 301 had 48% less than ±10mm with the remainder being less than ±20mm.
- Northings: Except 301 all points had 85% to 100% less than ±10mm with the remainder being less than ±20mm. 301 had 60% less than ±10mm with the remainder being less than ±20mm.
- AHD heights: Except 9014 and 301, between 40% and 68% were less than ±10mm, between 29% and 57% were in the 11mm and 20mm bracket and up to 5% were between 21mm and 30mm. Test point 301 and adjacent control point 9014 stood out as exhibiting particularly poor precision with between 3% and 7% less than ±10mm, between 16% and 38% in the 11mm and 20mm bracket, between 38% and 40% in the 21mm and 30mm bracket, between 12% and 27% in the 31mm and 40mm, between 2% and 11% in the 41mm and 50mm bracket and up to 3% greater than 50mm.

The 1200 receiver results from this test site showed generally acceptable precision with attendant and proportional accuracy, with the mean horizontal and vertical observations being better than 7mm and 11mm from true. The exceptions were the adjacent control point 9014 and the test point 301. These two points were the closest to the SCADA emitter in this group of observations which may have been a factor in the relatively different precision and accuracy when compared to the other observation groupings. Mean horizontal accuracy for 9014 and 301 was better than 10mm from true which agreed with the levels of precision they exhibited. The mean vertical accuracy was

22mm and 29mm different from true respectively, and again this agreed with the large spread of precision seen with these observations.

When comparing the 1200 observations to the 500 observations, there is some agreement in variations in precision and accuracy between the two. Test point 302 shows some relatively lower precision when measured by both the 1200 and 500 units. In either case the points closest to the antenna appear to exhibit relatively poor results. The combination of data might indicate that some degradation in precision and accuracy of the observed RTK points is attributable to the RFI of the adjacent SCADA unit.

4.3.3.3 Burrendong – Test Site C

The third and final test site at Burrendong dam was located on the storage intake tower. The series of test points 400 to 405 were placed at 10m intervals along the bridge that linked the intake tower to the mainland. The adjacent control point was known as 9013. Precision and accuracy for the 500 series of observations was as follows:

- Eastings: less than ±10mm for 62% to 98% with the majority of the remainder being less than ±20mm.
- Northings: less than ±10mm for between 80% and 97%, with the majority of the remainder being less than ±20mm.
- AHD heights: test points 400, 401 and 403 show between 68% and 83% were less than ±10mm, between 17% and 25% were in the 11mm and 20mm bracket and up to 6% being between 21mm and 30mm. Test point 405 showed a relative degradation in precision: 21% less than ±10mm, 25% in the 11mm and 20mm bracket, 30% in the 21mm and 30mm bracket, 19% in the 31mm and 40mm, 4% in the 41mm and 50mm bracket and 2% greater than 50mm. The adjacent control point 9013 showed 41% less than ±10mm, 32% in the 11mm and 20mm bracket, 20% in the 21mm and 30mm bracket, 6% in the 31mm and 40mm, with the remaining 1% being greater than 40mm.

All these test points exhibit a horizontal accuracy no greater than 9mm from true. At this site the horizontal accuracy was also proportional to the horizontal precision which was better than 20mm from true in all cases.

The three test points 400, 401 and 403, also exhibit strong height accuracy and precision. The mean height for test point 405 was 20mm different from true. This also correlated with its wide distribution of height precision. Whilst not as inaccurate or imprecise as 405, the adjacent control point, 9013, was also relatively poor in its range of heights.

Precision and accuracy for the 1200 series of observations was as follows:

- Eastings: less than ±10mm for 83% to 100% with the remainder being less than ±20mm.
- Northings: less than ±10mm for between 64% and 100%, with the remainder being less than ±20mm.
- AHD heights: between 57% and 86% were less than ±10mm, between 12% and 32% were in the 11mm and 20mm bracket, and up to 9% in the 21mm to 30mm bracket. The adjacent control point 9013 also showed 2% in the 31mm to 40mm bracket.

As for the 500 series observations, the 1200 group of points exhibited horizontal precision better than 20mm for all observations. In addition horizontal accuracy was better than 7mm from true for all points, and precision matched the variations in accuracy.
Height accuracy was also better than 7mm from true for all the height means. Only the adjacent control point showed slightly less precise observations although the percentage greater than 20mm from true were minor.

Since the 1200 receiver observations were relatively tightly grouped and showed good accuracy, the two relatively poor 500 receiver observation sets seem to be isolated. This lends itself to the GPS solution in these cases, being the source of the precision degradation.

Whilst performing observations at Burrendong Dam it was noted that the crest pillar, P11 that had been included in the control network, was also located approximately half way between the intake tower SCADA test site and the SCADA relay tower to the south of the dam. Both these test sites had test points up to a maximum distance of 60 meters from the SCADA emitter. Since P11 had line of sight to both SCADA emitters under investigation it was decided to perform RTK observations to P11 as well. The theory being that observations at this point would show wether the SCADA emitters would have any influence at longer ranges. P11 is approximately 750 meters from both SCADA antennas.

P11 was observed to with a 1200 receiver. Almost 100% of horizontal observations were within 10mm of true coordinates. 88% of observations were within 10mm of true height with the remaining 12% being within 20mm.

These results are consistent with the results achieved at the Newnes reference site. Although this is only one example it does indicate that somewhere between 60 and 750 meters of the SCADA radios at Burrendong dam, their influence falls away to zero.

The final observations for the Burrendong Dam test area involved setting the 1200 base receiver on the adjacent control station 9012. From here RTK observations were measured to the remaining two adjacent control stations; 9013 and 9014. Observations were also taken to the remote control station, 9011. As discussed previously these observations were designed to demonstrate RFI when both the base and rover receiver were influenced, and when just the base was influenced.

- Eastings: less than ±10mm for almost 100% of observations. The 9011 results showed approximately 3% of observations being between 11mm and 20mm.
- Northings: less than ±10mm for virtually all observations.
- AHD heights: The majority of heights for 9011 and 9014 were better than 20mm. 9013 however exhibited poor accuracy with the majority of its heights being between 31mm and 60mm.

For complete listings of the analysis summaries at Burrendong Dam refer to Appendix D, E and F

4.4 Conclusions

During the processing stage of the project several difficulties were encountered and dealt with on the path to obtaining final results for analysis.

The traverse data collection with the Trimble S6 total station was successful in the field but due to software problems, lost its initial role as an alternative provider of control coordinates. The static observations were generally reliable and offered excellent solution quality especially over the longer distances with the apparent exception of the remote control point 9003 at the Mt Lambie site. The results of an adjusted traverse control network would have been an excellent check against the static network.

Whilst the loss of the traverse data was not an issue at the Newnes reference site this was not the case at the actual test sites. Here the traverse data was still vital as it had been used to radiate the test point locations and as such was the only method of coordinating these points. Using the survey calculations package, foresight, the unadjusted traverse coordinates were adjusted to the static control network via a similarity transformation. This afforded a method of adjusting the traverse network for scale factor as well as an azimuth correction.

Moving forward from this point the project now had control coordinates for all points including test points.

Further issues arose at Mt Lambie however. At this site horizontal accuracy appears reliable however the heights have serious problems. Despite repeated analysis and recalculation of the raw data solution or source of the error was unavailable. Further field work was required at this site but time constraint prohibited that option. Analysis continued at Mt Lambie but focused on horizontal results apart from some of the control station to control station measurements which did appear to be valid.

Fortunately the Burrendong Dam test area did not exhibit the same height issues as Mt Lambie. Here comparisons between control values and RTK observations were entirely successful.

In the analysis it is clear that generally the RTK observations exhibited degraded accuracy and precision at the SCADA and RFI test sites. The challenge in analysing these results is in attributing the cause of the introduced error. Many sources of error of the observed magnitude are available including SCADA and RFI influences. Discussion of the results will continue and be expanded upon in the next chapter.

CHAPTER 5

ANALYSIS AND COMPARISONS

5.1 Introduction

The project to this point had produced several difficulties that were mostly overcome although not necessarily using ideal methods. The one obvious exception was the corruption of height results at the Mt Lambie site. No solution other than further field work was available to rectify that issue.

After final results had been produced it was clear that accuracy and precision had been degraded when RTK observations had been taken at up to 60m from SCADA antennas. Similarly the RTK results at Mt Lambie's SCADA and high general RFI environment were degraded up to 120m away from the RFI source. This chapter will analyse these comparisons and comment on the likely source of the degraded results.

5.2 Newnes State Forest – Reference Site

From the results acquired at the reference site it can be shown that it was a successful choice as a RFI low environment in which to perform RTK observations.

Horizontal components of the four RTK observation sets were almost always better than ±10mm from the true coordinate. The exception was the northing component of the 500 series results which saw between 10% and 20% of observations falling being within 20mm of true.

Heights will always demonstrate a lower level of accuracy than horizontal coordinates and this was the case with the reference site observations as well.

Again the 1200 results were superior to the 500 results. The 1200 receivers consistently delivered a precision better than 20mm in height, whilst the 500 equipment was better than 30mm in height.

Accuracy was also excellent being within 5mm for all coordinate means except the 500 measurement to 9033 which was within 10mm.

These results are generally better than expected in normal operations of these receivers. This high performance is a factor of the excellent sky view all these stations enjoyed as well as the low RFI environment and absence of infrastructure such as power lines that might cause multipath issues.

It is interesting to note the improvements in accuracy and precision offered by the newer equipment over the older. Whether this is due to the increased number of satellites available with the addition of the Russian GLONASS constellation to the U.S. GPS constellation, and/or improvements in the hardware and firmware is unknown and beyond the scope of this project. However this trend did continue in instances where test points were observed by both types of receiver.

5.3 Mt Lambie Test Site

As made clear previously, this site experienced major errors in the vertical component of RTK observations. The horizontal component was deemed valid and analysis in terms of RFI effect will focus on this however some discussion of the cause of the height problems is useful.

5.3.1 Errors in Heights

As noted earlier, the problems at Mt Lambie test site were extensively pursued from the raw data point of processing. Since no solution to the problem was found, such as an antenna height error, or a fault in the static GNSS processing, the only solution is to perform more field work.

There are three bodies of data that have potential to contain the source of the error; the static GNSS measurements, the RTK observations, and the traverse radiations.

The static network was processed and adjusted using a least squares method. The result of this adjustment was accepted and gave no indication of being the cause of the large miscloses in height. Thus it is difficult to single out the control network as the source of the errors.

The Trimble S6 total station acquired test point coordinates were adjusted to fit with the static control coordinates 9006 and 9007, the occupied station and back sight respectively. Since no error was apparent in the height of instrument and target it is again difficult to attribute the large variety of radiated test point heights to these observations.

The RTK observations were dependant on the static results for reference station coordinates. Therefore it is assumed that the base receiver coordinates are correct. All antenna types and heights were checked in the field and then in the processing stage and although errors were found, they were corrected.

However RTK observations to the control stations showed a constant error of approximately 200mm. Radiated test points were more volatile and showed a range of between -1.079m and 0.438m. This differing error between the two sets of control coordinates appears to indicate the error might be from two sources. Certainly the error constant between the control stations would place suspicion on either instrument height or the control coordinate values. Double checking of instruments heights in the field and in the processing stage means an error here would have to have to have been missed twice. It seems more likely that the control coordinates are the source of the error.

The errors at the radiated test points are not constant and of considerably greater magnitude than the control point observations. The most likely cause of these errors is some aspect of the traverse radiations. Although two of the test point coordinates (100 and 102) agree with the RTK observations (allowing for the 1200 error constant), the remaining four test points have an error range of between -0.5m and +0.4m. In all these cases if the probable 0.2m control point coordinate is allowed for, the 500 and 1200 observations are in agreement. Since 4 of the 6 test points are in error, it casts doubt on the pair of good test points and as such their height values may be coincidental. Subsequently none of the test point height information will be considered.

Since the observations from control point to control point are separate to the radiation derived coordinates, these values will be retained and analysed.

5.3.2 Comparisons with the Reference Site

Horizontal RTK observations at Mt Lambie typically showed precision better than ±20mm from the true coordinate. Proportion of observations less than ±10mm were however much less than the seen at the reference site.

Although precision varied between test points a subtle trend was apparent in which precision fell when moving from test points close to the SCADA emitters to the furthest test points. This is opposite to what one might expect if all the error was incurred by

RFI. This indicates that the trend line is caused by lengthening radiations from the total station instead. Discounting the trend still leaves the underlying degradation in observed coordinate precision and this can be attributed to SCADA RFI.
Accuracy of the various observation groups was comparable to the reference site with variations up to 14mm from true.
Indeed when all the observation accuracies were considered as a group it showed that for all the test point observations mean accuracy was ±5.5mm.

Measurements from control point to control point also displayed degradation in horizontal precision with greater proportions of observations moving from the sub 10mm bracket to the 11mm to 20mm bracket, when compared to the reference site. Several of the heights were deemed valid for this group of observations and these highlighted a considerable drop in precision. Typically when measuring between a remote point and an adjacent point observations that came in at less than ±10mm from true dropped from around 70% to no better than 40%. Also whilst the reference site had the majority of observations at better than ±30mm from true, the measurements at Mt Lambie moved into the next bracket and showed significant percentages of observations in the 31mm to 40mm bracket. Height accuracy was no better than 10mm from true which is also a slightly worse than the reference site accuracy levels but still within typical accuracy expectations.
Of final note was the series of measurements between 9006 and 9007. Both these control points were deemed to be within the zone affected by RFI. In this case just 16% of observations were less than 10mm from true. The bulk of observations fell in the 11mm to 20mm and 21mm to 30mm region. Accuracy also fell to a mean height of 20mm from true.
This final measurement shows a particularly poor accuracy which also weights the precision away from true. This has potential to be caused by both the base receiver and the rover receiver being affected by RFI. An alternative is that errors in the static network could be at fault. 10mm of error between the stations in the control values would also account for the relatively poor accuracy of this point cloud.

5.4 Burrendong Dam Test Site

Burrendong had three test sites and in these cases the RTK observations were affected by SCADA RFI only.

5.4.1 Comparisons with the Reference Site: Test Site A

Site A included test points 200 to 205 spread at 10m intervals from the Burrendong Dam SCADA relay antenna. The adjacent control station 9012 was approximately 20m away from the antenna.

The results at this test site showed a definite disparity of effect between the 1200 and 500 instruments.

The results garnered from the 500 instrument exhibited some slight reduction in precision but generally compared well with the reference site. Between 70% and 99% of horizontal observations were within ±10mm of true, while between 50% and 80% of heights were within ±10mm of true height. Precision rarely fell below ±20mm for the horizontal, and ±30mm for the vertical observations, again, this is in keeping with the reference site results.

The 1200 series results were markedly degraded relative to the 500 results. Whilst horizontal precision rarely exceed ±20mm from true, a significant proportion were within the 11mm to 20mm bracket. Similarly height precision only exceeded ±30mm occasionally however usually less than 50% of observations were better than ±10mm. This compares to the reference site norm for 1200 observations, where precision was predominantly better than ±20mm and 80% of observations better than ±10mm.

This evidence indicates that the SCADA equipment at this site was far more influential on the 1200 RTK system than the 500 equipment.

Indeed the SCADA radios at this site operated at a frequency much closer to the 1200 frequency than the 500. This might explain the different impact on either system.

5.4.2 Comparisons with the Reference Site: Test Site B

Site B included test points 300 to 305 which were spread at 10m intervals away from the SCADA pole. The adjacent control station 9014 was approximately 17m away from the antenna.

Results at test site B were somewhat inconsistent. Unlike the noticeable disparity between the two different instrument types at test site A, neither instrument showed a significantly different trend to the other beyond the generally better performance of the 1200 equipment.

For most of the test points both the 1200 and 500 horizontal observations were close (although not quite as tightly spread), to the reference site precision. However there were exceptions. Test points 300, 301 and 302 all showed marked drops in precision for the northing values only. In addition the 1200 horizontal precision in both easting and northing coordinates for test point 301 was also relatively down.

Height precision saw similar limits to that seen at the reference site, however a higher percentage of observations were in the lower precision ranges between ±10mm and ±30mm. Two 1200 measured points, the adjacent control point 9014 and the test point 301, showed particularly poor accuracy. The means of these two observation sets were 22mm and 29mm off true respectively. On first glance the precision of these two points is subsequently poor, however on closer inspection it can be seen that the majority of points spread themselves relatively closely around the mean values. Subsequently it can be said that although accuracy is low at these points, precision is still acceptable. In both these cases the poor height accuracy was not repeated by the 500 instrument observations.

The somewhat poor results in the northings for a few of the test points might indicate an error with the radiations however this is hard to justify without a correlating effect on the eastings. Since the line of radiations for this group of test points is in a south west direction, errors in radiations should affect eastings and northings equally.

If this site is have an effect on the RTK observations it is not affecting all points nor is it affecting one instrument more than the other.

The results from this test site are subsequently somewhat inconclusive. Some negative effects are apparent but no significant trends are forthcoming.

5.4.3 Comparisons with the Reference Site: Test Site C

Site C was located on the Burrendong Dam intake tower. The test points were numbered 400 to 405 which were spread at 10m intervals away from the SCADA pole and along the bridge linking the intake tower to the mainland. The adjacent control station 9013 was approximately 10m away from the antenna.

Generally the SCADA RFI at this test site appeared to have little influence upon the RTK results. Both the 500 and 1200 instruments yielded results that compared relatively well to the reference site in both horizontal and height components.

There were some minor individual exceptions to this trend. The precision of the horizontal component was slightly degraded for the 1200 observations at test point 400, and the 500 observations at test point 403.

Then in the heights, both instruments saw a degraded precision at the adjacent control point; 9013. The 500 receiver also recorded poor height accuracy of 19mm from true at 405. The precision at this point however was not spread widely and fitted with the reference site precisions for 500 observations.

Test site C showed the least trend for accuracy and precision degradation of all the sites at Burrendong dam. However even so, some aspects of the measured points were negatively affected relative to the reference site observations. At a site with excellent sky views and no alternative sources of degradation, the errors have the greatest potential to be caused by the SCADA RFI.

5.4.4 Comparisons with the Reference Site: P11

RTK observations were taken to P11 in order to test the influence of the SCADA radios at Burrendong dam when RTK observations were further away from the emitters than the 60m test radius. P11 is more than 700m from all three of the SCADA sites at Burrendong Dam and has line of sight to all three.

P11 showed good accuracy and precision in line with that shown at the reference site. As such it can be determined that at this range none of the SCADA emitters were influencing the RTK observations.

5.4.5 Comparisons with the Reference Site: Base Receiver on an Adjacent Control Point

To test the effect of SCADA RFI on both the RTK base alone and on the RTK base and the RTK rover, the 1200 RTK base was set on the adjacent control point at 9012 (site A). From here observations were taken to the other two adjacent control points, 9013 and 9014, and also to the remote control point 9011.

As shown in the results, these test measurements did not demonstrate any difference between the test point's horizontal component and the results seen at the reference site. However the observations to 9013 whilst being tightly grouped (good precision), exhibited poor accuracy, differing by 45mm from true. The source of this error is difficult to account for as the other measurements to this point showed good accuracy.

5.5 Proposed SCADA Mapping

Objective 5 & 6 for this project called for the creation of a digital map showing all SWC SCADA sites across NSW. Associated with this map would be zones of influence surrounding each site.

Due to the limited reliable information available within SWC as to the locations for active SCADA radios creating this map became unachievable within the projects timeframe.

In addition the exact limits of SCADA interference were not determined. Aside from this limit is clear that the effect varies between different SCADA radios.

With these twin problems, it became unfeasible to produce a map. Such an output based on currently available information would be unreliable.

Instead more general limitations on RTK surveying within SCADA environments are more applicable to this project. Such limitations will be discussed in the following summary and in the final chapter.

5.6 Summary

As demonstrated in Chapter 4 the Newnes State Forest site exhibited excellent precision and accuracy for the RTK observations measured there. Subsequently it qualifies as a valid reference site to which the SCADA and RFI influenced sites can be compared.

The Mt Lambie site offered a comparison of RTK observations to the reference site in what could be described as a high RFI environment.
Despite the presence of alternative sources of error, enough valid information was garnered here to compare with the reference site. The results show a definite degradation in precision of RTK observations affected by RFI. In the region of 20mm in horizontal coordinates and up to 40mm in height. Outliers can exceed these limits, up to ±60mm in height.
Interestingly with the minimum of 500 observations taken at each point overall mean accuracy did not deviate from true coordinates by more than 10mm in position and height.

Burrendong offered three alternative SCADA test sites. Site A exhibited a definite trend of degraded precision on the 1200 equipment. Generally 30% of observations went from being within ±10mm of true to being between ±11mm and ±20mm of true.
Sites B and C showed some individual losses in precision and accuracy but not the marked trend seen at site A.

Overall it can be shown that when operating in a SCADA environment generally RTK observations can potentially be affected by RFI. Certainly when operating within 60m of SCADA radios as powerful as 50W and having a similar frequency to the RTK radio, some degradation of results should be expected.
A principle understanding gained from this research has been that the effect of SCADA equipment can be erratic. Simply testing a single RTK observation against a known point and seeing good agreement is no guarantee that subsequent points will not be affected.
When operating in a more broad RFI location such as seen at Mt Lambie, the degrading effects will be more consistent.

CHAPTER 6

CONCLUSIONS

6.1 Introduction

This project was born out of anecdotal indications that in a practical operating environment SCADA radio equipment had a detrimental effect upon RTK surveying observations. This anecdotal effect was backed up by studies in related areas as performed by Mr Rafe Samuel Penington (2001) and Mr Stuart O'Leary (2003). These studies focused on a practical study of RTK observations in a power line environment and a laboratory based study on EMI effects on RTK. Both these studies demonstrated evidence that EMI indeed was a negative influence on RTK equipment.
Since SWC survey section routinely operates RTK equipment in SCADA equipped sites further specific study in this area had a high degree of relevance.
It was on these principles that this formal research project was based.

6.2 Discussion

The projects course encountered many challenges most of which were met and successfully resolved.
However some problems do require further field work to identify and rectify. The time limitations of the project prohibited that course of action however.
Fortunately enough valid data was acquired to produce good results that were able to be effectively analysed.

6.2.1 Results

Four test sites and one reference site were surveyed and produced a large quantity of analysable data. As noted above, some of the data was invalid for the test site at Mt Lambie, but enough remained to gain a good understanding of RFI effect at this site.

Importantly the reference data gave a good indication of best case potential for RTK GNSS observations and thus formed a good reference with which to compare the results from the test sites.

Definite indications of reduced precision were identified at the Mt Lambie test site and Burrendong Dam test site A. The other two test sites showed somewhat erratic results, varying between little effect with some observation groups, to considerable effect on others. No pattern or consistency was visible at these test sites.

When the SCADA radio details can be accessed it can be said that if the frequency of that radio is close to the frequency of the RTK radio, then degradations in accuracy are fairly certain.

The effect of SCADA radio networks can also be said to be limited by range. Certainly and effect was demonstrated out to 60m from the antenna, however no effect was then seen at 700m. The limit if the SCADA radio effect lies somewhere between these two distances but was not found by this project.

Ultimately the proven effect of RFI and SCADA on RTK observations requires any survey conducted within these zones to be mindful of the likely negative effect upon said results.

6.2.2 Limitations of the Study

Although the project was successful in identifying and quantifying SCADA interference upon RTK surveys there are some limits to the work.

As alluded to above, the range of test points proved to be insufficient to identify the limits of the SCADA interference. A second field work study would be required to place more test points at greater distances from the SCADA antennas. Ideally test site A at Burrendong dam would likely yield the most reliable data with further testing on the affected 1200 series equipment.

An obvious limitation of this body of work is the limited general understanding of radio in general. A more comprehensive and scientific study would involve professional knowledge in this area.

Continuing on this theme, the SCADA equipment tested during this project came with limited details. This limitation was outside the projects control as SWC itself was unable to provide additional data during the project time frame. SWC SCADA network was in the process of being audited over the projects study period.

Ideally further study would be done with a more detailed knowledge of the SCADA radios being tested. Extrapolating from the link between RFI frequency and the RTK equipment frequency, future SCADA test sites would be chosen that had closely matched radio frequencies so as to reinforce this probable cause and effect link.
With the above mentioned further study, and in conjunction with the expected complete SWC SCADA knowledge base, production of the proposed SCADA/RTK interference mapping would then become feasible and more reliable.

6.3 Implications

Traditional RTK survey practice involved the measuring of a single point. In these environments seen above this practice could see a difference from the true coordinate of more than 50mm in height. An average of points however is much more likely to deliver final coordinates within 10mm of true position.
Although a degrading effect has been seen on these RTK observations, which has been attributed to RFI and SCADA RFI, some perspective must be retained when discussing RTK observations.
When SWC utilises RTK surveying techniques it is done so with the understanding that heights are within 50mm of true.
For all but a few situations this has been proven to be a realistic expectation.
Ultimately the knowledge that RFI environments can impact on single point RTK solutions must be tempered with the accuracy limits of the equipment. If a survey required accuracies better than 50mm in height then a SWC surveyor would use different means than RTK to acquire that information.

6.4 Further Research and Recommendations

With the knowledge gained by this project, a clear path exists for extending the understanding of SCADA interference upon RTK surveys. Future studies would extend the range of testing points to some point between 60 and 700 meters to determine actual limits for SCADA sites.
In addition a more focused look at which SCADA radio frequencies affect any given RTK equipment the most would be beneficial.

Ideally any further research conducted in this area would be done so with the full cooperation of a professional in the field of radio science. The guidance and advice of such an individual would achieve more focused results with a better understanding of the causes and effects of RFI on RTK observations. In addition such an individual could help suggest mitigation strategies which could be field tested and verified.

6.5 Summary

This project has met all the stated goals originally specified excepting the production of SCADA mapping. This information required for such a map was unavailable or in the case of the RTK results, not representative enough to extrapolate out to every SWC SCADA site across NSW.

The project has quantified an effect on the accuracy of RTK observations when operating in SCADA and RFI affected environments. This effect is variable but definite nonetheless.

Future directions for additional research have been identified.

SWC survey section and readers of this project now have an understanding of the role SCADA RFI plays on RTK observations. Equipped with the knowledge garnered from this data informed decisions can be made when approaching survey tasks in sites such as tested within this project.

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APPENDIX A

PROJECT SPECIFICATION

University of Southern Queensland

FACULTY OF ENGINEERING AND SURVEYING

ENG 4111/4112 Research Project
PROJECT SPECIFICATION

FOR: **MATTHEW HOPSON**

TOPIC: SCADA Interference with RTK Surveys

SUPERVISORS: A/Prof. Dr Armando A Apan

ENROLMENT: ENG 4111 – S1, D, 2009
ENG 4112 – S2, D, 2009

PROJECT AIM: To investigate interference between SCADA radio transmissions and RTK radio transmissions. This research will primarily be focused on the SCADA network controlled by State Water Corporation.

PROGRAMME: **Issue A, 24th March 2009**

1. Conduct review of literature pertaining to SCADA radio frequencies and RTK radio frequencies. Research any existing studies related to RTK interference from SCADA and other radio frequencies.
2. Building upon the results from the review conducted in stage 1, field work will be carried out using two different RTK systems operating on two different radio frequencies. This field work can be conducted at any of the various State Water storages across NSW that utilise a SCADA system
3. The field gathered data will be analysed and arranged into a preliminary results document.
4. Create a methodology or series of operating restraints designed to minimise interference issues.
5. Submit an academic dissertation on the research.
6. Create a map showing current and proposed State Water SCADA sites.
7. Add to this map potential zones of influence from these SCADA sites.

AGREED: ________________ (Student) _________________ (Supervisors)

Date: / /2009 / /2009

Examiner/Co-examiner: ____

APPENDIX B

NEWNES REFERENCE SITE -RTK ANALYSIS

	E_misclose from CTRL		N_misclose from CTRL		AHD_misclose from CTRL			Coordinate quality
means:	0.002		0.005		-0.001			0.011
Standard Deviation:	0.003		0.003		0.008			0.001
range_highest:	0.010		0.014		0.022			0.018
range_lowest:	-0.005	**Percentage**	-0.006	**Percentage**	-0.024	**Percentage**		0.009
Total obs:	607	100.0%	607	100.0%	607	100.0%		
10mm or less:	607	100.0%	588	96.9%	479	78.9%		
11mm to 20mm:	0	0.0%	19	3.1%	122	20.1%		
21mm to 30mm:	0	0.0%	0	0.0%	6	1.0%		
31mm to 40mm:	0	0.0%	0	0.0%	0	0.0%		
41mm to 50mm:	0	0.0%	0	0.0%	0	0.0%		
greater than 50mm:	0	0.0%	0	0.0%	0	0.0%		

9030 RTK comparison with control coordinates. 1200 receiver.

	E_misclose from CTRL		N_misclose from CTRL		AHD_misclose from CTRL		Coordinate quality
means:	-0.001		-0.004		-0.005		0.016
Standard Deviation:	0.005		0.007		0.009		0.004
range_highest:	0.013		0.015		0.018		0.049
range_lowest:	-0.013	**Percentage**	-0.026	**Percentage**	-0.032	**Percentage**	0.009
Total obs:	502	100.0%	502	100.0%	502	100.0%	
10mm or less:	494	98.4%	413	82.3%	338	67.3%	
11mm to 20mm:	8	1.6%	84	16.7%	139	27.7%	
21mm to 30mm:	0	0.0%	5	1.0%	24	4.8%	
31mm to 40mm:	0	0.0%	0	0.0%	1	0.2%	
41mm to 50mm:	0	0.0%	0	0.0%	0	0.0%	
greater than 50mm:	0	0.0%	0	0.0%	0	0.0%	

9032 RTK comparison with control coordinates. 500 receiver.

	E_misclose from CTRL		N_misclose from CTRL		AHD_misclose from CTRL		Coordinate quality
means:	0.003		-0.001		0.003		0.012
Standard Deviation:	0.003		0.003		0.007		0.002
range_highest:	0.011		0.008		0.025		0.019
range_lowest:	-0.004	**Percentage**	-0.011	**Percentage**	-0.015	**Percentage**	0.009
Total obs:	542	100.0%	542	100.0%	542	100.0%	
10mm or less:	541	99.8%	541	99.8%	444	81.9%	
11mm to 20mm:	1	0.2%	1	0.2%	87	16.1%	
21mm to 30mm:	0	0.0%	0	0.0%	11	2.0%	
31mm to 40mm:	0	0.0%	0	0.0%	0	0.0%	
41mm to 50mm:	0	0.0%	0	0.0%	0	0.0%	
greater than 50mm:	0	0.0%	0	0.0%	0	0.0%	

9033 RTK comparison with control coordinates. 1200 receiver.

	E_misclose from CTRL		N_misclose from CTRL		AHD_misclose from CTRL			Coordinate quality
means:	-0.004		-0.005		-0.010			0.016
Standard Deviation:	0.003		0.005		0.010			0.002
range_highest:	0.008		0.009		0.022			0.022
range_lowest:	-0.014	**Percentage**	-0.019	**Percentage**	-0.038	**Percentage**		0.011
Total obs:	528	100.0%	528	100.0%	528	100.0%		
10mm or less:	523	99.1%	476	90.2%	257	48.7%		
11mm to 20mm:	5	0.9%	52	9.8%	191	36.2%		
21mm to 30mm:	0	0.0%	0	0.0%	74	14.0%		
31mm to 40mm:	0	0.0%	0	0.0%	6	1.1%		
41mm to 50mm:	0	0.0%	0	0.0%	0	0.0%		
greater than 50mm:	0	0.0%	0	0.0%	0	0.0%		

9033 RTK comparison with control coordinates. 500 receiver.

APPENDIX C

MT LAMBIE RTK - RESULTS ANALYSIS

	E_misclose from CTRL		N_misclose from CTRL		AHD_misclose from CTRL			Coordinate quality
means:	0.001		0.002		-0.010			0.022
Standard Deviation:	0.006		0.009		0.016			0.004
range_highest:	0.020		0.024		0.043			0.044
range_lowest:	-0.020	**Percentage**	-0.028	**Percentage**	-0.059	**Percentage**		0.013
Total obs:	658	100.0%	658	100.0%	658	100.0%		
10mm or less:	601	91.3%	482	73.3%	259	39.4%		
11mm to 20mm:	57	8.7%	154	23.4%	220	33.4%		
21mm to 30mm:	0	0.0%	22	3.3%	110	16.7%		
31mm to 40mm:	0	0.0%	0	0.0%	56	8.5%		
41mm to 50mm:	0	0.0%	0	0.0%	8	1.2%		
greater than 50mm:	0	0.0%	0	0.0%	5	0.8%		

9006 RTK comparison with control coordinates. 500 receiver

	E_misclose from CTRL		N_misclose from CTRL		AHD_misclose from CTRL		Coordinate quality
means:	-0.004		-0.004		0.192		0.014
Standard Deviation:	0.004		0.005		0.009		0.002
range_highest:	0.004		0.009		0.216		0.019
range_lowest:	-0.017	**Percentage**	-0.018	**Percentage**	0.164	**Percentage**	0.009
Total obs:	542	100.0%	542	100.0%	542	100.0%	
10mm or less:	516	95.2%	500	92.3%	0	0.0%	
11mm to 20mm:	26	4.8%	42	7.7%	0	0.0%	
21mm to 30mm:	0	0.0%	0	0.0%	0	0.0%	
31mm to 40mm:	0	0.0%	0	0.0%	0	0.0%	
41mm to 50mm:	0	0.0%	0	0.0%	0	0.0%	
greater than 50mm:	0	0.0%	0	0.0%	542	100.0%	

9006 RTK comparison with control coordinates. 1200 receiver

	E_misclose from CTRL		N_misclose from CTRL		AHD_misclose from CTRL		Coordinate quality
means:	-0.005		0.002		0.182		0.013
Standard Deviation:	0.004		0.004		0.008		0.002
range_highest:	0.004		0.014		0.206		0.019
range_lowest:	-0.015	**Percentage**	-0.008	**Percentage**	0.161	**Percentage**	0.009
Total obs:	533	100.0%	533	100.0%	533	100.0%	
10mm or less:	497	93.2%	525	98.5%	0	0.0%	
11mm to 20mm:	36	6.8%	8	1.5%	0	0.0%	
21mm to 30mm:	0	0.0%	0	0.0%	0	0.0%	
31mm to 40mm:	0	0.0%	0	0.0%	0	0.0%	
41mm to 50mm:	0	0.0%	0	0.0%	0	0.0%	
greater than 50mm:	0	0.0%	0	0.0%	533	100.0%	

100 RTK comparison with control coordinates. 1200 receiver

	E_misclose from CTRL		N_misclose from CTRL		AHD_misclose from CTRL		Coordinate quality
means:	-0.003		0.002		-0.004		0.019
Standard Deviation:	0.004		0.008		0.012		0.003
range_highest:	0.008		0.025		0.024		0.030
range_lowest:	-0.015	**Percentage**	-0.018	**Percentage**	-0.046	**Percentage**	0.012
Total obs:	554	100.0%	554	100.0%	554	100.0%	
10mm or less:	535	96.6%	454	81.9%	345	62.3%	
11mm to 20mm:	19	3.4%	96	17.3%	153	27.6%	
21mm to 30mm:	0	0.0%	4	0.7%	46	8.3%	
31mm to 40mm:	0	0.0%	0	0.0%	8	1.4%	
41mm to 50mm:	0	0.0%	0	0.0%	2	0.4%	
greater than 50mm:	0	0.0%	0	0.0%	0	0.0%	

100 RTK comparison with control coordinates. 500 receiver

	E_misclose from CTRL		N_misclose from CTRL		AHD_misclose from CTRL		Coordinate quality
means:	-0.002		0.007		-0.500		0.022
Standard Deviation:	0.005		0.006		0.013		0.004
range_highest:	0.011		0.023		-0.469		0.056
range_lowest:	-0.016	**Percentage**	-0.010	**Percentage**	-0.545	**Percentage**	0.014
Total obs:	506	100.0%	506	100.0%	506	100.0%	
10mm or less:	491	97.0%	372	73.5%	0	0.0%	
11mm to 20mm:	15	3.0%	127	25.1%	0	0.0%	
21mm to 30mm:	0	0.0%	7	1.4%	0	0.0%	
31mm to 40mm:	0	0.0%	0	0.0%	0	0.0%	
41mm to 50mm:	0	0.0%	0	0.0%	0	0.0%	
greater than 50mm:	0	0.0%	0	0.0%	506	100.0%	

101 RTK comparison with control coordinates. 500 receiver

	E_misclose from CTRL		N_misclose from CTRL		AHD_misclose from CTRL		Coordinate quality
means:	-0.005		-0.002		-0.313		0.013
Standard Deviation:	0.003		0.004		0.007		0.001
range_highest:	0.003		0.009		-0.292		0.019
range_lowest:	-0.015	**Percentage**	-0.013	**Percentage**	-0.333	**Percentage**	0.009
Total obs:	552	100.0%	552	100.0%	552	100.0%	
10mm or less:	515	93.3%	549	99.5%	0	0.0%	
11mm to 20mm:	37	6.7%	3	0.5%	0	0.0%	
21mm to 30mm:	0	0.0%	0	0.0%	0	0.0%	
31mm to 40mm:	0	0.0%	0	0.0%	0	0.0%	
41mm to 50mm:	0	0.0%	0	0.0%	0	0.0%	
greater than 50mm:	0	0.0%	0	0.0%	552	100.0%	

101 RTK comparison with control coordinates. 1200 receiver

	E_misclose from CTRL		N_misclose from CTRL		AHD_misclose from CTRL		Coordinate quality
means:	-0.008		0.002		0.008		0.026
Standard Deviation:	0.006		0.005		0.018		0.006
range_highest:	0.006		0.016		0.065		0.044
range_lowest:	-0.023	**Percentage**	-0.013	**Percentage**	-0.035	**Percentage**	0.016
Total obs:	505	100.0%	505	100.0%	505	100.0%	
10mm or less:	343	67.9%	473	93.7%	221	43.8%	
11mm to 20mm:	152	30.1%	32	6.3%	135	26.7%	
21mm to 30mm:	10	2.0%	0	0.0%	76	15.0%	
31mm to 40mm:	0	0.0%	0	0.0%	49	9.7%	
41mm to 50mm:	0	0.0%	0	0.0%	17	3.4%	
greater than 50mm:	0	0.0%	0	0.0%	7	1.4%	

102 RTK comparison with control coordinates. 500 receiver

	E_misclose from CTRL		N_misclose from CTRL		AHD_misclose from CTRL			Coordinate quality	
means:	-0.009		0.002			0.191			0.012
Standard Deviation:	0.003		0.004			0.009			0.001
range_highest:	0.002		0.014			0.210			0.017
range_lowest:	-0.020	**Percentage**	-0.009	**Percentage**		0.158	**Percentage**		0.009
Total obs:	546	100.0%	546	100.0%		546	100.0%		
10mm or less:	367	67.2%	534	97.8%		0	0.0%		
11mm to 20mm:	179	32.8%	12	2.2%		0	0.0%		
21mm to 30mm:	0	0.0%	0	0.0%		0	0.0%		
31mm to 40mm:	0	0.0%	0	0.0%		0	0.0%		
41mm to 50mm:	0	0.0%	0	0.0%		0	0.0%		
greater than 50mm:	0	0.0%	0	0.0%		546	100.0%		

102 RTK comparison with control coordinates.1200 receiver

	E_misclose from CTRL		N_misclose from CTRL		AHD_misclose from CTRL		Coordinate quality
means:	-0.007		-0.003		-0.325		0.024
Standard Deviation:	0.005		0.009		0.015		0.005
range_highest:	0.007		0.020		-0.281		0.044
range_lowest:	-0.021	**Percentage**	-0.027	**Percentage**	-0.363	**Percentage**	0.014
Total obs:	548	100.0%	548	100.0%	548	100.0%	
10mm or less:	379	69.2%	405	73.9%	0	0.0%	
11mm to 20mm:	168	30.7%	124	22.6%	0	0.0%	
21mm to 30mm:	1	0.2%	19	3.5%	0	0.0%	
31mm to 40mm:	0	0.0%	0	0.0%	0	0.0%	
41mm to 50mm:	0	0.0%	0	0.0%	0	0.0%	
greater than 50mm:	0	0.0%	0	0.0%	548	100.0%	

103 RTK comparison with control coordinates. 500 receiver

	E_misclose from CTRL		N_misclose from CTRL		AHD_misclose from CTRL		Coordinate quality
means:	-0.005		0.005		-0.152		0.018
Standard Deviation:	0.003		0.005		0.010		0.003
range_highest:	0.003		0.023		-0.127		0.030
range_lowest:	-0.016	**Percentage**	-0.008	**Percentage**	-0.181	**Percentage**	0.012
Total obs:	503	100.0%	503	100.0%	503	100.0%	
10mm or less:	466	92.6%	429	85.3%	0	0.0%	
11mm to 20mm:	37	7.4%	72	14.3%	0	0.0%	
21mm to 30mm:	0	0.0%	2	0.4%	0	0.0%	
31mm to 40mm:	0	0.0%	0	0.0%	0	0.0%	
41mm to 50mm:	0	0.0%	0	0.0%	0	0.0%	
greater than 50mm:	0	0.0%	0	0.0%	503	100.0%	

103 RTK comparison with control coordinates. 1200 receiver

	E_misclose from CTRL		N_misclose from CTRL		AHD_misclose from CTRL			Coordinate quality	
means:	-0.004		0.009			0.423			0.019
Standard Deviation:	0.006		0.007			0.013			0.004
range_highest:	0.016		0.045			0.465			0.037
range_lowest:	-0.023	**Percentage**	-0.017	**Percentage**		0.373	**Percentage**		0.012
Total obs:	620	100.0%	620	100.0%		620	100.0%		
10mm or less:	523	84.4%	399	64.4%		0	0.0%		
11mm to 20mm:	94	15.2%	178	28.7%		0	0.0%		
21mm to 30mm:	3	0.5%	36	5.8%		0	0.0%		
31mm to 40mm:	0	0.0%	6	1.0%		0	0.0%		
41mm to 50mm:	0	0.0%	1	0.2%		0	0.0%		
greater than 50mm:	0	0.0%	0	0.0%		620	100.0%		

104 RTK comparison with control coordinates. 500 receiver

	E_misclose from CTRL		N_misclose from CTRL		AHD_misclose from CTRL		Coordinate quality
means:	-0.014		0.009		0.654		0.025
Standard Deviation:	0.008		0.008		0.024		0.005
range_highest:	0.009		0.037		0.735		0.051
range_lowest:	-0.036	**Percentage**	-0.014	**Percentage**	0.596	**Percentage**	0.014
Total obs:	485	100.0%	485	100.0%	485	100.0%	
10mm or less:	126	26.0%	287	59.2%	0	0.0%	
11mm to 20mm:	270	55.7%	152	31.3%	0	0.0%	
21mm to 30mm:	83	17.1%	42	8.7%	0	0.0%	
31mm to 40mm:	6	1.2%	4	0.8%	0	0.0%	
41mm to 50mm:	0	0.0%	0	0.0%	0	0.0%	
greater than 50mm:	0	0.0%	0	0.0%	485	100.0%	

104 RTK comparison with control coordinates. 1200 receiver

	E_misclose from CTRL		N_misclose from CTRL		AHD_misclose from CTRL		Coordinate quality
means:	-0.009		0.005		0.624		0.022
Standard Deviation:	0.005		0.005		0.023		0.004
range_highest:	0.005		0.022		0.685		0.040
range_lowest:	-0.020	**Percentage**	-0.011	**Percentage**	0.562	**Percentage**	0.014
Total obs:	586	100.0%	586	100.0%	586	100.0%	
10mm or less:	363	61.9%	518	88.4%	0	0.0%	
11mm to 20mm:	223	38.1%	64	10.9%	0	0.0%	
21mm to 30mm:	0	0.0%	4	0.7%	0	0.0%	
31mm to 40mm:	0	0.0%	0	0.0%	0	0.0%	
41mm to 50mm:	0	0.0%	0	0.0%	0	0.0%	
greater than 50mm:	0	0.0%	0	0.0%	586	100.0%	

105 RTK comparison with control coordinates. 1200 receiver

	E_misclose from CTRL		N_misclose from CTRL		AHD_misclose from CTRL		Coordinate quality
means:	-0.001		-0.010		0.210		0.014
Standard Deviation:	0.003		0.004		0.007		0.011
range_highest:	0.017		0.003		0.229		0.259
range_lowest:	-0.009	**Percentage**	-0.024	**Percentage**	0.188	**Percentage**	0.010
Total obs:	501	100.0%	501	100.0%	501	100.0%	
10mm or less:	500	99.8%	268	53.5%	0	0.0%	
11mm to 20mm:	1	0.2%	230	45.9%	0	0.0%	
21mm to 30mm:	0	0.0%	3	0.6%	0	0.0%	
31mm to 40mm:	0	0.0%	0	0.0%	0	0.0%	
41mm to 50mm:	0	0.0%	0	0.0%	0	0.0%	
greater than 50mm:	0	0.0%	0	0.0%	501	100.0%	

9007 RTK comparison with control coordinates. 1200 receiver

	E_misclose from CTRL		N_misclose from CTRL		AHD_misclose from CTRL		Coordinate quality
means:	0.003		0.001		-0.180		0.017
Standard Deviation:	0.004		0.005		0.012		0.005
range_highest:	0.017		0.013		-0.139		0.036
range_lowest:	-0.008	**Percentage**	-0.014	**Percentage**	-0.230	**Percentage**	0.009
Total obs:	1333	100.0%	1333	100.0%	1333	100.0%	
10mm or less:	1320	99.0%	1293	97.0%	0	0.0%	
11mm to 20mm:	13	1.0%	40	3.0%	0	0.0%	
21mm to 30mm:	0	0.0%	0	0.0%	0	0.0%	
31mm to 40mm:	0	0.0%	0	0.0%	0	0.0%	
41mm to 50mm:	0	0.0%	0	0.0%	0	0.0%	
greater than 50mm:	0	0.0%	0	0.0%	1333	100.0%	

9003 RTK comparison with control coordinates. Base at adjacent control point 9006. 1200 receiver.

	E_misclose from CTRL		N_misclose from CTRL		AHD_misclose from CTRL		Coordinate quality
means:	0.006		0.003		0.010		0.022
Standard Deviation:	0.004		0.004		0.016		0.003
range_highest:	0.017		0.011		0.053		0.033
range_lowest:	-0.005	**Percentage**	-0.008	**Percentage**	-0.034	**Percentage**	0.014
Total obs:	512	100.0%	512	100.0%	512	100.0%	
10mm or less:	424	82.8%	509	99.4%	205	40.0%	
11mm to 20mm:	88	17.2%	3	0.6%	165	32.2%	
21mm to 30mm:	0	0.0%	0	0.0%	97	18.9%	
31mm to 40mm:	0	0.0%	0	0.0%	29	5.7%	
41mm to 50mm:	0	0.0%	0	0.0%	13	2.5%	
greater than 50mm:	0	0.0%	0	0.0%	3	0.6%	

9005 RTK comparison with control coordinates. Base at adjacent control point 9006. 1200 receiver.

	E_misclose from CTRL		N_misclose from CTRL		AHD_misclose from CTRL		Coordinate quality
means:	0.002		-0.007		0.020		0.014
Standard Deviation:	0.005		0.005		0.010		0.003
range_highest:	0.021		0.010		0.058		0.026
range_lowest:	-0.008	**Percentage**	-0.026	**Percentage**	-0.004	**Percentage**	0.009
Total obs:	956	100.0%	956	100.0%	956	100.0%	
10mm or less:	906	94.8%	744	77.8%	150	15.7%	
11mm to 20mm:	46	4.8%	203	21.2%	434	45.4%	
21mm to 30mm:	4	0.4%	9	0.9%	263	27.5%	
31mm to 40mm:	0	0.0%	0	0.0%	60	6.3%	
41mm to 50mm:	0	0.0%	0	0.0%	32	3.3%	
greater than 50mm:	0	0.0%	0	0.0%	17	1.8%	

9007 RTK comparison with control coordinates. Base at adjacent control point 9006. 1200 receiver

APPENDIX D

BURRENDONG SITE A - RTK ANALYSIS

	E_misclose from CTRL		N_misclose from CTRL		AHD_misclose from CTRL			Coordinate quality
means:	-0.008		-0.006		0.002			0.019
Standard Deviation:	0.004		0.004		0.012			0.003
range_highest:	0.005		0.006		0.036			0.030
range_lowest:	-0.020	**Percentage**	-0.018	**Percentage**	-0.039	**Percentage**		0.011
Total obs:	841	100.0%	841	100.0%	841	100.0%		
10mm or less:	616	73.2%	760	90.4%	515	61.2%		
11mm to 20mm:	225	26.8%	81	9.6%	249	29.6%		
21mm to 30mm:	0	0.0%	0	0.0%	67	8.0%		
31mm to 40mm:	0	0.0%	0	0.0%	10	1.2%		
41mm to 50mm:	0	0.0%	0	0.0%	0	0.0%		
greater than 50mm:	0	0.0%	0	0.0%	0	0.0%		

200 RTK comparison with control coordinates. 500 receiver

	E_misclose from CTRL		N_misclose from CTRL		AHD_misclose from CTRL		Coordinate quality
means:	-0.011		-0.008		-0.006		0.020
Standard Deviation:	0.004		0.004		0.016		0.004
range_highest:	-0.002		0.001		0.043		0.039
range_lowest:	-0.028	**Percentage**	-0.019	**Percentage**	-0.048	**Percentage**	0.013
Total obs:	687	100.0%	687	100.0%	687	100.0%	
10mm or less:	401	58.4%	497	72.3%	297	43.2%	
11mm to 20mm:	268	39.0%	190	27.7%	221	32.2%	
21mm to 30mm:	18	2.6%	0	0.0%	122	17.8%	
31mm to 40mm:	0	0.0%	0	0.0%	38	5.5%	
41mm to 50mm:	0	0.0%	0	0.0%	9	1.3%	
greater than 50mm:	0	0.0%	0	0.0%	0	0.0%	

200 RTK comparison with control coordinates. 1200 receiver

	E_misclose from CTRL		N_misclose from CTRL		AHD_misclose from CTRL		Coordinate quality
means:	-0.002		-0.003		-0.007		0.013
Standard Deviation:	0.003		0.004		0.008		0.002
range_highest:	0.008		0.010		0.019		0.021
range_lowest:	-0.009	**Percentage**	-0.014	**Percentage**	-0.027	**Percentage**	0.009
Total obs:	649	100.0%	649	100.0%	649	100.0%	
10mm or less:	649	100.0%	631	97.2%	409	63.0%	
11mm to 20mm:	0	0.0%	18	2.8%	212	32.7%	
21mm to 30mm:	0	0.0%	0	0.0%	28	4.3%	
31mm to 40mm:	0	0.0%	0	0.0%	0	0.0%	
41mm to 50mm:	0	0.0%	0	0.0%	0	0.0%	
greater than 50mm:	0	0.0%	0	0.0%	0	0.0%	

201 RTK comparison with control coordinates. 500 receiver

	E_misclose from CTRL		N_misclose from CTRL		AHD_misclose from CTRL		Coordinate quality
means:	-0.006		-0.009		0.006		0.013
Standard Deviation:	0.004		0.004		0.013		0.002
range_highest:	0.010		0.001		0.043		0.024
range_lowest:	-0.017	**Percentage**	-0.024	**Percentage**	-0.023	**Percentage**	0.009
Total obs:	1345	100.0%	1345	100.0%	1345	100.0%	
10mm or less:	1172	87.1%	874	65.0%	769	57.2%	
11mm to 20mm:	173	12.9%	459	34.1%	352	26.2%	
21mm to 30mm:	0	0.0%	12	0.9%	171	12.7%	
31mm to 40mm:	0	0.0%	0	0.0%	51	3.8%	
41mm to 50mm:	0	0.0%	0	0.0%	2	0.1%	
greater than 50mm:	0	0.0%	0	0.0%	0	0.0%	

201 RTK comparison with control coordinates. 1200 receiver

	E_misclose from CTRL		N_misclose from CTRL		AHD_misclose from CTRL		Coordinate quality
means:	-0.008		-0.010		0.013		0.011
Standard Deviation:	0.006		0.004		0.006		0.002
range_highest:	0.003		0.003		0.032		0.026
range_lowest:	-0.025	**Percentage**	-0.023	**Percentage**	-0.004	**Percentage**	0.007
Total obs:	989	100.0%	989	100.0%	989	100.0%	
10mm or less:	699	70.7%	551	55.7%	363	36.7%	
11mm to 20mm:	261	26.4%	436	44.1%	521	52.7%	
21mm to 30mm:	29	2.9%	2	0.2%	104	10.5%	
31mm to 40mm:	0	0.0%	0	0.0%	1	0.1%	
41mm to 50mm:	0	0.0%	0	0.0%	0	0.0%	
greater than 50mm:	0	0.0%	0	0.0%	0	0.0%	

202 RTK comparison with control coordinates. 1200 receiver

	E_misclose from CTRL		N_misclose from CTRL		AHD_misclose from CTRL		Coordinate quality
means:	-0.006		-0.010		0.011		0.011
Standard Deviation:	0.005		0.004		0.005		0.001
range_highest:	0.006		0.003		0.026		0.025
range_lowest:	-0.022	**Percentage**	-0.021	**Percentage**	-0.006	**Percentage**	0.008
Total obs:	839	100.0%	839	100.0%	839	100.0%	
10mm or less:	650	77.5%	450	53.6%	381	45.4%	
11mm to 20mm:	188	22.4%	387	46.1%	426	50.8%	
21mm to 30mm:	1	0.1%	2	0.2%	32	3.8%	
31mm to 40mm:	0	0.0%	0	0.0%	0	0.0%	
41mm to 50mm:	0	0.0%	0	0.0%	0	0.0%	
greater than 50mm:	0	0.0%	0	0.0%	0	0.0%	

203 RTK comparison with control coordinates. 1200 receiver

	E_misclose from CTRL		N_misclose from CTRL		AHD_misclose from CTRL		Coordinate quality
means:	-0.001		-0.011		-0.002		0.017
Standard Deviation:	0.006		0.007		0.014		0.003
range_highest:	0.021		0.009		0.040		0.030
range_lowest:	-0.017	**Percentage**	-0.041	**Percentage**	-0.041	**Percentage**	0.011
Total obs:	1438	100.0%	1438	100.0%	1438	100.0%	
10mm or less:	1337	93.0%	706	49.1%	760	52.9%	
11mm to 20mm:	100	7.0%	611	42.5%	481	33.4%	
21mm to 30mm:	1	0.1%	117	8.1%	171	11.9%	
31mm to 40mm:	0	0.0%	3	0.2%	25	1.7%	
41mm to 50mm:	0	0.0%	1	0.1%	1	0.1%	
greater than 50mm:	0	0.0%	0	0.0%	0	0.0%	

204 RTK comparison with control coordinates. 500 receiver

	E_misclose from CTRL		N_misclose from CTRL		AHD_misclose from CTRL		Coordinate quality
means:	-0.005		-0.007		0.004		0.019
Standard Deviation:	0.004		0.004		0.014		0.003
range_highest:	0.006		0.010		0.046		0.030
range_lowest:	-0.019	**Percentage**	-0.019	**Percentage**	-0.035	**Percentage**	0.012
Total obs:	930	100.0%	930	100.0%	930	100.0%	
10mm or less:	876	94.2%	708	76.1%	453	48.7%	
11mm to 20mm:	54	5.8%	222	23.9%	330	35.5%	
21mm to 30mm:	0	0.0%	0	0.0%	122	13.1%	
31mm to 40mm:	0	0.0%	0	0.0%	23	2.5%	
41mm to 50mm:	0	0.0%	0	0.0%	2	0.2%	
greater than 50mm:	0	0.0%	0	0.0%	0	0.0%	

204 RTK comparison with control coordinates. 1200 receiver

	E_misclose from CTRL		N_misclose from CTRL		AHD_misclose from CTRL		Coordinate quality
means:	-0.006		-0.011		0.011		0.013
Standard Deviation:	0.004		0.004		0.012		0.002
range_highest:	0.006		0.000		0.043		0.019
range_lowest:	-0.019	**Percentage**	-0.023	**Percentage**	-0.020	**Percentage**	0.009
Total obs:	1348	100.0%	1348	100.0%	1348	100.0%	
10mm or less:	1104	81.9%	714	53.0%	649	48.1%	
11mm to 20mm:	244	18.1%	622	46.1%	425	31.5%	
21mm to 30mm:	0	0.0%	12	0.9%	164	12.2%	
31mm to 40mm:	0	0.0%	0	0.0%	99	7.3%	
41mm to 50mm:	0	0.0%	0	0.0%	11	0.8%	
greater than 50mm:	0	0.0%	0	0.0%	0	0.0%	

205 RTK comparison with control coordinates. 1200 receiver

	E_misclose from CTRL		N_misclose from CTRL		AHD_misclose from CTRL			Coordinate quality
means:	0.000		0.005		-0.002			0.015
Standard Deviation:	0.004		0.004		0.008			0.002
range_highest:	0.011		0.018		0.028			0.022
range_lowest:	-0.012	**Percentage**	-0.006	**Percentage**	-0.031	**Percentage**		0.010
Total obs:	657	100.0%	657	100.0%	657	100.0%		
10mm or less:	654	99.5%	598	91.0%	517	78.7%		
11mm to 20mm:	3	0.5%	59	9.0%	132	20.1%		
21mm to 30mm:	0	0.0%	0	0.0%	7	1.1%		
31mm to 40mm:	0	0.0%	0	0.0%	1	0.2%		
41mm to 50mm:	0	0.0%	0	0.0%	0	0.0%		
greater than 50mm:	0	0.0%	0	0.0%	0	0.0%		

9012 RTK comparison with control coordinates. 500 receiver

	E_misclose from CTRL		N_misclose from CTRL		AHD_misclose from CTRL		Coordinate quality
means:	0.004		0.002		0.011		0.015
Standard Deviation:	0.003		0.006		0.008		0.003
range_highest:	0.013		0.021		0.036		0.028
range_lowest:	-0.006	**Percentage**	-0.013	**Percentage**	-0.025	**Percentage**	0.010
Total obs:	891	100.0%	891	100.0%	891	100.0%	
10mm or less:	868	97.4%	806	90.5%	388	43.5%	
11mm to 20mm:	23	2.6%	84	9.4%	417	46.8%	
21mm to 30mm:	0	0.0%	1	0.1%	82	9.2%	
31mm to 40mm:	0	0.0%	0	0.0%	4	0.4%	
41mm to 50mm:	0	0.0%	0	0.0%	0	0.0%	
greater than 50mm:	0	0.0%	0	0.0%	0	0.0%	

9012 RTK comparison with control coordinates. 1200 receiver

APPENDIX E

BURRENDONG SITE B - RTK ANALYSIS

	E_misclose from CTRL		N_misclose from CTRL		AHD_misclose from CTRL		Coordinate quality
means:	0.003		0.003		0.002		0.019
Standard Deviation:	0.005		0.003		0.011		0.003
range_highest:	0.016		0.012		0.034		0.030
range_lowest:	-0.013	**Percentage**	-0.005	**Percentage**	-0.028	**Percentage**	0.012
Total obs:	542	100.0%	542	100.0%	542	100.0%	
10mm or less:	498	91.9%	537	99.1%	364	67.2%	
11mm to 20mm:	44	8.1%	5	0.9%	138	25.5%	
21mm to 30mm:	0	0.0%	0	0.0%	37	6.8%	
31mm to 40mm:	0	0.0%	0	0.0%	3	0.6%	
41mm to 50mm:	0	0.0%	0	0.0%	0	0.0%	
greater than 50mm:	0	0.0%	0	0.0%	0	0.0%	

9014 RTK comparison with control coordinates. 500 receiver

	E_misclose from CTRL		N_misclose from CTRL		AHD_misclose from CTRL		Coordinate quality
means:	0.005		0.006		0.022		0.016
Standard Deviation:	0.003		0.005		0.009		0.003
range_highest:	0.014		0.023		0.065		0.029
range_lowest:	-0.004	**Percentage**	-0.009	**Percentage**	-0.002	**Percentage**	0.010
Total obs:	874	100.0%	874	100.0%	874	100.0%	
10mm or less:	838	95.9%	744	85.1%	64	7.3%	
11mm to 20mm:	36	4.1%	128	14.6%	333	38.1%	
21mm to 30mm:	0	0.0%	2	0.2%	346	39.6%	
31mm to 40mm:	0	0.0%	0	0.0%	107	12.2%	
41mm to 50mm:	0	0.0%	0	0.0%	18	2.1%	
greater than 50mm:	0	0.0%	0	0.0%	6	0.7%	

9014 RTK comparison with control coordinates. 1200 receiver

	E_misclose from CTRL		N_misclose from CTRL		AHD_misclose from CTRL		Coordinate quality
means:	-0.003		0.013		0.000		0.016
Standard Deviation:	0.004		0.005		0.008		0.002
range_highest:	0.008		0.026		0.034		0.022
range_lowest:	-0.016	**Percentage**	-0.004	**Percentage**	-0.026	**Percentage**	0.009
Total obs:	587	100.0%	587	100.0%	587	100.0%	
10mm or less:	557	94.9%	170	29.0%	472	80.4%	
11mm to 20mm:	30	5.1%	382	65.1%	108	18.4%	
21mm to 30mm:	0	0.0%	35	6.0%	6	1.0%	
31mm to 40mm:	0	0.0%	0	0.0%	1	0.2%	
41mm to 50mm:	0	0.0%	0	0.0%	0	0.0%	
greater than 50mm:	0	0.0%	0	0.0%	0	0.0%	

300 RTK comparison with control coordinates. 500 receiver

	E_misclose from CTRL		N_misclose from CTRL		AHD_misclose from CTRL			Coordinate quality
means:	-0.001		0.011		0.006			0.015
Standard Deviation:	0.003		0.004		0.008			0.002
range_highest:	0.007		0.024		0.026			0.021
range_lowest:	-0.011	**Percentage**	-0.002	**Percentage**	-0.016	**Percentage**		0.010
Total obs:	508	100.0%	508	100.0%	508	100.0%		
10mm or less:	507	99.8%	239	47.0%	357	70.3%		
11mm to 20mm:	1	0.2%	267	52.6%	136	26.8%		
21mm to 30mm:	0	0.0%	2	0.4%	15	3.0%		
31mm to 40mm:	0	0.0%	0	0.0%	0	0.0%		
41mm to 50mm:	0	0.0%	0	0.0%	0	0.0%		
greater than 50mm:	0	0.0%	0	0.0%	0	0.0%		

301 RTK comparison with control coordinates. 500 receiver

	E_misclose from CTRL		N_misclose from CTRL		AHD_misclose from CTRL		Coordinate quality
means:	-0.010		0.010		0.029		0.015
Standard Deviation:	0.005		0.004		0.011		0.004
range_highest:	0.001		0.022		0.061		0.027
range_lowest:	-0.020	**Percentage**	0.000	**Percentage**	-0.003	**Percentage**	0.009
Total obs:	512	100.0%	512	100.0%	512	100.0%	
10mm or less:	244	47.7%	305	59.6%	18	3.5%	
11mm to 20mm:	268	52.3%	206	40.2%	83	16.2%	
21mm to 30mm:	0	0.0%	1	0.2%	193	37.7%	
31mm to 40mm:	0	0.0%	0	0.0%	141	27.5%	
41mm to 50mm:	0	0.0%	0	0.0%	59	11.5%	
greater than 50mm:	0	0.0%	0	0.0%	18	3.5%	

301 RTK comparison with control coordinates. 1200 receiver

	E_misclose from CTRL		N_misclose from CTRL		AHD_misclose from CTRL		Coordinate quality
means:	-0.004		0.009		0.006		0.020
Standard Deviation:	0.007		0.014		0.018		0.005
range_highest:	0.019		0.037		0.038		0.033
range_lowest:	-0.018	**Percentage**	-0.028	**Percentage**	-0.051	**Percentage**	0.011
Total obs:	533	100.0%	533	100.0%	533	100.0%	
10mm or less:	395	74.1%	209	39.2%	227	42.6%	
11mm to 20mm:	138	25.9%	187	35.1%	160	30.0%	
21mm to 30mm:	0	0.0%	118	22.1%	93	17.4%	
31mm to 40mm:	0	0.0%	19	3.6%	36	6.8%	
41mm to 50mm:	0	0.0%	0	0.0%	16	3.0%	
greater than 50mm:	0	0.0%	0	0.0%	1	0.2%	

302 RTK comparison with control coordinates. 500 receiver

	E_misclose from CTRL		N_misclose from CTRL		AHD_misclose from CTRL		Coordinate quality
means:	-0.007		0.003		0.011		0.012
Standard Deviation:	0.003		0.003		0.006		0.002
range_highest:	0.000		0.014		0.030		0.019
range_lowest:	-0.016	**Percentage**	-0.004	**Percentage**	-0.014	**Percentage**	0.008
Total obs:	520	100.0%	520	100.0%	520	100.0%	
10mm or less:	454	87.3%	507	97.5%	206	39.6%	
11mm to 20mm:	66	12.7%	13	2.5%	294	56.5%	
21mm to 30mm:	0	0.0%	0	0.0%	20	3.8%	
31mm to 40mm:	0	0.0%	0	0.0%	0	0.0%	
41mm to 50mm:	0	0.0%	0	0.0%	0	0.0%	
greater than 50mm:	0	0.0%	0	0.0%	0	0.0%	

302 RTK comparison with control coordinates. 500 receiver

	E_misclose from CTRL		N_misclose from CTRL		AHD_misclose from CTRL		Coordinate quality
means:	-0.006		0.000		0.008		0.012
Standard Deviation:	0.002		0.003		0.006		0.002
range_highest:	0.001		0.011		0.023		0.019
range_lowest:	-0.012	**Percentage**	-0.009	**Percentage**	-0.008	**Percentage**	0.009
Total obs:	509	100.0%	509	100.0%	509	100.0%	
10mm or less:	507	99.6%	508	99.8%	345	67.8%	
11mm to 20mm:	2	0.4%	1	0.2%	159	31.2%	
21mm to 30mm:	0	0.0%	0	0.0%	5	1.0%	
31mm to 40mm:	0	0.0%	0	0.0%	0	0.0%	
41mm to 50mm:	0	0.0%	0	0.0%	0	0.0%	
greater than 50mm:	0	0.0%	0	0.0%	0	0.0%	

303 RTK comparison with control coordinates. 1200 receiver

	E_misclose from CTRL		N_misclose from CTRL		AHD_misclose from CTRL		Coordinate quality
means:	0.002		0.007		0.008		0.018
Standard Deviation:	0.004		0.006		0.010		0.005
range_highest:	0.014		0.045		0.033		0.117
range_lowest:	-0.010	**Percentage**	-0.005	**Percentage**	-0.023	**Percentage**	0.010
Total obs:	534	100.0%	534	100.0%	534	100.0%	
10mm or less:	522	97.8%	399	74.7%	322	60.3%	
11mm to 20mm:	12	2.2%	126	23.6%	152	28.5%	
21mm to 30mm:	0	0.0%	8	1.5%	57	10.7%	
31mm to 40mm:	0	0.0%	0	0.0%	3	0.6%	
41mm to 50mm:	0	0.0%	1	0.2%	0	0.0%	
greater than 50mm:	0	0.0%	0	0.0%	0	0.0%	

304 RTK comparison with control coordinates. 500 receiver

	E_misclose from CTRL		N_misclose from CTRL		AHD_misclose from CTRL			Coordinate quality
means:	0.000		0.005		0.008			0.013
Standard Deviation:	0.003		0.003		0.007			0.002
range_highest:	0.009		0.016		0.028			0.021
range_lowest:	-0.008	**Percentage**	-0.004	**Percentage**	-0.010	**Percentage**		0.009
Total obs:	534	100.0%	534	100.0%	534	100.0%		
10mm or less:	534	100.0%	500	93.6%	325	60.9%		
11mm to 20mm:	0	0.0%	34	6.4%	193	36.1%		
21mm to 30mm:	0	0.0%	0	0.0%	16	3.0%		
31mm to 40mm:	0	0.0%	0	0.0%	0	0.0%		
41mm to 50mm:	0	0.0%	0	0.0%	0	0.0%		
greater than 50mm:	0	0.0%	0	0.0%	0	0.0%		

304 RTK comparison with control coordinates. 1200 receiver

	E_misclose from CTRL		N_misclose from CTRL		AHD_misclose from CTRL		Coordinate quality
means:	0.005		0.002		0.008		0.014
Standard Deviation:	0.003		0.002		0.008		0.001
range_highest:	0.012		0.007		0.033		0.019
range_lowest:	-0.005	**Percentage**	-0.005	**Percentage**	-0.018	**Percentage**	0.011
Total obs:	582	100.0%	582	100.0%	582	100.0%	
10mm or less:	570	97.9%	582	100.0%	381	65.5%	
11mm to 20mm:	12	2.1%	0	0.0%	170	29.2%	
21mm to 30mm:	0	0.0%	0	0.0%	30	5.2%	
31mm to 40mm:	0	0.0%	0	0.0%	1	0.2%	
41mm to 50mm:	0	0.0%	0	0.0%	0	0.0%	
greater than 50mm:	0	0.0%	0	0.0%	0	0.0%	

305 RTK comparison with control coordinates. 1200 receiver

APPENDIX F

BURRENDONG SITE C - RTK ANALYSIS

	E_misclose from CTRL		N_misclose from CTRL		AHD_misclose from CTRL		Coordinate quality
means:	0.001		0.001		-0.012		0.020
Standard Deviation:	0.004		0.006		0.013		0.004
range_highest:	0.014		0.016		0.020		0.032
range_lowest:	-0.012	**Percentage**	-0.018	**Percentage**	-0.056	**Percentage**	0.011
Total obs:	800	100.0%	800	100.0%	800	100.0%	
10mm or less:	786	98.3%	747	93.4%	330	41.3%	
11mm to 20mm:	14	1.8%	53	6.6%	252	31.5%	
21mm to 30mm:	0	0.0%	0	0.0%	161	20.1%	
31mm to 40mm:	0	0.0%	0	0.0%	48	6.0%	
41mm to 50mm:	0	0.0%	0	0.0%	7	0.9%	
greater than 50mm:	0	0.0%	0	0.0%	2	0.3%	

9013 RTK comparison with control coordinates. 500 receiver

	E_misclose from CTRL		N_misclose from CTRL		AHD_misclose from CTRL			Coordinate quality
means:	0.002		-0.001		-0.005			0.019
Standard Deviation:	0.005		0.004		0.018			0.021
range_highest:	0.092		0.014		0.078			0.551
range_lowest:	-0.017	**Percentage**	-0.015	**Percentage**	-0.303	**Percentage**		0.011
Total obs:	1025	100.0%	1025	100.0%	1025	100.0%		
10mm or less:	1006	98.1%	1007	98.2%	590	57.6%		
11mm to 20mm:	15	1.5%	18	1.8%	310	30.2%		
21mm to 30mm:	1	0.1%	0	0.0%	95	9.3%		
31mm to 40mm:	0	0.0%	0	0.0%	23	2.2%		
41mm to 50mm:	1	0.1%	0	0.0%	2	0.2%		
greater than 50mm:	2	0.2%	0	0.0%	5	0.5%		

9013 RTK comparison with control coordinates. 1200 receiver

	E_misclose from CTRL		N_misclose from CTRL		AHD_misclose from CTRL		Coordinate quality
means:	0.002		-0.003		0.003		0.016
Standard Deviation:	0.004		0.004		0.010		0.003
range_highest:	0.013		0.008		0.036		0.026
range_lowest:	-0.014	**Percentage**	-0.018	**Percentage**	-0.030	**Percentage**	0.010
Total obs:	562	100.0%	562	100.0%	562	100.0%	
10mm or less:	553	98.4%	540	96.1%	385	68.5%	
11mm to 20mm:	9	1.6%	22	3.9%	143	25.4%	
21mm to 30mm:	0	0.0%	0	0.0%	32	5.7%	
31mm to 40mm:	0	0.0%	0	0.0%	2	0.4%	
41mm to 50mm:	0	0.0%	0	0.0%	0	0.0%	
greater than 50mm:	0	0.0%	0	0.0%	0	0.0%	

400 RTK comparison with control coordinates. 500 receiver

	E_misclose from CTRL		N_misclose from CTRL		AHD_misclose from CTRL		Coordinate quality
means:	0.004		-0.009		0.001		0.014
Standard Deviation:	0.004		0.004		0.007		0.002
range_highest:	0.015		0.003		0.023		0.022
range_lowest:	-0.004	**Percentage**	-0.021	**Percentage**	-0.018	**Percentage**	0.010
Total obs:	984	100.0%	984	100.0%	984	100.0%	
10mm or less:	903	91.8%	639	64.9%	853	86.7%	
11mm to 20mm:	81	8.2%	344	35.0%	127	12.9%	
21mm to 30mm:	0	0.0%	1	0.1%	4	0.4%	
31mm to 40mm:	0	0.0%	0	0.0%	0	0.0%	
41mm to 50mm:	0	0.0%	0	0.0%	0	0.0%	
greater than 50mm:	0	0.0%	0	0.0%	0	0.0%	

400 RTK comparison with control coordinates. 1200 receiver

	E_misclose from CTRL		N_misclose from CTRL		AHD_misclose from CTRL			Coordinate quality
means:	0.002		0.000		0.000			0.015
Standard Deviation:	0.004		0.005		0.009			0.002
range_highest:	0.012		0.016		0.022			0.022
range_lowest:	-0.009	**Percentage**	-0.013	**Percentage**	-0.030	**Percentage**		0.010
Total obs:	505	100.0%	505	100.0%	505	100.0%		
10mm or less:	498	98.6%	489	96.8%	381	75.4%		
11mm to 20mm:	7	1.4%	16	3.2%	113	22.4%		
21mm to 30mm:	0	0.0%	0	0.0%	11	2.2%		
31mm to 40mm:	0	0.0%	0	0.0%	0	0.0%		
41mm to 50mm:	0	0.0%	0	0.0%	0	0.0%		
greater than 50mm:	0	0.0%	0	0.0%	0	0.0%		

401 RTK comparison with control coordinates. 500 receiver

	E_misclose from CTRL		N_misclose from CTRL		AHD_misclose from CTRL		Coordinate quality
means:	-0.003		-0.002		-0.003		0.015
Standard Deviation:	0.003		0.004		0.008		0.004
range_highest:	0.006		0.007		0.017		0.029
range_lowest:	-0.010	**Percentage**	-0.016	**Percentage**	-0.034	**Percentage**	0.008
Total obs:	650	100.0%	650	100.0%	650	100.0%	
10mm or less:	650	100.0%	638	98.2%	512	78.8%	
11mm to 20mm:	0	0.0%	12	1.8%	117	18.0%	
21mm to 30mm:	0	0.0%	0	0.0%	20	3.1%	
31mm to 40mm:	0	0.0%	0	0.0%	1	0.2%	
41mm to 50mm:	0	0.0%	0	0.0%	0	0.0%	
greater than 50mm:	0	0.0%	0	0.0%	0	0.0%	

401 RTK comparison with control coordinates. 1200 receiver

	E_misclose from CTRL		N_misclose from CTRL		AHD_misclose from CTRL		Coordinate quality
means:	0.005		0.003		-0.001		0.013
Standard Deviation:	0.003		0.003		0.007		0.001
range_highest:	0.014		0.013		0.022		0.018
range_lowest:	-0.002	**Percentage**	-0.007	**Percentage**	-0.021	**Percentage**	0.009
Total obs:	566	100.0%	566	100.0%	566	100.0%	
10mm or less:	554	97.9%	560	98.9%	485	85.7%	
11mm to 20mm:	12	2.1%	6	1.1%	79	14.0%	
21mm to 30mm:	0	0.0%	0	0.0%	2	0.4%	
31mm to 40mm:	0	0.0%	0	0.0%	0	0.0%	
41mm to 50mm:	0	0.0%	0	0.0%	0	0.0%	
greater than 50mm:	0	0.0%	0	0.0%	0	0.0%	

402 RTK comparison with control coordinates. 1200 receiver

	E_misclose from CTRL		N_misclose from CTRL		AHD_misclose from CTRL		Coordinate quality
means:	0.009		0.003		0.002		0.015
Standard Deviation:	0.004		0.006		0.008		0.002
range_highest:	0.021		0.016		0.021		0.024
range_lowest:	-0.003	**Percentage**	-0.018	**Percentage**	-0.017	**Percentage**	0.010
Total obs:	502	100.0%	502	100.0%	502	100.0%	
10mm or less:	312	62.2%	454	90.4%	415	82.7%	
11mm to 20mm:	189	37.6%	48	9.6%	85	16.9%	
21mm to 30mm:	1	0.2%	0	0.0%	2	0.4%	
31mm to 40mm:	0	0.0%	0	0.0%	0	0.0%	
41mm to 50mm:	0	0.0%	0	0.0%	0	0.0%	
greater than 50mm:	0	0.0%	0	0.0%	0	0.0%	

403 RTK comparison with control coordinates. 500 receiver

	E_misclose from CTRL		N_misclose from CTRL		AHD_misclose from CTRL		Coordinate quality
means:	0.007		0.007		0.007		0.012
Standard Deviation:	0.004		0.003		0.008		0.002
range_highest:	0.016		0.017		0.028		0.017
range_lowest:	-0.003	**Percentage**	0.000	**Percentage**	-0.016	**Percentage**	0.009
Total obs:	505	100.0%	505	100.0%	505	100.0%	
10mm or less:	422	83.6%	430	85.1%	320	63.4%	
11mm to 20mm:	83	16.4%	75	14.9%	163	32.3%	
21mm to 30mm:	0	0.0%	0	0.0%	22	4.4%	
31mm to 40mm:	0	0.0%	0	0.0%	0	0.0%	
41mm to 50mm:	0	0.0%	0	0.0%	0	0.0%	
greater than 50mm:	0	0.0%	0	0.0%	0	0.0%	

403 RTK comparison with control coordinates. 1200 receiver

	E_misclose from CTRL		N_misclose from CTRL		AHD_misclose from CTRL		Coordinate quality
means:	0.002		0.003		0.003		0.013
Standard Deviation:	0.003		0.003		0.007		0.002
range_highest:	0.009		0.012		0.020		0.019
range_lowest:	-0.005	**Percentage**	-0.006	**Percentage**	-0.018	**Percentage**	0.008
Total obs:	613	100.0%	613	100.0%	613	100.0%	
10mm or less:	613	100.0%	612	99.8%	512	83.5%	
11mm to 20mm:	0	0.0%	1	0.2%	101	16.5%	
21mm to 30mm:	0	0.0%	0	0.0%	0	0.0%	
31mm to 40mm:	0	0.0%	0	0.0%	0	0.0%	
41mm to 50mm:	0	0.0%	0	0.0%	0	0.0%	
greater than 50mm:	0	0.0%	0	0.0%	0	0.0%	

404 RTK comparison with control coordinates. 1200 receiver

	E_misclose from CTRL		N_misclose from CTRL		AHD_misclose from CTRL		Coordinate quality
means:	0.007		0.004		0.019		0.020
Standard Deviation:	0.006		0.007		0.016		0.003
range_highest:	0.023		0.024		0.063		0.032
range_lowest:	-0.012	**Percentage**	-0.014	**Percentage**	-0.038	**Percentage**	0.013
Total obs:	509	100.0%	509	100.0%	509	100.0%	
10mm or less:	377	74.1%	408	80.2%	105	20.6%	
11mm to 20mm:	126	24.8%	97	19.1%	128	25.1%	
21mm to 30mm:	6	1.2%	4	0.8%	151	29.7%	
31mm to 40mm:	0	0.0%	0	0.0%	96	18.9%	
41mm to 50mm:	0	0.0%	0	0.0%	21	4.1%	
greater than 50mm:	0	0.0%	0	0.0%	8	1.6%	

405 RTK comparison with control coordinates. 500 receiver

	E_misclose from CTRL		N_misclose from CTRL		AHD_misclose from CTRL		Coordinate quality
means:	0.007		0.001		0.004		0.015
Standard Deviation:	0.005		0.004		0.008		0.002
range_highest:	0.021		0.014		0.028		0.023
range_lowest:	-0.004	**<u>Percentage</u>**	-0.015	**<u>Percentage</u>**	-0.022	**<u>Percentage</u>**	0.010
Total obs:	1008	100.0%	1008	100.0%	1008	100.0%	
10mm or less:	752	74.6%	989	98.1%	813	80.7%	
11mm to 20mm:	255	25.3%	19	1.9%	168	16.7%	
21mm to 30mm:	1	0.1%	0	0.0%	27	2.7%	
31mm to 40mm:	0	0.0%	0	0.0%	0	0.0%	
41mm to 50mm:	0	0.0%	0	0.0%	0	0.0%	
greater than 50mm:	0	0.0%	0	0.0%	0	0.0%	

405 RTK comparison with control coordinates. 1200 receiver

APPENDIX G

BURRENDONG CONTROL POINT TO CONTROL POINT - RTK ANALYSIS

	E_misclose from CTRL		N_misclose from CTRL		AHD_misclose from CTRL		Coordinate quality
means:	0.006		-0.001		0.003		0.014
Standard Deviation:	0.002		0.002		0.006		0.002
range_highest:	0.011		0.006		0.019		0.020
range_lowest:	-0.001	**Percentage**	-0.007	**Percentage**	-0.017	**Percentage**	0.009
Total obs:	565	100.0%	565	100.0%	565	100.0%	
10mm or less:	561	99.3%	565	100.0%	498	88.1%	
11mm to 20mm:	4	0.7%	0	0.0%	67	11.9%	
21mm to 30mm:	0	0.0%	0	0.0%	0	0.0%	
31mm to 40mm:	0	0.0%	0	0.0%	0	0.0%	
41mm to 50mm:	0	0.0%	0	0.0%	0	0.0%	
greater than 50mm:	0	0.0%	0	0.0%	0	0.0%	

P11 RTK comparison with control coordinates. Base at remote control point 9011. 1200 receiver.

	E_misclose from CTRL		N_misclose from CTRL		AHD_misclose from CTRL		Coordinate quality
means:	0.003		-0.002		0.004		0.014
Standard Deviation:	0.003		0.003		0.008		0.002
range_highest:	0.015		0.009		0.024		0.022
range_lowest:	-0.005	**Percentage**	-0.011	**Percentage**	-0.019	**Percentage**	0.010
Total obs:	550	100.0%	550	100.0%	550	100.0%	
10mm or less:	535	97.3%	549	99.8%	372	67.6%	
11mm to 20mm:	15	2.7%	1	0.2%	172	31.3%	
21mm to 30mm:	0	0.0%	0	0.0%	6	1.1%	
31mm to 40mm:	0	0.0%	0	0.0%	0	0.0%	
41mm to 50mm:	0	0.0%	0	0.0%	0	0.0%	
greater than 50mm:	0	0.0%	0	0.0%	0	0.0%	

9011 RTK comparison with control coordinates. Base at adjacent control point 9012. 1200 receiver.

	E_misclose from CTRL		N_misclose from CTRL		AHD_misclose from CTRL		Coordinate quality
means:	0.005		-0.004		0.045		0.016
Standard Deviation:	0.002		0.002		0.006		0.001
range_highest:	0.010		0.003		0.062		0.019
range_lowest:	-0.001	**Percentage**	-0.011	**Percentage**	0.024	**Percentage**	0.012
Total obs:	600	100.0%	600	100.0%	600	100.0%	
10mm or less:	600	100.0%	599	99.8%	0	0.0%	
11mm to 20mm:	0	0.0%	1	0.2%	0	0.0%	
21mm to 30mm:	0	0.0%	0	0.0%	13	2.2%	
31mm to 40mm:	0	0.0%	0	0.0%	101	16.8%	
41mm to 50mm:	0	0.0%	0	0.0%	374	62.3%	
greater than 50mm:	0	0.0%	0	0.0%	112	18.7%	

9013 RTK comparison with control coordinates. Base at adjacent control point 9012. 1200 receiver.

	E_misclose from CTRL		N_misclose from CTRL		AHD_misclose from CTRL		Coordinate quality
means:	0.005		0.000		0.012		0.011
Standard Deviation:	0.002		0.003		0.005		0.001
range_highest:	0.011		0.008		0.028		0.015
range_lowest:	0.000	**Percentage**	-0.009	**Percentage**	-0.008	**Percentage**	0.009
Total obs:	750	100.0%	750	100.0%	750	100.0%	
10mm or less:	746	99.5%	750	100.0%	298	39.7%	
11mm to 20mm:	4	0.5%	0	0.0%	413	55.1%	
21mm to 30mm:	0	0.0%	0	0.0%	39	5.2%	
31mm to 40mm:	0	0.0%	0	0.0%	0	0.0%	
41mm to 50mm:	0	0.0%	0	0.0%	0	0.0%	
greater than 50mm:	0	0.0%	0	0.0%	0	0.0%	

9014 RTK comparison with control coordinates. Base at adjacent control point 9012. 1200 receiver.

APPENDIX H

RESULTS FOR TRAVERSE DATA SIMILARITY TRANSFORMATIONS

JOB NAME: D:\Uni Work\Major project\Processing_adjustment results\Burrendong\S6 Traverse\Burrendong
Date: 25/10/2009

Point	Easting	Northing	Height	Code	Description		Misclose-Easting	Misclose-Northing	Misclose-Height	
1	696727.860	6383272.663	443.346	PDPY	9012	S6 Traverse	-0.006	-0.012	-0.212	
2	694115.516	6382757.238	454.044	PDPY	9010	S6 Traverse	0.000	0.000	0.312	
3	694253.223	6383023.166	439.182	PDPY	9011	S6 Traverse	-0.008	0.011	0.213	
4	697971.259	6384252.403	419.865	PDPY	9014	S6 Traverse	0.000	0.000	-0.176	
5	698028.622	6383611.687	365.609	PDPY	9013	S6 Traverse	0.022	-0.001	-0.136	
6	697708.777	6383653.946	365.028		P12	S6 Traverse				
7	697419.325	6383504.012	365.501	CREST PILLAR	P11	S6 Traverse	Corrected Radiation RLs			
8	696660.592	6383271.720	436.691	PDPY	205	S6 Traverse	436.479			
9	696687.779	6383266.982	441.234	PDPY	202	S6 Traverse	441.022			
10	696669.536	6383274.511	438.137	PDPY	204	S6 Traverse	437.925			
11	696697.448	6383264.405	442.025	PDPY	201	S6 Traverse	441.813			
12	696678.395	6383270.450	440.069	PDPY	203	S6 Traverse	439.857			
13	696707.139	6383261.816	443.593	PDPY	200	S6 Traverse	443.381			
14	696716.132	6383258.068	463.93	TOP ANTENNA	1000	S6 Traverse	463.718			
15	697915.190	6384238.470	408.065	PDPY	305	S6 Traverse	407.889			
16	697932.305	6384248.464	412.432	PDPY	303	S6 Traverse	412.256			
17	697949.639	6384257.985	416.451	PDPY	301	S6 Traverse	416.275			
18	697923.720	6384243.401	410.076	PDPY	304	S6 Traverse	409.900			
19	697940.927	6384253.289	414.359	PDPY	302	S6 Traverse	414.183			
20	697958.311	6384263.054	418.175	PDPY	300	S6 Traverse	417.999			
21	697967.044	6384268.514	426.283	LOW.ANTENNA	1001	S6 Traverse	426.107			
22	697967.019	6384268.599	440.525	TOP SCADA POLE	1002	S6 Traverse	440.349			
23	698033.070	6383620.599	365.588	TEXTA MARK	400	S6 Traverse	365.452			
24	698042.869	6383637.986	365.641	TEXTA MARK	402	S6 Traverse	365.505			
25	698052.694	6383655.331	365.629	TEXTA MARK	404	S6 Traverse	365.493			
26	698037.985	6383629.264	365.645	TEXTA MARK	401	S6 Traverse	365.509			
27	698047.699	6383646.696	365.641	TEXTA MARK	403	S6 Traverse	365.505			
28	698056.521	6383664.543	365.617	TEXTA MARK	405	S6 Traverse	365.481			
29	698050.346	6383837.413	373.178	PMSM	9015	S6 Traverse				
30	698060.929	6383673.531	365.601	TEXTA MARK	406	S6 Traverse	365.465			
9010	694115.516	6382757.238	454.356	ADJ	0.0012	Static GNSS				
9011	694253.215	6383023.177	439.395	ADJ	0.0011	Static GNSS				
9012	696727.854	6383272.651	443.134	ADJ	0.0014	Static GNSS	0.002	0.000	0.000	Means
9013	698028.644	6383611.686	365.473	ADJ	0.0014	Static GNSS				
9014	697971.259	6384252.403	419.689	ADJ	0.0011	Static GNSS				
9015	698050.374	6383837.419	373.049	ADJ	0.0032	Static GNSS				
P11	697419.331	6383504.004	365.292	CTRL	P11	Static GNSS				
P12	697708.791	6383653.943	364.849	ADJ	P12	Static GNSS				

400 series eastings adjusted by this amount to more accurately show RTK errors.

JOB NAME: D:\Uni Work\Major project\Processing_adjustment results\Mt Lambie\S6 Traverse\Mt LAmbie
Date: 25/10/2009

Point	Easting	Northing	Height	Code	Description	Origin	Misclose-Easting	Misclose-N	Misclose-Height	
1	777640.184	6292485.876	1277.291	9006	PDPY	S6 Traverse	0.000	0.000	0.411	
2	774474.667	6293224.86	1198.206	9005	PDPY	S6 Traverse	0.000	0.000	-0.343	
3	775581.994	6294835.587	1162.93	9003	PNAL	S6 Traverse	0.065	0.004	-0.495	
4	777733.298	6292432.34	1290.477	9007	LAMBIE TRIG	S6 Traverse	0.004	-0.002	0.427	
							Corrected Radiation RLs			
5	777520.809	6292474.138	1258.211	105	PDPY	S6 Traverse	1257.800			
6	777560.854	6292474.563	1266.452	103	PDPY	S6 Traverse	1266.041			
7	777600.775	6292478.216	1273.07	101	PDPY	S6 Traverse	1272.659			
8	777542.236	6292474.041	1261.962	104	PDPY	S6 Traverse	1261.551			
9	777580.954	6292477.77	1269.778	102	PDPY	S6 Traverse	1269.367			
10	777620.416	6292485.563	1275.366	100	PDPY	S6 Traverse	1274.955			
9003	775581.929	6294835.583	1163.425	ADJ	0.0016	Static GNSS				
9005	774474.667	6293224.86	1198.549	ADJ	0.0018	Static GNSS				
9006	777640.184	6292485.876	1276.88	ADJ	0.0022	Static GNSS				
9007	777733.294	6292432.342	1290.05	ADJ	0	Static GNSS				
27107	776127.671	6294352.704	1147.377	ADJ	0.0017	Static GNSS				
							0.017	0.001	0.000	Means

The heights of the test points have been adjusted to agree with the RL of 9006, the station from which they were radiated.

APPENDIX I

NEWNES REFERENCE SITE - STATIC OBSERVATIONS ADJUSTMENT REPORTS

Project Information
General Information
Adjustment Pre-Analysis
www.MOVE3.com

Created: 08-10-2009 07:35:45
Project name: Newnes Static_matt project
Processing kernel: MOVE3 3.3
Type: 3D inner constrained network on WGS 84 ellipsoid
Stations
Number of (partly) known
stations: 0
Number of unknown stations: 4
Total: 4
Observations
GPS coordinate differences: 18 (6 baselines)
Inner Constraints: 3
Total: 21
Unknowns
Coordinates: 12
Total: 12
Degrees of freedom: 9

Project Information
General Information
Network Adjustment
www.MOVE3.com

Created: 10/08/2009 07:37:11
Project name: Newnes Static_matt project
Date created: 09/03/2009 14:44:44
Time zone: 10h 00'
Coordinate system name: MGA 56
Application software: LEICA Geo Office 5.0
Processing kernel: MOVE3 3.4
Adjustment
Type: Inner constrained
Dimension: 3D
Coordinate system: WGS 1984
Height mode: Ellipsoidal
Number of iterations: 1
Maximum coord correction in last iteration: 0.0000 m (tolerance is met)
Stations
Number of (partly) known stations: 0
Number of unknown stations: 4
Total: 4
Observations
GPS coordinate differences: 18 (6 baselines)
Inner constraints: 3
Total: 21
Unknowns
Coordinates: 12
Total: 12
Degrees of freedom: 9
Testing
Alfa (multi dimensional): 0.2876
Alfa 0 (one dimensional): 5.0 %
Beta: 80.0 %
Sigma a-priori (GPS): 10.0
Critical value W-test: 1.96
Critical value T-test (2-dimensional): 2.42

Adjustment Results
Critical value T-test (3-dimensional): 1.89
Critical value F-test: 1.20
F-test: 0.20 (accepted)
Results based on a-posteriori variance factor
Coordinates
Station Coordinate Corr Sd
9030 Latitude 33° 21' 07.42624" S -0.0002 m 0.0002 m
Longitude 150° 15' 27.79326" E 0.0001 m 0.0002 m
Height 1095.6028 m -0.0001 m 0.0005 m
9031 Latitude 33° 21' 19.71689" S 0.0005 m 0.0003 m
Longitude 150° 15' 30.42815" E -0.0002 m 0.0002 m
Height 1084.4323 m -0.0005 m 0.0006 m
9032 Latitude 33° 21' 43.14550" S -0.0003 m 0.0002 m
Longitude 150° 15' 10.20588" E 0.0001 m 0.0002 m
Height 1082.4572 m 0.0001 m 0.0004 m
9033 Latitude 33° 21' 45.88968" S 0.0001 m 0.0003 m
Longitude 150° 14' 52.93948" E 0.0001 m 0.0003 m
Height 1087.6958 m 0.0005 m 0.0007 m
Observations and Residuals

Station Target Adj obs Resid Resid
(ENH) Sd
DX 9033 9031 -863.6437 m 0.0020 m -0.0008 m 0.0010 m
DY -622.9576 m -0.0003 m -0.0009 m 0.0006 m
DZ 675.4027 m 0.0001 m -0.0017 m 0.0007 m
DX 9030 9033 1018.7372 m 0.0012 m -0.0005 m 0.0009 m
DY 455.8686 m -0.0001 m -0.0006 m 0.0006 m
DZ -985.6044 m 0.0001 m -0.0009 m 0.0006 m
DX 9030 9032 760.6265 m 0.0000 m -0.0001 m 0.0006 m
DY 89.1568 m 0.0001 m 0.0004 m 0.0004 m
DZ -912.0993 m 0.0004 m -0.0001 m 0.0004 m
DX 9030 9031 155.0934 m -0.0008 m 0.0006 m 0.0007 m
DY -167.0890 m -0.0002 m -0.0006 m 0.0005 m
DZ -310.2018 m -0.0011 m 0.0012 m 0.0006 m
DX 9031 9032 605.5331 m -0.0001 m 0.0001 m 0.0007 m
DY 256.2458 m -0.0001 m -0.0005 m 0.0004 m
DZ -601.8975 m -0.0007 m 0.0004 m 0.0005 m
DX 9032 9033 258.1107 m -0.0002 m 0.0001 m 0.0008 m
DY 366.7118 m 0.0000 m 0.0001 m 0.0006 m
DZ -73.5052 m 0.0001 m 0.0001 m 0.0006 m
GPS Baseline Vector Residuals
Station Target Adj vector [m] Resid [m] Resid [ppm]
DV 9033 9031 1261.0017 0.0020 1.6
DV 9030 9033 1488.9787 0.0012 0.8
DV 9030 9032 1190.9772 0.0004 0.3
DV 9030 9031 384.9647 0.0014 3.7
DV 9031 9032 891.4106 0.0007 0.8
DV 9032 9033 454.4246 0.0002 0.4
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Testing and Estimated Errors

Absolute Error Ellipses (2D - 39.4% 1D - 68.3%)
Station A [m] B [m] A/B Phi Sd Hgt [m]
9030 0.0002 0.0002 1.1 -8° 0.0005
9031 0.0003 0.0002 1.3 13° 0.0006
9032 0.0002 0.0002 1.2 3° 0.0004
9033 0.0003 0.0003 1.1 -2° 0.0007
Observation Tests
Station Target MDB Red BNR W-Test T-Test
DX 9033 9031 0.0046 m 78 1.5 1.35 0.62
DY 0.0031 m 74 1.6 0.49
DZ 0.0038 m 77 1.5 -0.48
DX 9030 9033 0.0035 m 61 2.2 1.47 0.72
DY 0.0027 m 65 2.1 0.65
DZ 0.0029 m 61 2.2 -0.65
DX 9030 9032 0.0025 m 24 4.8 -0.52 1.50
DY 0.0019 m 29 4.4 0.89
DZ 0.0021 m 25 4.8 2.05
DX 9030 9031 0.0030 m 57 2.5 -0.65 1.90
DY 0.0021 m 55 2.5 -1.51
DZ 0.0025 m 55 2.5 -1.85
DX 9031 9032 0.0028 m 36 3.6 0.22 1.58
DY 0.0020 m 33 4.0 -1.10
DZ 0.0024 m 39 3.6 -2.06
DX 9032 9033 0.0032 m 41 3.3 -0.42 0.06
DY 0.0024 m 41 3.3 -0.20
DZ 0.0027 m 41 3.3 0.27
Redundancy:
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W-Test:

T-Test (3-dimensional):

Estimated Errors (Observations)

Estimated Errors For Observations With Rejected W-Tests (max 10)

Station Target W-Test Fact Est err

DZ 9031 9032 -2.06 1.1 -0.0017 m
DZ 9030 9032 2.05 1.0 0.0015 m

Estimated Errors For Observations With Rejected T-Tests (max 10)

Station Target T-Test Fact Est err

DX 9030 9031 1.90 1.0 -0.0014 m
DY -0.0003 m
DZ -0.0020 m

Project Information
GPS Baseline Loops
Loops and Misclosures
www.MOVE3.com

Created: 10/08/2009 07:42:00
Project name: Newnes Static_matt project
Date created: 09/03/2009 14:44:44
Time zone: 10h 00'
Coordinate system name: MGA 56
Application software: LEICA Geo Office 5.0
Processing kernel: MOVE3 3.4
Critical value W-test is: 1.96
Dimension: 3D
Loop 1
From To dX[m] dY[m] dZ[m]
9033 9032 -258.1105 -366.7118 73.5051
9032 9031 -605.5329 -256.2457 601.8982
9031 9033 863.6417 622.9579 -675.4028
X: -0.0017 m W-Test: -0.32
Y: 0.0004 m 0.11
Z: 0.0005 m 0.12
Easting: 0.0005 m W-Test: 0.13
Northing: 0.0013 m 0.30
Height: 0.0011 m 0.24
Closing error: 0.0018 m (0.7 ppm) Ratio:
(1:1431376)
Length: 2606.8360 m
Loop 2
From To dX[m] dY[m] dZ[m]
9030 9031 155.0926 -167.0892 -310.2029
9031 9033 863.6417 622.9579 -675.4028
9033 9030 -1018.7384 -455.8685 985.6044
X: -0.0040 m W-Test: -0.67
Y: 0.0002 m 0.05
Z: -0.0013 m -0.30
Easting: 0.0018 m W-Test: 0.40
Northing: 0.0009 m 0.18
Height: 0.0037 m 0.71
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Closing error: 0.0042 m (1.4 ppm) Ratio:(1:740179)
Length: 3134.9455 m
Loop 3
From To dX[m] dY[m] dZ[m]
9030 9031 155.0926 -167.0892 -310.2029
9031 9032 605.5329 256.2457 -601.8982
9032 9030 -760.6265 -89.1569 912.0989
X: -0.0009 m W-Test: -0.27
Y: -0.0004 m -0.16
Z: -0.0022 m -0.85
Easting: 0.0008 m W-Test: 0.30
Northing: -0.0015 m -0.53
Height: 0.0017 m 0.57
Closing error: 0.0024 m (1.0 ppm) Ratio:
(1:1023378)
Length: 2467.3532 m
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APPENDIX J

MT LAMBIE - STATIC OBSERVATIONS ADJUSTMENT REPORTS

Project Information
General Information
Check of Input Data

Adjustment Pre-Analysis

www.MOVE3.com

Created: 25-10-2009 15:57:48
Project name: Mt Lambie Control
Processing kernel: MOVE3 3.3
Type: 3D minimally constrained network on WGS 84 ellipsoid
Stations
Number of (partly) known
stations: 1
Number of unknown stations: 4
Total: 5
Observations
GPS coordinate differences: 30 (10 baselines)
Known coordinates: 3
Total: 33
Unknowns
Coordinates: 15
Total: 15
Degrees of freedom: 18
Observations and Approximate Coordinates
Critical value is 10.0 times W-test critical value of 1.96
Station Target Reading Error
DX 9007 9006 32.5511 m -18.8226 m
DY 9007 9006 90.4228 m 10.8720 m
DZ 9007 9006 49.6516 m -14.3707 m
DX 9007 9005 1373.3218 m -18.8244 m
DY 9007 9005 2993.3827 m 10.8727 m
DZ 9007 9005 633.3222 m -14.3709 m
DX 9007 9003 84.4940 m -18.8235 m
DY 9007 9003 2513.5774 m 10.8726 m
DZ 9007 9003 2021.7644 m -14.3721 m
DX 9007 27107 39.1067 m -18.8196 m
DY 9007 27107 1893.9922 m 10.8688 m
DZ 9007 27107 1641.0419 m -14.3740 m

Project Information
General Information
Network Adjustment
www.MOVE3.com

Created: 09/24/2009 10:01:35
Project name: Mt Lambie Control
Date created: 09/03/2009 14:44:26
Time zone: 10h 00'
Coordinate system name: MGA Geoid 55
Application software: LEICA Geo Office 5.0
Processing kernel: MOVE3 3.4
Adjustment
Type: Minimally constrained
Dimension: 3D
Coordinate system: WGS 1984
Height mode: Ellipsoidal
Number of iterations: 1
Maximum coord correction in last iteration: 0.0000 m (tolerance is met)
Stations
Number of (partly) known stations: 1
Number of unknown stations: 4
Total: 5
Observations
GPS coordinate differences: 30 (10 baselines)
Known coordinates: 3
Total: 33
Unknowns
Coordinates: 15
Total: 15
Degrees of freedom: 18
Testing
Alfa (multi dimensional): 0.4041
Alfa 0 (one dimensional): 5.0 %
Beta: 80.0 %
Sigma a-priori (GPS): 10.0
Critical value W-test: 1.96
Critical value T-test (2-dimensional): 2.42

Adjustment Results
Critical value T-test (3-dimensional): 1.89
Critical value F-test: 1.04
F-test: 0.16 (accepted)
Results based on a-posteriori variance factor
Coordinates
Station Coordinate Corr Sd
27107 Latitude 33° 27' 16.98500" S 1.7966 m 0.0010 m
Longitude 149° 58' 14.54344" E -1.5282 m 0.0005 m
Height 1147.4405 m -23.3370 m 0.0013 m
9003 Latitude 33° 27' 01.83225" S 1.7990 m 0.0010 m
Longitude 149° 57' 52.89789" E -1.5305 m 0.0005 m
Height 1163.5058 m -23.3378 m 0.0012 m
9005 Latitude 33° 27' 55.08748" S 1.7936 m 0.0010 m
Longitude 149° 57' 11.83701" E -1.5345 m 0.0005 m
Height 1198.5689 m -23.3389 m 0.0013 m
9006 Latitude 33° 28' 16.11330" S 1.7902 m 0.0012 m
Longitude 149° 59' 15.13297" E -1.5226 m 0.0007 m
Height 1276.8803 m -23.3398 m 0.0017 m
9007 Latitude 33° 28' 17.76232" S 0.0000 m - fixed

Longitude 149° 59' 18.79529" E 0.0000 m - fixed
Height 1290.0500 m 0.0000 m - fixed

Observations and Residuals

Station Target Adj obs Resid Resid
(ENH) Sd

DX 9007 9005 1373.3251 m -0.0011 m -0.0008 m 0.0011 m
DY 2993.3820 m 0.0016 m 0.0014 m 0.0009 m
DZ 633.3220 m 0.0005 m 0.0012 m 0.0010 m
DX 9005 9003 -1288.8288 m -0.0008 m 0.0001 m 0.0008 m
DY -479.8052 m 0.0003 m 0.0000 m 0.0006 m
DZ 1388.4435 m -0.0005 m 0.0010 m 0.0007 m
DX 9005 27107 -1334.2200 m 0.0013 m -0.0005 m 0.0009 m
DY -1099.3866 m -0.0002 m 0.0004 m 0.0007 m
DZ 1007.7229 m 0.0013 m -0.0017 m 0.0008 m
DX 9006 9003 51.9437 m -0.0011 m 0.0001 m 0.0013 m
DY 2423.1539 m 0.0005 m -0.0004 m 0.0009 m
DZ 1972.1142 m -0.0013 m 0.0018 m 0.0009 m
DX 9006 27107 6.5525 m 0.0014 m -0.0001 m 0.0013 m
DY 1803.5725 m -0.0006 m 0.0013 m 0.0009 m
DZ 1591.3936 m 0.0025 m -0.0026 m 0.0010 m
DX 9007 9003 84.4962 m -0.0010 m -0.0005 m 0.0010 m
DY 2513.5768 m 0.0012 m 0.0014 m 0.0008 m
DZ 2021.7655 m 0.0007 m 0.0008 m 0.0009 m
DX 9007 27107 39.1051 m 0.0027 m 0.0012 m 0.0011 m
DY 1893.9955 m -0.0029 m -0.0033 m 0.0009 m
DZ 1641.0449 m -0.0014 m -0.0024 m 0.0010 m
DX 27107 9003 45.3912 m 0.0022 m 0.0000 m 0.0009 m
DY 619.5813 m -0.0013 m -0.0002 m 0.0006 m
DZ 380.7206 m 0.0014 m -0.0029 m 0.0006 m
DX 9005 9006 -1340.7725 m 0.0002 m -0.0009 m 0.0014 m
DY -2902.9591 m 0.0009 m 0.0005 m 0.0010 m

DZ -583.6707 m 0.0004 m 0.0000 m 0.0011 m
DX 9007 9006 32.5525 m -0.0014 m 0.0007 m 0.0015 m
DY 90.4229 m -0.0001 m 0.0010 m 0.0011 m
DZ 49.6513 m 0.0004 m 0.0007 m 0.0012 m

GPS Baseline Vector Residuals

Station Target Adj vector [m] Resid [m] Resid [ppm]

DV 9007 9005 3353.7225 0.0020 0.6
DV 9005 9003 1954.2436 0.0010 0.5
DV 9005 27107 2001.0745 0.0018 0.9
DV 9006 9003 3124.6772 0.0018 0.6
DV 9006 27107 2405.2963 0.0029 1.2
DV 9007 9003 3226.8783 0.0017 0.5
DV 9007 27107 2506.3472 0.0042 1.7
DV 27107 9003 728.6217 0.0029 4.0
DV 9005 9006 3250.4637 0.0010 0.3
DV 9007 9006 108.1722 0.0014 13.1

Absolute Error Ellipses (2D - 39.4% 1D - 68.3%)

Station A [m] B [m] A/B Phi Sd Hgt [m]

27107 0.0010 0.0004 2.4 -17° 0.0013
9003 0.0010 0.0004 2.5 -17° 0.0012
9005 0.0011 0.0004 2.5 -17° 0.0013
9006 0.0012 0.0006 2.1 -17° 0.0017
9007 0.0000 0.0000 1.0 90° 0.0000

Observation Tests

Station Target MDB Red BNR W-Test T-Test

DX 9007 9005 0.0040 m 67 2.0 0.25 0.49
DY 0.0032 m 68 2.0 0.90

DZ 0.0053 m 70 1.9 -0.09
DX 9005 9003 0.0029 m 33 3.9 -0.78 0.92
DY 0.0023 m 33 3.9 -0.03
DZ 0.0035 m 32 4.0 -0.71
DX 9005 27107 0.0033 m 60 2.3 0.84 0.85
DY 0.0027 m 61 2.2 0.46
DZ 0.0040 m 63 2.1 0.79
DX 9006 9003 0.0043 m 53 2.7 0.05 0.78
DY 0.0033 m 48 2.8 0.24
DZ 0.0045 m 44 3.1 -1.27
DX 9006 27107 0.0047 m 65 2.0 -0.37 1.17
DY 0.0037 m 64 2.0 -0.33
DZ 0.0050 m 65 2.0 1.73
DX 9007 9003 0.0035 m 52 2.6 -0.12 0.64
DY 0.0028 m 53 2.6 0.67
DZ 0.0045 m 54 2.6 0.48
DX 9007 27107 0.0039 m 62 2.1 0.47 2.36
DY 0.0031 m 64 2.1 -1.18
DZ 0.0051 m 67 2.0 -0.82
DX 27107 9003 0.0029 m 43 3.2 0.86 3.12
DY 0.0023 m 40 3.3 -0.69
DZ 0.0033 m 35 4.0 1.25

DX 9005 9006 0.0060 m 81 1.3 0.48 0.14
DY 0.0048 m 83 1.3 0.61
DZ 0.0071 m 84 1.2 -0.08
DX 9007 9006 0.0061 m 79 1.4 -0.90 0.28
DY 0.0049 m 80 1.4 -0.71
DZ 0.0075 m 81 1.3 0.55
Redundancy:
W-Test:

T-Test (3-dimensional):

Estimated Errors For Observations With Rejected Antenna Hgt W-Tests (max 10)
Station Target W-Test Fact MDB [m] Est ant err [m]
27107 9003 -3.02 1.5 0.0055 -0.0060
Estimated Errors For Observations With Rejected T-Tests (max 10)
Station Target T-Test Fact Est err
DX 27107 9003 3.12 1.3 0.0047 m
DY -0.0027 m
DZ 0.0030 m
DX 9007 27107 2.36 1.1 0.0043 m
DY -0.0045 m
DZ -0.0019 m

Project Information
GPS Baseline Loops
Loops and Misclosures
www.MOVE3.com

Created: 09/24/2009 10:54:02
Project name: Mt Lambie Control
Date created: 09/03/2009 14:44:26
Time zone: 10h 00'
Coordinate system name: MGA Geoid 55
Application software: LEICA Geo Office 5.0
Processing kernel: MOVE3 3.4
Critical value W-test is: 1.96
Dimension: 3D
Loop 1
From To dX[m] dY[m] dZ[m]
9005 9003 -1288.8296 -479.8049 1388.4430
9003 9006 -51.9426 -2423.1544 -1972.1129
9006 9005 1340.7723 2902.9582 583.6703
X: 0.0002 m W-Test: 0.02
Y: -0.0011 m -0.15
Z: 0.0003 m 0.05
Easting: 0.0008 m W-Test: 0.11
Northing: -0.0001 m -0.01
Height: -0.0008 m -0.09
Closing error: 0.0011 m (0.1 ppm) Ratio:
(1:7375574)
Length: 8329.3831 m
Loop 2
From To dX[m] dY[m] dZ[m]
9005 9006 -1340.7723 -2902.9582 -583.6703
9006 27107 6.5539 1803.5719 1591.3962
27107 9005 1334.2187 1099.3867 -1007.7242
X: 0.0003 m W-Test: 0.03
Y: 0.0004 m 0.06
Z: 0.0017 m 0.20
Easting: -0.0005 m W-Test: -0.06
Northing: 0.0014 m 0.16
Height: -0.0009 m -0.10

Closing error: 0.0017 m (0.2 ppm) Ratio:
(1:4397674)
Length: 7656.8347 m
Loop 3
From To dX[m] dY[m] dZ[m]
9007 9005 1373.3239 2993.3836 633.3225
9005 9006 -1340.7723 -2902.9582 -583.6703
9006 9007 -32.5512 -90.4229 -49.6517
X: 0.0004 m W-Test: 0.03
Y: 0.0025 m 0.27
Z: 0.0005 m 0.05
Easting: -0.0024 m W-Test: -0.23
Northing: 0.0010 m 0.09
Height: 0.0005 m 0.04
Closing error: 0.0026 m (0.4 ppm) Ratio:
(1:2577117)
Length: 6712.3581 m
Loop 4
From To dX[m] dY[m] dZ[m]

9007 9005 1373.3239 2993.3836 633.3225
9005 9003 -1288.8296 -479.8049 1388.4430
9003 9007 -84.4953 -2513.5780 -2021.7662
X: -0.0010 m W-Test: -0.15
Y: 0.0007 m 0.14
Z: -0.0007 m -0.12
Easting: -0.0002 m W-Test: -0.03
Northing: 0.0001 m 0.01
Height: 0.0014 m 0.23
Closing error: 0.0014 m (0.2 ppm) Ratio:
(1:6036472)
Length: 8534.8468 m

Loop 5

From To dX[m] dY[m] dZ[m]

9007 9005 1373.3239 2993.3836 633.3225
9005 27107 -1334.2187 -1099.3867 1007.7242
27107 9007 -39.1078 -1893.9926 -1641.0435
X: -0.0026 m W-Test: -0.35
Y: 0.0043 m 0.72
Z: 0.0032 m 0.45
Easting: -0.0024 m W-Test: -0.38
Northing: 0.0051 m 0.72
Height: 0.0019 m 0.27
Closing error: 0.0060 m (0.8 ppm) Ratio:
(1:1318413)
Length: 7861.1421 m

Loop 6

From To dX[m] dY[m] dZ[m]

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27107 9005 1334.2187 1099.3867 -1007.7242
9005 9003 -1288.8296 -479.8049 1388.4430
9003 27107 -45.3934 -619.5801 -380.7220
X: -0.0043 m W-Test: -0.83
Y: 0.0018 m 0.47
Z: -0.0033 m -0.77
Easting: 0.0006 m W-Test: 0.14
Northing: -0.0002 m -0.04
Height: 0.0056 m 1.20
Closing error: 0.0057 m (1.2 ppm) Ratio:(1:826092)
Length: 4683.9396 m

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APPENDIX K

BURRENDONG - STATIC OBSERVATIONS ADJUSTMENT REPORTS

Project Information
General Information
Check of Input Data

Adjustment Pre-Analysis

www.MOVE3.com

Created: 07-10-2009 10:43:09
Project name: Burrendong Static_Matt Project
Processing kernel: MOVE3 3.3
Type: 3D minimally constrained network on WGS 84 ellipsoid

Stations

Number of (partly) known
stations: 1
Number of unknown stations: 7
Total: 8

Observations

GPS coordinate differences: 75 (25 baselines)
Known coordinates: 3
Total: 78

Unknowns

Coordinates: 24
Total: 24
Degrees of freedom: 54

Observations

Critical value is 1.0 times W-test critical value of 1.96

Station Target Reading Error

DZ 9010 9011 234.1528 m 0.0000 m
DZ 9010 9011 234.1487 m -0.0041 m

Project Information
General Information
Network Adjustment
www.MOVE3.com

Created: 10/07/2009 10:45:12
Project name: Burrendong Static_Matt Project
Date created: 10/04/2009 17:34:36
Time zone: 10h 00'
Coordinate system name: MGA Geoid 55
Application software: LEICA Geo Office 5.0
Processing kernel: MOVE3 3.4
Adjustment
Type: Minimally constrained
Dimension: 3D
Coordinate system: WGS 1984
Height mode: Ellipsoidal
Number of iterations: 0
Maximum coord correction in last iteration: 0.0000 m (tolerance is met)
Stations
Number of (partly) known stations: 1
Number of unknown stations: 7
Total: 8
Observations
GPS coordinate differences: 75 (25 baselines)
Known coordinates: 3
Total: 78
Unknowns
Coordinates: 24
Total: 24
Degrees of freedom: 54
Testing
Alfa (multi dimensional): 0.5617
Alfa 0 (one dimensional): 5.0 %
Beta: 80.0 %
Sigma a-priori (GPS): 10.0
Critical value W-test: 1.96
Critical value T-test (2-dimensional): 2.42

Adjustment Results
Critical value T-test (3-dimensional): 1.89
Critical value F-test: 0.96
F-test: 0.49 (accepted)
Results based on a-posteriori variance factor
Coordinates
Station Coordinate Corr Sd
9010 Latitude 32° 40' 32.94095" S 0.0000 m 0.0004 m
Longitude 149° 04' 12.88018" E 0.0000 m 0.0004 m
Height 480.1725 m 0.0000 m 0.0011 m
9011 Latitude 32° 40' 24.22297" S 0.0000 m 0.0003 m
Longitude 149° 04' 17.96473" E 0.0000 m 0.0003 m
Height 465.2180 m 0.0000 m 0.0010 m
9012 Latitude 32° 40' 14.54845" S 0.0000 m 0.0005 m
Longitude 149° 05' 52.72961" E 0.0000 m 0.0004 m
Height 469.0396 m 0.0000 m 0.0012 m
9013 Latitude 32° 40' 02.70820" S 0.0000 m 0.0006 m
Longitude 149° 06' 42.38112" E 0.0000 m 0.0004 m
Height 391.4264 m 0.0000 m 0.0012 m
9014 Latitude 32° 39' 41.95208" S 0.0000 m 0.0004 m

Longitude 149° 06' 39.69032" E 0.0000 m 0.0003 m
Height 445.6430 m 0.0000 m 0.0010 m
9015 Latitude 32° 39' 55.36845" S 0.0000 m 0.0019 m
Longitude 149° 06' 43.04247" E 0.0000 m 0.0009 m
Height 399.0042 m 0.0000 m 0.0025 m
P11 Latitude 32° 40' 06.59578" S 0.0000 m - fixed
Longitude 149° 06' 19.08506" E 0.0000 m - fixed
Height 391.2230 m 0.0000 m - fixed
P12 Latitude 32° 40' 01.54326" S 0.0000 m 0.0010 m
Longitude 149° 06' 30.07686" E 0.0000 m 0.0006 m
Height 390.7906 m 0.0000 m 0.0018 m
Observations and Residuals
Station Target Adj obs Resid Resid
(ENH) Sd
DX P11 9014 -666.6237 m 0.0001 m -0.0002 m 0.0008 m
DY -226.8707 m 0.0002 m 0.0002 m 0.0005 m
DZ 609.7552 m 0.0002 m -0.0001 m 0.0005 m
DX P11 9013 -367.2844 m 0.0041 m -0.0013 m 0.0010 m
DY -487.6485 m -0.0009 m -0.0015 m 0.0007 m
DZ 100.7098 m 0.0007 m -0.0037 m 0.0007 m
DX P11 9011 1819.3563 m -0.0006 m 0.0003 m 0.0008 m
DY 2589.1512 m 0.0000 m -0.0002 m 0.0005 m
DZ -497.0706 m -0.0006 m 0.0007 m 0.0005 m
DX P11 9010 2001.0306 m 0.0001 m 0.0002 m 0.0009 m
DY 2634.7408 m -0.0003 m 0.0006 m 0.0006 m
DZ -731.2204 m 0.0009 m -0.0007 m 0.0006 m
DX 9011 P12 -2038.2002 m 0.0016 m -0.0006 m 0.0015 m
DY -2791.9858 m -0.0003 m -0.0005 m 0.0010 m
DZ 628.3351 m 0.0005 m -0.0016 m 0.0009 m
DX 9011 9015 -2305.6980 m -0.0009 m 0.0001 m 0.0022 m
DY -3025.6604 m 0.0004 m 0.0001 m 0.0016 m
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DZ 784.0410 m -0.0006 m 0.0011 m 0.0015 m
DX 9011 9013 -2186.6407 m 0.0009 m 0.0001 m 0.0008 m
DY -3076.7997 m -0.0006 m -0.0005 m 0.0005 m
DZ 597.7804 m 0.0001 m -0.0010 m 0.0005 m
DX 9011 9012 -1409.4265 m 0.0014 m -0.0007 m 0.0007 m
DY -2034.1375 m 0.0000 m -0.0001 m 0.0005 m
DZ 248.8254 m 0.0006 m -0.0013 m 0.0005 m
DX 9014 P12 447.7798 m -0.0012 m 0.0005 m 0.0015 m
DY 24.0361 m 0.0001 m -0.0003 m 0.0010 m
DZ -478.4908 m -0.0010 m 0.0015 m 0.0009 m
DX 9014 9015 180.2820 m 0.0010 m -0.0006 m 0.0022 m
DY -209.6385 m 0.0001 m 0.0004 m 0.0016 m
DZ -322.7848 m 0.0010 m -0.0013 m 0.0015 m
DX 9014 9013 299.3393 m -0.0003 m -0.0003 m 0.0008 m
DY -260.7778 m 0.0005 m 0.0007 m 0.0005 m
DZ -509.0454 m 0.0005 m 0.0002 m 0.0005 m
DX 9014 9012 1076.5534 m 0.0001 m -0.0005 m 0.0008 m
DY 781.8845 m 0.0006 m 0.0006 m 0.0006 m
DZ -858.0004 m 0.0005 m -0.0001 m 0.0006 m
DX 9014 9011 2485.9800 m 0.0000 m 0.0000 m 0.0006 m
DY 2816.0219 m 0.0000 m -0.0003 m 0.0004 m
DZ -1106.8258 m -0.0003 m 0.0002 m 0.0004 m
DX 9013 P12 148.4405 m -0.0011 m -0.0006 m 0.0016 m
DY 284.8139 m 0.0014 m 0.0021 m 0.0010 m
DZ 30.5546 m 0.0015 m 0.0006 m 0.0010 m
DX 9013 9015 -119.0573 m 0.0003 m 0.0010 m 0.0023 m
DY 51.1393 m -0.0013 m -0.0003 m 0.0016 m
DZ 186.2606 m 0.0002 m -0.0009 m 0.0015 m

DX 9013 9012 777.2141 m 0.0041 m -0.0013 m 0.0010 m
DY 1042.6622 m -0.0010 m -0.0016 m 0.0006 m
DZ -348.9550 m 0.0007 m -0.0038 m 0.0007 m
DX 9010 P12 -2219.8745 m 0.0004 m 0.0011 m 0.0015 m
DY -2837.5754 m -0.0016 m -0.0010 m 0.0010 m
DZ 862.4849 m -0.0005 m -0.0008 m 0.0009 m
DX 9010 9015 -2487.3723 m 0.0004 m -0.0013 m 0.0022 m
DY -3071.2500 m 0.0012 m -0.0013 m 0.0016 m
DZ 1018.1908 m -0.0017 m 0.0011 m 0.0015 m
DX 9010 9014 -2667.6543 m -0.0006 m 0.0000 m 0.0007 m
DY -2861.6115 m 0.0004 m -0.0011 m 0.0005 m
DZ 1340.9756 m -0.0017 m 0.0016 m 0.0005 m
DX 9010 9013 -2368.3150 m 0.0004 m 0.0000 m 0.0009 m
DY -3122.3893 m -0.0002 m -0.0008 m 0.0006 m
DZ 831.9302 m -0.0006 m -0.0001 m 0.0006 m
DX 9010 9011 -181.6743 m 0.0027 m -0.0007 m 0.0006 m
DY -45.5896 m -0.0009 m 0.0010 m 0.0004 m
DZ 234.1498 m 0.0030 m -0.0040 m 0.0004 m
DX 9010 9011 -181.6743 m -0.0010 m 0.0002 m 0.0006 m
DY -45.5896 m 0.0003 m -0.0004 m 0.0004 m
DZ 234.1498 m -0.0011 m 0.0014 m 0.0004 m
DX 9010 9012 -1591.1009 m -0.0035 m -0.0013 m 0.0006 m
DY -2079.7270 m 0.0036 m 0.0005 m 0.0004 m
DZ 482.9752 m -0.0025 m 0.0054 m 0.0005 m
DX 9010 9012 -1591.1009 m -0.0006 m 0.0009 m 0.0006 m
DY -2079.7270 m -0.0007 m 0.0004 m 0.0004 m
DZ 482.9752 m 0.0004 m -0.0001 m 0.0005 m
DX 9010 9012 -1591.1009 m 0.0023 m -0.0006 m 0.0006 m
DY -2079.7270 m -0.0007 m -0.0021 m 0.0004 m

DZ 482.9752 m -0.0010 m -0.0014 m 0.0005 m

GPS Baseline Vector Residuals

Station Target Adj vector [m] Resid [m] Resid [ppm]
DV P11 9014 931.4821 0.0003 0.3
DV P11 9013 618.7417 0.0042 6.8
DV P11 9011 3203.2547 0.0008 0.3
DV P11 9010 3388.3131 0.0009 0.3
DV 9011 P12 3513.4385 0.0017 0.5
DV 9011 9015 3884.0165 0.0011 0.3
DV 9011 9013 3821.7058 0.0011 0.3
DV 9011 9012 2487.1897 0.0015 0.6
DV 9014 P12 655.7727 0.0016 2.5
DV 9014 9015 425.0175 0.0014 3.4
DV 9014 9013 645.5512 0.0008 1.2
DV 9014 9012 1583.1852 0.0008 0.5
DV 9014 9011 3916.0106 0.0003 0.1
DV 9013 P12 322.6253 0.0023 7.1
DV 9013 9015 226.8984 0.0014 6.1
DV 9013 9012 1346.4680 0.0043 3.2
DV 9010 P12 3704.5320 0.0017 0.5
DV 9010 9015 4081.2143 0.0021 0.5
DV 9010 9014 4135.6276 0.0019 0.5
DV 9010 9013 4006.2874 0.0008 0.2
DV 9010 9011 299.8501 0.0041 13.8
DV 9010 9011 299.8501 0.0015 5.0
DV 9010 9012 2662.7301 0.0056 2.1
DV 9010 9012 2662.7301 0.0010 0.4
DV 9010 9012 2662.7301 0.0026 1.0

Absolute Error Ellipses (2D - 39.4% 1D - 68.3%)

Station A [m] B [m] A/B Phi Sd Hgt [m]
9010 0.0004 0.0004 1.1 -18° 0.0011
9011 0.0003 0.0003 1.1 -29° 0.0010
9012 0.0005 0.0004 1.2 -14° 0.0012
9013 0.0006 0.0004 1.4 -11° 0.0012
9014 0.0004 0.0003 1.1 -17° 0.0010
9015 0.0019 0.0008 2.4 -12° 0.0025
P11 0.0000 0.0000 1.0 0° 0.0000
P12 0.0010 0.0006 1.6 -7° 0.0018
Observation Tests
Station Target MDB Red BNR W-Test T-Test
DX P11 9014 0.0026 m 44 3.0 0.09 0.27
DY 0.0020 m 50 2.9 0.70
DZ 0.0021 m 50 3.0 0.64
DX P11 9013 0.0057 m 90 1.0 1.53 0.88
DY 0.0038 m 85 1.1 0.71
DZ 0.0045 m 85 1.1 -0.42
DX P11 9011 0.0026 m 47 3.0 -0.38 0.72
DY 0.0020 m 51 2.8 -0.98
DZ 0.0020 m 46 3.2 -0.97

DX P11 9010 0.0043 m 86 1.2 -0.64 0.27
DY 0.0034 m 86 1.1 -0.13
DZ 0.0031 m 83 1.3 0.87
DX 9011 P12 0.0054 m 62 2.2 0.90 0.34
DY 0.0036 m 62 2.2 0.53
DZ 0.0047 m 62 2.2 0.02
DX 9011 9015 0.0070 m 58 2.3 -0.17 0.07
DY 0.0050 m 60 2.3 0.01
DZ 0.0076 m 59 2.3 -0.26
DX 9011 9013 0.0029 m 62 2.2 0.34 0.30
DY 0.0021 m 61 2.2 -0.34
DZ 0.0027 m 62 2.2 -0.06
DX 9011 9012 0.0036 m 84 1.3 1.10 0.48
DY 0.0026 m 81 1.4 0.85
DZ 0.0036 m 84 1.2 -0.05
DX 9014 P12 0.0054 m 62 2.2 -0.54 0.38
DY 0.0037 m 61 2.2 -0.41
DZ 0.0047 m 61 2.2 -0.65
DX 9014 9015 0.0076 m 69 1.8 0.39 0.11
DY 0.0054 m 71 1.8 0.29
DZ 0.0082 m 70 1.8 0.23
DX 9014 9013 0.0029 m 57 2.4 0.06 0.45
DY 0.0021 m 56 2.5 0.66
DZ 0.0027 m 58 2.4 0.75
DX 9014 9012 0.0038 m 82 1.4 0.39 0.19
DY 0.0028 m 80 1.4 0.65
DZ 0.0039 m 83 1.2 0.20
DX 9014 9011 0.0021 m 50 2.8 0.32 0.28
DY 0.0015 m 49 2.8 -0.11
DZ 0.0018 m 50 2.8 -0.90
DX 9013 P12 0.0068 m 79 1.4 -0.10 0.44
DY 0.0046 m 78 1.4 0.47
DZ 0.0059 m 78 1.5 0.87
DX 9013 9015 0.0081 m 74 1.6 -0.61 0.21
DY 0.0058 m 75 1.6 -0.78
DZ 0.0088 m 75 1.6 0.42
DX 9013 9012 0.0043 m 79 1.4 2.36 2.11
DY 0.0031 m 79 1.4 1.24
DZ 0.0043 m 82 1.3 -0.62

DX 9010 P12 0.0084 m 89 1.0 -0.44 0.22
DY 0.0055 m 86 1.1 -0.76
DZ 0.0071 m 87 1.1 -0.10
DX 9010 9015 0.0128 m 92 0.8 0.61 0.19
DY 0.0085 m 88 0.9 0.67
DZ 0.0139 m 91 0.8 -0.58
DX 9010 9014 0.0034 m 84 1.2 0.65 1.06
DY 0.0025 m 82 1.3 0.20
DZ 0.0029 m 82 1.3 -1.73
DX 9010 9013 0.0048 m 88 1.0 0.30 0.09
DY 0.0034 m 87 1.1 0.09
DZ 0.0046 m 88 1.0 -0.49
DX 9010 9011 0.0023 m 63 1.8 1.34 8.51
DY 0.0017 m 75 1.7 1.59
DZ 0.0020 m 73 1.8 3.63
DX 9010 9011 0.0021 m 67 2.3 -0.05 1.44
DY 0.0015 m 55 2.4 -0.09
DZ 0.0018 m 60 2.3 -1.63

DX 9010 9012 0.0038 m 91 1.1 1.02 2.13
DY 0.0026 m 90 1.2 1.35
DZ 0.0029 m 81 1.3 -1.37
DX 9010 9012 0.0024 m 32 3.5 -3.49 4.38
DY 0.0018 m 47 2.9 -2.82
DZ 0.0022 m 46 3.6 1.66
DX 9010 9012 0.0052 m 95 0.7 1.14 0.60
DY 0.0035 m 91 0.8 0.37
DZ 0.0054 m 95 0.6 -1.00
Redundancy:
W-Test:

T-Test (3-dimensional):

Estimated Errors (Observations)
Estimated Errors For Observations With Rejected W-Tests (max 10)
Station Target W-Test Fact Est err
DZ 9010 9011 3.63 1.9 0.0026 m
DX 9010 9012 -3.49 1.8 -0.0030 m
DY -2.82 1.4 -0.0018 m
DX 9013 9012 2.36 1.2 0.0036 m
Estimated Errors For Observations With Rejected T-Tests (max 10)
Station Target T-Test Fact Est err
DX 9010 9011 8.51 2.1 0.0040 m
DY -0.0011 m
DZ 0.0043 m
DX 9010 9012 4.38 1.5 -0.0020 m

DY -0.0008 m
DZ 0.0007 m
DX 9010 9012 2.13 1.1 -0.0037 m
DY 0.0039 m
DZ -0.0028 m
DX 9013 9012 2.11 1.1 0.0052 m
DY -0.0012 m
DZ 0.0009 m

Project Information
GPS Baseline Loops
Loops and Misclosures
www.MOVE3.com
(c) 1993-2006 Grontmij
Licensed to Leica Geosystems AG
Created: 10/07/2009 10:47:09
Project name: Burrendong Static_Matt Project
Date created: 10/04/2009 17:34:36
Time zone: 10h 00'
Coordinate system name: MGA Geoid 55
Application software: LEICA Geo Office 5.0
Processing kernel: MOVE3 3.4
Critical value W-test is: 1.96
Dimension: 3D
Loop 1
From To dX[m] dY[m] dZ[m]
9010 9014 -2667.6549 -2861.6111 1340.9739
9014 9011 2485.9800 2816.0219 -1106.8261
9011 9010 181.6716 45.5904 -234.1528
9011 9010 181.6753 45.5893 -234.1487
181.6735 45.5898 -234.1508 Average
X: -0.0015 m W-Test: -0.50
Y: 0.0006 m 0.32
Z: -0.0030 m -1.50
Easting: 0.0003 m W-Test: 0.11
Northing: -0.0017 m -0.73
Height: 0.0030 m 1.15
Closing error: 0.0034 m (0.4 ppm) Ratio:
(1:2439687)
Length: 8351.4883 m
Loop 2
From To dX[m] dY[m] dZ[m]
9010 9014 -2667.6549 -2861.6111 1340.9739
9014 9013 299.3390 -260.7773 -509.0449
9013 9010 2368.3146 3122.3895 -831.9296
X: -0.0013 m W-Test: -0.27
Y: 0.0011 m 0.35
Z: -0.0006 m -0.19
Easting: -0.0003 m W-Test: -0.07

Northing: 0.0004 m 0.11
Height: 0.0018 m 0.42
Closing error: 0.0018 m (0.2 ppm) Ratio:
(1:4815208)
Length: 8787.4648 m
Loop 3
From To dX[m] dY[m] dZ[m]
9011 9010 181.6716 45.5904 -234.1528
9011 9010 181.6753 45.5893 -234.1487
181.6735 45.5898 -234.1508 Average
9010 9013 -2368.3146 -3122.3895 831.9296
9013 9011 2186.6398 3076.8003 -597.7806
X: -0.0014 m W-Test: -0.32
Y: 0.0006 m 0.23
Z: -0.0017 m -0.61
Easting: 0.0001 m W-Test: 0.04
Northing: -0.0006 m -0.20
Height: 0.0022 m 0.60
Closing error: 0.0023 m (0.3 ppm) Ratio:

(1:3559847)
Length: 8127.8434 m
Loop 4
From To dX[m] dY[m] dZ[m]
9011 9014 -2485.9800 -2816.0219 1106.8261
9014 9015 180.2830 -209.6384 -322.7838
9015 9011 2305.6989 3025.6600 -784.0405
X: 0.0020 m W-Test: 0.26
Y: -0.0003 m -0.05
Z: 0.0019 m 0.36
Easting: -0.0008 m W-Test: -0.12
Northing: 0.0006 m 0.10
Height: -0.0026 m -0.38
Closing error: 0.0027 m (0.3 ppm) Ratio:
(1:3004868)
Length: 8225.0445 m
Loop 5
From To dX[m] dY[m] dZ[m]
9011 9014 -2485.9800 -2816.0219 1106.8261
9014 9012 1076.5535 781.8851 -857.9999
9012 9011 1409.4252 2034.1375 -248.8260
X: -0.0013 m W-Test: -0.32
Y: 0.0006 m 0.22
Z: 0.0002 m 0.07
Easting: 0.0002 m W-Test: 0.05
Northing: 0.0009 m 0.30
Height: 0.0011 m 0.31
Closing error: 0.0014 m (0.2 ppm) Ratio:

(1:5517936)
Length: 7986.3849 m
Loop 6
From To dX[m] dY[m] dZ[m]
9014 9011 2485.9800 2816.0219 -1106.8261
9011 P12 -2038.1986 -2791.9861 628.3355
P12 9014 -447.7786 -24.0362 478.4918
X: 0.0028 m W-Test: 0.56
Y: -0.0005 m -0.14
Z: 0.0012 m 0.40
Easting: -0.0011 m W-Test: -0.28
Northing: -0.0004 m -0.12
Height: -0.0029 m -0.68
Closing error: 0.0031 m (0.4 ppm) Ratio:
(1:2595177)
Length: 8085.2212 m
Loop 7
From To dX[m] dY[m] dZ[m]
9010 9011 -181.6716 -45.5904 234.1528
9010 9011 -181.6753 -45.5893 234.1487
-181.6735 -45.5898 234.1508 Average
9011 P11 -1819.3557 -2589.1512 497.0712
P11 9010 2001.0307 2634.7405 -731.2195
X: 0.0015 m W-Test: 0.37
Y: -0.0006 m -0.21
Z: 0.0024 m 0.90
Easting: -0.0003 m W-Test: -0.10
Northing: 0.0011 m 0.38
Height: -0.0026 m -0.75
Closing error: 0.0029 m (0.4 ppm) Ratio:
(1:2384697)
Length: 6891.4176 m
Loop 8

From To dX[m] dY[m] dZ[m]
9013 9014 -299.3390 260.7773 509.0449
9014 P12 447.7786 24.0362 -478.4918
P12 9013 -148.4394 -284.8153 -30.5561
X: 0.0001 m W-Test: 0.02
Y: -0.0018 m -0.44
Z: -0.0030 m -0.79
Easting: 0.0015 m W-Test: 0.31
Northing: -0.0031 m -0.69
Height: 0.0008 m 0.15
Closing error: 0.0035 m (2.1 ppm) Ratio:(1:466556)
Length: 1623.9493 m
Loop 9
From To dX[m] dY[m] dZ[m]

9013 9011 2186.6398 3076.8003 -597.7806
9011 9015 -2305.6989 -3025.6600 784.0405
9015 9013 119.0570 -51.1380 -186.2608
X: -0.0021 m W-Test: -0.25
Y: 0.0023 m 0.38
Z: -0.0009 m -0.16
Easting: -0.0009 m W-Test: -0.13
Northing: 0.0008 m 0.13
Height: 0.0030 m 0.42
Closing error: 0.0033 m (0.4 ppm) Ratio:
(1:2424180)
Length: 7932.6206 m
Loop 10
From To dX[m] dY[m] dZ[m]
9013 9011 2186.6398 3076.8003 -597.7806
9011 9012 -1409.4252 -2034.1375 248.8260
9012 9013 -777.2183 -1042.6613 348.9543
X: -0.0036 m W-Test: -0.82
Y: 0.0016 m 0.53
Z: -0.0003 m -0.09
Easting: 0.0005 m W-Test: 0.15
Northing: 0.0019 m 0.54
Height: 0.0035 m 0.90
Closing error: 0.0040 m (0.5 ppm) Ratio:
(1:1925805)
Length: 7655.3641 m
Loop 11
From To dX[m] dY[m] dZ[m]
9010 9014 -2667.6549 -2861.6111 1340.9739
9014 P12 447.7786 24.0362 -478.4918
P12 9010 2219.8741 2837.5770 -862.4844
X: -0.0023 m W-Test: -0.29
Y: 0.0021 m 0.42
Z: -0.0023 m -0.50
Easting: -0.0006 m W-Test: -0.10
Northing: -0.0003 m -0.05
Height: 0.0038 m 0.58
Closing error: 0.0039 m (0.5 ppm) Ratio:
(1:2193937)
Length: 8495.9326 m
Loop 12
From To dX[m] dY[m] dZ[m]
9010 9011 -181.6716 -45.5904 234.1528
9010 9011 -181.6753 -45.5893 234.1487
-181.6735 -45.5898 234.1508 Average
9011 9015 -2305.6989 -3025.6600 784.0405
9015 9010 2487.3719 3071.2488 -1018.1892

X: -0.0005 m W-Test: -0.04
Y: -0.0011 m -0.14
Z: 0.0020 m 0.25
Easting: 0.0012 m W-Test: 0.13
Northing: 0.0016 m 0.18
Height: -0.0012 m -0.12
Closing error: 0.0024 m (0.3 ppm) Ratio:
(1:3494541)
Length: 8265.0797 m

Loop 13

From To dX[m] dY[m] dZ[m]

9013 9010 2368.3146 3122.3895 -831.9296
9010 P11 -2001.0307 -2634.7405 731.2195
P11 9013 -367.2803 -487.6494 100.7105
X: 0.0036 m W-Test: 0.53
Y: -0.0003 m -0.08
Z: 0.0005 m 0.11
Easting: -0.0015 m W-Test: -0.31
Northing: -0.0013 m -0.27
Height: -0.0030 m -0.52
Closing error: 0.0036 m (0.5 ppm) Ratio:
(1:2221269)
Length: 8013.3401 m

Loop 14

From To dX[m] dY[m] dZ[m]

9014 9010 2667.6549 2861.6111 -1340.9739
9010 P11 -2001.0307 -2634.7405 731.2195
P11 9014 -666.6236 -226.8705 609.7554
X: 0.0006 m W-Test: 0.13
Y: 0.0001 m 0.04
Z: 0.0011 m 0.35
Easting: -0.0004 m W-Test: -0.12
Northing: 0.0007 m 0.19
Height: -0.0010 m -0.24
Closing error: 0.0013 m (0.1 ppm) Ratio:
(1:6756122)
Length: 8455.4220 m

Loop 15

From To dX[m] dY[m] dZ[m]

9010 9011 -181.6716 -45.5904 234.1528
9010 9011 -181.6753 -45.5893 234.1487
-181.6735 -45.5898 234.1508 Average
9011 9012 -1409.4252 -2034.1375 248.8260
9012 9010 1591.1043 2079.7235 -482.9727
9012 9010 1591.1014 2079.7277 -482.9756
9012 9010 1591.0986 2079.7278 -482.9742
1591.1014 2079.7263 -482.9742 Average
X: 0.0028 m W-Test: 0.84

Y: -0.0010 m -0.44
Z: 0.0026 m 1.09
Easting: -0.0006 m W-Test: -0.23
Northing: 0.0006 m 0.23
Height: -0.0039 m -1.33
Closing error: 0.0040 m (0.7 ppm) Ratio:
(1:1378728)
Length: 5449.7690 m