University of Southern Queensland
Faculty of Engineering and Surveying

An Investigation into the Australian Height Datum on Ballina Island

A dissertation submitted by

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Abstract

Australian Height Datum (AHD) is the national height datum used in Australia, and is realised with the use of permanent survey marks, that have been connected to the AHD network by the NSW state government. This report investigated the AHD on Ballina Island on the North Coast of NSW by analysing the permanent survey mark infrastructure that supports it.

Through the use of survey techniques such as Precise Differential Levelling, Rapid Static GNSS, and Reciprocal EDM Height Traversing, the inter-relationship (order) of a sample of the permanent survey marks in the subject area were able to be investigated, and compared with the AHD value stated for the recently installed Ballina CORS, and the value of MSL determined at the Ballina tide gauge over the last 24 years.

From the results of the varied surveys it has been concluded that the majority of the permanent survey mark network only fits a 3rd order relationship or less, and that the inter-relationship between the permanent survey mark infrastructure, and the recently installed CORS lays between 4th to 5th order. Furthermore, the relationship between the AHD in Ballina, and the value of MSL was derived, and determined to befit that of 3rd order standards.

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ENG4111 Research Project Part 1 & ENG4112 Research Project Part 2

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Professor Frank Bullen
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<u>Certification</u>

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

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

Matthew Stanley
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Signature

Date

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Acronyms

The following terms have been used throughout the course of this report.

AHD	Australian Height Datum
CORS	Continuously Operating Reference Station
DCP	Development Control Plan
EDM	Electromagnetic Distance Measurement
GNSS	Global Navigation Satellite System
ICSM	Inter-governmental Committee on Surveying and Mapping
LPMA	Land and Property Management Authority
LWOST	Low Water Ordinary Spring Tide
MSL	Mean Sea Level
RINEX	Receiver Independent Exchange Format
RRVD	Richmond River Valley Datum
RTK	Real Time Kinematik
SCIMS	Survey Control Information Management Service
TGBM	Tide Gauge Benchmark

Chapter 1: Introduction

Background

Australian Height Datum (AHD) is the national height datum used in Australia. It was adopted in 1971 at the culmination of many years of spirit levelling work undertaken across the continent, and was adjusted to fit the mean sea level observations of 30 tide gauges. The AHD is realised on the most part in New South Wales, with the use of permanent survey marks that have been connected to the AHD network, through various means such as spirit levelling, trigonometric and EDM heighting, and more recently the use of the Global Navigation Satellite System (GNSS).

The responsibility for coordinating these marks with respect to AHD, is predominantly the duty of the New South Wales Land and Property Management Authority (LPMA), which is the new departmental conglomerate encompassing the older land and planning divisions, such as Land and Property Information (LPI), Soil Conservation Service (SCS), and the Board of Surveying and Spatial Information (BOSSI) (LPMA, 2010). The AHD values given to the permanent survey marks are qualified to the class and order system, which serves as a statement of the marks precision and accuracy with regards to surrounding marks, and the absolute value of AHD.

There are many cases for the need of an accurate singular height datum network such as the AHD. Some of the practical uses by surveyors include the assignment of height covenants on land, to provide a benchmark datum for vertical subdivisions, and to aid in complying with development conditions such as minimum floor levels. The latter is particularly relevant on Ballina Island, which forms the subject area for this investigation. Ballina Island is the local term for the central part of the township of Ballina, which is situated on the Far North Coast of New South Wales.

Project Aim

The aim of this project therefore was to investigate the AHD on Ballina Island, by looking into the possibility of any degradation of the established network of permanent survey marks. In addition the project seeked to investigate, whether any differences exist in the values of AHD between the permanent survey mark infrastructure, the newly established Ballina Continuously Operating Reference Station (CORS), and the local value of Mean Sea level (MSL), as observed at the Ballina Tide Gauge.

Project Justification

The Ballina Island subject area forms the centre of the Ballina Shire Council Local Government Area, and is home to the majority of the service infrastructure, commercial and retail, along with a large proportion of residential land use. Geologically and topographically the Ballina Island area is constituted of mostly river gravels, alluvium, sand and clay (NSWDM, 1967) at a relative height of about 1-2m AHD.

As Ballina Island is such a low lying area, virtually surrounded by the waterways of North Creek and the Richmond River as shown in figure 1.1, Ballina Shire Council as part of its Development Control Plan (DCP), stipulate minimum habitable floor heights for buildings and residences in the area. Currently this level is 500mm above the minimum fill levels stipulated in the Ballina DCP, which for the subject area corresponds to 2m AHD (BSC, 2006).

Due to the nature of these requirements, the responsibility of ensuring that the regulations are met, is placed solely on the surveyor, who is charged with bringing vertical control with relation to AHD onto any new building site, and certifying it during construction. In order to carry out these duties as well as others, the surveyor needs to rely on the local permanent survey mark infrastructure, to provide them with accurate heights with relation to AHD.

Figure 1.1 – Ballina Island (Source: Google Earth, 2010)

Proposed Approach

In order to carry out the aims of the project, and carry out a full investigation of the AHD in the subject area, the aspect of order, in relation to height datum quality, was to be determined and assessed in three sections as outlined below.

The first section devised and observed a precise differential level network, to class LB standards. This network was to incorporate a large sample of permanent survey marks of 2nd order accuracy, that were part of the vertical control survey of 1992, and located throughout the Ballina Island subject area. From this survey the task was to analyse the network, and determine whether or not any degradation had taken place in the network in the 18 years since it was established. In addition a mean value of AHD for the sample of permanent survey marks was to be determined.

The second part of the survey was to devise and observe a static Global Navigation Satellite System (GNSS) survey, connecting the differential level network to the Ballina CORS, with the aim of determining whether any difference exists between the AHD values of the two networks, and to establish the true order between them.

Finally the third section was to devise and observe a reciprocal EDM heighting network, to connect the permanent survey mark network and the Ballina CORS, to the Ballina tide gauge, and determine what difference, if any, exists between the value of AHD determined, and MSL.

Summary

AHD is the national height datum for Australia, and its accurate determination is relied upon for a variety of purposes. This chapter briefly introduced the datum, including some background into the AHD such as its derivation, propagation, and uses. The subject area for this project was identified as the area known locally as Ballina Island, which is home to the majority of the retail, and a large amount of residential land use in the area.

The aim of this project was identified as being an investigation, through three different survey methods, of the interrelationship between a sample of the 18 year old class LB network of permanent survey marks located in the subject area, the newly established CORS that is also located on Ballina Island, and the value of MSL at Ballina tide gauge, located adjacent to the southern breakwall at South Ballina.

The following chapter will summarise the literature, with regard to different height datum systems, the AHD derivation and propagation, and benchmark infrastructure.

Chapter 2: Literature Review

Introduction

The current literature is rife with investigations into AHD, mostly with regards to the original derivation in 1971, the methods implemented, and the differential levelling network observed. In the proceeding sections, the components for deriving a vertical control network are identified, with some focus placed on definition and analyses of the AHD. With respect to the different components, the various height systems available are defined, along with the adopted systems for the derivation of AHD.

In addition the methods for propagating AHD are examined, and the types of benchmark infrastructure utilised are identified with some notes on potential stability. Because the subject area is located in New South Wales, the following discussion will focus largely on infrastructure and practices with relation to this state only.

Height Systems & Datums

Heights are generally related to a particular datum or reference plane, which is primarily dependant on what type of height system has been employed. Featherstone & Kuhn (2006), in their review of height systems, identify two main types, those that are related to gravity, and those that are not.

Height Systems Not Related To Gravity

Height systems that are not related to gravity are generally described as being geometrically derived. The most common geometric height system is the ellipsoidal height system, which is described as being the distance measured along a straight line, normal to a reference ellipsoid and a point of interest on the earths surface (Featherstone & Kuhn, 2006). This relationship is best described as shown in figure 2.1.

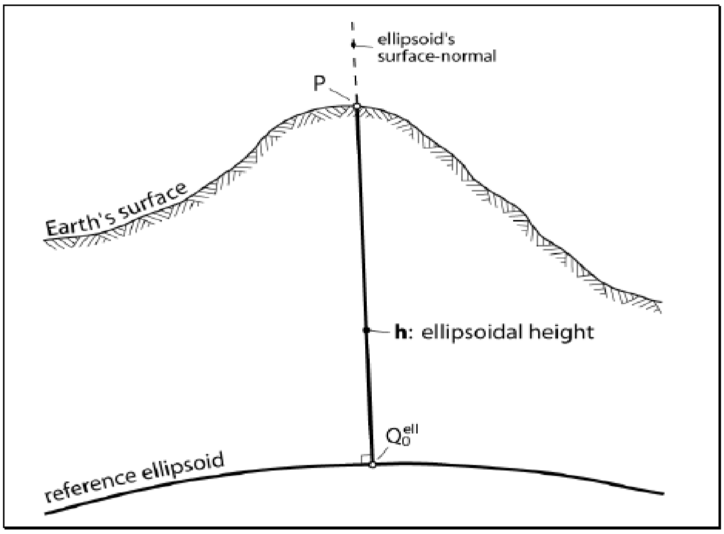

Figure 2.1 – The Ellipsoidal Height System (Featherstone & Kuhn, 2006)

The ellipsoidal height system is predominately used when deriving a height by utilising GNSS equipment. Due to the position derived by GNSS equipment being made with reference to an ellipsoid, any height derived from this equipment is subsequently made as an ellipsoidal height (Featherstone & Kuhn, 2006). In light of this, the datum that is employed for ellipsoidal heights is generally the reference ellipsoid itself. In Australia the reference ellipsoid for ellipsoidal heights is the International Terrestrial Reference Frame, locked at epoch 2000 (ITRF2000) (Featherstone & Kuhn, 2006).

Height Systems Related to Gravity

Any object on the earth's surface is ultimately enacted on and influenced by gravity. As such it stands to reason that any height system that is to be utilised should take the influence of gravity into account. To ignore the effects of gravity potential as is the case in the ellipsoidal height system outlined above, can lead to instances where a negative change in ellipsoidal height, can have a positive change in gravity potential, and thus from a design perspective, objects and fluids can appear to move uphill.

Height systems that are related to gravity, generally utilise the geoid as their datum plane. The geoid can be defined as an equipotential surface, perpendicular to the direction of gravity (Johnstone & Featherstone, 1998), where gravity potential is equal to zero. For all intents and purposes, the value of mean sea level is approximately coincident, and generally adopted as this surface (Johnstone & Featherstone, 1998).

Featherstone & Kuhn (2006) identify 5 main types of gravity dependant height systems, these 5 systems are briefly summarised below;

- **Geopotential Numbers** – Essentially speaking, Geopotential Numbers are defined by Featherstone & Kuhn (2006, p.6-7), as 'the difference between the Earth's gravity potential at the point of interest *W*, and that on the reference geopotential surface chosen W_o', ie the geoid. Since geopotential numbers are required to be converted into dimensions of length to be effective, these measurements are normally used in addition to spirit levelling exercises (Featherstone & Kuhl, 2006).

- **The Dynamic Height System** – This system uses geopotential numbers, and divides them by a constant value of gravity to give a measurement of length. The main failing of this system alone, comes about due to the variation of the value of gravity, as adopting a constant value for all latitudes can lead to distorted height values (Featherstone & Kuhn, 2006).

- **The Orthometric Height System** – The orthometric system is defined as the length of the curved line that is normal to the Earth's gravity field, from a point of interest at the Earth's surface, to the geoid (Featherstone & Kuhn, 2006). The curved nature of this line is due to the change in orientation of an equipotential surface, with the change in mass-density distribution inside the topography. In order to physically model these changes, it would be necessary to take gravity readings at every point along this line, inside the topography, a situation that is virtually impossible to attain (Featherstone & Kuhn, 2006). The system is demonstrated further in figure 2.2.

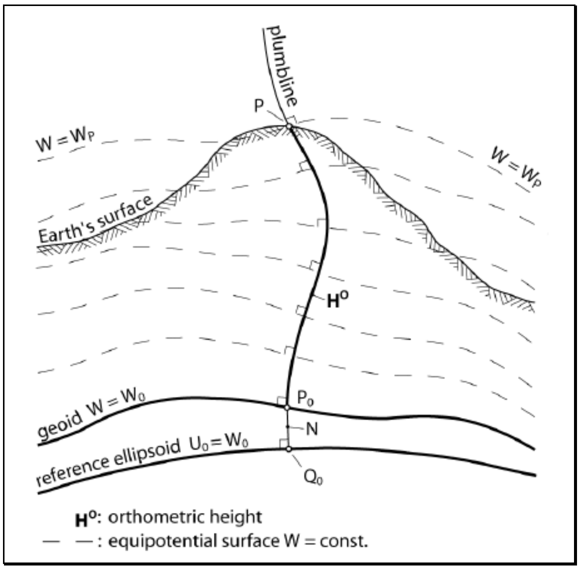

Figure 2.2 – The Orthometric Height System (Featherstone & Kuhn, 2006)

- **The Normal Height System** – In order to define the normal height system, two new surfaces are introduced, the telluroid, and the quasigeoid. The telluroid is a surface defined by projecting a point on the Earth's surface (P in figure 2.3), along the ellipsoidal normal, until it reaches a point on the normal gravity field, that coincides with the gravity potential value identified at P. This separation distance is termed the height anomaly (ζ). The quasigeoid is defined as 'a non equipotential surface of the Earth's gravity field that coincides reasonably closely with the geoid' (Featherstone & Kuhn, 2006, p.13). The separation distance between the quasigeoid and the reference ellipsoid, along the ellipsoid normal, is identical to the height anomaly. From here the correction for the distance along the normal plumbline, can be calculated from the reference ellipsoid, to the point on the telluroid, due to determination of the geopotential number, through the measurement of gravity values at P (Featherstone & Kuhn, 2006). This system is further described in figure 2.3.

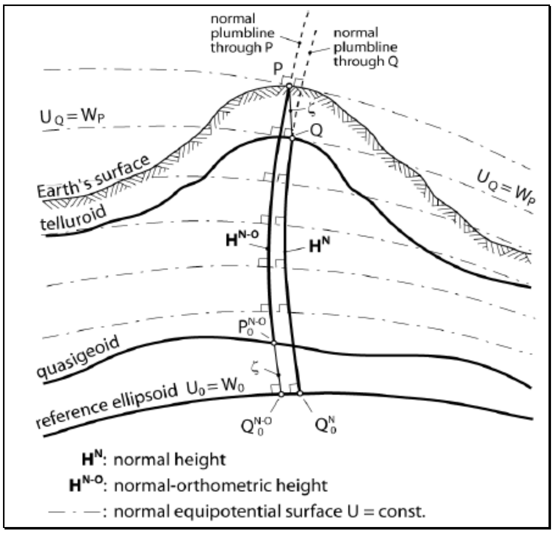

Figure 2.3 – The Normal Height System (Featherstone & Kuhn, 2006)

- **The Normal – Orthometric Height System** – This system utilises similar concepts of the normal and orthometric height systems, of determining corrections for spirit levelling, however it negates the need to take gravity measurements along the levelling traverse (Featherstone & Kuhn, 2006). This system utilises an approximation of gravity - the normal gravity field, to determine normal geopotential numbers, which are used to determine the corrections. Fluctuations of the normal gravity field, are correspondent to change in north-south position only, and as such determination of the normal geopotential numbers, is reliant only on the recording of approximate latitude (Featherstone & Kuhn, 2006).

Tide Gauges and Height Datums

As was noted previously, gravitational methods generally require a gravitational model known as the geoid, as the datum for the height system. As such MSL has been identified as being a close approximation for the geoid, and determination of this surface has generally been reliant on tidal observations, through the installation and accurate survey of tide gauges (IOC, 2006).

The first tide gauge installed in Australia was located at Williamstown in Victoria in 1859, followed by Fort Denison in Sydney in 1866 (Roelse et al. 1975). There are a number of different types of tide gauges employed at the present, including the Stilling Well and Float, Pressure Systems, Acoustic Systems and Radar Systems (IOC, 2006). Most installations in New South Wales are of the float and pressure types, and generally all standard tide gauge installations require the following infrastructure;

- A data recording device (now normally digital).
- At least one water level sensor.
- A means of communication to users.
- Some means of independently checking the height and time recorded.
- A station height datum.
- A tide gauge bench mark (TGBM) to which a relative height difference to the tide gauge is known.
- Additional recovery benchmarks in case of TGBM destruction or disturbance.
- A standard time zone.
- Documentation outlining levelling procedures used.

(ICSM, 2004)

The Australian Permanent Committee on Tides and Mean Sea Level (PCTMSL, n.d.) have published a document outlining all of the steps to be carried out, during survey of all tide gauges. The most relevant steps to this investigation include;

- Installation of benchmarks of a durable nature, in areas so as to be free of disturbance, and located approximately 100 metres apart.
- Levelling between the zero of the tide staff and the benchmarks, and connection of the tide staff datum to the national levelling survey, to third order accuracy, as set down under the Intergovernmental Committee on Surveying and Mapping's (ICSM) Special Publication 1 – Standards and Practices for Control Surveys.

Determining accurate MSL from tide gauges is complex, with varied factors having influence on results. The ICSM (2004) have identified that weather related affects such as storm surges created by wind and atmospheric lows, can have a great deal of impact on the data recorded. In addition poor sighting of tide gauges in harbours and river mouths, can introduce distortions in the tidal profiles due to shallow waters (compound tides) (ICSM, 2004), and the mixing of fresh and salt water can have the effect of increasing buoyancy.

The ICSM (2004) have also stated that for correct datum definition by MSL observation, it is recommended that at least 18.6 years of data needs to be collected at any one tide gauge, in order to encompass one full lunar nodal cycle. This is termed the Tidal Datum Epoch (ICSM, 2004).

Australian Height Datum

AHD was adopted in 1971 as the sole vertical geodetic datum on the Australian mainland (GA, 2010). A separate version of AHD as defined by levelling between tide gauges at Burnie and Hobart was adopted for Tasmania (GA, 2010), with no connection having been made between the two. The following section will analyse the mainland version, looking at the history and development of the datum, the height system and the reference plane used, and outline some of the issues that have become apparent in the years since its adoption.

Height Datum History in New South Wales

Prior to 1971, heights in New South Wales were referred to Standard Datum, which was related to MSL at Fort Denison in Sydney Harbour. The value for MSL was calculated in 1897 from 13 years of tidal observation records (NSWDL, 1976a). In an effort to make this datum more accessible, a connection was made between the tide gauge at Fort Denison, to a brass plug placed in the wall of the Department of Lands building in Macquarie Street, Sydney, with a reduced level of 8.821m (NSWDL,1976a).

A network of 1st order levelling followed in 1954 along the eastern seaboard of New South Wales, with the intention of extending standard datum into country areas (NSWDL,1976a). This was later supplemented in 1961 by federal government funded 3rd order networks, that extended the survey over the rest of the state, which were to form part of the Australian Levelling Survey (NSWDL,1976a). As these surveys progressed into regional areas, interim heights on Standard Datum were assigned for benchmarks in these areas, until a final adjustment was done for the complete survey, with final values published in 1968. The aforementioned levelling surveys additionally connected to tide gauges at Coffs Harbour, Camp Cove (Sydney), Port Kembla and Eden (NSWDL,1976a).

In 1971 with the recent derivation of the AHD completed, the decision was made to abandon Standard Datum in New South Wales, and instead adopt the new national system (NSWDL,1976a).

Australian Height Datum Derivation

The AHD was the final culmination of 161,000 kilometres of spirit levelling observations, taken in the years between 1945 and 1970 (Roelse et al. 1975). In the process of undertaking the level network, connection was made to 30 tide gauges around the Australian mainland (Filmer & Featherstone, 2009; Roelse et al. 1975). MSL was determined at these gauges from tidal observations, spanning a two year period between 1966 and 1968, for 29 of the 30 gauges, and from 1957 to 1960 at the Karumba gauge (Roelse et al. 1975).

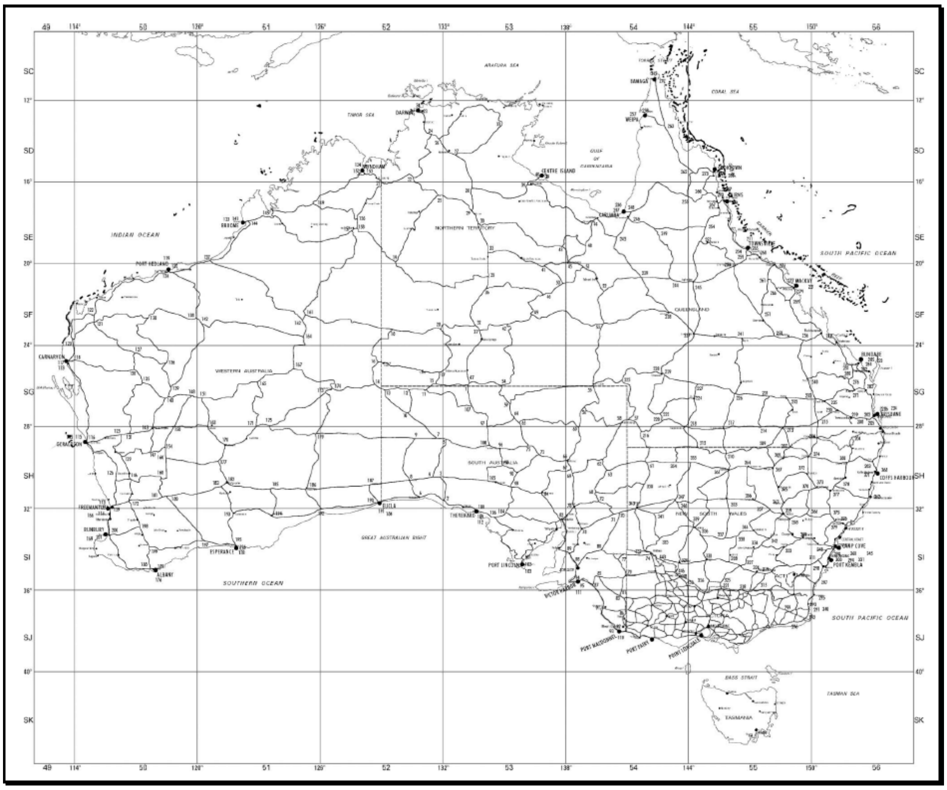

Figure 2.4 – Australian Levelling Survey (Filmer & Featherstone, 2009)

In terms of the height system adopted for the derivation of the AHD, it has been recognised by Filmer & Featherstone (2009), as a version of the normal – orthometric system. This is due to a truncated form of orthometric correction being utilised, with normal gravity being adopted from the GRS67 reference ellipsoid (Featherstone & Kuhn, 2006). In addition Featherstone & Kuhn (2006) state that most of the latitudes used to derive the values for the normal geopotential numbers necessary for the calculation of the corrections, were generally only scaled from aerial photography, with a precision in the order of about 1 mile (1.7km).

The normal - orthometric corrections were applied to the predominately 3rd order Australian Levelling Survey, as part of a fully constrained least squares adjustment, whereby the MSL value observed at the 30 tide gauges connected to during the level work, were held fixed at zero (Roelse et al. 1975). This has resulted in a distorting of the levelling network, in order to make it fit the observed sea level plane (Roelse et al, 1975). Featherstone & Kuhn (2006) state that this is in contrast to other national datums, such as the Ordnance Datum Newlyn (ODN) utilised in England (IOC, 2006). Under this regime the MSL value is only held fixed at one gauge, and the network undergoes a free-net adjustment. An adjustment of this sort was carried out on the Australian Levelling Survey by Roelse et al. (1975), and the results indicated a separation of up to 1.5m between the two planes.

Australian Height Datum – Some Issues

Australian Height Datum has since its adoption been recognised as a third order mapping datum, and as such suffers from a few issues. One such issue has become apparent due to the 1st order re-levelling of a section between Coffs Harbour and Cairns in the mid 1970's. Morgan (1992) identifies that there are some major discrepancies between the re-levelled data, and that observed during the Australian Levelling Survey by using 3rd order, one-way techniques. Morgan (1992) states that the isolated discrepancies call into question other sections of the survey that were observed using these methods, and as such, that the AHD is in need of readjustment, with these sections either re-observed, or at least down-weighted.

Kearsley et al. (1993) in their investigation into national height datum development, identify concerns with the constrained least squares method used for the adjustment of the AHD. According to Kearsley et al. (1993) this is due to MSL not being coincident with the geoid due to the influence of sea surface topography, and the poor sighting of some tide gauges leading to incorrect determination of MSL. In addition Kearsley et al. (1993) identify that the method of holding only one tide gauge fixed, and undertaking a free-net adjustment, as was the case in the development of Standard Datum in New South Wales, suffers from the same flaws as those outlined for the constrained method, with the additional problem that it ignores the derivation of MSL at all the other tide gauges.

The large scale development and use of GNSS equipment for a variety of spatial uses in the last 20 years, has identified other issues with the AHD. Due to GNSS equipment determining a three dimensional position with relation to a reference ellipsoid, it has been necessary to develop accurate geoid models for conversion of ellipsoidal height values, that are independent of the influence of gravity, to orthometric heights. These geoid models are normally determined using a combination of satellite orbit analyses, and terrestrial gravity measurements (Kearsley, 1988).

The latest in the series of Australian gravimetric geoids is AusGeoid98, and it has been identified by Featherstone & Kuhn (2006) and Luton & Johnston (2001) as having a general north-south inclination from the AHD plane of between 1 and 1.5 metres. This provides problems with the derivation of absolute AHD values from GNSS observations only, and makes local connection to AHD benchmarks still necessary, if AHD needs to be determined with confidence and accuracy. Interestingly enough, Morgan (1992) also notes that the free net adjustment of the original Australian Levelling Survey, indicates a north south inclination along the east coast of Australia of 1.5m from the adopted AHD surface.

Another potential problem that may be attributed to the AHD is that of an incorrect definition of MSL, due to the limited observation time at the 30 tide gauges that were used to fix it. Roelse et al. (1975) state that observations for mean sea level at 29 of the 30 gauges utilised, were taken over a two year period from 1st January 1966, to 31st December 1968, and from 1st January 1957, to 31st December 1960 at the Karumba gauge. This is contrast with the recommendations outlined previously for an observational record length of one Tidal Datum Epoch, or 18.6 years, as defined by ICSM (2004).

Permanent Survey Mark Infrastructure in NSW

In order to propagate and make the AHD available to users all over the country, networks of state control marks have been established, with state government authorities being assigned the task of coordinating this infrastructure, with values related to both horizontal and vertical datums.

There are a number of different types of Permanent Survey Marks in use in New South Wales, and they are stipulated in Schedule 4 of the Surveying Regulation 2006 (NSW). Of the varied marks the two most common types in use in urban areas such as Ballina Island, are the Type 2 State Survey Mark (SSM) and the Type 4 Permanent Mark (PM) as depicted in figures 2.5 and 2.6. The Type 2 SSM is a brass plaque, with a pre-stamped number identifier, that is set into concrete kerb, whereas the Type 4 Permanent Mark, is a steel pin, set into a sub surface concrete block, covered with a cast iron box, which is set flush with the natural ground surface.

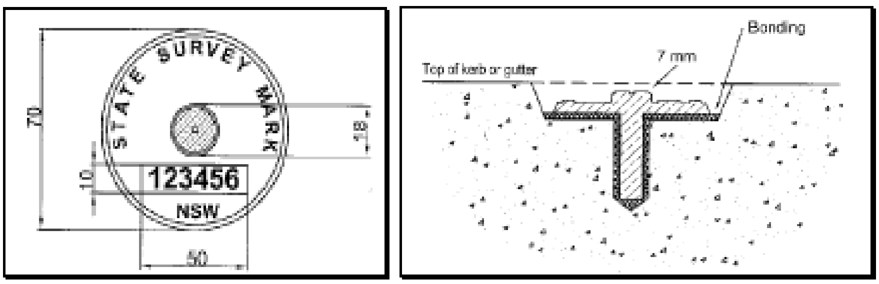

Figure 2.5 – Type 2: State Survey Mark (Surveying Regulation, 2006, NSW)

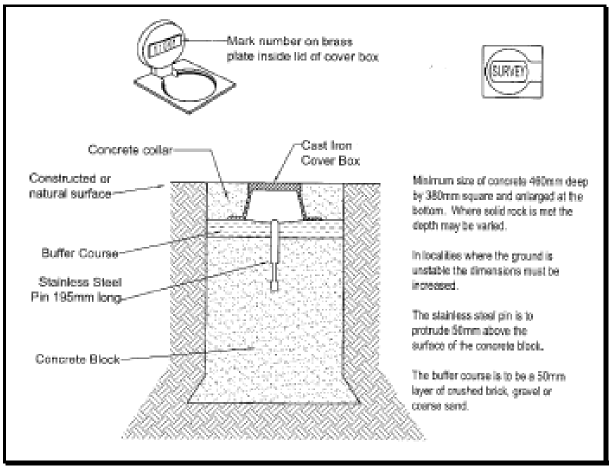

Figure 2.6 – Type 4: Permanent Mark (Surveying Regulation, 2006, NSW)

In New South Wales the assigning of accurate heights for the permanent survey marks with relation to AHD is carried out by the LPMA. The assignment of accurate levels is conducted under the class and order system, as stipulated in ICSM's Standards and Practices for Control Surveys. This document defines the class of a levelling survey to be reliant upon;

- The network design;
- the survey practices adopted;
- the equipment and instruments used; and
- the reduction techniques adopted.

(ICSM, 2007 pA-12)

In addition the LPMA also assign an order to the Permanent Survey Marks and this is reliant on how well the marks value fits with the height values of the existing surrounding infrastructure (ICSM, 2007).

In the Ballina Island subject area, the majority of the permanent survey marks AHD value is of a second order nature, having a class and order of LB - L2 respectively. It is apparent from mark information available from the LPMA, that the heights of this order were assigned on 17th August 1992 and were part of an AHD densification survey, assigning vertical control to 98 Permanent Survey Marks in the Ballina – West Ballina area (Halls, 1992). During the course of this survey, eight existing permanent survey marks were held fixed and adopted as the source of AHD, all of them with values to first order standards, and originally included as part of the National Levelling Adjustment of Australia in 1971 (Halls, 1992).

Despite the large order of accuracy that is expected in the process of assigning height values to permanent survey marks, there still exists the possibility of degradation of a network, through movement of the marks themselves over time. During the aforementioned determination of second order heights by the Department of Lands in 1992, it was reported that five Type 4 Permanent Marks were found to have moved since the last adjustment in 1971, and as such were required to have their values adjusted, and their class and order downgraded to that of the survey (Halls, 1992).

Such movement of subsurface marks has been identified in Sliwa (1987), with some of the reasons for movement including settlement of surrounding building construction, and changes in ground water level. The change in groundwater level probably affects sandy soils like that found in the subject area the least, this is due to the permeability of sand, as opposed to clay which tends to expand and contract a lot more with changes in water content. In addition Lazzarini (in Sliwa, 1987) also notes that the settlement of newly constructed buildings can have an influence on benchmark infrastructure around them, especially within a distance of twice the height and four times the width of any new building.

Summary

This section has identified the concepts behind the derivation of the AHD including a review of the height systems that are in existence, as well as the methods for deriving MSL. In addition some of the issues with the AHD have been identified and the types and some issues for the permanent survey marks used to define the AHD in the subject area have been identified.

With this section having identified all the necessary background information into height datum derivation and propagation the next chapter marks the beginning of the investigation into the height network in the subject area.

Chapter 3: Testing of the Ballina Island Network of Permanent Survey Marks.

Introduction

AHD was first brought onto Ballina Island as a result of the adjustment of 1^{st} order geodetic levelling of section 202-203 of the Australian Levelling Survey (NSWDL, 1971). This survey traced a route through Ballina Island as indicated in figure 3.1. As a result of this survey, connections were made and AHD to Class LA, Order L1 standards was assigned to the following permanent survey marks that reside in the subject area;

- PM37060 (RL 1.359);
- PM7888 (RL1.486);
- PM37148 (RL1.517);
- PM37147 (RL 1.335);
- PM37144 (RL 1.593); and,
- PM37145 (RL 1.566).

Figure 3.1 – Pre 1971 1st Order Route (Google Earth, 2010)

The majority of the permanent survey marks in the subject area however, are the result of further 2nd order differential levelling that took place in early 1992 (Halls, 1992). This survey was conducted for the purposes of extending the framework of vertical control, by levelling 98 permanent survey marks on Ballina Island, and West Ballina. Upon completion of this survey, five permanent survey marks that were heighted in the initial 1st order network, were assigned new AHD heights due to movement over the ensuing 20 year period (Halls, 1992).

The purpose of this survey is to investigate the integrity of the 2nd order network of permanent survey marks, located in the subject area of Ballina Island, as indicated in figure 3.2. As a consequence it is also intended to connect to those marks of 1st order origin that reside in the subject area, in order to ascertain whether any additional movement in these marks has occurred.

Survey Design

For the purposes of investigating the permanent survey mark network, a Class LB differential levelling survey was designed. As the majority of the permanent survey marks that are located in the test area are a product of the 2nd order levelling survey undertaken in 1992, the subject route that was adopted in 1992 was replicated by this survey, both surveys are shown in figures 3.2 & 3.3 below. In addition to this route a further leg was devised in an attempt to replicate the 1st order route undertaken originally.

Figure 3.2 – Proposed Class LB Level Network (Google Earth, 2010)

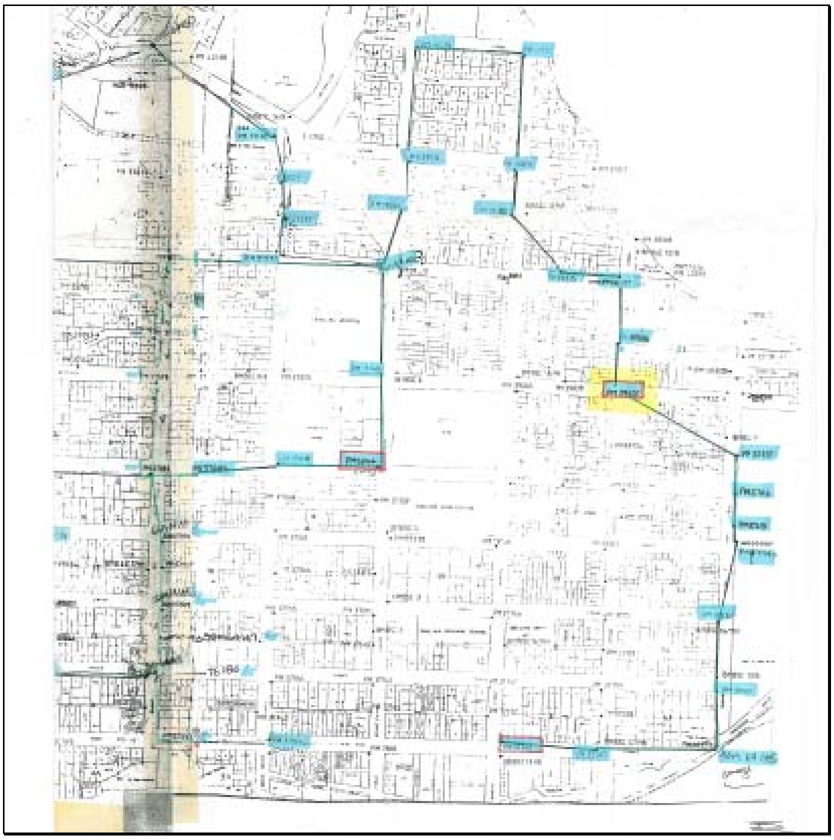

Figure 3.3 – Part of 1992 Department of Lands Level Network (Halls, 1992)

The Intergovernmental Committee on Surveying & Mapping (ICSM) in the publication '*Standards & Practices for Control Surveys (SP1)*' (ICSM, 2007), outlines best practice methodologies for achieving control surveys of various class and order. As far as was practical SP1 was the guideline that was utilised whilst conducting the collection and reduction of all field observations.

Equipment

In line with the 'Best Practice Guidelines' by ICSM (2007), equipment to be utilised to carry out a class LB level survey should meet accuracies of 0.4mm/km whether using either an optical instrument with parallel plate micrometer, or a digital instrument. In the case of this survey, the instrument used was a Leica DNA03 digital level, with achievable accuracies of 0.3mm/km, when used in conjunction with two way levelling techniques (Leica, 2002).

One of the key pre-requisites to higher order levelling is the use of invar staffs. The expense of these staffs has been prohibitive to acquisition for the purposes of this project, and so a Leica geodetic fibreglass staff, with handles and fixed bubble was used in its place. The coefficient of expansion between the two staves is the major difference between using invar staves to fibreglass. The difference between the two, that equates to around 6.7ppm/°C (fibreglass 8 ppm/°C (Rueger, 1997) and invar 1.3 ppm/°C (Cooper, 1982)), was kept to a minimum due to the absence of extreme temperature and height differences in the subject area. The latter is a result of the relatively flat nature of the topography in the subject area. This essentially results in measurements being made to the same part of the staff each time, and so the effect of the invar staffs superior stability it is hoped will have been fairly inconsequential.

Survey Procedures & Techniques

The network was observed using the two-way method, and leap frog progression, to observe the network in a series of 10 closed loops ranging from 320 to 1,200m in length. In order to further satisfy class LB requirements of ICSM (2007), the following procedures were enacted;

- An umbrella was utilised to shade the instrument throughout observations in order to prevent differential heating and cooling of the instrument.
- Solid change points were created in the form of nails in concrete paths and kerb throughout the survey, so as to eliminate the possibility of movement of portable change points.
- A 2 peg test was carried out on the instrument at the beginning of each days observation, this eliminated any errors in collimation that exceeded 1.5mm/80m.
- In order to eliminate booking errors staff readings were recorded both digitally and manually to the nearest 0.1mm, being an average of 5 measurements per sight, and standard deviations noted to being within a tolerance of ±1mm.
- Maximum line of sight length was kept to 60m.

- Each leg of the survey was checked to ensure that each loop misclosure satisfied the class LB requirements of $8\sqrt{d}$, where *d* is the length of the loop in kilometres.
- The instrument was levelled unsystematically in order to eliminate systematic errors that can be attributable to automatic levels.

A further requirement under ICSM (2007) is that an even number of instrument set ups is necessary between benchmarks. This is mainly done as outlined by Cooper (1982), to eliminate the zero error in a levelling staff when utilising 2 staves for the survey. Cooper (1982) further notes that the effect of zero error when using only one staff for observations, is eliminated with each set up. As only 1 staff was utilised in the conducting of the survey, it was decided when 2 permanent survey marks were located less than 120m apart, that only 1 instrument set up would be required.

The effect of the earth's curvature has the effect of increasing the value of the staff reading. It is stated in Cooper (1982) that the effects of the curvature of the earth can be negated by ensuring that backsight and foresight distances at each set up, are kept as close as is possible to equal, provided that the coefficient of refraction is the same. This is echoed by ICSM (2007) in their class LB requirement to keep backsight and foresight lengths to within 2% of the sight distance.

By adopting the equation for the estimation of curvature as proposed by Bannister & Raymond (1984);

$$\boxed{CorrectonForCurvature = 0.078(d)^2}$$

where d is the length of sight in kilometres, and allowing for a radius of the earth of 6,370km, and a line of sight of 60m as adhered to in this survey,

$$\boxed{\begin{aligned} CorrectonForCurvature &= 0.078(d)^2 \\ CorrectonForCurvature &= 0.078(0.06)^2 \\ CorrectonForCurvature &= 0.00028 \end{aligned}}$$

would constitute an increase in staff reading of 0.28mm. Since the requirement for recording staff measurements is to be of the precision of the nearest 0.1mm for class LB surveys, as stipulated by ICSM (2007), a difference of 0.05mm (and thus affecting the recorded measurement) would be observed where a difference of 8.9m in backsight and foresight distances occurs. Therefore where ICSM (2007) requires a minimum of 2% of sight distance, estimates after Bannister & Raymond (1984) allows for a far more lenient value of around 6%.

Cooper (1982) identifies that refraction of the line of sight tends to become an issue when sighting along uneven topography. This is due to the differing thermal properties of air with relation to its proximity to the ground. Cooper (1982) further identifies that this is less of an issue when surveys are conducted in relatively flat areas, and as such ICSM (2007) states a minimum ground clearance of 0.5m for class LB surveys.

With regards to this survey the effects of refraction would be fairly inconsequential, as long as the concept of equal backsight and foresight distances were observed. This is due once again to the relatively flat nature of the topography in the subject area, creating a situation where the line of collimation of the instrument remains a fairly constant height above the earth's surface. As such any effects of refraction observed along a backsight, would equal that observed along a foresight of equal length, and thus negating it.

Finally, another consideration taken into account whilst conducting the survey, was the possible change in instrument height between backsight and foresight readings. Belshaw (in Cooper, 1982) outlines the effect of a change in instrument height over time, due to the release of stresses on the tripod feet, upon digging them into soil. This difference it was indicated can reach up to 2.4mm over a period of 6 minutes. The effect of this was reduced whilst carrying out the survey, by setting the instrument so far as was practicable on concrete footpaths and other hard surfaces.

Reduction of Measurements

Raw observation data was downloaded from the instrument into Leica's Geo Office software. Leica Geo Office provides a complete reduction suite for GPS, TPS and Level observations. From here the data was exported into Microsoft Excel for analysis, with least squares adjustment carried out using Adjust Version 5

Results

Analysis of Survey

Upon reduction of the observed level network, the following raw data results were observed as indicated in figure 3.4 below. The table shows the individual loops constituting the network, including the forward and backward observed height differences, the resultant misclose of each loop, the one way level leg length, and the misclose allowable for each loop, using ICSM's (2007) class LB formula $8\sqrt{d}$.

Loops 1 through to 7 in the following table constitute the main control loop which starts and finishes on PM37056. The combined level loop resulted in a one way levelled distance of 5.6km with a final misclose on PM37056 of 10.7mm, easily satisfying ICSM's (2007) requirements of 26.8mm for the network.

Loops 8, 9 and 12 were all observed as internal ties, with the aim of strengthening the control loop. Loop 8 traversed Grant Street as per the original Department of Lands survey in 1992 and loop 9 traversed Martin Street as per the 1st order network observed as part of the Australian Levelling Network.

Loop	From	To	Forward	Back	Misclose	Distance	Allowable Misclose
1	PM37056	PM37040	0.1978	-0.1978	0.0000	500.0	0.0080
2	PM37040	PM37144	0.1719	-0.1746	-0.0027	709.5	0.0095
3	PM37144	PM42055	-0.2429	0.2391	-0.0038	864.2	0.0105
4	PM42055	PM39317	0.2745	-0.2763	-0.0018	873.5	0.0106
5	PM39317	CP20	0.3336	-0.3346	-0.0010	1184.1	0.0123
6	CP20	CP24	-0.5485	0.5478	-0.0007	702.0	0.0095
7	CP24	PM37056	-0.1940	0.1933	-0.0007	770.4	0.0099
Total			**-0.0076**	**-0.0031**	**-0.0107**	**5603.6**	**0.0268**
8	PM37060	PM37083	-0.0164	0.0166	-0.0002	546.2	0.0084
9	PM37148	PM37145	0.0328	-0.0332	-0.0004	1004.6	0.0113
12	PM39315	CP36	-0.2055	0.2057	-0.0002	319.38605	0.0064

Figure 3.4 – Table Showing Raw Data Miscloses – Class LB Ballina Island Loop

In order to eliminate the miscloses in the various level loops, the raw observations under went a least squares regression adjustment. This was carried out using the Adjust software - Version 5 by CG Consultants. The network was adjusted under a ‘free’ adjustment routine, whereby only one permanent survey mark was held fixed at its published SCIMS height value. Due to the fact that it was the start and end point for the main control loop, PM37056, with a published height of 1.229, was chosen to be the control point for the adjustment.

Analysis of Existing Permanent Survey Mark Infrastructure

Due to the least squares adjustment carried out on the survey being free, no other constraints were placed upon the observations other than a weighting that was based purely on the approximate distance measured between permanent survey marks. The resulting height differences (ΔHt) were compared against the height differences between the published AHD heights for the permanent survey marks, as supplied by the LPMA. The deviation between the two sets of height differences are plotted in figure 3.5.

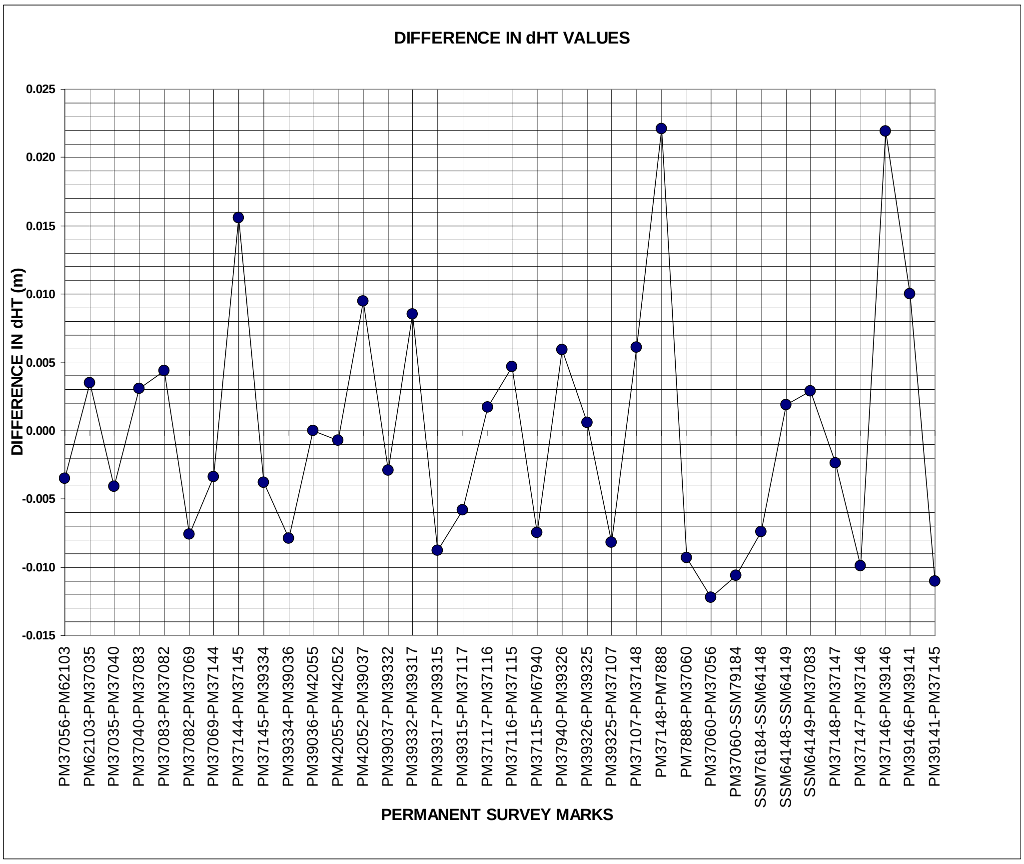

Figure 3.5 – Graph Showing Deviation Between Published and Observed Height Differences

From the above results there appears to be quite a bit of variation in height differences between the permanent survey marks published heights, and the differences observed by survey. Most notably from these results are the differences between PM37148 and PM7888, and PM37146 and PM39146 both of which appear to have a variation in height differences of up to 22mm from their published heights.

Once again looking back at ICSM (2007), we can utilise the formulas for the allowable misclose variation, this time to test the quality of the published height differences between the permanent marks. This approach gives a better indication of the quality of the height differences, because it factors in the distance component between the marks. Figure 3.6 shows the allowable variation in height difference between adjacent permanent survey marks, based on the distance between them. The allowable variation has been calculated for control survey orders 2^{nd}, 3^{rd}, 4^{th} and 5^{th} and is essentially the r-value as stated in ICSM (2007). Furthermore, plotted against the allowable variation, is the derived r-value for the difference between the published height difference between the permanent survey marks, and the height difference that was observed as part of this survey. It should be noted that all r-values for the purpose of this graph were reduced to positives.

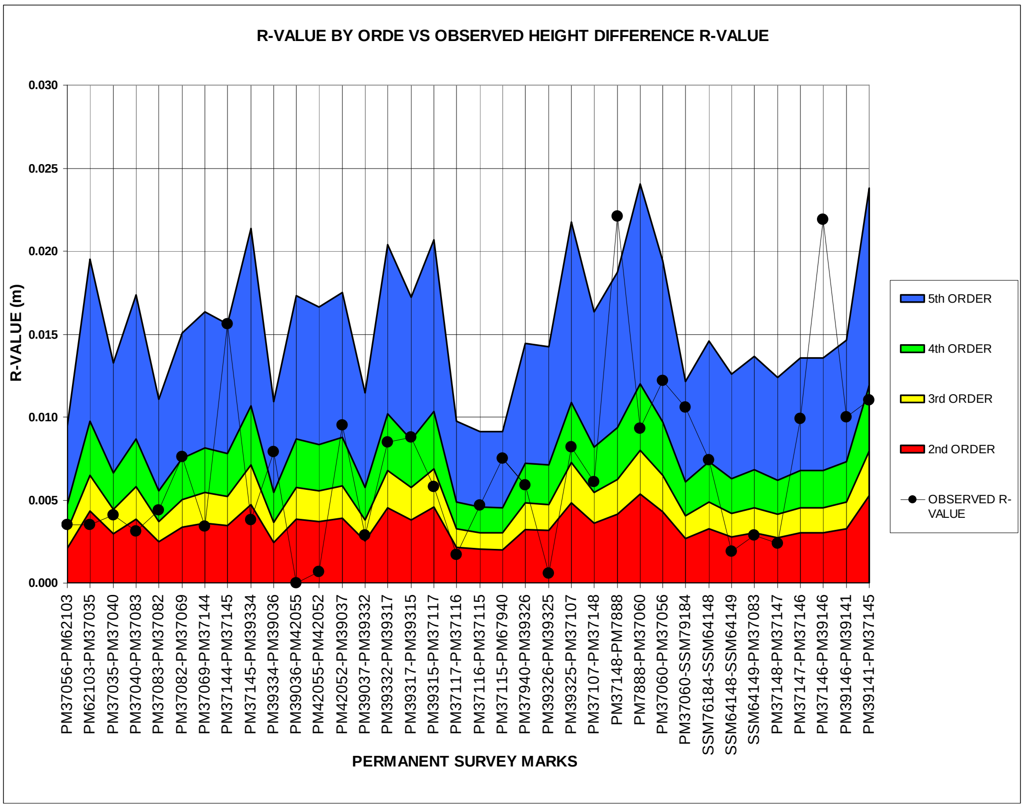

Figure 3.6 – Graph Showing the Derived Order of Existing Published Height Differences

As can be seen from the above graph, many of the published height differences in the network do not meet the standards set down for a 2nd order network, and indeed for the two height differences mentioned previously, being between PM37148 and PM7888, and PM37146 and PM39146 don't even comply with the variation set down for a 5th order relationship. A break down of the percentage of height differences and their corresponding orders is simplified in figure 3.7.

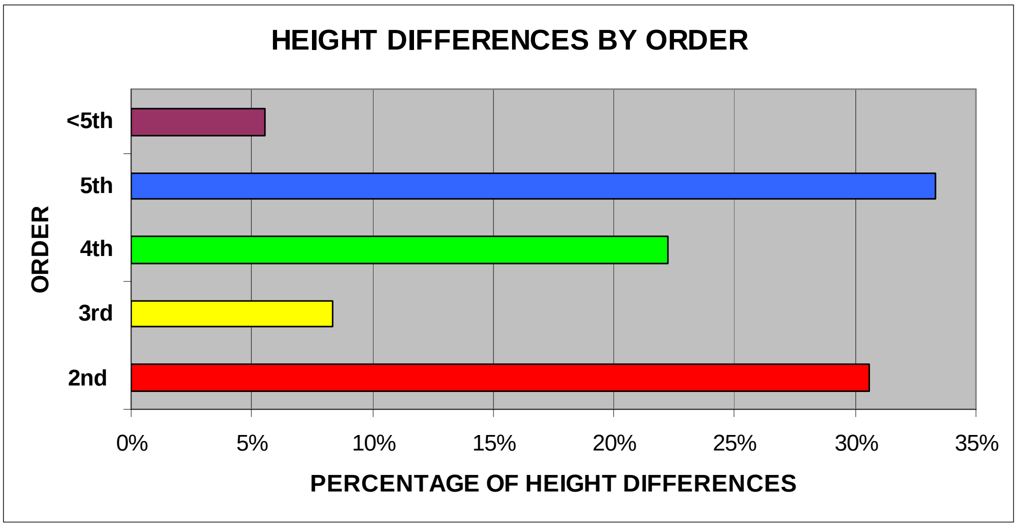

Figure 3.7 – Graph Showing the Percentage of Height Differences by Order

From this graph it can be determined that almost 70% of the height differences measured between permanent survey marks in the study area, have a variation from the actual observed height differences that correspond to a third order relationship or less.

Determination of a Value for AHD

In order to determine a value for AHD from the network, actual observed AHD values for the 38 individual permanent survey marks in the subject area, were determined by adopting the published SCIMS AHD value for PM37056, of RL1.229, as mentioned in the previous section. The difference between the observed and the published AHD value for each permanent survey mark was then determined resulting in the following figure 3.8.

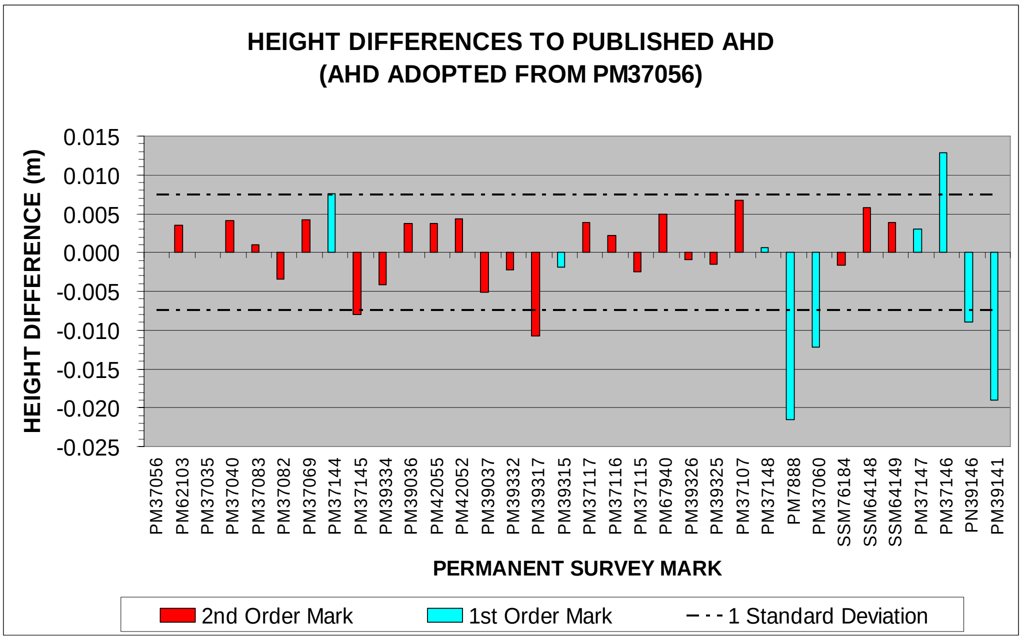

Figure 3.8 – Graph Showing the Deviation from AHD as Determined from PM37056

Based upon these results, it was determined that the mean of the differences was -0.0008, and as such is the amount that the calculated AHD values of the permanent survey marks should be adjusted by, in order to calculate the true value of AHD as propagated by this selection of permanent survey marks (ie moving away from the adoption of the published height of PM37056). However due to the large departures from the original 1992 network as shown above and in the previous section, it is therefore prudent to remove the influence of these marks when determining the mean, in order to gain a better indication of the true value of AHD. To this end all absolute height differences that lay outside of one standard deviation were excluded, and the mean recalculated with the results presented in figure 3.9 below.

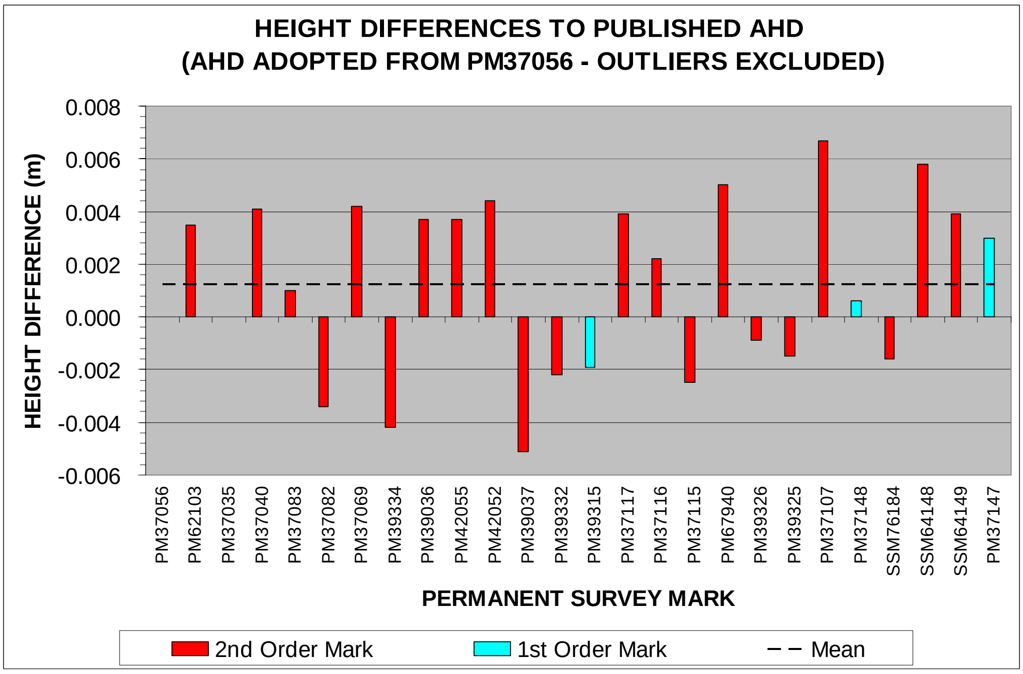

Figure 3.9 – Graph Showing the Deviation from AHD as Determined from PM37056 (Outliers Excluded)

As can be seen from the above graph, the mean has shifted from -0.0008m to 0.0012m due to the exclusion of the outliers that were beyond one standard deviation of the total mean. Therefore it is most likely that the true value of AHD actually lies 0.0012m above the value of RL1.229 for PM37056 as quoted by LPMA. To this end the best value of AHD for the permanent survey marks sampled in the subject area are depicted in figure 3.10;

Permanent Survey Mark	***RL (AHD71)***	***RL (Survey)***	***Height Difference***	***Permanent Survey Mark***	***RL (AHD71)***	***RL (Survey)***	***Height Difference***
PM37056	1.229	1.2302	0.0012	PM37117	1.278	1.2831	0.0051
PM62103	1.401	1.4057	0.0047	PM37116	1.358	1.3614	0.0034
PM37035	1.199	1.2002	0.0012	PM37115	1.424	1.4227	-0.0013
PM37040	1.423	1.4283	0.0053	PM67940	1.362	1.3682	0.0062
PM37083	1.329	1.3312	0.0022	PM39326	0.922	0.9223	0.0003
PM37082	1.367	1.3648	-0.0022	PM39325	1.219	1.2187	-0.0003
PM37069	1.551	1.5564	0.0054	PM37107	1.299	1.3069	0.0079
PM37144	1.593	1.6018	0.0088	PM37148	1.517	1.5188	0.0018
PM37145	1.559	1.5522	-0.0068	PM7888	1.486	1.4657	-0.0203
PM39334	1.441	1.4380	-0.0030	PM37060	1.359	1.3480	-0.0110
PM39036	1.838	1.8429	0.0049	SSM76184	1.481	1.4806	-0.0004
PM42055	1.356	1.3609	0.0049	SSM64148	1.338	1.3450	0.0070
PM42052	1.190	1.1956	0.0056	SSM64149	1.337	1.3421	0.0051
PM39037	1.142	1.1381	-0.0039	PM37147	1.335	1.3392	0.0042
PM39332	1.048	1.0470	-0.0010	PM37146	1.807	1.8211	0.0141
PM39317	1.646	1.6365	-0.0095	PM39146	1.559	1.5512	-0.0078
PM39315	1.689	1.6883	-0.0007	PM39141	1.735	1.7172	-0.0178

Figure 3.10 – Table Depicting the Published and Derived AHD Values

Summary

This section has seen the first part of fieldwork as conducted to achieve the objectives of the project. The section has outlined the background to the supply of AHD infrastructure in the subject area, as well as the methods and procedures implemented to test the AHD infrastructure. Results of the class LB survey in terms of the observed height differences were reported, as was the value of AHD derived as a best fit from the sampled Permanent Survey Mark infrastructure.

Chapter 4: Testing of the Ballina Continuously Operating Reference Station to the Network of Permanent Survey Marks

Introduction

The Continuously Operating Reference Station (CORS) network in New South Wales is a network of Global Navigation Satellite System (GNSS) receivers operated by the NSW LPMA. The network is termed CORSnet-NSW and is a state-wide expansion of the original SYDnet network also implemented by LPMA (Jannsen et al, 2010). CORSnet-NSW has been identified by Jannsen et al. (2010) to consist of some 29 continuously operating receivers across the state as of January 2010, with the role out to eventually number 70 by 2013.

CORSnet-NSW, like other CORS networks, has been beneficial to the surveying community, in that by connecting to this network, the user can work in Real Time Kinematic (RTK) mode, without the requirement of having to establish their own base station. The system works with the aid of a mobile phone, which downloads and provides to a users roving unit, RTK corrections that are uploaded to a server by the CORS network. Additionally raw data in Receiver Independent Exchange

(RINEX) format is continuously logged and stored by the LPMA, and made available to end users for the purposes of conducting post processed surveys.
The reference stations themselves are given three dimensional coordinates made with reference to the Geodetic Datum of Australia (GDA97) for horizontal position and AHD71 for vertical. The stations, like the permanent survey mark infrastructure in the previous section, have a class and order qualification made to them, with respect to how well they tie in with surrounding control.

The Ballina CORS was installed atop the LPMA building located in the subject area of Ballina Island prior to February 2009. The station which has been given the reference of Trigonometric Station 12089, constitutes a Leica GRX 1200GGPro receiver, mounted atop a steel pillar fixed to the upper eastern wall of the building. The vertical position of the station is quoted by the Survey Control Information Management Service (SCIMS) to be 6.991m with respect to AHD, and qualifies the position to be within the tolerances set down under a class and order of A – 1 respectively. The order of the station is determined through connection between the mark, and a selection of pre existing control marks in what LPMA (2010b) calls a local tie survey.

In addition to the coordinates for the station as provided by SCIMS, the LPMA (2010c) has also published coordinates for its CORS network sites with relation to a new realisation of GDA94, entitled GDA94(2010). The new horizontal coordinate system has been derived from direct connection to the Australian

Fiducial Network (AFN) and has resulted in a shift in horizontal coordinates of up to 0.3m and vertical of up to 0.7m.

Since the Ballina CORS was established some time after the permanent survey mark network investigated in the previous chapter, the aim of this survey is therefore to test the integrity of the height order of the Ballina CORS with respect to this network. In order to achieve this, the value of AHD as determined previously for the network of permanent survey marks, will be compared to that currently published for the Ballina CORS.

Survey Design

Since the Ballina CORS is GNSS dependant in terms of methods of connection to the mark itself, these are the methods that were utilised in order to carry out this survey. As stated previously the Ballina CORS has been given a height value that is qualified with a class and order of A – 1 respectively. Under the guidelines set out in ICSM (2007) there are a range of GNSS survey methods available to be used in order to gain results that satisfy the requirements of a class A survey. The different survey types are as follows;

- Classic Static;
- Quick (or Rapid) Static;
- Stop and Go, and;
- Real Time Kinematic (RTK).

This is in contrast to higher class surveys such as 2A & 3A, which stipulate that they are to be conducted using Classic Static methods only. In terms of other requirements that need to be satisfied for a GNSS survey to be considered class A under ICSM (2007) are as follows;

- A Minimum station spacing of 500m;
- Typical station spacing between 500m and 10km;
- At least 20% of the stations occupied must be occupied three times, and;
- All occupied stations must be occupied no less than twice.

For the higher class surveys such as 2A and 3A, the number of station occupations that need to be occupied three times increases to 40 and 50% respectively, as does the minimum (1.5 and 5km) and typical station spacing.

The location of the Ballina CORS atop the LPMA building is approximately 100m from the southern leg of the class LB differential level network at its minimum, and 1.5km from the furthest extent of the level network to the north. Due to the location of the Ballina CORS with relation to that of the permanent survey mark network, it was decided that rapid static methods would be implemented in order to connect the two. The reason behind the selection of this method, was predominantly to do with the fact that minimum and typical station spacing, would not be satisfied for a class 2A survey in the subject area, and accuracies over the shorter baseline lengths between classic and rapid static methods, would be relatively comparable.

In preparation for this part of the overall investigation contained in this project, a number of GNSS stations were established throughout the differential level network, and included;

- Saunders – RL1.535 – Peg placed in Saunders Oval;
- Cawarra – RL1.5917 – Peg placed in Cawarra Park, and;
- PM37117 – RL1.2819 – Permanent survey mark found adjacent to Kingsford Smith Park.

In addition to these stations, two other stations were placed in order to facilitate the MSL - AHD derivation survey conducted in the following chapter, and are as follows;

- Stn 2 – RL1.7693 – Galvanised iron nail in bitumen, River Street, Richmond River - northern bank, and;
- Stn 4 – RL unknown – Peg placed, South Wall access track, Richmond River - southern bank.

The network devised to connect these stations and the Ballina CORS is shown in figure 4.1.

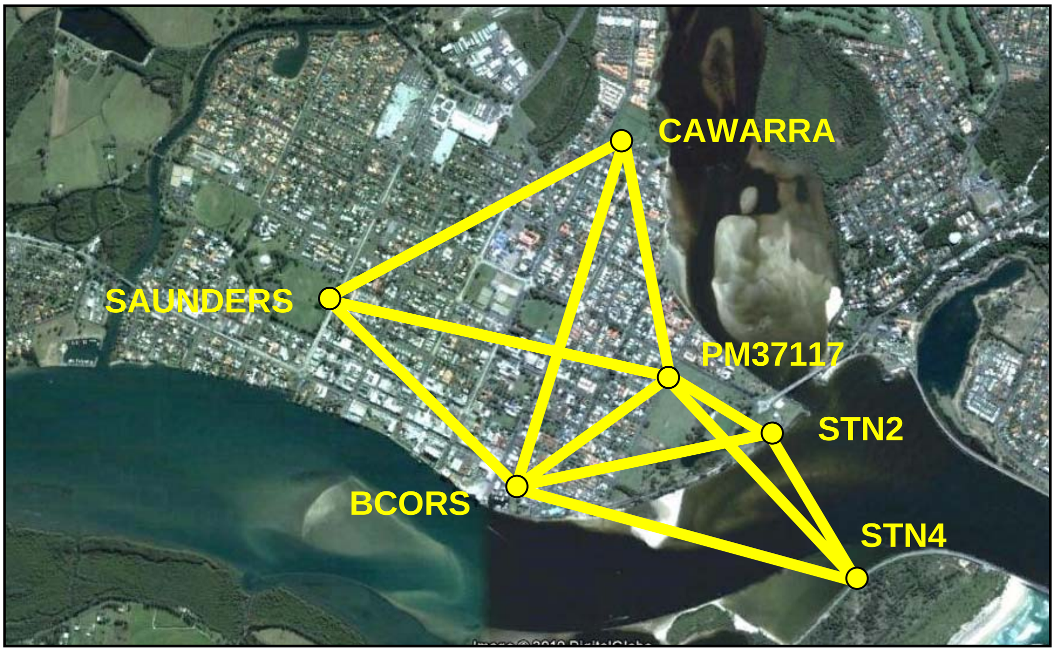

Figure 4.1 – Rapid Static Survey Network (Google Earth, 2010)

Survey Procedures & Techniques

The network as depicted in figure 4.1 was observed in 7 different sessions, and the session plan that was utilised is reprinted below in figure 4.2. The session plan was devised whilst attempting to satisfy ICSM’s (2007) guidelines pertaining to a class A rapid static survey, with respect to total number of baselines observed per session, and independent occupations per station. As can be determined from the session plan (figure 4.2) all of the stations in the network have been independently occupied twice, and three of the five stations (60%), have been independently occupied three times or more.

Session	*Saunders*	*Cawarra*	*PM37117*	*Stn 2*	*Stn 4*	*BCORS*	*Baseline 1*	*Baseline 2*
1							Saunders - Cawarra	Cawarra - BCORS
2							Cawarra – PM37117	PM37117 - BCORS
3							PM37117 - Stn 2	Stn 2 - BCORS
4							Stn 2 - Stn 4	Stn 4 - BCORS
5							PM37117 - Stn 4	PM37117 - BCORS
6							Saunders – PM37117	Saunders - BCORS
7							Stn 2 - Cawarra	Stn 2 - BCORS

Key:	
	Receiver 1
	Receiver 2
	BCORS

Figure 4.2 – Rapid Static Survey Session Plan

With regard to the number of independent baselines that can be observed in any one session, ICSM (2007) states that it can be calculated from the formula;

$$\boxed{IndependantBaselines = n - 1}$$

where *n* is equal to the number of receivers being utilised for the survey. In order to carry out the survey, in addition to the Ballina CORS permanently operating receiver, two Leica Viva GS-15 dual frequency GNSS receivers were used to observe the remainder of the network, bringing the total number of receivers used to three. Under this regime the number of independent baselines per session was calculated as being two (ie $n – 1 = 3 – 1 = 2$) which once again satisfies ICSM’s (2007) recommendations for a class A survey of two per session.

As previously stated the rapid static survey was conducted utilising two Leica GS-15 dual frequency receivers. According to Leica Geosystems (2009) the GS-15 receivers are capable of achieving accuracies of 5mm +0.5ppm in the horizontal plane, and 10mm +0.5ppm in the vertical when used under rapid static conditions. Since the longest baseline observed in the network is approximately 1.6km (BCORS to Cherry), this results in a minimum vertical accuracy of each height of ± 10.8mm.

In terms of session length, ICSM (2007) states in its guidelines pertaining to Rapid Static surveys, that session lengths should be planned so as to ensure that enough time elapses for ambiguities to be resolved, and that in order to determine this time frame, manufacturers should be consulted. It was therefore decided that each session would be observed for a total duration of 20 minutes, with a logging epoch of 1 second. This time frame was assured during consultation with Leica representatives, to be more than adequate.

Reduction of Measurements

A number of steps were involved in the download and reduction process of the rapid static network. Raw data from the GS-15 receivers was downloaded into Leica Geo Office, together with RINEX data for the Ballina CORS, that was provided by the LPMA office in Ballina. Baselines were then processed, and loop misclosures checked to ensure that no gross errors were evident. Baseline vector data was then imported into Star*Net version 6.0.25 software, and underwent a minimally constrained least squares adjustment. AusGeoid98 corrections were then applied to the adjusted ellipsoidal heights to give orthometric heights, and these were adjusted to a local value of AHD.

Results

The final derived results of the various steps described above for the reduction of the rapid static survey, are provided in the table below shown as figure 4.3.

Station	*AHD*	*Ellipsoidal (BCORS)*	*Geoid Seperation (AusGeoid98)*	*Orthometric Heights (AusGeoid98)*	*Difference (AHD-Orthometric)*	*Adjusted Orthometric Heights*	*Difference AHD-Adj Orthometric*
Cawarra	1.5917	39.1900	37.445	1.7450	-0.1533	1.5936	-0.0019
Saunders	1.5350	39.1162	37.440	1.6762	-0.1412	1.5248	0.0102
PM37117	1.2819	38.8396	37.404	1.4356	-0.1537	1.2842	-0.0022
Stn 2	1.7693	39.3169	37.390	1.9269	-0.1576	1.7755	-0.0061
Stn 4	----	42.0163	37.365	4.6513	----	4.4999	----
BCORS	6.9910	44.5210	37.398	7.1230	----	6.9716	0.0194

Figure 4.3 – Table Showing Rapid Static Survey Results

The first column of the table shows the AHD values for the stations Cawarra, Saunders, PM37117 and Stn 2 as per the derived value of AHD, based on the differential level network observations in the previous section. As such the orthometric integrity of the height differences between these stations is of class LB and therefore to a high degree of accuracy. The AHD value shown for the Ballina

CORS, is the value that is quoted by SCIMS, and therefore does not bear any relationship to the other four stations. Station 4 does not have a value with relation to AHD as yet, due to its location on the southern bank of the Richmond River.

Column 2 shows the adjusted ellipsoidal height values for all the stations in the network with relation to the Ballina CORS. Upon reduction of the baseline vectors using Leica Geo Office and the checking of loop closures, the baseline vectors underwent a minimally constrained least squares adjustment, whereby the MGA94 (2010) coordinates for the Ballina CORS were held fixed. The coordinates used are reprinted in figure 4.4 below;

Ballina Continuously Operating Reference Station	
Easting MGA94(2010)	550,009.893
Northing MGA94(2010)	6,805,990.018
Ellipsoidal Height (GRS80)	44.521

Figure 4.4 – Ballina CORS Coordinates (LPMA, 2010b)

The result of this adjustment is the ellipsoidal height values for the remaining five stations, as derived by GNSS, and with relation to the fixed value of the Ballina CORS.

As was stated in the literature review, GNSS heights are made with relation to a reference ellipsoid. The separation distance between the reference ellipsoid and the geoid, known as an *N-value*, can be determined by the application of a geoid model. AusGeoid98 is the latest geoid model on offer from Geoscience Australia and provides a 2' or 3.6km grid of *N-values* over the entire Australian continent. The separation values given in column 3 are based on this system, using interpolation software AG98LGO, Version 1.3 (Abbey, 2004).

Orthometric heights are an approximation of AHD at best, and are a result of the application of a geoid model to ellipsoidal heights. The relationship between the three is given by the formula;

$$\boxed{H = h - N}$$

Where: H = the orthometric height;

h = the ellipsoid height, and;

N = the geoid – ellipsoid separation.

The application of this formula gives the orthometric heights in column 4, and the resulting difference between the derived orthometric heights and AHD is shown in column 5.

The variation in the difference values in column 5, is put down as measurement inaccuracies between the relatively well fixed differential levels and the slightly looser GNSS heights (each height by Rapid Static methods was previously determined to be ± 10.8mm). Due to these vagaries, the AHD-orthometric differences were meaned to give a separation value between the orthometric GNSS heights, and the value for local AHD. This separation value was then applied to the orthometric heights for all seven stations, and the resultant values for all the stations on local AHD derived, and shown in column 6.

Column 7 depicts the differences between the differentially levelled stations, and the GNSS derived stations with respect to stations Cawarra, Saunders, PM37117 and Stn 2 only. As can be seen all differences are within the 10.8mm stated by the manufacturer, as the accuracy to be expected from the equipment under this regime. The difference in values for that of the Ballina CORS, derived as 19.4mm is partially to do with the equipment error, but more to the point, is a difference between the value with respect to AHD given by SCIMS, and the local value of AHD determined by the differential level survey, conducted in the previous section.

Class & Order Qualification

The above results show that some differences do appear to exist between the value of AHD as per the permanent survey mark network, and the value of AHD as per the Ballina CORS. However some qualification is still required to establish whether or not the differences are within the tolerances of the stated order.

As identified previously, class is a measure of the precision of a survey, in terms of the relative differences in position between stations in the survey. In order to assign class to a survey, ICSM (2007) identifies that the allowable length of the semi-major axis for any given baseline derived by a GNSS survey, is given in millimetres by;

$$\boxed{r = c(d + 0.2)}$$

Where: r = semi major axis (mm);

c = an empirically derived factor, and;

d = the length of the baseline (km).

Using this formula, together with the semi major axis results attained as a result of the least squares adjustment carried out in Star*Net, the following c-values were derived for horizontal and vertical precision.

Station From	*To*	*Semi Major Axis (mm)*	*Distance (km)*	*C-Value (Horizontal)*	*Vertical SD (mm)*	*C-Value (Vertical)*
BCORS	Cherry	3.22	1.620	1.8	3.18	1.7
BCORS	Kerr	3.72	1.212	2.6	3.80	2.7
BCORS	PM37117	2.74	0.776	2.8	2.84	2.9
BCORS	Stn 2	2.87	0.999	2.4	2.83	2.4
BCORS	Stn 4	3.55	1.479	2.1	3.59	2.1
Cherry	Kerr	3.71	1.484	2.2	3.40	2.0
Cherry	PM37117	3.22	1.109	2.5	2.92	2.2
Cherry	Stn 2	3.41	1.453	2.1	3.13	1.9
Kerr	PM37117	3.64	1.535	2.1	3.46	2.0
PM37117	Stn 2	3.06	0.438	4.8	2.84	4.4
PM37117	Stn 4	3.56	1.154	2.6	3.50	2.6
Stn 2	Stn 4	3.58	0.726	3.9	3.37	3.6

Figure 4.5 – GNSS Survey Precision Statistics

Since class is stated as being a factor of not only the mathematical precision of a survey, but also a factor of the procedures that are used, the main test here is that since the procedures that were implemented for this survey allow for a survey of class A or less, does the mathematical precision fit a survey of the class required. Referring back to ICSM (2007), in order to be deemed a class A survey, a c-value of 7.5 or less must be attained. As can be seen from the results in figure 4.5, the largest c-value in a horizontal plane is 4.8 and in the vertical 4.4, both of which correspond to the baseline measured between stations PM37117 and Stn 2. Since these values are less than 7.5 it would appear that the rapid static survey is of class A precision.

Order however is assigned on the basis of how well the absolute value of the survey corresponds with the adjacent control. In terms of AHD, the four stations, Cawarra, Saunders, PM37117, and Stn 2 all have derived AHD values as per the network of permanent survey marks that were sampled in the previous section. With the class A results of the rapid static survey, it has been possible to derive an AHD value for the Ballina CORS based on the permanent survey marks. The following table in figure 4.6, shows the difference in height between the published SCIMS value for the Ballina CORS and the four stations, as well as the difference in height between the derived AHD value for Ballina CORS and the four stations, as determined by the rapid static survey.

From	*To*	*Distance (km)*	*Height Difference by AHD*	*Height Difference by Survey*	*Misclose*	*C-Value*
BCORS	Cawarra	1.620	5.4560	5.4366	0.0194	15.3
BCORS	Saunders	1.212	5.3993	5.3799	0.0194	17.7
BCORS	PM37117	0.776	5.7091	5.6897	0.0194	22.1
BCORS	Stn 2	0.999	5.2217	5.2023	0.0194	19.5

Figure 4.6 – Rapid Static Survey Order Statistics

Furthermore the two calculated height differences has allowed a misclose to be determined between the two, and utilising the formula to determine class and order for differential levels, the corresponding c-values could be calculated using;

$$\boxed{r = c\sqrt{d}}$$

Where r = allowable misclose;

c = an empirically derived factor, and;

d = the distance between stations (km).

Since the differential level network observed in the previous section was observed to 2^{nd} order standards only, this is the maximum order that is achievable in this survey. However, the corresponding c-values derived in figure 4.6, state that based on the c-values by order stated in ICSM (2007), the best that can be assigned to the Ballina CORS based on the permanent survey marks adjacent to it, is closer to 5^{th} order, with the two closest stations (PM37117 and Stn 2) having c-values between 18 and 36. However the connection between the two furthest stations, do fit a 4^{th} order relationship, with c-values lying between 12 and 18.

Summary

This section has described the methods and procedures used in order to determine a comparison of the AHD value between the recently established Ballina CORS and the permanent survey mark infrastructure located adjacent to it. Through the course of this section, it has been shown that indeed a difference does exist between the two in the vicinity of 19.4mm, and the relationship between the two is closer to 5^{th} order, which is in contrast to the SCIMS stated relationship of 1^{st} order.

Chapter 5: Derivation of an AHD value for Mean Sea Level as Observed at Ballina Tide Gauge.

Introduction

The derivation of AHD on the Australian continent as identified in chapter 2, was carried out by forcing a majority 3rd order differential level network, that connected 30 tide gauges scattered around the continent, to the MSL value, that was observed at each one of the tide gauges. The value for MSL that was used for the derivation of AHD, was a result of the analysis of approximately 2 years worth of tide level observations.

It is held by ICSM (2004), that in order to use MSL data as the basis for the definition of a height datum, that the data used should be from a minimum of 18.6 years worth of records. This 18.6 year period is the time duration that defines one tidal datum epoch. The tidal datum epoch is generally calculated as being the time taken for the positions of the earth sun and moon to repeat, and as such the time taken for the entire tidal system to repeat (ICSM, 2004).

As was also outlined in chapter 2, there are other limitations that have been identified with the derivation of AHD, including some questions regarding errors in some 3rd order one way levelling techniques, and not observing the effects of sea surface topography to name but a few. The result has been the classification of AHD as being no more than a 3rd order mapping datum.

Although not a part of the derivation of the AHD having only been installed in 1986, the Ballina tide gauge at its present location, adjacent to the southern breakwall at the mouth of the Richmond River, has been recording data since installation. As such Manly Hydraulics Laboratory (MHL) holds complete MSL records for the last 24 years, relative to Richmond River Valley Datum.

Since the Ballina tide gauge does have sufficient data to satisfy the requirements of one tidal datum epoch, the purpose of this survey therefore, is to derive a value for MSL with relation to AHD, as propagated by the sample of permanent survey marks on Ballina Island and determined in chapter 3. The aim of this process is to determine if AHD is the best representation of MSL in the subject area.

Survey Design

The tide gauge at Ballina is a Zwarts type, electromagnetic system, and consists of two copper tubes approximately 50mm in diameter, that are mounted to a steel 'I – beam' (MHL, n.d.). With this type of system, water level measurements are made with reference to the length of the un-immersed section of tube. As a result there is no visible gauge staff with which to directly connect to the tide gauge. Instead, surveyed height connection is made to a series of tide gauge benchmarks that have a set height above the same datum with which the tide measurements are made (ICSM, 2004). In the case of the Ballina gauge there are three of these benchmarks, with heights made with respect to Richmond River Valley Datum (RRVD). RRVD is also stipulated as being a realisation of the local level of Low Water at Ordinary Spring Tide (LWOST) which is the datum reference that has been stated by MHL when quoting their derived value of MSL.

The location of the Ballina tide gauge, adjacent to the southern bank of the Richmond River, along with the associated tide gauge benchmarks as depicted in figure 5.1, has led to the necessary implementation of reciprocal EDM heighting methods. These methods were necessary in order to transfer the determined AHD height value, from the permanent survey mark network located on the northern bank, across to the southern side of the Richmond River.

Figure 5.1 – Location of Ballina Tide Gauge and Benchmarks (Google Earth, 2010)

In order to make this surveyed connection, three main tasks were necessary, and are as follows;

- To carry out a reciprocal EDM height network in the form of a braced quadrilateral, transferring height differences between two stations located on the northern bank of the Richmond River, to two stations on the southern bank.
- To carry out a differential level survey that connected the two reciprocal EDM heighting stations located on the northern bank of the Richmond River, with the class LB differential level survey, and;
- To carry out a differential level survey, that incorporated the three tide gauge benchmarks and the two stations placed on the southern bank of the Richmond River, in order to connect the reciprocal EDM heighting survey, and the Ballina Tide Gauge.

In addition to these tasks the height difference determined from the GNSS based connection between Stations 2 and 4, will also be used as a check on the results achieved with the reciprocal heighting.

With respect to the methods, procedures and equipment utilised whilst conducting the two differential level surveys, the procedures as outlined in the section detailing the class LB differential level network on Ballina Island were strictly adhered to, and are not reiterated here.

As with the other aspects of this project, procedures utilised whilst carrying out the reciprocal EDM heighting survey were aligned as far as was practical with the guidelines set down by ICSM (2007). The practical guidelines followed were;

- Observing two sets of six vertical and horizontal angle observations in line with that for class B trigonometric heighting observations.
- Keeping observation times between 10am and 4pm, once again as stated for class B trigonometric heighting observations.
- Observing two sets of six electronic distance measurement (EDM) readings to each station.

The observations that are outlined above were conducted utilising two Geodimeter 700 total stations. Ideally when utilising two instruments for reciprocal EDM heighting it is best practice to make vertical angle observations simultaneously, as this eliminates the effects of refraction. However, this requires specialist equipment to allow for the attachment of prism assemblies to the total stations, and this equipment was not readily available for the project.

Due to the inability to make observations simultaneously, the effects of refraction were required to be accounted for during the reduction procedures. However, in order to make the refraction effect as small as possible, the observations were made with two instruments concurrently, as the turnaround time of around 20-30 mins to relocate from the northern to the southern side of the Richmond River, that would have been required if only one instrument was used, was seen to be too great.

Prior to the observation of the reciprocal heighting network, it was necessary to ensure that both the total stations' distance measuring features were aligned and functioning correctly. In order to ensure this, both instruments were placed over the LPMA certified EDM baseline located at Kingscliff, near the NSW - Queensland border. The baseline test resulted in two different corrections being determined for the instruments that were later applied to the measured slope distances. It should be further qualified that throughout the observation of the network, changes in temperature and pressure were constantly monitored and 'dialled in' to both the instruments, for the purposes of on-board calculation, and application of first velocity (atmospheric) corrections.

Results

The initial part of the survey was to determine the reduced levels of two stations on the northern side of the Richmond River, with respect to the AHD as derived by the class LB differential network. This was carried out by utilising the same methods and equipment as the aforementioned survey, to observe a separate loop that started and ended on SSM92282, itself a part of the main differential network, and included connection to reciprocal heighting stations 1 and 2. The resultant AHD values for the reciprocal heighting stations 1 and 2 were therefore determined as follows;

- Stn 1 – RL2.2671 – Galvanised Iron Nail in Bitumen.
- Stn 2 – RL1.7693 – Galvanised Iron Nail in Bitumen.

The second part of the survey was the transferring of the AHD from Ballina Island, across the Richmond River to South Ballina, via reciprocal EDM heighting. As indicated in figure 5.2, this was carried out in a braced quadrilateral format, with two sets of six slope distances, horizontal, and vertical angles observed from each station to the other three stations. A summary of the resultant measurements is shown in the table in figure 5.3.

Figure 5.2 – Reciprocal EDM Heighting Network (Google Earth, 2010)

From	*To*	*Horizontal Angle*	*Vertical Angle*	*Slope Distance*	*h (inst)*	*h (target)*
1	3	0°00'00.00"	89°56'57.83"	882.8096	1.579	1.398
1	2	287°06'47.25"	90°04'36.33"	485.9994	1.579	1.445
1	4	335°32'58.00"	89°52'19.50"	950.9213	1.579	1.536
2	4	0°00'00.00"	89°47'20.17"	726.1058	1.547	1.536
2	3	26°31'12.25"	89°54'48.33"	873.5258	1.547	1.398
2	1	101°30'37.92"	89°57'29.83"	485.9993	1.547	1.480
3	4	0°00'00.00"	89°49'37.33"	393.9749	1.515	1.536
3	1	272°29'45.50"	90°04'27.33"	882.8056	1.515	1.480
3	2	304°37'05.67"	90°06'29.33"	873.5223	1.515	1.445
4	3	0°00'00.00"	90°13'07.83"	393.9745	1.675	1.398
4	1	68°02'46.00"	90°09'01.33"	950.9258	1.675	1.480
4	2	98°05'57.00"	90°14'13.17"	726.1052	1.675	1.445

Figure 5.3 – Reduced Reciprocal EDM Heighting Measurements

The measurements as summarised above are the result of the following reduction procedures;

- Horizontal angles have been determined by taking the mean value of all 12 observations.
- Vertical angles were calculated by taking the mean of all 6 face left and face right observations, and calculating and applying the vertical circle correction.
- The mean was taken of all 12 slope distance observations, and the correction determined from the Kingscliff baseline test was applied.

Having determined the reduced observations in figure 5.3, the one way height differences were calculated using;

$$\boxed{H_2 - H_1 = d_{1-2} \times \cos z_{1-2} + \left(\frac{1-k}{2R}\right) \times \left(d_{1-2} \sin z_1\right)^2 + h_i - h_t}$$

Where: $d_{1\text{-}2}$ = slope distance from 1 – 2;

$Z_{1\text{-}2}$ = observed zenith angle from 1 – 2;

R = The earths radius – 6,370,000m;

k = The coefficient of refraction – 0.07;

h_i = The height of instrument, and;

h_t = The height of target.

After Hamilton (n.d.).

The results of applying the above formula to the observations in figure 5.3 are the one way height differences shown in figure 5.4;

From	***To***	***Forward ΔH***	***Reverse ΔH***	***Difference***	***Mean ΔH***
1	2	-0.4998	0.4381	-0.0617	-0.4690
1	3	1.0176	-1.0521	-0.0345	1.0349
1	4	2.2320	-2.2346	-0.0026	2.2333
2	3	1.5246	-1.5231	0.0015	1.5239
2	4	2.7243	-2.7348	-0.0105	2.7296
3	4	1.1797	-1.2165	-0.0368	1.1981

Figure 5.4 – One–Way Height Differences From Reciprocal EDM Heighting.

As can be seen from the above table, there are some very large differences that exist between the forward and reverse ΔH's. With regard to the 61.7mm difference between stations 1 & 2, this is most likely to do with a large variation in the coefficient of refraction, due to the sight lines traversing predominately bitumen roadway. The same can most likely be said for the line between stations 3 and 4, as this sight line also traversed roadway, except the surface in this instance was compacted gravel/dirt.

For the remainder four lines that actually traversed the Richmond River, it would appear that the close correlation between forward and reverse ΔH's, confirms the coefficient of refraction adopted of 0.07. The only exception remains with the line between stations 1 and 3, whose forward and reverse ΔH differences remain inexplicably large (34.5mm).

The three dimensional network was adjusted once again using the Star*Net version 6.0.25 software, under the following conditions;

- The horizontal position of stations 1 and 2 were held fixed – the horizontal coordinates were assumed on a local coordinate system, and the inter-relationship based on the measured horizontal distance.
- The vertical position of stations 1 and 2 were held fixed at the AHD heights determined previously.
- The ΔH between stations 3 and 4 determined by differential levelling was held fixed.

The results of the first run failed to pass a Chi^2 test at the 5% level, with further analysis indicating a standard residual for the ΔH observation from station 3 to 1 well in excess of the others at 4.8. The adjustment was run again, this time excluding the station 3 to 1 observation, and the results having passed all statistical testing are as follows;

- Station 3 – RL3.2937 – Dumpy peg placed in access track.
- Station 4 – RL4.4977 – Dumpy peg placed in access track.

It should also be qualified at this point that the AHD value for station 4 as determined here as RL4.4977 agrees within 2.2mm of the level determined for the station in the GNSS survey in the preceding section (RL4.4999).

With the AHD values determined for stations 3 and 4, it was then possible to determine the heights of the three tide gauge bench marks, with connection made via differential level observations. As with the other differential level runs, the procedures and equipment used satisfied ICSM's (2007) standards and practices for a class LB control survey. The results of the differential survey are as follows in figure 5.5.

Tide Gauge BM	Height (AHD) By Survey	Height (RRVD) As Quoted By DPW (2001)	ΔHt
PWD100	4.7455	5.581	-0.8356
SSBM	3.1444	3.979	-0.8346
PWD99	5.8398	6.678	-0.8382
		Mean ΔHt	-0.8361

Figure 5.5 – Determined and Quoted Heights of Tide Gauge Benchmarks

The above table indicates in the first row the height determined for each of the tide gauge benchmarks with relation to the value of AHD derived on Ballina Island. The height in the second row is the height as determined by the Department of Public Works (DPW, 2001) for the same three benchmarks with respect to RRVD. This allowed for a difference between the two datums to be determined with the overall relationship depicted by;

$$\boxed{AHD = RRVD(LWOST) - 0.8361}$$

Manly Hydraulics Laboratory (MHL) as stated previously, are the custodians of the tidal observation data that has been collected at the Ballina tide gauge since its installation in 1986. MHL (2010) has quoted that the MSL value as observed at the gauge is 0.817m ± 0.05m with relation to LWOST (RRVD), having excluded the effects of any localised flooding and storm surges. Therefore the value of MSL with relation to AHD can be determined as follows;

$$\boxed{\begin{aligned} &AHD = RRVD(LWOST) - 0.8361 \\ &AHD_{MSL} = 0.817 - 0.8361 \\ &AHD_{MSL} = -0.0191 \end{aligned}}$$

As indicated above the value of MSL with respect to the Ballina Island value of AHD is RL-0.019 ± 0.05. The relationship between the various height planes is summarised in figure 5.6.

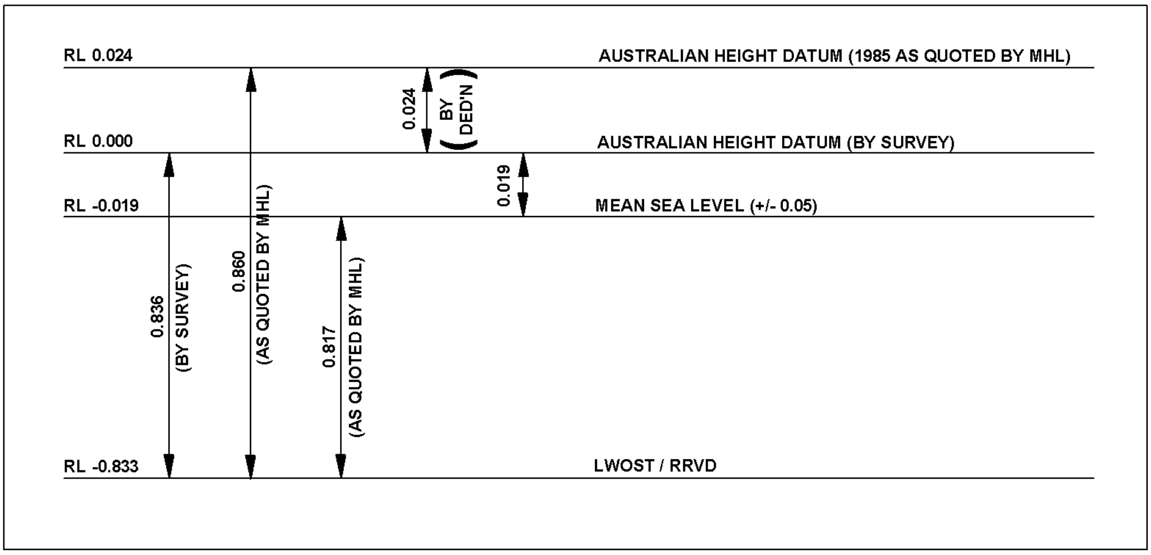

Figure 5.6 –Derived Height Plane Relationships

Class & Order Qualification

As with the previous chapters, precision of the various surveys carried out in order to determine the aforementioned value of MSL, needs to be quantified, as does the accuracy with which the AHD network fits the absolute value of MSL.

To begin with, the class of the differential level survey can be determined through the application of the formula for allowable maximum misclose, as presented by ICSM (2007);

$$\boxed{r = c\sqrt{d}}$$

Where: r = The allowable misclose (mm);

c = an empirically derived factor, and;

d = the length of the level run (km)

The results for the two differential level runs conducted on either side of the Richmond River are summarised in figure 5.7;

Loop	From	To	Forward	Back	Misclose	Distance	Allowable Misclose – Class LB
10	SSM92282	STN 2	-0.3337	0.3327	-0.0010	695.059	0.0094
11	STN 3	PWD99	2.5461	-2.5462	-0.0001	1027.7101	0.0115

Figure 5.7 – Results of Differential Level Runs

As can be seen from the above table, the observed misclose for the two level runs easily satisfies the allowable misclose for a class LB survey, which is the highest precision possible whilst using the adopted observation procedures.

In order to determine the class of the reciprocal EDM heighting survey, it is necessary to adopt the formula for maximum value of the semi major axis of the respective line error ellipses. This formula as presented in ICSM (2007) is as follows;

$$\boxed{r = c(d + 0.2)}$$

Where: r = semi major axis (mm)

c = an empirically derived factor, &

d = the length of the line (km)

The resultant semi major axis of the error ellipses for each line in the least squares adjustment, are shown below in figure 5.8.

From	***To***	***Distance (km)***	***Vertical (mm)***	***C-Value***
1	2	0.486	0 (Fixed)	-
1	3	0.882	3.40	3.1
1	4	0.950	3.40	3.0
2	3	0.874	3.40	3.2
2	4	0.726	3.40	3.7
3	4	0.394	0 (Fixed)	-

Figure 5.8 – Reciprocal EDM Heighting Class Statistics

The above table indicates that the c-value for the four ΔH's that were used to transfer the AHD from Ballina Island across to the southern break-wall, are in the range set down by ICSM (2007) for a class A survey, being in the range between 3 and 7.5. However due to the constraining height differences and the methods used only meeting class B standards, this is the maximum class that is able to be assigned to the combined network.

As with the assigning of the order of the GNSS survey in the previous chapter, the method of assigning order to the value of AHD with respect to the value of MSL will utilise the maximum misclose formula for differential levels, as indicated in ICSM (2007) as follows;

$$\boxed{r = c\sqrt{d}}$$

The difference here is that no horizontal location has been determined for the Ballina tide gauge, and as such the distance from the tide gauge to the closest section of the Ballina Island class LB differential level network is unknown. For the purposes of this exercise, it was therefore decided to scale a distance utilising the distance measuring tool in 'Google earth' software version 5.2.1.1588 (2010) with the approximate distance determined to be 1.22km. Therefore the c-value for the order between the two datums can be determined by;

$$\boxed{\begin{aligned} c &= \frac{r}{\sqrt{d}} \\ c &= \frac{19.2}{\sqrt{1.22}} \\ c &= 17.4 \end{aligned}}$$

The determined c-value of 17.4 corresponds to a third order relationship as it lays between the c-values of second and third order as stated by ICSM (2007) of 15 and 30 respectively. Therefore the relationship between the value of AHD and the value of MSL, as observed over the past 24 years at Ballina tide gauge differs by 19.2mm, and is a third order relationship.

Summary

Throughout the course of this section, the various methods and procedures that were required to transfer the value of AHD, as determined by the class LB differential level survey, across to South Ballina for the purposes of connection to the Ballina tide gauge were described. Furthermore the value of RL-19.2mm AHD was determined for MSL as has been observed at the gauge over the past 24 years, with the relationship between the two conforming to third order standards only.

Chapter 6: Discussion

Introduction

The preceding three chapters have outlined the methods, procedures, and results of the various surveys that were necessary in order to investigate the status of the AHD network on Ballina Island. In order to accomplish this, the inter-relationship between different mark types, different ages of infrastructure and different realisations of sea level height datums were compared.

In the following sections some rationale is put forward and discussed with relation to the reasoning behind the observed results of the surveys.

The Permanent Survey Mark Infrastructure

The objective of the survey in chapter 3 was to determine whether or not the accuracy of the inter-relationship between a sample of the permanent survey marks located in the subject area is still to the stated order. To test this inter-relationship, a class LB differential level network was designed to incorporate a sample of marks. Of these permanent survey marks the majority were of class and order LB - L2 respectively and were a result of one heighting campaign conducted by the

Department of Lands in 1992. A small selection of LA – L1 marks, of a vintage some 20 years older then the 2nd order network were also included in the survey.

The result of this survey has indicated that 31% (11), of the height differences between permanent survey marks, still agree with the derived height differences from the SCIMS published heights, to the standards set down for a 2nd order relationship. The remaining 69% (25) of height differences measured, have a relationship to 3rd order or lower, and of this 69%, 6% (2) lay outside the standards set for a 5th order relationship.

The movement of permanent survey marks in the subject area is not a new occurrence. Vertical movement of a selection of these marks was reported by Halls (1992) in a report accompanying the results of the 2nd order AHD densification survey that was conducted in 1992. Two of the marks that were identified in Halls' (1992) report were PM37107 and PM37145. The former was found too have moved upwards by 5mm over the 20 year period, (RL1.294 to RL1.299) and the latter was found to have sunk by 7mm (RL1.566 to RL1.559). It should also be added, that further movement of these marks has been identified as a result of this survey, over the ensuing 18 year period. The movement noted for PM37107 has been determined as lifting a further 7.9mm, taking its current RL to 1.3069, and PM37145 has continued sinking a further 6.8mm, to RL1.5522.

These results confirm the questionable nature of the stability of the predominately alluvial sand and clay soil types in the subject area. Sliwa (1987) identified that the influence of clay in soils can have an effect on benchmark stability, especially due to the expansion and contraction of clays with changing water content.

Another possible reason identified for the movement of permanent survey marks in the area, is disturbance due to construction works. The NSW Surveying and Spatial Information Regulation (2006), states in clause 44(1)(c) that any new permanent survey mark placed, must ‘be identified in a sketch plan prepared in accordance with approved standards’. Furthermore, in section 4 of the same clause it states that these sketches ‘must be forwarded to the Surveyor-General within two months of the placement of the survey mark concerned’. The sketch plans aid with the location of permanent survey marks, by showing measurements to surrounding features such as fence posts, power poles and telecommunications pits, and when completed well, can give a snapshot of the surrounding area at the time of placement.

Through the course of study of the aforementioned sketches for four of the worst performing permanent survey marks, it has been identified that some degree of construction works either adjacent to, or above has been carried out since placement, and could possibly be a cause for the marks movement. A summary of the survey marks and the apparent works completed has been provided below.

PM37144 - This mark has seen an upwards shift of 8.8mm since originally heighted in 1992. Construction works since placement has seen a reworking of the entire intersection including the installation of kerb and guttering, piping of an open stormwater flow-path immediately adjacent to the mark, and the concreting in of the cast iron cover box into a footpath. The permanent mark sketch plan and a current photograph of the intersection has been provided in figure's 6.1 - 6.3.

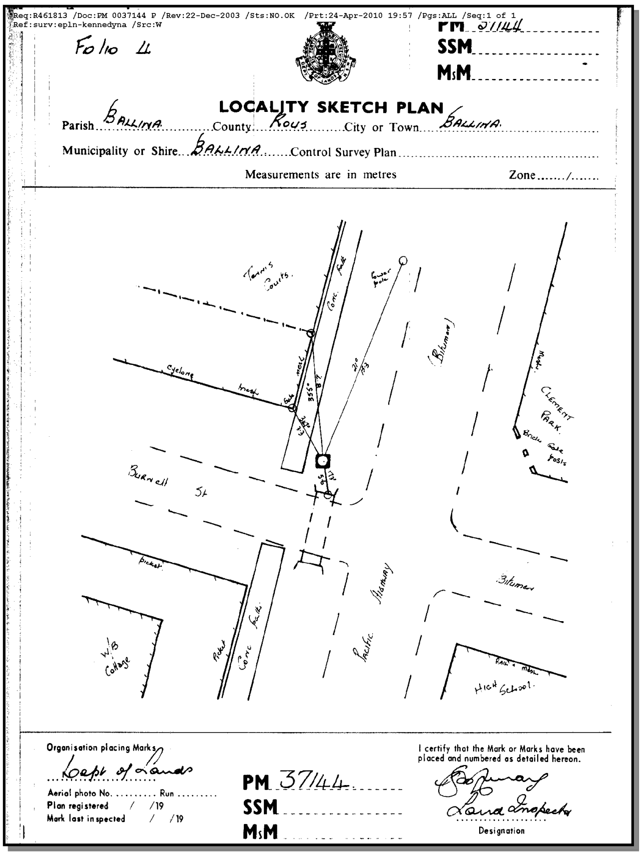

Figure 6.1 – PM37144 Intersection Upon Mark Placement (Source: LPMA, 2010d)

Figure 6.2 – PM37144 Intersection on 24/10/10

Figure 6.3 – PM37144 Intersection on 24/10/10

PM39317 – This mark has sunk 9.5mm since heighted in 1992. Works in the area have included the installation of kerb and guttering, the placement of a concrete footpath, and the apparent relocation of a sewer manhole that is now located immediately adjacent to the mark. Once again the locality sketch plan and recent photographs of the area are shown in figures 6.4 – 6.6.

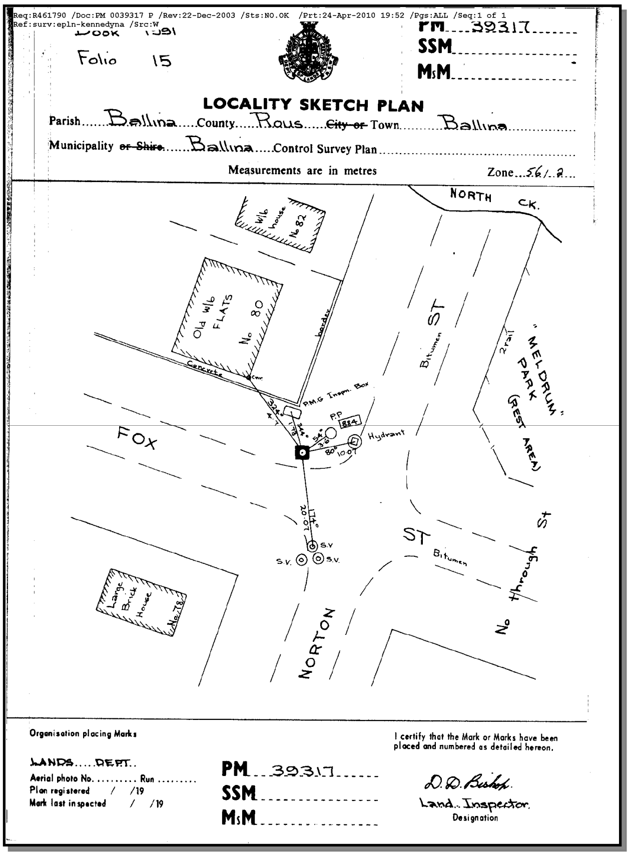

Figure 6.4 – PM39317 Intersection Upon Mark Placement (Source: LPMA, 2010d)

Figure 6.5 – PM39317 Intersection on 24/10/10

Figure 6.6 – PM39317 Intersection on 24/10/10

PM37060 – This mark is one of the original class LA marks and has dropped 11mm since it was checked in 1992. Works in the vicinity of this mark since placement have included the removal and subsequent extension of kerb and guttering into adjacent Grant Street, the addition of landscaping, the construction of the motel and adjacent brick fencing, and the concreting in of the PM cover box into a new footpath. This is depicted in the following figures 6.7 – 6.9.

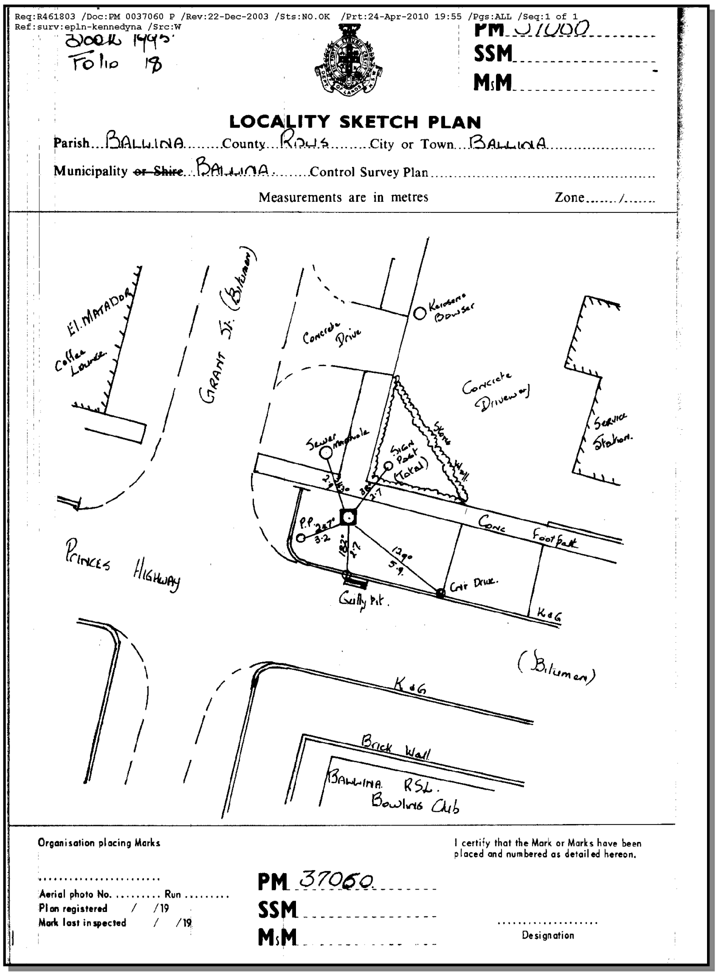

Figure 6.7 – PM 37060 Intersection Upon Mark Placement (Source: LPMA, 2010d)

Figure 6.8 – PM37060 Intersection on 24/10/10

Figure 6.9 – PM37060 Intersection on 24/10/10

PM7888 – This mark was found to be the worst performer of all the marks surveyed, and it has sunk 20.3mm since having last been surveyed in 1971. There have been extensive works done adjacent to the mark, these include the removal of a service station and erection of a single storey electrical store, the placement of a telecommunications pillar 0.5m to the west of the mark, and reworking of the surrounding intersection with new footpath, landscaping, and kerb and guttering.

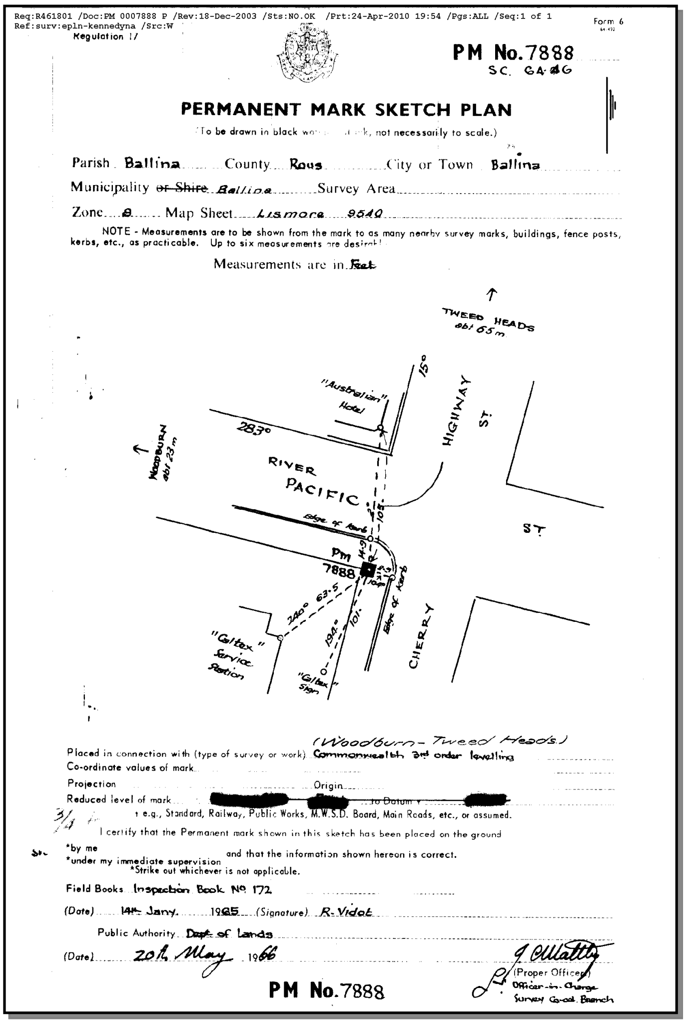

Figure 6.10 – PM 7888 Intersection Upon Mark Placement (Source: LPMA, 2010d)

Figure 6.11 – PM7888 Intersection on 24/10/10

Figure 6.12 – PM7888 Intersection on 24/10/10

In addition to these improvements, this intersection was up until the 1990's the Pacific Highway, and as such was exposed to a great deal of heavy vehicle traffic. Where PM7888 is located is on the external bend of where heavy vehicles were braking and turning right when entering the intersection from the north, and exiting to the west. It is possible that such repeated heavy vehicle movement could have contributed to some of this vertical displacement. The intersection configuration when the mark was placed as opposed to now is shown in figures 6.10 – 6.12

It is identified here that the derivation of the mean value of AHD as conducted in chapter 3 is not ideal for deriving order relationships between marks. A much better option, especially due to the level of movement that has been observed in the network, would have been to make a connection to existing permanent survey marks outside of the dubious subject area, and located in more stable areas such as adjacent East Ballina. Due to time constraints on field work, external connection was outside of the scope of this investigation.

The Ballina Continuously Operating Reference Station

The survey outlined in chapter 4 compared the determined value of AHD as purported through the 1992 network of 2nd order permanent survey marks sampled in the subject area, to the AHD value of the newly installed Ballina Continuously Operating Reference Station, also located on the Ballina Island subject area.

The CORS networks are subject to the same class and order system of dealing with mark precision and accuracy as the traditional permanent survey mark networks. The order of these stations is assigned as a result of local tie surveys, which connect the station to existing infrastructure through GNSS methods. In order to determine the relationship to the derived value of AHD from the permanent survey marks to the CORS, GNSS methods were utilised in this survey to connect four stations that were levelled as part of the survey in chapter 3 to the CORS. The result of the connection determined from chapter 4 was a difference of 19.4mm between the value of AHD determined from the permanent survey mark network, to that determined by the LPMA's local tie survey. This difference resulted in a 5th order relationship being derived from the two values.

The local tie survey that was conducted by LPMA that has given the Ballina CORS its final coordinates is adjustment report number 233873, and the report was compiled by Grinter (2009). Analysis of this report indicates that three marks were connected to on Ballina Island, and held fixed in the final adjustment and height derivation. The marks used were PM39315, PM37060 and PM7888. During the course of the class LB differential levelling survey in chapter 3, it was found that PM39315, which is located approximately 1.5km from the CORS, agreed exceptionally well with the derived AHD value, differing by only 0.7mm. However the inclusion of PM37060 and PM7888 in this survey, located approximately 700m and 300m from the CORS respectively, is particularly problematic. Both of these marks were the subject of previous discussion, and have indicated a difference of

-11mm and -20.3mm respectively. Due to the observed value of AHD for the Ballina CORS by this survey being 19.4mm lower than the published value, it is most likely that the difference determined is a direct result of the differences observed between these two marks.

Mean Sea Level at Ballina Tide Gauge

The purpose of this survey was to determine whether or not the value of AHD in the subject area is the best representation of MSL available. It has been identified in chapter 2 that AHD was originally derived by constraining a continent wide differential level network, to the value of MSL observed at 30 tide gauges around the Australian coastline.

The survey outlined in chapter 5 indicates that the value of MSL as observed over the past 24 years at Ballina tide gauge, currently resides 19.2mm below the zero value of AHD, as per the sampled permanent survey mark infrastructure. Based on the distance between the tide gauge located at South Ballina, the relationship between the derived AHD and the quoted MSL, was determined as a 3rd order relationship.

One of the issues surrounding the determination of AHD has already been identified in this paper, as the inadequate duration of tidal observation times to accurately determine the value of MSL. This begs question of whether such issues have manifested themselves with regards to the comparison of AHD and MSL as determined here, where sufficient tide gauge records are available to satisfy the minimum required duration outlined by ICSM (2004), of one tidal datum epoch. Indeed the situation of an incorrect value of MSL adopted from the AHD derivation gauges, can only be substantiated by a levelled connection between a gauge with adequate observation time such as the Ballina tide gauge, and the aforementioned AHD gauges, and is beyond the scope of this project.

Findings by Morgan (1992) indicate that re-levelling of the section between primary AHD tide gauges located at Coffs Harbour and Brisbane in 1976, turned up negligible variation in the form of 22.1mm from the original height difference determined during the establishment of AHD in 1971. Of this variation Morgan (1992) goes on to identify that 10.5mm of this is attributable to the 349km section between Coffs Harbour and Tweed Heads. This would indicate that determination of AHD in the subject area didn’t suffer from some of the large errors experienced in other sections of the country, such as that between Bundaberg and Cairns as also identified by Morgan (1992), and as such should be a fairly reliable indicator of MSL.

In addition, it has been identified by Holgate & Woodworth (2004) that the decade of the 1990’s saw a period of accelerated global sea level rise in the vicinity of 3.7mm/year. If this rate was observed throughout the period, or indeed the more conservative figures of 1-2mm/year over the past 100 years, the overall effect would have seen a positive value of MSL with respect to AHD at the Ballina tide gauge. In actuality the opposite has occurred with the results of the survey in the subject area, indicating that the AHD value of MSL is currently RL-0.0192. This would indicate, especially with regards to the observed sea level rise, that the original value of AHD as determined from the tide gauge observations prior to 1971, was quite substantially higher than the true value of MSL. Indeed by using the change of 1-2mm/year would mean that the 1968 value of MSL would have been between 42-84mm lower than it is currently.

One of the issues related to the determination of MSL for AHD as outlined in chapter 2, was the identification of buoyancy of water at river mouths due to the inclusion of fresh water. This may have been a factor in the determination of an MSL value used as the zero point for AHD that is substantially higher than that observed at Ballina.

The qualification by Manly Hydraulics Laboratory of the value of MSL quoted at Ballina tide gauge of being ± 50mm, and the fact that the difference between MSL and AHD of 19.2mm is encompassed in the range of that qualification, would suggest that it is quite possible that the MSL is in fact coincident with the local value of AHD.

Implications and Recommendations

Prior to the commencement of fieldwork for this investigation, it was accepted that there was a high possibility that there had been some quite substantial movement of permanent survey marks in the subject area. What this series of surveys has shown is that in areas of dubious stability, it is difficult to maintain a certain standard of quality when it comes to the inter-relationship of permanent survey marks.

There are two main implications that have come out of this investigation. Firstly, due to the amount of movement that has been shown to be able to occur over an 18 year period, it is advisable in the interest of survey correctness to conduct check surveys on a semi regular basis, especially in areas known to have stability issues. However, it is recognised that such surveys are expensive and time consuming, and since there is AHD infrastructure already existing that is guaranteed by the State of NSW, such surveys are therefore of a low priority.

Secondly, this investigation has highlighted a need for further investigation of the accuracy of permanent survey marks before they are merely adopted for the derivation of values for new survey infrastructure, such as continuously operating reference stations. It is recommended here that in areas of potential disturbance and settlement that checks are made out to marks that are of a more stable nature.

Summary

Throughout this section the findings of the surveys conducted in chapters 3, 4 and 5 were discussed with relation to some of the possible reasons for the results obtained. With regards to the permanent mark survey, soil type, together with human interference with the surrounding areas, were identified as contributors to the overall degradation of the network. In terms of the connection to the Ballina CORS, the adoption of some of the poorer performing marks in the differential level survey having been adopted for LPMA’s local tie surveys, has been identified as the reason behind the 19.4mm overall difference in height between the two networks. Finally in terms of the derivation of the AHD value of MSL, it has been difficult to identify any concrete reasons behind the 19.2mm difference between the datums, with the measured difference being within the order of accuracy quoted by Manly Hydraulics Laboratory, it has been determined that it is quite feasible that the two are indeed coincident, however with the observed rise in sea level identified in Holgate & Woodworth (2004) it is unlikely that they always have been.

Chapter 7: Conclusion

Introduction

The Australian Height Datum was derived in 1971 with the adjustment of some 161,000km of spirit leveling observations, connecting 30 tide gauges around Australia. With the adoption of the AHD as the national height datum in Australia, its value is propagated throughout the country with the assigning of values with relation to it, to a wide variety of permanent survey marks.

Project Aims and Results

The aim of the class LB differential level survey was to connect to a sample of the permanent survey marks in the subject area of Ballina Island, and determine whether the network was still to the stated 2nd order standards with respect to the vertical inter-relationship between the sampled marks. The results of the survey indicated that the majority (69%) of the height differences sampled were shown to belong to a 3rd order relationship or lower. Throughout the course of the discussion in chapter 6, it was identified that some of the potential reasons behind the observed differences, lay in the unstable geotechnical nature of the subject area, and the degree of human interference through construction works adjacent to the marks in the ensuing 18 years since placement.

The aim of the second survey was to test the relationship between the 18 year old permanent survey mark infrastructure to the recently established Ballina Continuously Operating Reference Station. In order to determine this, a rapid static GNSS survey was developed, connecting four stations part of the differential network, with the CORS receiver. The results of this survey has shown a 19.4mm difference between the two networks, with the majority of the difference attributable to adoption of some control marks for the establishment of the published CORS coordinates, that have been shown to have undergone some vertical movement, as ascertained from the results of the differential level survey.

Finally, the third survey was to determine whether or not AHD is a good representation of MSL in the subject area. A reciprocal EDM heighting survey was developed to transfer the value of AHD from the permanent survey mark infrastructure, across the Richmond River to the Ballina tide gauge, where it was compared to MSL. This survey determined that the relationship between AHD and MSL is in the vicinity of 3rd order, which further strengthens statements observed in chapter 2, that the AHD is little more than a 3rd order mapping datum.

Future Work

As a result of this work recommendation is made that the AHD on Ballina Island should undergo a re-adjustment, as it appears that natural and man made forces have conspired against the network in the 18 years since establishment, with the majority of marks sampled in this investigation having degraded to a 3rd order relationship or less. It is recommended here that during any re-adjustment of the network, that connection be made to more stable control marks outside of the Ballina Island subject area, so as to eliminate the possibility of adoption of marks that are as equally as dubious.

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Appendix A: Project Specification

University of Southern Queensland

FACULTY OF ENGINEERING & SURVEYING

ENG4111/ENG4112 RESEARCH PROJECT
PROJECT SPECIFICATION

FOR: **MATTHEW STANLEY**

TOPIC: INVESTIGATION OF THE AUSTRALIAN HEIGHT DATUM (AHD) VALUES OF VARIOUS STATE CONTROL MARKS ON BALLINA ISLAND.

SUPERVISOR: Associate Professor Kevin McDougall

ENROLMENT: ENG4111 – External – Semester 1 – 2010
ENG4112 – External – Semester 2 – 2010

PROJECT AIM: To investigate whether their has been any degradation, of the 1992 established network of second order Permanent Survey Marks on Ballina Island and investigate if any differences exist in the values of AHD between this survey mark infrastructure, the newly established Continuously Operating Reference Station (CORS) at Ballina and the local value of Mean Sea level (MSL) as observed at the Ballina Breakwater Tide Gauge

PROGRAM: **Issue B – 24th April 2010**.

1/ Research the methods used for derivation of the Australian Height Datum and the methods used for extending the height control into the subject area.

2/ Devise and carry out a precise level network incorporating a large proportion of state control marks of 2nd order accuracy that were part of the heighting survey of 17th August 1992, throughout the Ballina Island subject area.

3/ Devise and carry out a static GNSS survey connecting the level network to the Ballina Continuously Operating Reference Station and to the tide gauge located at South Ballina.

4/ Adjust and analyse the network and determine;

- If there has been any degradation through settlement or other means in the relative height between the 2nd order state control marks over the past 18 years.
- If there is any variation between the value of the Australian Height Datum as per the recently installed Continuously Operating Reference Station and the 18 year old 2nd order control marks.
- If there is any variation between the AHD and the local value of MSL in the Ballina subject area.

6/ Submit an academic dissertation of the research including any other trends that may become apparent throughout the course of conducting the research.

AGREED ______________(student) ______________(supervisor)
Date: / / 2010 Date: / / 2010

Examiner/Co-examiner:

Appendix B: Differential Level Network Data

Loop 1 Raw Data: Kerr Street

Point ID	Backsight	Foresight	Rise/Fall	Distance	Station
101	1.6281			31.9	PM37056
102		1.4526	0.1755	37.1	PM62103
102	1.7454			57.7	PM62103
103		1.6454	0.1000	54.1	CP1
103	1.4958			57.9	CP1
104		1.4146	0.0812	58.6	CP2
104	1.5567			33.1	CP2
105		1.9435	-0.3868	32.5	PM37035
105	1.8048			48.4	PM37035
106		1.5296	0.2752	45.5	CP3
106	1.5266			19.7	CP3
107		1.5739	-0.0473	22.6	PM37040
107	1.6145			22.6	PM37040
108		1.5674	0.0471	19.7	CP3
108	1.5193			45.5	CP3
109		1.7945	-0.2752	48.4	PM37035
109	1.9059			32.5	PM37035
110		1.5187	0.3872	33.0	CP2
110	1.4408			58.7	CP2
111		1.5216	-0.0808	57.9	CP1
111	1.673			54.2	CP1
112		1.7736	-0.1006	57.5	PM62103
112	1.5714			32.6	PM62103
113		1.7469	-0.1755	38.2	PM37056
Sum =	19.4823	19.4823			
Misclose =	0.0000				

Loop 2 Raw Data: Burnett Street

Point ID	Backsight	Foresight	Rise/Fall	Distance	Station
201	1.7459			60.5	PM37040
202		1.5924	0.1535	60.2	CP4
202	1.4046			55.9	CP4
203		1.6562	-0.2516	56.4	PM37083
203	1.3729			45.5	PM37083
204		1.3392	0.0337	49.5	PM37082
204	1.743			53.9	PM37082
205		1.5216	0.2214	54.4	CP5
205	1.6113			31.1	CP5
206		1.6413	-0.0300	35.6	PM37069
206	1.5623			57.0	PM37069
207		1.3579	0.2044	57.0	CP6
207	1.3589			44.3	CP6
208		1.5184	-0.1595	47.5	PM37144
208	1.548			47.5	PM37144
209		1.3885	0.1595	44.3	CP6
209	1.367			56.9	CP6
210		1.5722	-0.2052	57.0	PM37069
210	1.7036			34.0	PM37069
211		1.6736	0.0300	33.8	CP5
211	1.482			54.5	CP5
212		1.7037	-0.2217	53.9	PM37082
212	1.476			49.6	PM37082
213		1.5095	-0.0335	45.6	PM37083
213	1.6962			56.2	PM37083
214		1.4461	0.2501	55.9	CP4
214	1.681			60.3	CP4
215		1.8348	-0.1538	60.5	PM37040
Sum =	21.7527	21.7554			
Misclose =	-0.0027				

Loop 3 Raw Data: Cherry Street

Point ID	Backsight	Foresight	Rise/Fall	Distance	Station
301	1.5977			51.1	PM37144
302		1.4675	0.1302	48.6	CP7
302	1.6367			44.0	CP7
303		1.8169	-0.1802	43.9	PM37145
303	1.9066			57.3	PM37145
304		1.5526	0.354	57.1	CP8
304	1.5127			56.9	CP8
305		1.4997	0.013	64.8	CP9
305	1.2464			58.9	CP9
306		1.7292	-0.4828	57.5	PM39334
306	2.0643			49.5	PM39334
307		1.6594	0.4049	42.9	PM39036
307	0.9191			57.6	PM39036
308		1.2457	-0.3266	60.2	CP10
308	1.3942			56.6	CP10
309		1.5496	-0.1554	57.5	PM42055
309	1.5101			57.5	PM42055
310		1.355	0.1551	56.6	CP10
310	1.3115			60.2	CP10
311		0.9846	0.3269	57.6	PM39036
311	1.5179			42.8	PM39036
312		1.9228	-0.4049	49.6	PM39334
312	1.7418			58.3	PM39334
313		1.2592	0.4826	58.1	CP9
313	1.4076			59.8	CP9
314		1.4226	-0.015	61.6	CP8
314	1.4715			57.1	CP8
315		1.8263	-0.3548	57.3	PM37145
315	1.7778			43.9	PM37145
316		1.5981	0.1797	44.0	CP7
316	1.4278			48.6	CP7
317		1.5583	-0.1305	51.1	PM37144
Sum =	24.4437	24.4475			
Misclose =	-0.0038				

Loop 4 Raw Data: Cawarra – Martin - Fox Streets

Point ID	Backsight	Foresight	Rise/Fall	Distance	Station
401	1.8442			58.5	PM42055
402		1.6098	0.2344	60.7	CP11
402	1.3075			45.9	CP11
403		1.7066	-0.3991	48.9	PM42052
403	1.9336			53.3	PM42052
404		1.6075	0.3261	55.7	CP12
404	1.5214			61.2	CP12
405		1.9059	-0.3845	66.9	PM39037
405	1.8144			51.1	PM39037
406		1.9061	-0.0917	50.6	PM39332
406	1.8679			54.5	PM39332
407		1.4688	0.3991	59.0	CP13
407	1.6513			60.1	CP13
408		1.5224	0.1289	56.9	CP14
408	1.4318			44.3	CP14
409		1.3705	0.0613	45.8	PM39317
409	1.312			45.9	PM39317
410		1.3738	-0.0618	44.2	CP14
410	1.4476			57.1	CP14
411		1.5761	-0.1285	60.0	CP13
411	1.4802			59.0	CP13
412		1.8794	-0.3992	54.5	PM39332
412	1.7997			50.8	PM39332
413		1.7092	0.0905	51.0	PM39037
413	1.8973			67.0	PM39037
414		1.5139	0.3834	61.1	CP12
414	1.5557			55.8	CP12
415		1.8824	-0.3267	53.2	PM42052
415	1.6904			48.9	PM42052
416		1.2898	0.4006	45.9	CP11
416	1.6055			60.7	CP11
417		1.8401	-0.2346	58.5	PM42055
Sum =	26.1605	26.1623			
Misclose=	-0.0018				

Loop 5 Raw Data: Norton – Bentinck - Owen Streets

Point ID	Backsight	Foresight	Rise/Fall	Distance	Station
501	1.4515			60.6	PM39317
502		1.5149	-0.0634	59.0	CP15
502	1.7007			51.2	--------
503		1.5855	0.1152	58.1	PM39315
503	1.5885			58.1	--------
504		1.878	-0.2895	59.6	CP16
504	1.7333			58.0	--------
505		1.3965	0.3368	62.5	CP17
505	1.6439			44.6	--------
506		2.097	-0.4531	47.1	PM37117
506	1.9348			36.6	--------
507		1.8564	0.0784	36.8	PM37116
507	1.7377			30.9	--------
508		1.6765	0.0612	33.4	PM37115
508	1.6692			31.5	--------
509		1.7238	-0.0546	32.6	PM67940
509	1.6789			55.2	--------
510		1.7181	-0.0392	58.9	CP18
510	1.4789			22.5	--------
511		1.8855	-0.4066	24.5	PM39326
511	2.0463			53.5	--------
512		1.6147	0.4316	57.2	CP19
512	1.6769			22.7	--------
513		1.8126	-0.1357	23.2	PM39325
513	1.9299			49.4	--------
514		1.1774	0.7525	56.8	CP20
514	1.2206			56.8	--------
515		1.9734	-0.7528	49.4	PM39325
515	1.8163			23.2	--------
516		1.6804	0.1359	22.8	CP19
516	1.6508			57.1	--------
517		2.0832	-0.4324	53.5	PM39326
517	1.9421			24.5	--------
518		1.5348	0.4073	22.5	CP18
518	1.7288			58.9	--------
519		1.6899	0.0389	55.2	PM67940
519	1.8662			32.5	--------
520		1.8117	0.0545	31.6	PM37115
520	1.7808			33.2	--------
521		1.8421	-0.0613	31.3	PM37116
521	1.8185			36.1	--------
522		1.8966	-0.0781	36.9	PM37117
522	2.0421			46.7	--------
523		1.5897	0.4524	44.7	CP17

523	1.4321			62.4	--------
524		1.7687	-0.3366	57.9	CP16
524	1.925			59.6	--------
525		1.6357	0.2893	58.0	PM39315
525	1.6146			58.1	--------
526		1.7296	-0.115	51.2	CP15
526	1.5551			59.0	--------
527		1.4918	0.0633	60.6	PM39317
Sum =	44.6635	44.6645			
Misclose=	-0.0010				

Loop 6 Raw Data: River Street (Owen – Cherry Streets)

Point ID	Backsight	Foresight	Rise/Fall	Distance	Station
601	1.8602			10.5	CP20
602		1.7276	0.1326	6.8	SSM92282
602	1.4723			56.0	--------
603		2.0539	-0.5816	62.4	CP21
603	1.5942			55.7	--------
604		1.8101	-0.2159	68.2	PM37107
604	1.8904			58.2	--------
605		1.607	0.2834	57.1	CP22
605	1.5948			44.4	--------
606		1.6658	-0.071	46.4	PM37148
606	1.9167			58.1	--------
607		1.6809	0.2358	59.3	CP23
607	1.5152			59.8	--------
608		1.847	-0.3318	59.2	CP24
608	1.868			59.0	--------
609		1.5378	0.3302	59.9	CP23
609	1.6605			59.3	--------
610		1.8964	-0.2359	58.2	PM37148
610	1.6617			46.5	--------
611		1.5901	0.0716	44.4	CP22
611	1.558			57.0	--------
612		1.8406	-0.2826	58.3	PM37107
612	1.8042			58.9	--------
613		1.5881	0.2161	65.0	CP21
613	2.0135			62.4	--------
614		1.4322	0.5813	55.9	SSM92282
614	1.4424			8.0	--------
615		1.5753	-0.1329	9.0	CP20
Sum=	23.8521	23.8528			
Misclose=	-0.0007				

Loop 7 Raw Data: River Street (Cherry – Kerr Streets)

Point ID	Backsight	Foresight	Rise/Fall	Distance	Station
701	2.0499			18.2	CP24
702		2.0078	0.0421	16.5	PM7888
702	1.9474			61.2	--------
703		1.5912	0.3562	59.3	CP25
703	1.4326			63.8	--------
704		1.7764	-0.3438	62.5	CP26
704	1.735			57.7	--------
705		1.7277	0.0073	60.0	CP27
705	1.6171			39.9	--------
706		1.7548	-0.1377	41.7	PM37060
706	1.8001			60.5	--------
707		1.4515	0.3486	64.1	CP28
707	1.5511			46.8	--------
708		1.5274	0.0237	47.1	CP29
708	1.5913			30.5	--------
709		2.0817	-0.4904	41.4	PM37056
709	1.9585			37.4	--------
710		1.4679	0.4906	34.4	CP29
710	1.544			47.1	--------
711		1.5679	-0.0239	46.8	CP28
711	1.4585			62.0	--------
712		1.8074	-0.3489	62.7	PM37060
712	1.7779			41.5	--------
713		1.6405	0.1374	39.9	CP27
713	1.7153			60.1	--------
714		1.7227	-0.0074	57.8	CP26
714	1.8204			62.4	--------
715		1.477	0.3434	63.8	CP25
715	1.5817			59.3	--------
716		1.9377	-0.356	61.2	PM7888
716	2.016			18.0	--------
717		2.0579	-0.0419	15.2	CP24
Sum=	27.5968	27.5975			
Misclose=	-0.0007				

Loop 8 Raw Data: Grant Street

Point ID	*Backsight*	*Foresight*	*Rise/Fall*	*Distance*	*Station*
801	1.7073			59.1	PM37060
802		1.5744	0.1329	54.9	SSM76184
802	1.3531			56.8	--------
803		1.4236	-0.0705	52.7	CP30
803	1.4974			26.2	--------
804		1.5622	-0.0648	28.8	SSM64148
804	1.658			64.0	--------
805		1.6611	-0.0031	57.9	SSM64149
805	1.6165			58.4	--------
805		1.7795	-0.163	59.9	CP31
805	1.5895			13.0	--------
807		1.4374	0.1521	13.1	PM37083
807	1.4649			13.1	--------
808		1.6169	-0.152	13.0	CP31
808	1.7452			59.9	--------
809		1.5825	0.1627	58.5	SSM64149
809	1.6818			57.9	--------
810		1.6792	0.0026	64.1	SSM64148
810	1.5982			28.8	--------
811		1.5332	0.065	26.2	CP30
811	1.4443			52.7	--------
812		1.3735	0.0708	56.8	SSM76184
812	1.7552			63.0	--------
813		1.8877	-0.1325	53.8	PM37060
Sum=	19.1114	19.1112			
Misclose=	0.0002				

Loop 9 Raw Data: Martin Street (River – Bentinck Streets)

Point ID	Backsight	Foresight	Rise/Fall	Distance	Station
901	1.7573			63.5	PM37148
902		1.9371	-0.1798	54.8	PM37147
902	1.795			59.8	--------
903		1.3409	0.4541	58.4	CP32
903	1.6278			11.3	--------
904		1.6	0.0278	12.1	PM37146
904	1.4841			59.8	--------
905		1.6674	-0.1833	58.2	CP33
905	1.5877			11.7	--------
906		1.6745	-0.0868	12.2	PM39146
906	1.7079			57.5	--------
907		1.4273	0.2806	58.5	CP34
907	1.593			22.8	--------
908		1.7077	-0.1147	26.5	PM39141
908	1.6591			63.1	--------
909		1.4776	0.1815	58.2	CP35
909	1.598			63.5	--------
910		2.0138	-0.4158	58.0	CP36
910	1.6068			60.6	--------
911		1.401	0.2058	61.1	CP37
911	1.5721			35.2	--------
912		1.7087	-0.1366	37.5	PM37145
912	1.6871			37.5	--------
913		1.551	0.1361	35.1	CP37
913	1.3008			61.4	--------
914		1.507	-0.2062	60.3	CP36
914	1.9587			58.2	--------
915		1.6126	0.3461	62.8	CP38
915	1.5088			58.9	--------
916		1.6198	-0.111	63.2	PM39141
916	1.705			26.4	--------
917		1.5902	0.1148	22.8	CP34
917	1.3835			58.5	--------
918		1.6642	-0.2807	57.5	--------
918	1.6343			12.2	--------
919		1.5481	0.0862	11.6	CP33
919	1.6063			58.2	--------
920		1.4226	0.1837	59.7	PM37146
920	1.5462			12.1	--------
921		1.6724	-0.1262	13.0	CP39
921	1.4015			58.6	--------
922		1.7571	-0.3556	58.2	PM37147
922	1.9594			55.5	--------
923		1.7798	0.1796	63.1	PM37148
Sum=	35.6804	35.6808			
Misclose=	-0.0004				

Loop 12 Raw Data: Bentinck Street (Norton – Martin Streets)

Point ID	*Backsight*	*Foresight*	*Rise/Fall*	*Distance*	*Station*
1201	2.1026			64.7	PM39315
1202		1.5732	0.5294	54.2	CP52
1202	1.3686			48.7	--------
1203		1.8529	-0.4843	47.0	CP53
1203	1.6462			54.0	--------
1204		1.8968	-0.2506	50.7	CP36
1204	1.9451			50.8	--------
1205		1.694	0.2511	54.0	CP53
1205	1.8803			47.0	--------
1206		1.396	0.4843	48.7	CP52
1206	1.6633			54.3	--------
1207		2.193	-0.5297	64.5	PM39315
Sum =	10.6061	10.6059			
Misclose=	0.0002				

Differential Level Network – Least Squares Adjustment Report

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***********   Least Squares Adjustment of Differential Leveling   ***********
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Level Data
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******************
Benchmark stations
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   Station      Elevation
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   PM37056          1.229

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Observed Elevation Differences
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      From        To         Elevation Difference        S
==========================================================
   PM37056   PM62103              0.1755        69.904450
   PM62103   PM37035             -0.2056       293.904550
   PM37035   PM37040              0.2279       136.201600
   PM37040   PM37083             -0.0981       232.981500
   PM37083   PM37082              0.0337        95.087950
   PM37082   PM37069              0.1914       175.587450
   PM37069   PM37144              0.0449       205.805650
   PM37144   PM37145             -0.0500       187.561500
   PM37145   PM39334             -0.1158       352.349900
   PM39334   PM39036              0.4049        92.335000
   PM39036   PM42055             -0.4820       231.927000
   PM42055   PM42052             -0.1647       213.989200
   PM42052   PM39037             -0.0584       237.105600
   PM39037   PM39332             -0.0917       101.783800
   PM39332   PM39317              0.5893       320.589700
   PM39317   PM39315              0.0518       228.953750
   PM39315   PM37117             -0.4058       329.598100
   PM37117   PM37116              0.0784        73.216100
   PM37116   PM37115              0.0612        64.384900
   PM37115   PM67940             -0.0546        64.053200
   PM67940   PM39326             -0.4458       161.095300
   PM39326   PM39325              0.2959       156.582350
   PM39325      CP20              0.7525       106.214200
      CP20  SSM92282              0.1326        17.156900
  SSM92282   PM37107             -0.7975       242.302900
   PM37107   PM37148              0.2124       206.137700
   PM37148      CP24             -0.0960       236.377200
      CP24    PM7888              0.0421        33.927500
    PM7888   PM37060             -0.1180       446.032500
   PM37060   PM37056             -0.1181       290.431600
   PM37060  SSM76184              0.1329       115.369300
  SSM76184  SSM64148             -0.1353       164.427200
  SSM64148  SSM64149             -0.0031       121.933650
  SSM64149   PM37083             -0.0109       144.465650
   PM37148   PM37147             -0.1798       118.423050
   PM37147   PM37146              0.4819       141.741250
   PM37146   PM39146             -0.2701       141.852100
   PM39146   PM39141              0.1659       165.294600
   PM39141      CP36             -0.2343       242.942500
      CP36   PM37145              0.0692       194.344600
   PM62103   PM37056             -0.1755        69.904450
   PM37035   PM62103              0.2058       293.904550
   PM37040   PM37035             -0.2281       136.201600
   PM37083   PM37040              0.0963       232.981500
   PM37082   PM37083             -0.0335        95.087950
   PM37069   PM37082             -0.1917       175.587450
   PM37144   PM37069             -0.0457       205.805650
   PM37145   PM37144              0.0492       187.561500
   PM39334   PM37145              0.1128       352.349900
   PM39036   PM39334             -0.4049        92.335000
   PM42055   PM39036              0.4820       231.927000
   PM42052   PM42055              0.1660       213.989200
   PM39037   PM42052              0.0567       237.105600
   PM39332   PM39037              0.0905       101.783800
   PM39317   PM39332             -0.5895       320.589700
   PM39315   PM39317             -0.0517       228.953750
   PM37117   PM39315              0.4051       329.598100
   PM37116   PM37117             -0.0781        73.216100
   PM37115   PM37116             -0.0613        64.384900
   PM67940   PM37115              0.0545        64.053200
   PM39326   PM67940              0.4462       161.095300
   PM39325   PM39326             -0.2965       156.582350
      CP20   PM39325             -0.7528       106.214200
  SSM92282      CP20             -0.1329        17.156900
   PM37107  SSM92282              0.7974       242.302900
   PM37148   PM37107             -0.2110       206.137700
      CP24   PM37148              0.0943       236.377200
    PM7888      CP24             -0.0419        33.927500
   PM37060    PM7888              0.1174       446.032500
   PM37056   PM37060              0.1178       290.431600
  SSM76184   PM37060             -0.1325       115.369300
  SSM64148  SSM76184              0.1358       164.427200
  SSM64149  SSM64148              0.0026       121.933650
   PM37083  SSM64149              0.0107       144.465650
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PM37147	PM37148	0.1796	118.423050
PM37146	PM37147	-0.4818	141.741250
PM39146	PM37146	0.2699	141.852100
PM39141	PM39146	-0.1659	165.294600
CP36	PM39141	0.2351	242.942500
PM37145	CP36	-0.0701	194.344600
CP36	PM39315	0.2057	319.386050
PM39315	CP36	-0.2055	319.386050

Reference Variance = 0.000000001533
Reference So = ±0.000039
Degrees of freedom = 45

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Adjusted Elevation Differences
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From	To	Elevation Difference	V	S
PM37056	PM62103	0.1755	0.00004	0.00023
PM62103	PM37035	-0.2055	0.00008	0.00042
PM37035	PM37040	0.2281	0.00018	0.00031
PM37040	PM37083	-0.0971	0.00104	0.00039
PM37083	PM37082	0.0336	-0.00008	0.00026
PM37082	PM37069	0.1916	0.00018	0.00035
PM37069	PM37144	0.0453	0.00043	0.00038
PM37144	PM37145	-0.0496	0.00043	0.00036
PM37145	PM39334	-0.1142	0.00157	0.00048
PM39334	PM39036	0.4049	0.00002	0.00026
PM39036	PM42055	-0.4820	0.00005	0.00040
PM42055	PM42052	-0.1653	-0.00061	0.00039
PM42052	PM39037	-0.0575	0.00090	0.00040
PM39037	PM39332	-0.0911	0.00062	0.00027
PM39332	PM39317	0.5895	0.00017	0.00046
PM39317	PM39315	0.0518	-0.00000	0.00040
PM39315	PM37117	-0.4052	0.00059	0.00046
PM37117	PM37116	0.0783	-0.00010	0.00023
PM37116	PM37115	0.0613	0.00010	0.00022
PM37115	PM67940	-0.0545	0.00010	0.00022
PM67940	PM39326	-0.4459	-0.00008	0.00034
PM39326	PM39325	0.2963	0.00042	0.00033
PM39325	CP20	0.7527	0.00023	0.00028
CP20	SSM92282	0.1328	0.00016	0.00011
SSM92282	PM37107	-0.7973	0.00023	0.00041
PM37107	PM37148	0.2119	-0.00055	0.00038
PM37148	CP24	-0.0951	0.00089	0.00040
CP24	PM7888	0.0420	-0.00009	0.00016
PM7888	PM37060	-0.1176	0.00037	0.00053
PM37060	PM37056	-0.1178	0.00032	0.00042
PM37060	SSM76184	0.1326	-0.00025	0.00028
SSM76184	SSM64148	-0.1356	-0.00032	0.00033
SSM64148	SSM64149	-0.0029	0.00020	0.00029
SSM64149	PM37083	-0.0109	0.00004	0.00031
PM37148	PM37147	-0.1796	0.00017	0.00029
PM37147	PM37146	0.4819	0.00003	0.00032
PM37146	PM39146	-0.2699	0.00018	0.00032
PM39146	PM39141	0.1660	0.00010	0.00034
PM39141	CP36	-0.2346	-0.00026	0.00040
CP36	PM37145	0.0697	0.00046	0.00036
PM62103	PM37056	-0.1755	-0.00004	0.00023
PM37035	PM62103	0.2055	-0.00028	0.00042
PM37040	PM37035	-0.2281	0.00002	0.00031
PM37083	PM37040	0.0971	0.00076	0.00039
PM37082	PM37083	-0.0336	-0.00012	0.00026
PM37069	PM37082	-0.1916	0.00012	0.00035
PM37144	PM37069	-0.0453	0.00037	0.00038
PM37145	PM37144	0.0496	0.00037	0.00036
PM39334	PM37145	0.1142	0.00143	0.00048
PM39036	PM39334	-0.4049	-0.00002	0.00026
PM42055	PM39036	0.4820	-0.00005	0.00040
PM42052	PM42055	0.1653	-0.00069	0.00039
PM39037	PM42052	0.0575	0.00080	0.00040
PM39332	PM39037	0.0911	0.00058	0.00027
PM39317	PM39332	-0.5895	0.00003	0.00046
PM39315	PM39317	-0.0518	-0.00010	0.00040
PM37117	PM39315	0.4052	0.00011	0.00046
PM37116	PM37117	-0.0783	-0.00020	0.00023
PM37115	PM37116	-0.0613	0.00000	0.00022
PM67940	PM37115	0.0545	0.00000	0.00022
PM39326	PM67940	0.4459	-0.00032	0.00034
PM39325	PM39326	-0.2963	0.00018	0.00033
CP20	PM39325	-0.7527	0.00007	0.00028
SSM92282	CP20	-0.1328	0.00014	0.00011
PM37107	SSM92282	0.7973	-0.00013	0.00041
PM37148	PM37107	-0.2119	-0.00085	0.00038
CP24	PM37148	0.0951	0.00081	0.00040
PM7888	CP24	-0.0420	-0.00011	0.00016
PM37060	PM7888	0.1176	0.00023	0.00053
PM37056	PM37060	0.1178	-0.00002	0.00042
SSM76184	PM37060	-0.1326	-0.00015	0.00028
SSM64148	SSM76184	0.1356	-0.00018	0.00033
SSM64149	SSM64148	0.0029	0.00030	0.00029
PM37083	SSM64149	0.0109	0.00016	0.00031
PM37147	PM37148	0.1796	0.00003	0.00029
PM37146	PM37147	-0.4819	-0.00013	0.00032

```
   PM39146   PM37146            0.2699           0.00002 0.00032
   PM39141   PM39146           -0.1660          -0.00010 0.00034
      CP36   PM39141            0.2346          -0.00054 0.00040
   PM37145      CP36           -0.0697           0.00044 0.00036
      CP36   PM39315            0.2058           0.00007 0.00043
   PM39315      CP36           -0.2058          -0.00027 0.00043


*******************
Adjusted Elevations
*******************

   Station      Elevation       S
====================================
   PM37056        1.229
   PM62103        1.405      0.0002
   PM37035        1.199      0.0005
   PM37040        1.427      0.0005
   PM37083        1.330      0.0005
   PM37082        1.364      0.0006
   PM37069        1.555      0.0006
   PM37144        1.601      0.0007
   PM37145        1.551      0.0007
   PM39334        1.437      0.0009
   PM39036        1.842      0.0009
   PM42055        1.360      0.0009
   PM42052        1.194      0.0009
   PM39037        1.137      0.0009
   PM39332        1.046      0.0009
   PM39317        1.635      0.0009
   PM39315        1.687      0.0008
   PM37117        1.282      0.0009
   PM37116        1.360      0.0009
   PM37115        1.422      0.0009
   PM67940        1.367      0.0009
   PM39326        0.921      0.0009
   PM39325        1.217      0.0009
      CP20        1.970      0.0009
  SSM92282        2.103      0.0008
   PM37107        1.306      0.0008
   PM37148        1.518      0.0007
      CP24        1.422      0.0007
    PM7888        1.464      0.0007
   PM37060        1.347      0.0004
  SSM76184        1.479      0.0005
  SSM64148        1.344      0.0005
  SSM64149        1.341      0.0005
   PM37147        1.338      0.0008
   PM37146        1.820      0.0008
   PM39146        1.550      0.0008
   PM39141        1.716      0.0008
      CP36        1.481      0.0008
```

Appendix C: Rapid Static GNSS Survey Data

GNSS Station Level Loop – Cawarra

From	To	Backsight	Foresight	Rise/Fall	RL
PM42055		1.56			1.3597
	CP		1.095	0.465	1.8247
CP		1.223			
	Cawarra		1.456	-0.233	1.5917
Cawarra		1.482			
	CP		1.25	0.232	1.8237
CP		1.183			
	PM42055		1.647	-0.464	1.3597

GNSS Station Level Loop – Saunders

From	To	Backsight	Foresight	Rise/Fall	RL
PM37035		1.83			1.199
	Saunders		1.494	0.336	1.535
Saunders		1.515			
	PM37035		1.852	-0.337	1.198

GNSS Baseline Vector Report

Processing Summary
Project Static

Project Information

Project name:	Project Static
Date created:	10/12/2010 21:29:28
Time zone:	10h 00'
Coordinate system name:	WGS 1984
Application software:	LEICA Geo Office 7.0
Start date and time:	07/17/2010 10:48:15
End date and time:	07/17/2010 15:53:30
Manually occupied points:	14
Processing kernel:	PSI-Pro 2.0
Processed:	10/12/2010 22:41:42

Processing Parameters

Parameters	**Selected**
Cut-off angle:	15°
Ephemeris type:	Broadcast
Solution type:	Automatic
GNSS type:	Automatic
Frequency:	Automatic
Fix ambiguities up to:	80 km
Min. duration for float solution (static):	5' 00"
Sampling rate:	Use all
Tropospheric model:	Hopfield
Ionospheric model:	Automatic
Use stochastic modelling:	Yes
Min. distance:	8 km
Ionospheric activity:	Automatic

Baseline Overview

Cawarra - PM37117	**Reference: Cawarra**	**Rover: PM37117**
Coordinates:		
Latitude:	28° 51' 31.58201" S	28° 52' 07.34761" S
Longitude:	153° 34' 09.22113" E	153° 34' 14.35400" E
Ellip. Hgt:	39.3512 m	38.9950 m
Solution type:	Phase: all fix	
GNSS type:	GPS / GLONASS	
Frequency:	L1 and L2	
Ambiguity:	Yes	

BCORS - PM37117	**Reference: BCORS**	**Rover: PM37117**
Coordinates:		
Latitude:	28° 52' 21.63009" S	28° 52' 07.34379" S
Longitude:	153° 33' 50.71950" E	153° 34' 14.32005" E
Ellip. Hgt:	44.5554 m	38.8730 m

Solution type:	Phase: all fix	
GNSS type:	GPS / GLONASS	
Frequency:	L1 and L2	
Ambiguity:	Yes	
Stn2 - Stn4	**Reference: Stn2**	**Rover: Stn4**
Coordinates:		
Latitude:	28° 52' 16.11148" S	28° 52' 34.94847" S
Longitude:	153° 34' 27.08539" E	153° 34' 43.20796" E
Ellip. Hgt:	38.9695 m	41.6673 m
Solution type:	Phase: all fix	
GNSS type:	GPS / GLONASS	
Frequency:	L1 and L2	
Ambiguity:	Yes	
BCORS - Stn4	**Reference: BCORS**	**Rover: Stn4**
Coordinates:		
Latitude:	28° 52' 21.63009" S	28° 52' 34.91810" S
Longitude:	153° 33' 50.71950" E	153° 34' 43.19059" E
Ellip. Hgt:	44.5554 m	42.0532 m
Solution type:	Phase: all fix	
GNSS type:	GPS / GLONASS	
Frequency:	L1 and L2	
Ambiguity:	Yes	
Saunders - Cawarra	**Reference: Saunders**	**Rover: Cawarra**
Coordinates:		
Latitude:	28° 51' 52.95073" S	28° 51' 31.58568" S
Longitude:	153° 33' 20.09400" E	153° 34' 09.21627" E
Ellip. Hgt:	36.5113 m	36.5827 m
Solution type:	Phase: all fix	
GNSS type:	GPS / GLONASS	
Frequency:	L1 and L2	
Ambiguity:	Yes	
BCORS - Cawarra	**Reference: BCORS**	**Rover: Cawarra**
Coordinates:		
Latitude:	28° 52' 21.63009" S	28° 51' 31.57815" S
Longitude:	153° 33' 50.71950" E	153° 34' 09.18723" E
Ellip. Hgt:	44.5554 m	39.2226 m
Solution type:	Phase: all fix	
GNSS type:	GPS / GLONASS	
Frequency:	L1 and L2	
Ambiguity:	Yes	
PM37117 - Saunders	**Reference: PM37117**	**Rover: Saunders**
Coordinates:		
Latitude:	28° 52' 07.29575" S	28° 51' 52.89517" S
Longitude:	153° 34' 14.31674" E	153° 33' 20.06143" E
Ellip. Hgt:	39.7924 m	40.0655 m
Solution type:	Phase: all fix	
GNSS type:	GPS / GLONASS	
Frequency:	L1 and L2	

Ambiguity:	Yes	
BCORS - Saunders	**Reference: BCORS**	**Rover: Saunders**
Coordinates:		
Latitude:	28° 52' 21.63009" S	28° 51' 52.94317" S
Longitude:	153° 33' 50.71950" E	153° 33' 20.06482" E
Ellip. Hgt:	44.5554 m	39.1511 m
Solution type:	Phase: all fix	
GNSS type:	GPS / GLONASS	
Frequency:	L1 and L2	
Ambiguity:	Yes	
Stn4 - PM37117	**Reference: Stn4**	**Rover: PM37117**
Coordinates:		
Latitude:	28° 52' 34.89438" S	28° 52' 07.32004" S
Longitude:	153° 34' 43.22240" E	153° 34' 14.35202" E
Ellip. Hgt:	40.9809 m	37.8039 m
Solution type:	Phase: all fix	
GNSS type:	GPS / GLONASS	
Frequency:	L1 and L2	
Ambiguity:	Yes	
BCORS - PM37117	**Reference: BCORS**	**Rover: PM37117**
Coordinates:		
Latitude:	28° 52' 21.63009" S	28° 52' 07.34376" S
Longitude:	153° 33' 50.71950" E	153° 34' 14.32013" E
Ellip. Hgt:	44.5554 m	38.8730 m
Solution type:	Phase: all fix	
GNSS type:	GPS / GLONASS	
Frequency:	L1 and L2	
Ambiguity:	Yes	
Cawarra - Stn2	**Reference: Cawarra**	**Rover: Stn2**
Coordinates:		
Latitude:	28° 51' 31.58201" S	28° 52' 16.08506" S
Longitude:	153° 34' 09.22113" E	153° 34' 27.10201" E
Ellip. Hgt:	39.3512 m	39.4806 m
Solution type:	Phase: all fix	
GNSS type:	GPS / GLONASS	
Frequency:	L1 and L2	
Ambiguity:	Yes	
BCORS - Stn2	**Reference: BCORS**	**Rover: Stn2**
Coordinates:		
Latitude:	28° 52' 21.63009" S	28° 52' 16.08121" S
Longitude:	153° 33' 50.71950" E	153° 34' 27.06806" E
Ellip. Hgt:	44.5554 m	39.3518 m
Solution type:	Phase: all fix	
GNSS type:	GPS / GLONASS	
Frequency:	L1 and L2	
Ambiguity:	Yes	
PM37117 - Stn2	**Reference: PM37117**	**Rover: Stn2**
Coordinates:		

Latitude:	28° 52' 07.29575" S	28° 52' 16.03311" S
Longitude:	153° 34' 14.31674" E	153° 34' 27.06478" E
Ellip. Hgt:	39.7924 m	40.2653 m
Solution type:	Phase: all fix	
GNSS type:	GPS / GLONASS	
Frequency:	L1 and L2	
Ambiguity:	Yes	

BCORS - Stn2	**Reference: BCORS**	**Rover: Stn2**
Coordinates:		
Latitude:	28° 52' 21.63009" S	28° 52' 16.08117" S
Longitude:	153° 33' 50.71950" E	153° 34' 27.06803" E
Ellip. Hgt:	44.5554 m	39.3515 m
Solution type:	Phase: all fix	
GNSS type:	GPS / GLONASS	
Frequency:	L1 and L2	
Ambiguity:	Yes	

GNSS Baseline Misclose Report

Loops and Misclosures

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Created: 10/12/2010 23:03:47

Project Information

Project name:	Project Static
Date created:	10/12/2010 21:29:28
Time zone:	10h 00'
Coordinate system name:	WGS 1984
Application software:	LEICA Geo Office 7.0
Processing kernel:	MOVE3 4.0.1
Critical value W-test is:	1.96
Dimension:	3D

GPS Baseline Loops

Loop 1

From	To	dX[m]	dY[m]	dZ[m]
Cawarra	Stn2	376.5144	-728.2913	-1199.9658
Stn2	PM37117	37.8242	366.9938	235.7966
PM37117	Cawarra	-414.3470	361.3026	964.1610

X:	-0.0085 m	W-Test:	-4.43	⚠
Y:	0.0051 m		4.47	⚠
Z:	-0.0082 m		-6.32	⚠
Easting:	-0.0008 m	W-Test:	-0.63	
Northing:	-0.0024 m		-1.71	
Height:	0.0126 m		7.49	⚠
Closing error:	0.0129 m	(4.3 ppm)	Ratio:(1:233444)	
Length:	3001.0339 m			

Loop 2

From	To	dX[m]	dY[m]	dZ[m]
Cawarra	Saunders	877.0965	1050.7151	-576.0333
Saunders	PM37117	-462.7611	-1412.0180	-388.1340
PM37117	Cawarra	-414.3470	361.3026	964.1610

X:	-0.0117 m	W-Test:	-5.72	⚠
Y:	-0.0004 m		-0.33	
Z:	-0.0063 m		-4.44	⚠
Easting:	0.0055 m	W-Test:	4.12	⚠
Northing:	-0.0006 m		-0.37	
Height:	0.0121 m		6.73	⚠

Closing error:	0.0133 m	(3.2 ppm)	Ratio:(1:310608)
Length:	4130.6115 m		

Loop 3

From	To	dX[m]	dY[m]	dZ[m]
Stn2	PM37117	37.8242	366.9938	235.7966
PM37117	Stn4	16.4169	-881.8208	-744.9476
Stn4	Stn2	-54.2434	514.8352	509.1484

X:	-0.0023 m	W-Test:	-0.99
Y:	0.0082 m		5.67
Z:	-0.0026 m		-1.62

Easting:	-0.0063 m	W-Test:	-3.81
Northing:	0.0004 m		0.24
Height:	0.0063 m		3.04

Closing error:	0.0089 m	(3.8 ppm)	Ratio:(1:260316)
Length:	2318.4390 m		

Loop 4

From	To	dX[m]	dY[m]	dZ[m]	
PM37117	Stn4	16.4169	-881.8208	-744.9476	
Stn4	BCORS	454.0048	1362.2196	357.0342	
BCORS	PM37117	-470.4167	-480.3963	387.9141	
BCORS	PM37117	-470.4181	-480.3982	387.9149	
		-470.4174	-480.3973	387.9145	Average

X:	0.0042 m	W-Test:	1.19
Y:	0.0015 m		0.65
Z:	0.0010 m		0.43

Easting:	-0.0032 m	W-Test:	-1.24
Northing:	-0.0006 m		-0.22
Height:	-0.0032 m		-1.02

Closing error:	0.0046 m	(1.4 ppm)	Ratio:(1:738803)
Length:	3410.3289 m		

Loop 5

From	To	dX[m]	dY[m]	dZ[m]	
PM37117	Saunders	462.7611	1412.0180	388.1340	
Saunders	BCORS	7.6612	-931.6217	-776.0467	
BCORS	PM37117	-470.4167	-480.3963	387.9141	
BCORS	PM37117	-470.4181	-480.3982	387.9149	
		-470.4174	-480.3973	387.9145	Average

X:	0.0049 m	W-Test:	1.18
Y:	-0.0010 m		-0.42
Z:	0.0018 m		0.58

Easting:	-0.0013 m	W-Test:	-0.49
Northing:	-0.0008 m		-0.24
Height:	-0.0051 m		-1.38

Closing error:	0.0053 m	(1.5 ppm)	Ratio:(1:661887)
Length:	3524.5413 m		

Loop 6

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

Saunders	Cawarra	-877.0965	-1050.7151	576.0333	
Cawarra	BCORS	884.7595	119.0972	-1352.0793	
BCORS	Saunders	-7.6612	931.6217	776.0467	

X:	0.0018 m	W-Test:	0.43
Y:	0.0038 m		1.72
Z:	0.0008 m		0.26
Easting:	-0.0042 m	W-Test:	-1.54
Northing:	0.0007 m		0.22
Height:	-0.0003 m		-0.08
Closing error:	0.0043 m	(1.0 ppm)	Ratio: (1:1006271)
Length:	4317.7084 m		

Loop 7

From	To	dX[m]	dY[m]	dZ[m]	
PM37117	Stn2	-37.8242	-366.9938	-235.7966	
Stn2	BCORS	508.2443	847.3867	-152.1146	
Stn2	BCORS	508.2444	847.3875	-152.1134	
		508.2443	847.3871	-152.1140	Average
BCORS	PM37117	-470.4167	-480.3963	387.9141	
BCORS	PM37117	-470.4181	-480.3982	387.9149	
		-470.4174	-480.3973	387.9145	Average

X:	0.0027 m	W-Test:	1.02	
Y:	-0.0040 m		-2.56	⚠
Z:	0.0039 m		2.08	⚠
Easting:	0.0024 m	W-Test:	1.30	
Northing:	0.0014 m		0.68	
Height:	-0.0056 m		-2.38	⚠
Closing error:	0.0062 m	(2.8 ppm)	Ratio:(1:356620)	
Length:	2213.8528 m			

GNSS Least Squares Reduction Report

```
                STAR*NET-DEMO Version 6.0.25
        Copyright 1988-2002 Starplus Software, Inc.
                 Licensed for Demo Use Only
             Run Date: Tue Oct 12 2010 22:46:50


         Summary of Files Used and Option Settings
         =========================================

               Project Folder and Data Files

Project Name    PROJECT STATIC MINIMALLY CONSTRAINED
Project Folder  C:\DOCUMENTS AND SETTINGS\...\RAPID STATIC\PROJECT_STATIC
Data File List  C:\Documents and Settings\...\free adjustment coords.txt
                Vectors-Project Static

                  Project Option Settings

STAR*NET Run Mode                    : Adjust with Error Propagation
Type of Adjustment                   : 3D
Project Units                        : Meters; DMS
Coordinate System                    : UTM;      Zone 0056
Ellipsoid                            : WGS-84
  Major Axis; 1 / Flattening         :   6378137.000; 298.257223563000
Geoid Height                         : 0.0000 (Default, Meters)
Longitude Sign Convention            : Positive West
Input/Output Coordinate Order        : East-North
Angle Data Station Order             : At-From-To
Distance/Vertical Data Type          : Slope/Zenith
Convergence Limit; Max Iterations    : 0.010000; 10
Default Coefficient of Refraction    : 0.070000
Create Coordinate File               : Yes
Create Geodetic Position File        : Yes
Create Ground Scale Coordinate File  : No
Create Dump File                     : No
GPS Vector Standard Error Factors    : 8.0000
GPS Vector Centering (Meters)        : 0.00150
GPS Vector Transformations           : None
```

```
                    Summary of Unadjusted Input Observations
                    ========================================

                    Number of Entered Stations (Meters) = 1

Fixed Stations              E               N          Elev   Description
BCORS                  555009.8930     6805990.0180     44.5210  BALLINA CORS

                Number of GPS Vector Observations (Meters) = 14

From                            DeltaX          StdErrX         CorrelXY
To                              DeltaY          StdErrY         CorrelXZ
                                DeltaZ          StdErrZ         CorrelYZ
(V1 project static baselines.asc)
BCORS                        -884.7595           0.0028          -0.1668
Cawarra                      -119.0972           0.0023           0.1916
                             1352.0793           0.0024          -0.0952
(V5 project static baselines.asc)
BCORS                        -470.4181           0.0034          -0.3244
PM37117                      -480.3982           0.0026           0.3925
                              387.9149           0.0028          -0.2172
(V2 project static baselines.asc)
BCORS                        -470.4167           0.0026          -0.1493
PM37117                      -480.3963           0.0023           0.1489
                              387.9141           0.0024          -0.0911
(V6 project static baselines.asc)
BCORS                          -7.6612           0.0034          -0.2853
Saunders                      931.6217           0.0026           0.3353
                              776.0467           0.0029          -0.1966
(V7 project static baselines.asc)
BCORS                        -508.2444           0.0029          -0.2056
Stn2                         -847.3875           0.0024           0.1233
                              152.1134           0.0024          -0.0988
(V3 project static baselines.asc)
BCORS                        -508.2443           0.0026          -0.1409
Stn2                         -847.3867           0.0023           0.1751
                              152.1146           0.0024          -0.1055
(V4 project static baselines.asc)
BCORS                        -454.0048           0.0029          -0.2529
Stn4                        -1362.2196           0.0026           0.2117
                             -357.0342           0.0025          -0.1318
(V8 project static baselines.asc)
Cawarra                       414.3470           0.0022          -0.0417
PM37117                      -361.3026           0.0022           0.0413
                             -964.1610           0.0022          -0.0256
(V9 project static baselines.asc)
Cawarra                       376.5144           0.0024          -0.0872
Stn2                         -728.2913           0.0022           0.0528
                            -1199.9658           0.0022          -0.0378
(V11 project static baselines.asc)
PM37117                       462.7611           0.0024          -0.0963
Saunders                     1412.0180           0.0022           0.1110
                              388.1340           0.0023          -0.0611
(V10 project static baselines.asc)
PM37117                       -37.8242           0.0023          -0.0412
Stn2                         -366.9938           0.0022           0.0612
                             -235.7966           0.0022          -0.0317
(V12 project static baselines.asc)
Saunders                     -877.0965           0.0023          -0.0405
Cawarra                     -1050.7151           0.0022           0.0537
                              576.0333           0.0022          -0.0212
(V13 project static baselines.asc)
Stn2                           54.2434           0.0023          -0.0757
Stn4                         -514.8352           0.0022           0.0639
                             -509.1484           0.0022          -0.0396
(V14 project static baselines.asc)
Stn4                          -16.4169           0.0026          -0.1474
PM37117                       881.8208           0.0023           0.1787
```

```
           Adjustment Statistical Summary
           ==============================

          Convergence Iterations  =      2

          Number of Stations      =      6

          Number of Observations  =     42
          Number of Unknowns      =     15
          Number of Redundant Obs =     27

Observation   Count   Sum Squares          Error
                        of StdRes          Factor
 GPS Deltas      42        23.255          0.928

      Total      42        23.255          0.928

      The Chi-Square Test at 5.00% Level Passed
           Lower/Upper Bounds (0.735/1.265)
```

Adjusted Station Information

Adjusted Coordinates (Meters)

Station	E	N	Elev	Description
BCORS	555009.8930	6805990.0180	44.5210	BALLINA CORS
Cawarra	555517.5586	6807528.0077	39.1900	
PM37117	555651.3322	6806426.6314	38.8396	
Saunders	554183.6124	6806876.7921	39.1162	
Stn2	555995.3781	6806156.0667	39.3169	
Stn4	556429.3056	6805574.2252	42.0163	

Adjusted Positions and Ellipsoid Heights (Meters)
(Average Geoid Height = 0.000 Meters)

Station	Latitude	Longitude	Ellip Ht
BCORS	-28-52-21.629758	-153-33-50.719997	44.5210
Cawarra	-28-51-31.577807	-153-34-09.187688	39.1900
PM37117	-28-52-07.343437	-153-34-14.320600	38.8396
Saunders	-28-51-52.942850	-153-33-20.065341	39.1162
Stn2	-28-52-16.080834	-153-34-27.068560	39.3169
Stn4	-28-52-34.917788	-153-34-43.191062	42.0163

Convergence Angles (DMS) and Grid Factors at Stations
(Grid Azimuth = Geodetic Azimuth - Convergence)
(Elevation Factor Includes a 0.00 Meter Geoid Height Correction)

Station	Convergence Angle	Factors: Scale	x Elevation	= Combined
BCORS	-0-16-20.59	0.99963734	0.99999301	0.99963035
Cawarra	-0-16-29.07	0.99963803	0.99999384	0.99963188
PM37117	-0-16-31.86	0.99963822	0.99999390	0.99963212
Saunders	-0-16-05.54	0.99963623	0.99999386	0.99963009
Stn2	-0-16-38.09	0.99963869	0.99999382	0.99963252
Stn4	-0-16-46.04	0.99963929	0.99999340	0.99963270
Project Averages:	-0-16-28.53	0.99963797	0.99999364	0.99963161

```
                    Adjusted Observations and Residuals
                    ===================================

          Adjusted GPS Vector Observations Sorted by Names (Meters)

From                Component          Adj Value      Residual   StdErr StdRes
To
(V1 project static baselines.asc)
BCORS                Delta-N           1540.9530        0.0002   0.0022   0.1
Cawarra              Delta-E            500.5343       -0.0011   0.0022   0.5
                     Delta-U             -5.5376        0.0018   0.0030   0.6
                     Length            1620.2164
(V5 project static baselines.asc)
BCORS                Delta-N            439.8197       -0.0004   0.0024   0.2
PM37117              Delta-E            639.5919       -0.0009   0.0023   0.4
                     Delta-U             -5.7287        0.0010   0.0039   0.2
                     Length             776.2423
(V2 project static baselines.asc)
BCORS                Delta-N            439.8197        0.0005   0.0023   0.2
PM37117              Delta-E            639.5919        0.0014   0.0022   0.6
                     Delta-U             -5.7287        0.0009   0.0028   0.3
                     Length             776.2423
(V6 project static baselines.asc)
BCORS                Delta-N            883.1627       -0.0004   0.0025   0.2
Saunders             Delta-E           -830.7933        0.0007   0.0024   0.3
                     Delta-U             -5.5203       -0.0006   0.0039   0.2
                     Length            1212.5280
(V7 project static baselines.asc)
BCORS                Delta-N            170.7946        0.0011   0.0024   0.5
Stn2                 Delta-E            985.0473       -0.0000   0.0023   0.0
                     Delta-U             -5.2824       -0.0005   0.0030   0.2
                     Length             999.7584
(V3 project static baselines.asc)
BCORS                Delta-N            170.7946       -0.0000   0.0023   0.0
Stn2                 Delta-E            985.0473        0.0007   0.0022   0.3
                     Delta-U             -5.2824       -0.0002   0.0028   0.1
                     Length             999.7584
(V4 project static baselines.asc)
BCORS                Delta-N           -409.1905       -0.0009   0.0023   0.4
Stn4                 Delta-E           1421.8969       -0.0006   0.0023   0.3
                     Delta-U             -2.6762       -0.0026   0.0032   0.8
                     Length            1479.6063
(V8 project static baselines.asc)
Cawarra              Delta-N          -1101.1272       -0.0008   0.0022   0.4
PM37117              Delta-E            139.1053        0.0013   0.0021   0.6
                     Delta-U             -0.4474        0.0058   0.0023   2.5
                     Length            1109.8791
(V9 project static baselines.asc)
Cawarra              Delta-N          -1370.1375        0.0008   0.0022   0.4
Stn2                 Delta-E            484.5722       -0.0001   0.0022   0.0
                     Delta-U             -0.0393       -0.0024   0.0024   1.0
                     Length            1453.3021
(V11 project static baselines.asc)
PM37117              Delta-N            443.2617        0.0003   0.0022   0.1
Saunders             Delta-E          -1470.4097        0.0018   0.0022   0.8
                     Delta-U              0.0918        0.0035   0.0026   1.4
                     Length            1535.7688
(V10 project static baselines.asc)
PM37117              Delta-N           -269.0061       -0.0009   0.0022   0.4
Stn2                 Delta-E            345.4701       -0.0022   0.0022   1.0
                     Delta-U              0.4623        0.0043   0.0023   1.9
                     Length             437.8517
(V12 project static baselines.asc)
Saunders             Delta-N            657.6948       -0.0000   0.0021   0.0
Cawarra              Delta-E           1331.3747        0.0024   0.0021   1.1
                     Delta-U             -0.0991        0.0027   0.0023   1.1
                     Length            1484.9650
(V13 project static baselines.asc)
```

Stn2	Delta-N	-579.9479	0.0010	0.0022	0.5
Stn4	Delta-E	436.8986	-0.0017	0.0022	0.8
	Delta-U	2.6580	0.0017	0.0024	0.7
	Length	726.1040			
(V14 project static baselines.asc)					
Stn4	Delta-N	848.9139	0.0003	0.0022	0.1
PM37117	Delta-E	-782.4086	-0.0024	0.0022	1.1
	Delta-U	-3.2814	0.0003	0.0028	0.1
	Length	1154.4820			

GPS Vector Residual Summary (Meters)
(Sorted by 3D Residual Length)

From	To	N	E	Up	2D	3D	Length	VectID
Cawarra	PM37117	-0.001	0.001	0.006	0.002	0.006	1110	8
PM37117	Stn2	-0.001	-0.002	0.004	0.002	0.005	438	10
PM37117	Saunders	0.000	0.002	0.004	0.002	0.004	1536	11
Saunders	Cawarra	-0.000	0.002	0.003	0.002	0.004	1485	12
BCORS	Stn4	-0.001	-0.001	-0.003	0.001	0.003	1480	4
Stn2	Stn4	0.001	-0.002	0.002	0.002	0.003	726	13
Cawarra	Stn2	0.001	-0.000	-0.002	0.001	0.003	1453	9
Stn4	PM37117	0.000	-0.002	0.000	0.002	0.002	1154	14
BCORS	Cawarra	0.000	-0.001	0.002	0.001	0.002	1620	1
BCORS	PM37117	0.000	0.001	0.001	0.002	0.002	776	2
BCORS	PM37117	-0.000	-0.001	0.001	0.001	0.001	776	5
BCORS	Stn2	0.001	-0.000	-0.000	0.001	0.001	1000	7
BCORS	Saunders	-0.000	0.001	-0.001	0.001	0.001	1213	6
BCORS	Stn2	-0.000	0.001	-0.000	0.001	0.001	1000	3

Adjusted Azimuths (DMS) and Horizontal Distances (Meters)
==
(Relative Confidence of Azimuth is in Seconds)

From	To	Grid Azimuth	Grid Dist / Grnd Dist	95% RelConfidence Azi	Dist	PPM
BCORS	Cawarra	18-16-02.00	1619.6100 1620.2077	0.40	0.0032	1.9883
BCORS	PM37117	55-45-27.90	775.9352 776.2215	0.72	0.0027	3.4812
BCORS	Saunders	317-01-20.86	1212.0676 1212.5160	0.62	0.0036	3.0011
BCORS	Stn2	80-26-08.95	999.3764 999.7448	0.59	0.0028	2.8173
BCORS	Stn4	106-19-37.37	1479.0590 1479.6042	0.49	0.0035	2.3864
Cawarra	PM37117	173-04-29.11	1109.4706 1109.8790	0.59	0.0032	2.8933
Cawarra	Saunders	243-58-44.25	1484.4170 1484.9650	0.51	0.0037	2.4716
Cawarra	Stn2	160-47-52.07	1452.7676 1453.3021	0.48	0.0034	2.3345
PM37117	Saunders	287-03-04.21	1535.2022 1535.7687	0.49	0.0035	2.3056
PM37117	Stn2	128-10-56.03	437.6904 437.8514	1.44	0.0030	6.9288
PM37117	Stn4	137-36-50.21	1154.0533 1154.4776	0.63	0.0036	3.0810
Stn2	Stn4	143-17-06.19	725.8323 726.0990	1.01	0.0036	4.9294

Error Propagation
=================

Station Coordinate Standard Deviations (Meters)

Station	E	N	Elev
BCORS	0.000000	0.000000	0.000000
Cawarra	0.001296	0.001313	0.001624
PM37117	0.001096	0.001118	0.001449
Saunders	0.001468	0.001517	0.001936
Stn2	0.001148	0.001169	0.001444
Stn4	0.001438	0.001445	0.001830

Station Coordinate Error Ellipses (Meters)
Confidence Region = 95%

Station	Semi-Major Axis	Semi-Minor Axis	Azimuth of Major Axis	Elev
BCORS	0.000000	0.000000	0-00	0.000000
Cawarra	0.003220	0.003167	19-01	0.003183
PM37117	0.002737	0.002682	1-50	0.002840
Saunders	0.003718	0.003591	9-53	0.003795
Stn2	0.002865	0.002804	15-43	0.002830
Stn4	0.003547	0.003510	149-41	0.003586

Relative Error Ellipses (Meters)
Confidence Region = 95%

Stations From	To	Semi-Major Axis	Semi-Minor Axis	Azimuth of Major Axis	Vertical
BCORS	Cawarra	0.003220	0.003167	19-01	0.003183
BCORS	PM37117	0.002737	0.002682	1-50	0.002840
BCORS	Saunders	0.003718	0.003591	9-53	0.003795
BCORS	Stn2	0.002865	0.002804	15-43	0.002830
BCORS	Stn4	0.003547	0.003510	149-41	0.003586
Cawarra	PM37117	0.003216	0.003182	17-10	0.002916
Cawarra	Saunders	0.003705	0.003643	13-56	0.003403
Cawarra	Stn2	0.003412	0.003364	21-59	0.003130
PM37117	Saunders	0.003635	0.003538	10-02	0.003459
PM37117	Stn2	0.003061	0.003027	13-55	0.002836
PM37117	Stn4	0.003558	0.003536	158-28	0.003501
Stn2	Stn4	0.003578	0.003561	146-07	0.003371

Elapsed Time = 00:00:00

Appendix D: Reciprocal EDM Heighting Data

Loop 10 Raw Data – Northern Bank, Richmond River

Point ID	Backsight	Foresight	Rise/Fall	Distance	Station
1002	1.785			58.2	SSM92282
1003		1.5515	0.2335	60.0	CP40
1003	1.5698			41.2	--------
1004		1.6394	-0.0696	41.7	STN1
1004	1.582			59.1	--------
1005		1.6718	-0.0898	59.2	CP41
1005	1.9855			59.3	--------
1006		1.351	0.6345	63.4	CP42
1006	1.6157			61.7	--------
1007		2.0664	-0.4507	61.5	CP43
1007	1.3502			60.0	--------
1008		1.9138	-0.5636	57.9	STN5
1008	1.579			7.0	
1009		1.607	-0.028	5.0	STN2
1009	1.633			5.0	
1010		1.605	0.028	7.0	STN5
1010	1.8782			58.0	--------
1011		1.3149	0.5633	59.8	CP43
1011	2.0409			61.6	--------
1012		1.5913	0.4496	61.7	CP42
1012	1.36			63.5	--------
1013		1.995	-0.635	59.1	CP41
1013	1.6959			58.9	--------
1014		1.6049	0.091	59.2	STN1
1014	1.6561			41.7	--------
1015		1.5864	0.0697	41.1	CP40
1015	1.5621			59.1	--------
1016		1.796	-0.2339	59.1	SSM92282
Sum=	23.2934	23.2944			
Misclose=	-0.0010				

Loop 11 Raw Data – Southern Bank, Richmond River

Point ID	Backsight	Foresight	Rise/Fall	Distance	Station
1101	2.1429			60.5	STN3
1102		1.485	0.6579	62.9	CP44
1102	1.7946			62.5	--------
1103		1.3059	0.4887	64.5	CP45
1103	1.66			4.8	--------
1104		1.3552	0.3048	5.8	PWD100
1104	1.2541			6.0	--------
1105		1.559	-0.3049	4.9	CP45
1105	1.5659			60.6	--------
1106		1.5862	-0.0203	60.4	CP46
1106	1.6953			13.9	--------
1107		1.6175	0.0778	11.3	STN4
1107	1.9778			59.0	--------
1108		1.4795	0.4983	53.9	CP47
1108	2.0747			59.5	--------
1109		1.3468	0.7279	61.0	CP48
1109	1.8619			58.6	--------
1110		1.8909	-0.029	59.1	CP49
1110	1.0349			42.4	--------
1111		3.5854	-2.5505	50.4	SSBM
1111	3.6638			44.3	--------
1112		1.1706	2.4932	45.3	CP50
1112	1.7175			37.2	--------
1113		1.5153	0.2022	39.1	PWD99
1113	1.4166			39.2	--------
1114		1.6191	-0.2025	37.0	CP50
1114	1.7642			45.2	--------
1115		1.5352	0.229	43.4	CP51
1115	1.5211			45.2	--------
1116		1.6923	-0.1712	47.5	CP49
1116	1.8764			59.1	--------
1117		1.8474	0.029	58.5	CP48
1117	1.3625			60.9	--------
1118		2.0905	-0.728	59.6	CP47
1118	1.4805			53.9	--------
1119		1.979	-0.4985	59.1	STN4
1119	1.6367			13.0	--------
1120		1.7142	-0.0775	11.9	CP46
1120	1.6552			60.3	--------
1121		1.6348	0.0204	60.7	CP45
1121	1.6943			6.5	--------
1122		1.389	0.3053	7.3	PWD100
1122	1.2904			7.4	--------
1123		1.5956	-0.3052	6.6	CP45
1123	1.3691			63.4	--------
1124		1.8571	-0.488	63.6	CP44
1124	1.5085			62.8	--------
1125		2.1675	-0.659	60.6	STN3
Sum=	41.0189	41.019			
Misclose=	-0.0001				

Reciprocal EDM Heighting Data

At	From	To	Deg	Min	Sec	Deg	Min	Sec	Deg	Min	Sec	Slope Distance	Corrected Slope Distance	Horizontal Distance	Deg	Min	Sec	Deg	Min	Sec	Slope Distance	Corrected Slope Distance	Horizontal Distance
3	4	1	272	29	49	89	49	38				393.979			90	4	35				882.813		
			272	29	39	89	49	42				393.979			90	4	31				882.813		
			272	29	48	89	49	39				393.979			90	4	37				882.813		
			272	29	44	89	49	47				393.979			90	4	30				882.813		
			272	29	45	89	49	40				393.978			90	4	37				882.813		
			272	29	46	89	49	39	89	49	40.833	393.978			90	4	42	90	4	35.333	882.813		
			272	29	50	270	10	30				393.979			269	55	40				882.816		
			272	29	43	270	10	27				393.979			269	55	40				882.815		
			272	29	42	270	10	22				393.979			269	55	46				882.816		
			272	29	47	270	10	26				393.979			269	55	36				882.816		
			272	29	46	270	10	21				393.979			269	55	41				882.816		
			272	29	47	270	10	28	270	10	25.667	393.979		3 - 4	269	55	40	269	55	40.5	882.816		3 - 1
		M	272	29	45.5				89	49	37.333	393.9788	393.97489	393.9731				90	4	27.333	882.8144	882.805589	882.8049
		SD			3.119						SD	0.0004								SD	0.0015		

At	From	To	Deg	Min	Sec	Deg	Min	Sec	Deg	Min	Sec	Slope Distance	Corrected Slope Distance	Horizontal Distance
3	1	2	32	7	22	90	6	32				873.531		
			32	7	25	90	6	34				873.531		
			32	7	23	90	6	40				873.531		
			32	7	20							873.531		
			32	7	10							873.531		
			32	7	21				90	6	35.333	873.531		
						269	53	32				873.531		
						269	53	39				873.532		
						269	53	39				873.531		
												873.531		
												873.531		
									269	53	36.667	873.531		3 - 2
		M	32	7	20.17				90	6	29.333	873.5311	873.52235	873.5207
		SD			5.269						SD	0.0003		

At	From	To	Deg	Min	Sec	Deg	Min	Sec	Deg	Min	Sec	Slope Distance	Corrected Slope Distance	Horizontal Distance	Deg	Min	Sec	Deg	Min	Sec	Slope Distance	Corrected Slope Distance	Horizontal Distance
1	3	4	335	32	56	89	57	9				882.813			89	52	30				950.93		
			335	32	57	89	57	15				882.814			89	52	32				950.93		
			335	32	57	89	57	10				882.815			89	52	30				950.931		
			335	32	53	89	57	10				882.815			89	52	29				950.931		
			335	32	57	89	57	14				882.815			89	52	28				950.931		
			335	32	52	89	57	13	89	57	11.833	882.815			89	52	31	89	52	30	950.931		
			335	32	59	270	3	16				882.816			270	7	52				950.931		
			335	32	56	270	3	16				882.816			270	7	52				950.931		
			335	32	66	270	3	16				882.815			270	7	50				950.931		
			335	32	63	270	3	16				882.815			270	7	51				950.931		
			335	32	63	270	3	15				882.815			270	7	50				950.931		
			335	32	58	270	3	17	270	3	16	882.815		1 - 3	270	7	52	270	7	51.167	950.931		1 - 4
		M	335	32	58				89	56	57.833	882.8149	882.80962	882.8093				89	52	19.5	950.9308	950.921324	950.9167
		SD			4.122						SD	0.0008								SD	0.0004		

At	From	To	Deg	Min	Sec	Deg	Min	Sec	Deg	Min	Sec	Slope Distance	Corrected Slope Distance	Horizontal Distance
1	3	2	287	6	49	90	4	58				486.003		
			287	6	47	90	4	47				486.003		
			287	6	47	90	4	49				486.002		
			287	6	46	90	4	44				486.002		
			287	6	42	90	4	48				486.002		
			287	6	48	90	4	44	90	4	48.333	486.002		
			287	6	49	269	55	37				486.002		
			287	6	42	269	55	37				486.002		
			287	6	50	269	55	34				486.003		
			287	6	50	269	55	34				486.003		
			287	6	49	269	55	32				486.002		
			287	6	48	269	55	39	269	55	35.5	486.002		1 - 2
		M	287	6	47.25				90	4	36.333	486.0023	485.99942	485.999
		SD			2.734						SD	0.0006		

At	From	To	Deg	Min	Sec	Deg	Min	Sec	Deg	Min	Sec	Slope Distance	Corrected Slope Distance	Horizontal Distance	Deg	Min	Sec	Deg	Min	Sec	Slope Distance	Corrected Slope Distance	Horizontal Distance
4	3	1	68	2	51	90	9	11				950.936			90	13	12				393.979		
			68	2	48	90	9	3				950.935			90	13	4				393.978		
			68	2	39	90	9	12				950.935			90	13	14				393.979		
			68	2	52	90	9	8				950.935			90	13	12				393.979		
			68	2	48	90	9	7				950.935			90	13	7				393.979		
			68	2	44	90	9	3	90	9	7.3333	950.935			90	13	7	90	13	9.3333	393.979		
			68	2	43	269	51	6				950.936			269	46	42				393.978		
			68	2	47	269	51	3				950.936			269	46	55				393.978		
			68	2	41	269	51	4				950.936			269	46	56				393.978		
			68	2	41	269	51	5				950.935			269	46	56				393.978		
			68	2	48	269	51	3				950.935			269	46	53				393.978		
			68	2	50	269	51	6	269	51	4.5	950.935		*4 - 1*	269	46	57	269	46	53.167	393.978		*4 - 3*
		M	68	2	46				90	9	1.3333	950.9353	950.92582	950.9225				90	13	7.8333	393.9784	393.974477	393.9716
		SD			4.285						SD	0.0005								SD	0.0005		

At	From	To	Deg	Min	Sec	Deg	Min	Sec	Deg	Min	Sec	Slope Distance	Corrected Slope Distance	Horizontal Distance
4	3	2	98	5	61	90	14	21				726.113		
			98	5	58	90	14	22				726.113		
			98	5	56	90	14	16				726.113		
			98	5	52	90	14	19				726.113		
			98	5	63	90	14	20				726.113		
			98	5	50	90	14	17	90	14	19.167	726.113		
			98	5	51	269	45	53				726.112		
			98	5	65	269	45	54				726.112		
			98	5	54	269	45	50				726.112		
			98	5	50	269	45	55				726.112		
			98	5	59	269	45	50				726.112		
			98	5	65	269	45	53	269	45	52.5	726.112		*4 - 2*
		M	98	5	57				90	14	13.167	726.1125	726.10524	726.099
		SD			5.673						SD	0.0005		

At	From	To	Deg	Min	Sec	Deg	Min	Sec	Deg	Min	Sec	Slope Distance	Corrected Slope Distance	Horizontal Distance	Deg	Min	Sec	Deg	Min	Sec	Slope Distance	Corrected Slope Distance	Horizontal Distance
2	4	3	26	31	16	89	55	3				873.531			89	47	31				726.111		
			26	31	13	89	55	3				873.531			89	47	26				726.111		
			26	31	10	89	55	4				873.531			89	47	30				726.11		
			26	31	14	89	55	2				873.531			89	47	26				726.11		
			26	31	7	89	55	5				873.531			89	47	34				726.11		
			26	31	10	89	55	0	89	55	2.8333	873.531			89	47	34	89	47	30.167	726.11		
			26	31	19	270	5	27				873.531			270	12	46				726.11		
			26	31	24	270	5	26				873.531			270	12	46				726.11		
			26	31	5	270	5	25				873.531			270	12	49				726.11		
			26	31	4	270	5	26				873.531			270	12	49				726.11		
			26	31	13	270	5	26				873.531			270	12	57				726.11		
			26	31	12	270	5	25	270	5	25.833	873.531		2 - 3	270	12	51	270	12	49.667	726.11		2 - 4
		M	26	31	12.25				89	54	48.333	873.5310	873.52576	873.5248				89	47	20.167	726.1102	726.10581	726.1009
		SD			5.723						SD	0.0000								SD	0.0004		

At	From	To	Deg	Min	Sec	Deg	Min	Sec	Deg	Min	Sec	Slope Distance	Corrected Slope Distance	Horizontal Distance
2	4	1	101	30	46	89	57	43				486.002		
			101	30	41	89	57	47				486.002		
			101	30	35	89	57	42				486.002		
			101	30	36	89	57	44				486.002		
			101	30	39	89	57	38				486.002		
			101	30	33	89	57	43	89	57	42.833	486.002		
			101	30	37	270	2	40				486.003		
			101	30	45	270	2	38				486.003		
			101	30	36	270	2	41				486.002		
			101	30	32	270	2	46				486.002		
			101	30	37	270	2	49				486.002		
			101	30	38	270	2	45	270	2	43.167	486.002		2 - 1
		M	101	30	37.92				89	57	29.833	486.0022	485.99925	485.9992
		SD			4.295						SD	0.0004		

Reciprocal EDM Heighting Least Squares Reduction Report

```
                    STAR*NET-DEMO Version 6.0.25
            Copyright 1988-2002 Starplus Software, Inc.
                     Licensed for Demo Use Only
                 Run Date: Sun Oct 17 2010 09:58:18

             Summary of Files Used and Option Settings
             =========================================

                   Project Folder and Data Files

Project Name    TRIG HEIGHTING ADJUST
Project Folder  C:\DOCUMENTS AND SETTINGS\...\FIELD DATA\BRACED QUAD
Data File List  LEVEL NETWORK.txt

                      Project Option Settings

STAR*NET Run Mode                    : Adjust with Error Propagation
Type of Adjustment                   : 3D
Project Units                        : Meters; DMS
Coordinate System                    : LOCAL
Apply Average Scale Factor           : 1.0000000000
Input/Output Coordinate Order        : East-North
Angle Data Station Order             : At-From-To
Distance/Vertical Data Type          : Hor Dist/DE
Convergence Limit; Max Iterations    : 0.010000; 10
Default Coefficient of Refraction    : 0.070000
Earth Radius                         : 6372000.00 Meters
Create Coordinate File               : No
Create Ground Scale Coordinate File  : No
Create Dump File                     : No

                 Instrument Standard Error Settings

Project Default Instrument
  Distances (Constant)               :     0.001000 Meters
  Distances (PPM)                    :     0.000000
  Angles                             :     4.000000 Seconds
  Directions                         :     3.000000 Seconds
  Azimuths & Bearings                :     4.000000 Seconds
  Zeniths                            :    10.000000 Seconds
  Elevation Differences (Constant)   :     0.010000 Meters
  Elevation Differences (PPM)        :     0.000000
  Differential Levels                :     0.005000 Meters / Km
  Centering Error Instrument         :     0.002000 Meters
  Centering Error Target             :     0.002000 Meters
  Centering Error Vertical           :     0.002000 Meters
```

Summary of Unadjusted Input Observations
==

Number of Entered Stations (Meters) = 2

Fixed Stations	E	N	Elev	Description
1	5000.0000	8000.0000	2.2670	
2	5485.9990	8000.0000	1.7699	

Number of Angle Observations (DMS) = 8

At	From	To	Angle	StdErr
3	4	1	272-29-45.50	3.10
3	1	2	32-07-20.17	5.30
1	3	4	335-32-58.00	4.10
1	3	2	287-06-47.25	2.70
4	3	1	68-02-46.00	4.30
4	3	2	98-05-57.00	5.70
2	4	3	26-31-12.25	5.70
2	4	1	101-30-37.92	4.30

Number of Distance Observations (Meters) = 10

From	To	Distance	StdErr	HI	HT	Type
3	1	882.8049	0.0030	0.000	0.000	H
1	3	882.8093	0.0030	0.000	0.000	H
2	4	726.1009	0.0030	0.000	0.000	H
3	2	873.5207	0.0030	0.000	0.000	H
1	4	950.9167	0.0030	0.000	0.000	H
1	2	485.9992	0.0030	0.000	0.000	H
4	1	950.9225	0.0030	0.000	0.000	H
4	2	726.0991	0.0030	0.000	0.000	H
2	3	873.5248	0.0030	0.000	0.000	H
2	1	485.9993	0.0030	0.000	0.000	H

Number of Differential Level Observations (Meters) = 8

From	To	Elev Diff	StdErr	Length
4	2	-2.7348	0.0043	726
2	4	2.7243	0.0043	726
1	3	1.0176	0.0047	883
3	2	-1.5231	0.0047	874
2	3	1.5246	0.0047	874
4	1	-2.2346	0.0049	951
1	4	2.2320	0.0049	951
3	4	1.2040	FIXED	394

```
          Adjustment Statistical Summary
          ==============================

        Convergence Iterations  =      2

        Number of Stations      =      4

        Number of Observations  =     26
        Number of Unknowns      =      6
        Number of Redundant Obs =     20

Observation   Count   Sum Squares        Error
                        of StdRes       Factor
     Angles       8         2.111        0.586
  Distances      10         4.572        0.771
 Level Data       8         7.889        1.132

      Total      26        14.573        0.854

      The Chi-Square Test at 5.00% Level Passed
           Lower/Upper Bounds (0.692/1.307)
```

Adjusted Coordinates (Meters)

Station	E	N	Elev	Description
1	5000.0000	8000.0000	2.2670	
2	5485.9990	8000.0000	1.7699	
3	5259.7749	7156.2798	3.2937	
4	5630.8891	7288.5024	4.4977	

Adjusted Observations and Residuals
===================================

Adjusted Angle Observations (DMS)

At	From	To	Angle	Residual	StdErr	StdRes
3	4	1	272-29-49.40	0-00-03.90	3.10	1.3
3	1	2	32-07-21.70	0-00-01.53	5.30	0.3
1	3	4	335-32-58.54	0-00-00.54	4.10	0.1
1	3	2	287-06-47.49	0-00-00.24	2.70	0.1
4	3	1	68-02-47.94	0-00-01.94	4.30	0.5
4	3	2	98-05-59.49	0-00-02.49	5.70	0.4
2	4	3	26-31-11.60	-0-00-00.65	5.70	0.1
2	4	1	101-30-37.39	-0-00-00.53	4.30	0.1

Adjusted Distance Observations (Meters)

From	To	Distance	Residual	StdErr	StdRes
3	1	882.8062	0.0013	0.0030	0.4
1	3	882.8062	-0.0031	0.0030	1.0
2	4	726.1005	-0.0004	0.0030	0.1
3	2	873.5222	0.0015	0.0030	0.5
1	4	950.9205	0.0038	0.0030	1.3
1	2	485.9990	-0.0002	0.0030	0.1
4	1	950.9205	-0.0020	0.0030	0.7
4	2	726.1005	0.0014	0.0030	0.5
2	3	873.5222	-0.0026	0.0030	0.9
2	1	485.9990	-0.0003	0.0030	0.1

Adjusted Differential Level Observations (Meters)

From	To	Elev Diff	Residual	StdErr	StdRes
4	2	-2.7278	0.0070	0.0043	1.6
2	4	2.7278	0.0035	0.0043	0.8
1	3	1.0267	0.0091	0.0047	1.9
3	2	-1.5238	-0.0007	0.0047	0.2
2	3	1.5238	-0.0008	0.0047	0.2
4	1	-2.2307	0.0039	0.0049	0.8
1	4	2.2307	-0.0013	0.0049	0.3
3	4	1.2040	0.0000	FIXED	0.0

Adjusted Bearings (DMS) and Horizontal Distances (Meters)
===
(Relative Confidence of Bearing is in Seconds)

From	To	Bearing	Distance	95% RelConfidence Brg	Dist	PPM
1	2	N90-00-00.00E	485.9990	0.00	0.0000	0.0007
1	3	S17-06-47.49E	882.8062	2.55	0.0047	5.2856
1	4	S41-33-48.95E	950.9205	2.56	0.0046	4.8667
2	3	S15-00-34.21W	873.5222	2.58	0.0047	5.3544
2	4	S11-30-37.39E	726.1005	3.34	0.0048	6.5710
3	4	N70-23-23.11E	393.9653	3.25	0.0148	37.5707

Error Propagation

Station Coordinate Standard Deviations (Meters)

Station	E	N	Elev
1	0.000000	0.000000	0.000000
2	0.000000	0.000000	0.000000
3	0.004619	0.001477	0.001738
4	0.004469	0.002615	0.001738

Station Coordinate Error Ellipses (Meters)
Confidence Region = 95%

Station	Semi-Major Axis	Semi-Minor Axis	Azimuth of Major Axis	Elev
1	0.000000	0.000000	0-00	0.000000
2	0.000000	0.000000	0-00	0.000000
3	0.011307	0.003611	88-54	0.003406
4	0.012149	0.003610	62-53	0.003406

Relative Error Ellipses (Meters)
Confidence Region = 95%

Stations From	To	Semi-Major Axis	Semi-Minor Axis	Azimuth of Major Axis	Vertical
1	2	0.000000	0.000000	0-00	0.000000
1	3	0.011307	0.003611	88-54	0.003406
1	4	0.012149	0.003610	62-53	0.003406
2	3	0.011307	0.003611	88-54	0.003406
2	4	0.012149	0.003610	62-53	0.003406
3	4	0.014825	0.006159	73-57	0.000000

Elapsed Time = 00:00:00