Atlas Geophysics Report Number R2016074

Daly Basin Gravity Survey

Geoscience Australia

Attention: Mr Phill Wynne

Report completed by:

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1.0 Company Overview

Atlas Geophysics Pty Ltd is an Australian company based in Morley, Western Australia, whose mission is to provide the highest quality geophysical resource data to the mining, petroleum and exploration industry in a safe and timely manner. Through experience, innovation and excellence, the company will exceed its client's expectations and will continually develop its technologies and methodologies to maintain its reputation for being the best in the business.

The company specialises in the acquisition, processing and interpretation of potential field datasets, with particular emphasis on gravity. The director of the company, Leon Mathews B.Sc. Hons (Geophysics), has over 19 years of experience in the field of gravity and brings to the company, a young, vibrant and motivated approach to project management. Strategically, through development and research, the company aims to expand into other geophysical acquisition markets that encompass methods such as electrical, electromagnetic, induced polarisation and reflection seismic. The company also has interests in developing an airborne platform capable of acquiring high quality magnetic and radiometric data so it can offer its clients a complete airborne and ground geophysical solution.

Atlas Geophysics Pty Ltd is committed to the values and principles of Health, Safety and Environment. To this end, the company aims to prevent injuries and occupational illness to its employees and minimise any adverse environmental impact its activities may have.

2.0 Project Brief

Atlas Geophysics project P2016074 required the acquisition and processing of **1,798** new regional gravity stations on behalf of Geoscience Australia (GA), funded by the Northern Territory Geological Survey. The gravity survey, referred to as the "Daly Basin Gravity" was assigned GA project number 201680.

The survey covered a single large area within the Daly River Basin, in the Northern Territory of Australia (Figure 1).

Atlas Geophysics Pty Ltd completed the acquisition of the dataset using helicopter-borne gravity methods. The survey commenced on 13th July 2016 with survey cessation on 21st July 2016.

2.1 Location, Access and Terrain

The gravity survey spanned an area approximately 36,000 kilometres square (Figure 1) and covered all or parts of the following 1:250,000 map sheets in the Northern Territory.

- Cape Stott
- Pine Creek
- Katherine
- Fergusson River
- Port Keats

The survey area lies south of the Stuart Highway, with the township of Katherine in the east and the small community of Wadeye/Port Keats in the west. To the north lies the spectacular Litchfield National Park. In the eastern sections, the survey area was coincident with several "Restricted Operations Zones" (ROZ) so regular communications and permissions with Tindal Air Base were required.

With careful planning, the survey was executed mainly from Daly River, with a small component of the survey conducted out of Manbulloo, west of Katherine.

Vehicular access was reasonable, with the Daly River Road which is sealed from Adelaide River to Daly River, used frequently for refuelling and pilot change overs. The unsealed section of this road from Daly River to Wadeye was also used despite being very rough in places. Some helicopter ferry was required to reach some of the more remote sections of the survey.

As the survey area is vast, many terrain types were encountered. Terrain varied from heavily vegetated areas with tall trees, to open swamp grass and coastal scenes. Some spectacular sandstone formations, gorges and areas of high relief were encountered. Numerous stations were offset or omitted for safety reasons, but on the whole, an excellent coverage was obtained by the helicopter crew despite trying condtions.

2.2 Survey Configuration

For the most part, the survey was carried out using a 4km x 4km square grid configuration. A small section of the grid was infilled to 2km and 1km spacing. Attempting to infill the grid was quite tedious, and dangerous at times, so the spacing is somewhat irregular here, but still provides a satisfactory level of detail over the 4km spaced area.

Appendix A contains a station location plot of the acquired gravity stations.

Figure 1: Location of Daly Basin Gravity Survey

3.0 Personnel and Subcontractors

Atlas Geophysics Pty Ltd engages only fit, motivated and safe working professionals to conduct its gravity operations. Acquisition staff members are from a range of backgrounds, usually from the geoscience or geotechnical fields, and all are trained in senior first aid, bush survival, and advanced four wheel driving. Overseeing the acquisition and processing is the company's team of geophysicists and data processors – a team with a combined total of over 20 years of experience in the acquisition, processing and quality control of gravity data.

3.1 Project Supervision

Supervising the project from Perth Operations was director Leon Mathews. Leon has been involved in the acquisition, processing and interpretation of potential field data for over 19 years and has directly overseen the acquisition and processing of over 1,500,000 gravity stations.

Leon was responsible for project supervision, as well as for conducting the processing and quality control of the gravity data on a daily basis.

All final data processing, QC, reporting and delivery was performed by Leon Mathews.

3.2 Acquisition/Other Personnel

Other personnel participating in field acquisition of the gravity data on this project were:

Ambrose Talent	*Supervising Geophysical Technician*
Cam Hoogendyk	Geophysical Technician

Pilots as supplied by the contractor.

4.0 Equipment and Instrumentation

4.1 GNSS Receiver Equipment

Leading edge dual-frequency GNSS technologies from Leica Geosystems such as the GPS1200 have been utilised on the project to allow for post-processed kinematic (PPK) centimetre level accuracy 3D positions. System specifications for the receivers utilised can be found in the attached brochures (Figures 2-4). The GPS1200 system is equipped with future proof GNSS technology which is capable of tracking all available GNSS signals including the currently available GLONASS. These new generation receivers, in conjunction with full GNSS tracking and processing, offer a new level of unmatched solution accuracy and reliability, especially when compared to existing conventional L1, L2 GNSS technologies.

The use of GNSS technology in addition to GNSS provides very significant advantages:

- Increased satellite signal observations
- Markedly increased spatial distribution of visible satellites
- Reduced Horizontal and Vertical Dilution of Precision (DOP) factors
- Improved post-processed-kinematic (PPK) performance
- Decreased occupation times means faster acquisition

Eight GPS1200 geodetic grade receivers were utilised to conduct the survey. Two receivers were used as post-processed kinematic (PPK) rovers in the helicopter, with the other receivers used as base stations for logging static data on multiple control stations.

On the helicopter, the GNSS antennas were mounted on the tail-boom of the aircraft and a fixed aluminium bracket at the front of the aircraft, with the receivers mounted on a custom mount inside the cabin.

Navigation between gravity stations was facilitated by a Garmin 296 GNSS receiver operating in autonomous mode.

4.2 Gravity Instrumentation

Complementing the company's GNSS technologies is the latest in gravity instrumentation from Scintrex Ltd, the Scintrex CG-5 (Figure 5). The CG-5 digital automated gravity meter offers all of the features of the low noise industry standard CG-3M micro-gravity unit, but is smaller and lighter. It also offers improved noise rejection. By constantly monitoring tilt sensors electronically, the CG-5 automatically compensates for errors in gravity meter tilt. Due to a low mass and the excellent elastic properties of fused quartz, tares are virtually eliminated.

The CG-5 can be transported over very rough terrain, on quad bikes, foot, vehicle or helicopter without taring or drifting. In terms of repeatability, the CG-5 outperforms all existing gravity meter technologies, with a factory quoted repeatability of better than 0.005 mGal.

Table 1 below lists the gravity meters used on the project.

Gravity Meter Type	Gravity Meter Code	Gravity Meter Serial Number
Scintrex CG-5	A2	40241

Table 1: Gravity meters used on the project

4.3 Other Equipment

The company utilised the following additional equipment to fully support the operations:

- Two HP Laptop computers for data download and processing
- Four Iridium satellite phones for long distance communications and scheduled calls
- Personal Protective Equipment for all personnel
- Batteries, battery chargers, solar cells, UPS System
- Survey consumables
- Tools, engineering and maintenance equipment for vehicle servicing
- First aid and survival kits
- Tyres and recovery equipment
- Satellite tracking and communication devices.

Leica GPS1200
Fast, accurate, rugged and reliable

SMARTTRACK+

GNSS technology
GPS1200's SmartTrack+ measurement engine now utilizes two global navigation satellite systems increasing the number of tracked satellites. The new SmartTrack+ measurement engine tracks all available GNSS signals (L2C and GLONASS). More satellites means higher productivity, accuracy and reliability. SmartTrack+ acquires satellites within seconds, is ideal in urban canyons and obstructed areas where other receivers often fail. GPS1200 with SmartTrack+ is designed to support the future signals GPS L5 and Galileo.

SmartCheck+
Continuously checking provides the highest possible reliability. A unique, built-in integrity monitoring system checks all results immediately. SmartCheck+ now processes GPS and GLONASS measurements simultaneously for centimeter-accuracy, 20 Hz RTK at 30 km and more. Initialize within seconds and survey in obstructed areas with a GX1230/ATX1230 (GPS only) sensor or increase productivity with a GX1230 GG/ATX1230 GG (GPS and GLONASS).

GLONASS
For many years the GLONASS system was not reliable enough in terms of satellite availability and system performance. With recent launches and commitment from the Russian government, reliability and availability are significantly improved. Under normal conditions there are 2 to 5 additional satellites compared to a GPS only constellation – and even more satellites will be available over the next two years. Now is the time to invest in hybrid GNSS technology.

"The GLONASS system should be created before 2008, as it was originally planned ... We have the possibility. Let us see what can be done in 2006 – 2007"

(Russian President Vladimir Putin December 26th 2005).

Exceptionally rugged
Don't worry about how your crews handle GPS1200. It's built to MIL specs to withstand the roughest use. With its strong, precision-machined magnesium housing, GPS1200 stands up to drops and falls and the jolts and vibrations of machines.

Immune to bad weather
Designed for temperatures from –40° C to +65° C (storage +80° C). GPS1200 shrugs off arctic cold and blistering heat. Fully waterproof – withstands immersion to 1 m – sand and dustproof, it operates perfectly in any conditions from tropical rainfall to desert sandstorms. GPS1200 just keeps on working.

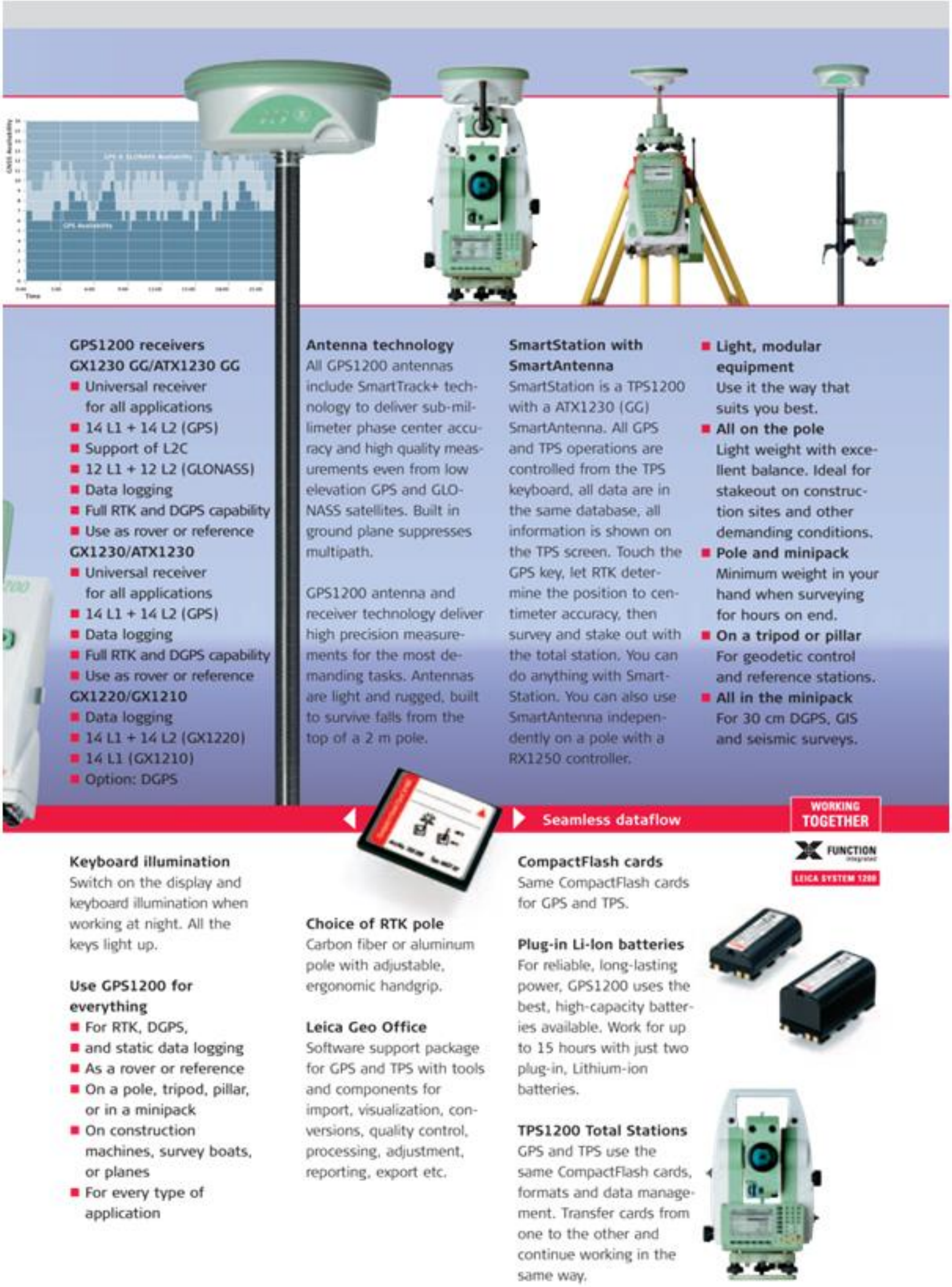
High contrast touch screen
The high quality 1/4 VGA (11 lines by 32 characters) with optional colour option (RX1250) touch screen guarantees perfect clarity and contrast. Whether in fading light or bright sunshine, you can always read the display perfectly. Operate using the touch screen or the QWERTY keyboard, which-ever you prefer.

With or without controller
Connect the controller to the receiver when you need to input information and make full use of the on-board functions and programs.

RTK/DGPS communication
Radio modems, GSM, GPRS and CDMA modules fit in waterproof housings attached to the receiver. Attach either one or two devices for RTK/DGPS reference and rover applications.

With *Bluetooth*® Wireless-Technology built in to the RX1250 controller complete cable free operation and connectivity to compatible wireless products is available.

Figure 2: Leica GPS1200 product brochure



GPS1200 receivers
GX1230 GG/ATX1230 GG
- Universal receiver for all applications
- 14 L1 + 14 L2 (GPS)
- Support of L2C
- 12 L1 + 12 L2 (GLONASS)
- Data logging
- Full RTK and DGPS capability
- Use as rover or reference

GX1230/ATX1230
- Universal receiver for all applications
- 14 L1 + 14 L2 (GPS)
- Data logging
- Full RTK and DGPS capability
- Use as rover or reference

GX1220/GX1210
- Data logging
- 14 L1 + 14 L2 (GX1220)
- 14 L1 (GX1210)
- Option: DGPS

Antenna technology
All GPS1200 antennas include SmartTrack+ technology to deliver sub-millimeter phase center accuracy and high quality measurements even from low elevation GPS and GLONASS satellites. Built in ground plane suppresses multipath.

GPS1200 antenna and receiver technology deliver high precision measurements for the most demanding tasks. Antennas are light and rugged, built to survive falls from the top of a 2 m pole.

SmartStation with SmartAntenna
SmartStation is a TPS1200 with a ATX1230 (GG) SmartAntenna. All GPS and TPS operations are controlled from the TPS keyboard, all data are in the same database, all information is shown on the TPS screen. Touch the GPS key, let RTK determine the position to centimeter accuracy, then survey and stake out with the total station. You can do anything with SmartStation. You can also use SmartAntenna independently on a pole with a RX1250 controller.

- **Light, modular equipment**
  Use it the way that suits you best.
- **All on the pole**
  Light weight with excellent balance. Ideal for stakeout on construction sites and other demanding conditions.
- **Pole and minipack**
  Minimum weight in your hand when surveying for hours on end.
- **On a tripod or pillar**
  For geodetic control and reference stations.
- **All in the minipack**
  For 30 cm DGPS, GIS and seismic surveys.

Seamless dataflow

WORKING TOGETHER
X FUNCTION integrated
LEICA SYSTEM 1200

Keyboard illumination
Switch on the display and keyboard illumination when working at night. All the keys light up.

Use GPS1200 for everything
- For RTK, DGPS,
- and static data logging
- As a rover or reference
- On a pole, tripod, pillar, or in a minipack
- On construction machines, survey boats, or planes
- For every type of application

Choice of RTK pole
Carbon fiber or aluminum pole with adjustable, ergonomic handgrip.

Leica Geo Office
Software support package for GPS and TPS with tools and components for import, visualization, conversions, quality control, processing, adjustment, reporting, export etc.

CompactFlash cards
Same CompactFlash cards for GPS and TPS.

Plug-in Li-Ion batteries
For reliable, long-lasting power, GPS1200 uses the best, high-capacity batteries available. Work for up to 15 hours with just two plug-in, Lithium-ion batteries.

TPS1200 Total Stations
GPS and TPS use the same CompactFlash cards, formats and data management. Transfer cards from one to the other and continue working in the same way.

Figure 3: Leica GSP1200 product brochure

Leica GPS1200

Technical specifications and system features

GPS1200 receivers	GX1230 receiver	GX1220 receiver	GX1210 receiver	ATX1230 SmartAntenna / RX1250
GPS technology	SmartTrack	SmartTrack	SmartTrack	SmartTrack
Type	Dual frequency	Dual frequency	Single frequency	Dual frequency
Channels	12 L1 + 12 L2 / WAAS / EGNOS	12 L1 + 12 L2 / WAAS / EGNOS	12 L1 / WAAS / EGNOS	12 L1 + 12 L2 / WAAS / EGNOS
RTK	Yes, SmartCheck	No	No	Yes, SmartCheck
DGPS + WAAS / EGNOS	Yes	Optional	Optional	Yes
Status indicators	3 LED indicators: for power, tracking, memory.			
Ports	1 power port, 3 serial ports, 1 controller port, 1 antenna port.			1 power/controller port, Bluetooth port
Supply voltage, Consumption	Nominal 12 VDC. 5.2 W receiver + controller + antenna			ATX1230: 2.4 W, RX1250 1.1 W
Event input and PPS	Optional: 1 PPS output port 2 event input ports	Optional: 1 PPS output port 2 event input ports	Optional: 1 PPS output port 2 event input ports	
Standard antenna Built in groundplane	SmartTrack AX1202 Built in groundplane	SmartTrack AX1202 Built in groundplane	SmartTrack AX1201 Built in goundplane	SmartTrack ATX1230 Built in goundplane

The following apply to all receivers except where stated.

Power supply	Two Li-Ion 3.8Ah/7.2V plug into receiver. One Li-Ion 1.9Ah/7.2V plugs into ATX1230 and RX1250.
Plug-in Li-Ion batteries Same for GPS and TPS	Power receiver + controller + SmartTrack antenna for about 15 hours (for data logging).
	Power receiver + controller + SmartTrack antenna + low power radio modem or phone for about 10 hours (for RTK/DGPS).
	Power SmartAntenna + RX1250 controller for about 5 hours (for RTK/DGPS)
External power	External power input 10.5 V to 28 V.
Weights	Receiver 1.20 kg. Controller 0.48 kg (RX1210) and 0.75 kg (RX1250). SmartTrack antenna 0.44 kg. SmartAntenna 1.12 kg. Plug-in Li-Ion battery 0.09 kg (1.9Ah) and 0.19 kg (1.9Ah).
	Carbon fiber pole with SmartTrack antenna and RX1210 controller: 1.80 kg.
	All on pole: carbon fiber pole with SmartAntenna, RX1250 controller and plug-in batteries: 2.84 kg.

Temperature ISO9022 MIL-STD-810F	Operation:	Receiver	−40°C to +65°C
	Antennas		−40°C to +70°C
	Controllers		−30°C to +65°C
	Storage:	Receiver	−40°C to +80°C
	Antennas		−55°C to +85°C
	Controllers		−40°C to +80°C
Humidity ISO9022, MIL-STD-810F	Receiver, antennas and controllers Up to 100% humidity.		
Protection against water, dust and sand IP67, MIL-STD-810F	Receiver, antennas and controllers: Waterpoof to 1m temporary submersion. Dust tight		
Shock/drop onto hard surface	Receiver: withstands 1m drop onto hard surface. Antennas: withstand 1.5m drop onto hard surface.		
Topple over on pole	Receiver, antennas and controllers: withstand fall if pole topples over.		
Vibrations ISO9022 MIL-STD-810F	Receiver, antennas and controllers: withstand vibrations on large construction machines. No loss of lock.		

Figure 4: Leica GPS1200 technical specifications

SPECIFICATIONS

Sensor Type
Fused Quartz using electrostatic nulling

Reading Resolution
1 microGal

Standard Field Repeatability
< 5 microGal

Operating Range
8,000 mGal without resetting

Residual Long-Term Drift (static)
Less than 0.02 mGal/day

Range of Automatic Tilt Compensation
± 200 arc sec

Tares
Typically less than 5 microGals for shocks up to 20 G.

Automated Corrections
Tide, Instrument Tilt, Temperature, Noisy Sample, Seismic Noise Filter.

Dimensions
31 cm (H) x 22 cm x 21 cm
12 in (H) x 8.5 in x 8 in

Weight (including batteries)
8 kg, (17.5 lbs.)

Battery Capacity
2 x 6Ah (10.8V) rechargeable Litium-Ion Smart Batteries. Full day operation in normal survey conditions with two fully charged batteries.

Power Consumption
4.5 Watts at 25°C

Standard Operating Temperature Range
-40°C to +45°C

Ambient Temperature Coefficient
0.2 microGal/°C (typical)

Pressure Coefficient
0.15 microGal/kPa (typical)

Magnetic Field Coefficient
1 microGal/Gauss (typical)

Memory
Flash Technology (data security)
Standard 12 MBytes

Digital Data Output
RS-232 C and USB interface
Is optimized for Win XP™

Analog Data Output
Strip-Chart Recorder

Display Screen
¼ VGA 320 x 240 pixels

Keypad
27 key alpha/numeric

Standard System
- CG-5 Console
- Tripod base
- 2 rechargeable batteries
- Battery Charger, 110/240 V
- External Power 110/240 V
- RS-232 and USB Cables
- Carrying Bag
- Data dump and utilities software
- Operating Manual (CD)
- Transit Case

GPS
Enables GPS station referencing from an external 12 channel smart GPS antenna being connected via the RS-232 port. Standard GPS accuracy: <15m DGPS (WAAS) < 3m. Client has the option to use other higher accuracy GPS receivers outputting NMEA data string through the serial port.

OPTIONS

High Temperature Option
For use in climates that may exceed the normal operating temperate of 45°C. Allows operating temperatures of up to 55°C. This option is intended to be used in climates above freezing and needs to be ordered at the time of purchase.

Battery Belt
Suggested for cold weather operation.

COMPLETE GRAVITY SOLUTIONS

Special Applications
Please contact LRS Scintrex or your local representative.

Training Programs
LRS Scintrex can provide training programs at our office in Canada or at your location.

Application Software
LRS Scintrex can provide software packages to support your data processing, interpretation and mapping needs.

An ISO 9001:2000 registered company

* All specifications are subject to change without notice.

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Figure 5: Scintrex CG-5 specifications

5.0 Vehicle and Helicopter Transportation

5.1 Helicopters

A single R44 helicopter was supplied to the project (Photo 1). The helicopter was serviced in accordance with CASA specifications with 100 hourly services carried out in Katherine.

The helicopter was equipped with an EPIRB device, comprehensive first aid kit and survival kit. Communications were via VHF radio and Iridium satellite phone. Helicopter movements were tracked using a satellite tracking system.

Aviation fuel and oils were supplied ex Katherine.

5.2 Support Vehicles

Facilitating refuelling operations were two 4WD Toyota Landcruiser utilities and an Isuzu FTS750 truck. A Toyota 4WD Landcruiser utility was used for crew and pilot transport, helicopter refuels and crew changeovers. The vehicles were fitted with the following equipment:

- Iridium satellite phone
- Garmin navigation grade GNSS receiver with moving map display
- Spare navigation grade GNSS receiver with batteries
- First aid and survival kit
- Two spare tyres
- Recovery equipment for tyre repair
- Recovery equipment including winch for bogging, stranding.
- Comprehensive tool-kit
- 10L of drinking water
- Satellite tracking device

All vehicles used on the project were supplied, serviced and maintained by Atlas Geophysics. The field crew carried out daily pre-start checks on all vehicles and these have been documented in Atlas Geophysics pre-start log books.

Photo 1: Helicopter and operator

6.0 Camping / Accommodation

The survey crew were accommodated and messed at each of the logistical bases.

7.0 Communications, Internet and Scheduled Calls

The primary method of communication for the field crews was via Iridium satellite phones. The helicopter crews made scheduled calls to the field operations base at hourly intervals. In addition to scheduled calls, the position of the helicopters was reported to the operations base at 10 minute intervals using satellite tracking technology.

Internet connections for client contact and data server access were established using a Telstra Turbo Gateway NextG internet modem and a Broadband Global Area Network (BGAN) satellite internet network system for remote locations.

8.0 Survey Methodology

All gravity data were acquired using Atlas Geophysics Pty Ltd helicopter-borne techniques. These techniques, which involve concurrent GNSS and gravity acquisition, allow for rapid acquisition of very high quality data.

8.1 Gravity and GNSS Control Establishment

Two new primary GNSS/Gravity control stations were established during this survey (Table 2).

At each primary control station, a permanent monument was erected to mark and witness the station. The monument consisted of a 40cm star picket driven into the ground with about 10cm protruding alongside a small square concrete slab set level in concrete. The star picket marked the position of the GNSS control station and the concrete slab marked the position of the gravity control station. A steel star picket of 1.5m length was placed within 0.5m of each control point and carried an Atlas Geophysics Pty Ltd witness plaque numbered with a unique station number (Figure 6).

Control Station ID	Lat / Long / Ht (GDA94)	Observed Gravity (AAGD07 $\mu m/s^2$)
201607400001 (GA 20168000001) *Daly River*	-13 45 53.27018 130 42 44.00121 61.274	9783241.97
201607400003 (GA 20168000003) *Manbulloo*	-14 30 58.94377 132 12 5.56967 147.031	9783328.35

Table 2: Gravity and GNSS control stations used to control the survey

Details of all primary control stations have been recorded on an Atlas Geophysics Pty Ltd control station summary sheet. This sheet includes the geodetic coordinates, observed gravity value, station description, locality sketch, locality map and a digital photo of the station. The sheet is contained in Appendix B.

Figure 6: Atlas Geophysics Pty Ltd survey witness plaque

8.1.1 GNSS Control

Primary GNSS control was established for all control stations and this allowed all position and height information obtained from the gravity survey to be tied to the Geocentric Datum of Australia (GDA94), the Geodetic Reference System 1980 (GRS80) and Australian Height Datum (AHD).

Secondary GNSS control was used to restrict kinematic baseline length. 6 separate remote, control stations were established in the field and all were marked with a 40cm steel rod driven into the ground with about 1cm protruding (not identified). In the field, whilst the survey was underway, temporary coordinates for these stations were established using static base-line processing to the primary control station over a minimum ten hour period.

Upon final processing, coordinates for all primary and secondary control stations were obtained using the 5 second static GNSS data logged at each station whilst the gravity survey was underway. The static data has been submitted to Geoscience Australia's AUSPOS processing system to produce first-order geodetic coordinates accurate to better than 10mm for the x, y and z observables. Multiple days of static GNSS data have been submitted to ensure accuracy and reliability of the solution.

Initial surveying was conducted using adopted control station coordinates since the AUSPOS system requires approximately two weeks before a Final Ephemeris Solution can be delivered. The adopted coordinates were derived from an autonomous GNSS measurement at the primary control station giving an accuracy of better than 0.5m for x, y coordinates and better than 15m for the z coordinate. Once the final ephemeris solution for the control station coordinates was delivered by AUSPOS, all control and field GNSS measurements had the necessary DC shift applied to give accurate, absolute positions for east, north and elevation. A listing of final coordinates for all control stations are contained in Appendix C.

8.1.2 Gravity Control

Gravity control was established at each of the primary control stations. Once tied to the Australian Fundamental Gravity Network (AFGN), the gravity control stations allowed all field gravity observations to be tied to the Australian Absolute Gravity Datum 2007 (AAGD07).

An accurate observed or absolute gravity value for each control station 1 was established via a minimum of two "ABA" ties with the project gravity meter to the nearest AFGN station. Table 3 summarises the control ties conducted and Appendix D contains the control tie data. Expected accuracy of the tie surveys would be better than 0.1 $\mu m/s^2$ (or 0.01 mGal).

Control Station ID	AFGN station tied to	Date of tie
201607400001 (GA 20168000001) *Daly River*	1991900332 CS1 War Graves Memorial	25/07/2016
201607400003 (GA 20168000003) *Manbulloo*	1980902318 Tindal Airport Carport	02/08/2016 05/08/2016

Table 3: Primary gravity control stations used to control the survey

8.2 GNSS Data Acquisition, Processing and Quality Control

GNSS data were collected in static mode at each of the control stations and in kinematic mode with the helicopters using geodetic grade Leica GPS1200 receivers. Rigorous post-processing of the recorded kinematic data allowed for excellent GNSS ambiguity resolution and 3-D solution coordinate qualities better than 5cm for each of the gravity station locations. Atlas Geophysics QC procedures have ensured the final GNSS data have met and exceeded contract specifications.

8.2.1 GNSS Acquisition

Each GSL was positioned using navigation grade Garmin receivers fitted to custom mounts inside the cockpit of the helicopter. Accuracy of the positioning system was better than 5m and where practicable, the helicopter crew landed as close to the programmed station location as possible. Where it was too dangerous to land, stations were moved from the programmed coordinate.

For the kinematic helicopter operations, the GNSS sensors were mounted on a fixed aluminium bracket at the front of the aircraft (primary) and on the tail boom of the aircraft (secondary backup, with phase data logged by the receivers inside the cockpit. Data were logged at five second epochs onto Compact Flashcards (CF) for later downloading and processing. Static data were also concurrently logged at the primary and secondary GNSS control stations to allow for later kinematic processing.

8.2.2 GNSS Processing

The acquired raw GNSS data were processed nightly using Novatel Waypoint Grafnav v8.60 post-processing software (Figure 7). GrafNav is a fully-featured kinematic and static GNSS post-processing package that uses Waypoint's robust GNSS processing carrier phase kinematic (CPK) filter engine. The software is capable of processing raw kinematic GNSS data from most GNSS receivers and allows the user to process the roving data from as many as eight separate control stations to achieve accuracies at the centimetre level. The software can automatically switch from static to kinematic processing and has a fixed static solution for static initialisation of short or medium baselines that are below 30km. Kinematic Ambiguity Resolution (KAR) allows the session to start in kinematic mode and can help fix otherwise unrecoverable cycle slips. Ionospheric processing and modelling is also included with the software and can help improve accuracy, especially over long baselines. Advantages of the Waypoint processing engine over other packages include:

Fast Processing – The Grafnav engine is one of the fastest on the market. For a single base station, a 2.40 Mhz PIII CPU can expect to process GNSS data at 670 epochs/second. This means that a 4-hour 2 Hz data set will process one direction in 22 seconds. For two bases, processing takes 250 epochs/second or about 1 minute for the same 4-hour data set. For 4 bases, these times are 50 epochs/second or about 5 minutes.

Reliable OTF Processing – Waypoint's on-the-fly KAR algorithm has had years of development and testing. Various implementations and numerous options are available to control this powerful feature.

Multi-Base (MB) processing – With Version 8.60, GrafNav now supports true multiple control station processing where all of the baselines are incorporated into one sophisticated Kalman filter. This can spatially de-correlate some of the error sources while also allowing integer ambiguity determination using the closest base station. Satellite drop-outs at one base will also be compensated by the others. The two biggest advantages are improved overall accuracies and much less operator effort required to process and QC such data.

Accurate Static Processing – Three modes of static processing are implemented in the main processing kernel.

Dual Frequency Support – Full dual frequency GNSS processing comes with the software. For ambiguity resolution, this entails wide/narrow lane solutions for KAR, fixed static and quick static. The GrafNav kernel implements two ionospheric processing modes including the iono-free and relative models. The relative model is especially useful for airborne applications where initialisation is near the base station, and this method is much less susceptible to L2 phase cycle slips.

Forward and Reverse – Processing can be performed in both the forward and reverse directions. GrafNav also has the ability to combine these two solutions to obtain a globally optimum one.

GLONASS – The GrafNav kernel has the ability to also process GLONASS data. This is especially advantageous for applications in forested areas, where the additional satellite coverage can improve accuracies.

Velocity Determination – Since the GrafNav kernel includes the L1 doppler measurement in its Kalman filter, velocity determination is very accurate. In addition to this, a considerable amount of code has been added specifically for the detection and removal of Doppler errors.

High Dynamics – The GrafNav kernel can handle extremely high dynamics from missiles, rockets, dropped ordinances, and fast flying aircraft.

Long Baseline - Because precise ephemeris and dual frequency processing is supported, long baselines accuracies can be as good as 0.1 PPM.

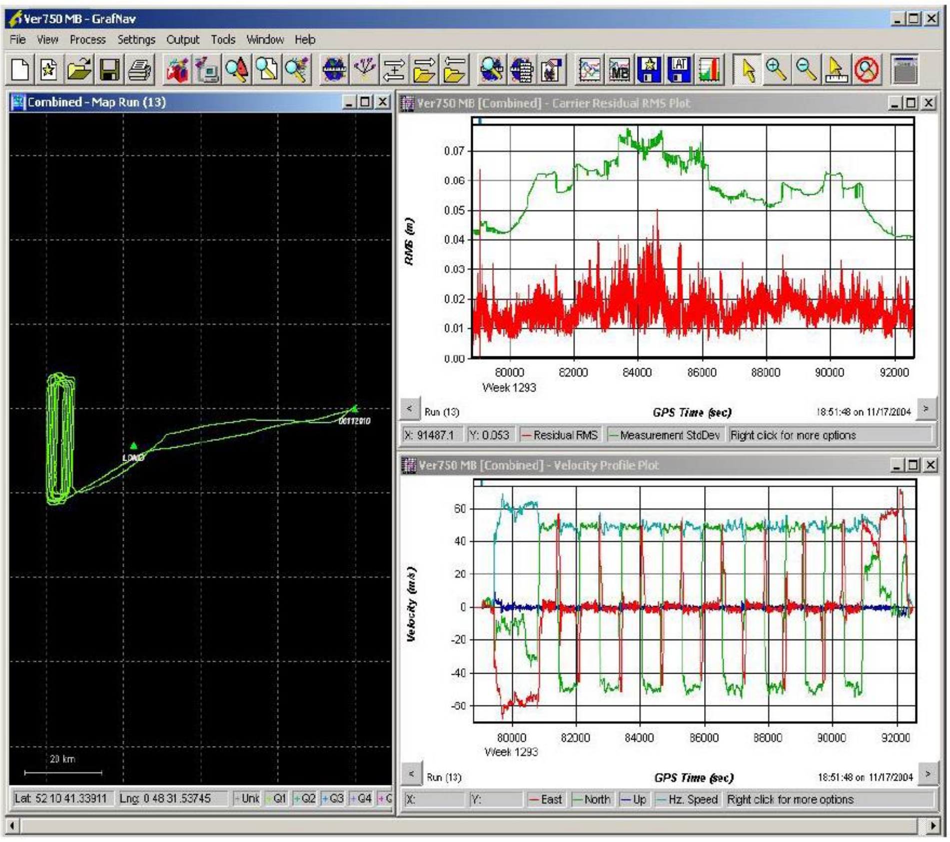


Figure 7: Waypoint Grafnav Processing Software

Once each epoch was processed to give a solution for the WGS84 position and elevation at ground level (i.e. corrected for sensor height), conversion between GNSS derived WGS84/GDA94 coordinates to Map Grid of Australia (MGA) coordinates was conducted within Waypoint. For most practical applications, where a horizontal accuracy of only a metre or greater is required, GDA94 coordinates can be considered the same as WGS84. MGA94 coordinates were obtained by projecting the GNSS-derived WGS84 coordinates using a Universal Transverse Mercator (UTM) projection with zone 52. For more information about WGS84, GDA94 and MGA94 coordinates, the reader is asked to visit the Geoscience Australia website http://www.ga.gov.au/earth-monitoring/geodesy/

Elevations above the Australian Height Datum (AHD) were modelled using Waypoint 8.60 software and the latest geoid model for Australia, AUSGEOID09. Information about the geoid and the modelling process used to extract separations (N values) can be found at http://www.ga.gov.au/geodesy/ausgeoid/. To obtain AHD elevation, the modelled N value is subtracted from the GNSS derived WGS84/GRS80 ellipsoidal height (Figure 8).

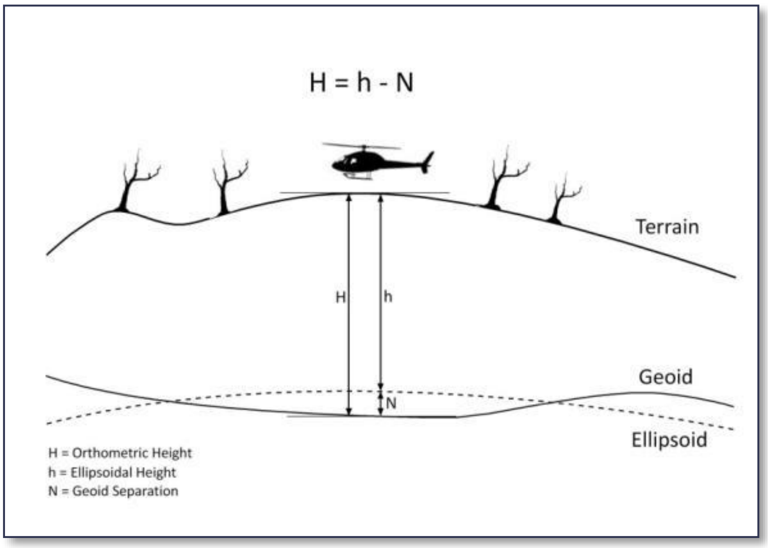


Figure 8: Geoid-Ellipsoid Separation

8.2.3 GNSS Quality Control

Rigorous quality control procedures were applied to the acquired GNSS data on a daily basis using Waypoint GrafNav's built in QC tools. Some of the tools used on this project include:

Combined Separation Plot: This plot shows the difference between the forward and reverse solutions (Figure 9). A perfect solution would have a separation of zero as this indicated the carrier phase ambiguities have been determined to be exactly the same value in both directions. A separation of better than 0.1m on a helicopter survey would indicate that the data is of high quality.

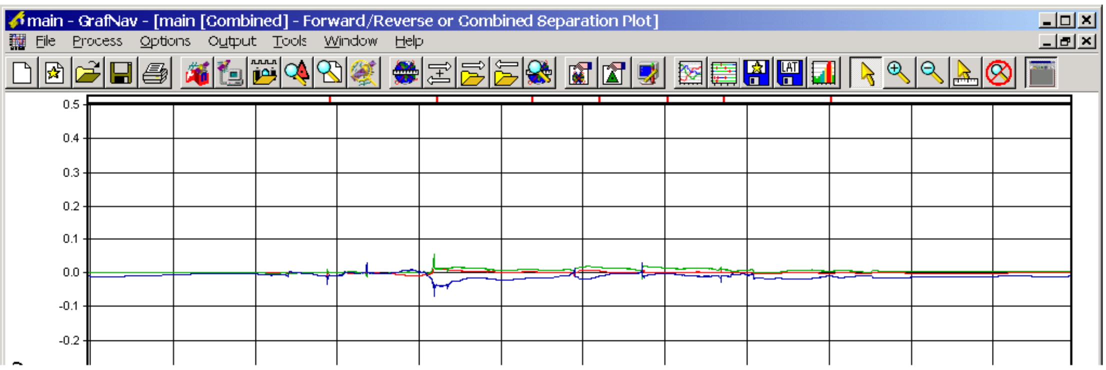


Figure 9: Combined Separation Plot

Float or Fixed Ambiguity Status Plot: This plot shows if the final solution is float or fixed (Figure 10). Fixed integer ambiguities generally have better accuracies (usually < 10cm accuracy). Ideally the plot should show fixed as this indicated an integer ambiguity fix on both forward and reverse directions.

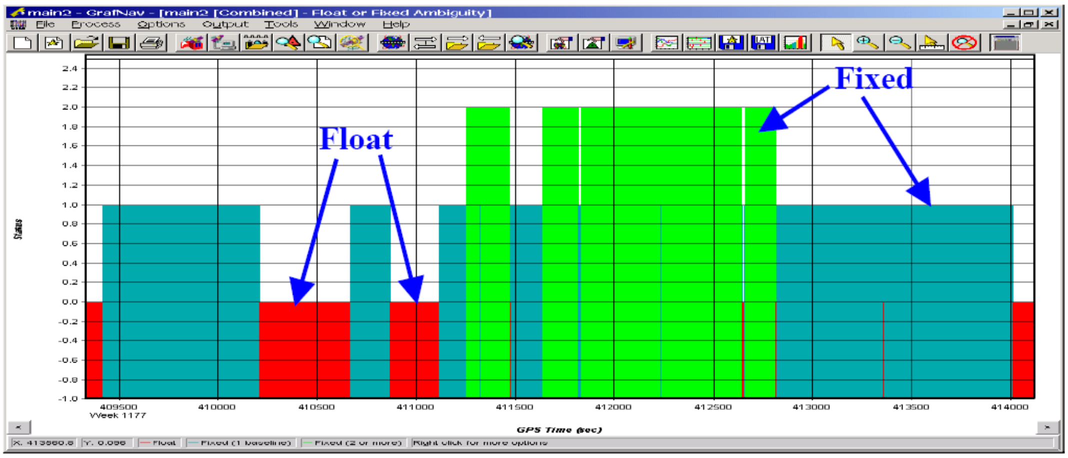


Figure 10: Float or Fixed Ambiguity Status Plot

Quality Factor Plot: This plot shows the quality of the final solution (Figure 11). There are five different quality factors plotted and these factors are also output in the Atlas Geophysics Pty Ltd GNSS data file.

Quality 1 – Fixed Integer (Green)
Quality 2 – Stable Float (Aqua)
Quality 3 – Converging Float (Blue)
Quality 4 – DGNSS or worse (Red)
Quality 5 – Single Point (Yellow)

Increasing quality factors indicate a worse solution. This is not a perfect indication, but it can be useful to isolate problems.

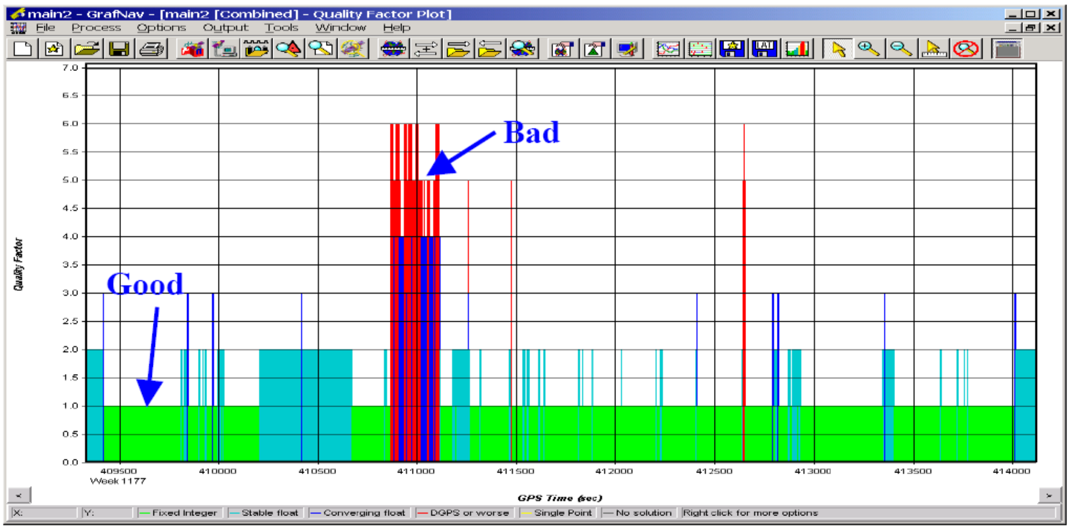


Figure 11: Quality factor plot

Complementing Waypoint GrafNav QC tools is the company's own in-house GNSS quality control software. A module built into AGRIS (Atlas Geophysics Reduction and Information Software) allows the user to import the Waypoint output files and examine quality factors such as station repeatability between multiple control stations, coordinate velocity, dilution of precision, coordinate quality factor and standard error for each gravity station location. The procedure is carried out before merging the positional data with gravity data for final reduction to Bouguer Anomaly. Comprehensive statistics, repeatability analysis and histogram plotting are also performed.

QC procedures were applied to the GNSS data on a daily basis and any gravity stations not conforming to contract specifications were repeated by the company at no cost to the client.

8.3 Gravity Data Acquisition, Processing and Quality Control

Gravity data were gained using the company's rapid acquisition, high accuracy helicopter-borne techniques. The company's own in-house reduction and QC software was used to reduce the data on a daily basis to ensure quality and integrity. Final delivered data met and exceeded contract specifications.

8.3.1 Calibration of the Gravity Meter

The gravity meter used for survey on this project was calibrated pre and post survey on the Guildford Cemetery – Helena Valley Primary School calibration range (2010990117-2010990217) in Western Australia. The calibration process has validated the gravity meter's scale factor to ensure reduction of the survey data produces correct Observed Gravities from measured dial reading values.

Table 4 summarises the results of the calibration ties and lists the resultant scale factor for the survey gravity meter. Appendix E contains the reduced data used to create the summary.

PRE SURVEY CALIBRATION RUN 30/06/2016				
Meter Code	Meter SN	Calc 2010990217 AAGD07 (µm/s²)	Diff (µm/s²)	Scale
A2	40241	9794483.82	-0.03	0.999283

POST SURVEY CALIBRATION RUN 03/10/2016				
Meter Code	Meter SN	Calc 2010990217 AAGD07 (µm/s²)	Diff (µm/s²)	Scale
A2	40241	9794483.81	-0.04	0.999283

Table 4: Gravity meter scale factors

Weekly tilt-tests and cycles were conducted to ensure the meter's drift and tilt correction factors were valid. Gravity meter drift rates were monitored on a day to day basis using AGRIS software.

8.3.2 Acquisition of the Gravity Data

Gravity data were acquired concurrently with GNSS data using a Scintrex CG-5 gravity meter. Data were acquired in a single shift of ten hours duration, with each shift consisting of a single loop controlled by observations at the gravity control stations. Each loop contained a minimum of two repeated readings so that an interlocking network of closed loops was formed. A total of **9.03%** repeats were acquired for quality control purposes. Repeat readings were evenly distributed on a time-basis throughout each of the gravity loops.

The gravity acquisition crew consisted of a single gravity operator and pilot per helicopter. The pilot was responsible for safely navigating to each station, and once at the station, the operator disembarked from the helicopter and acquired the gravity data. The observation point was always situated in front of the aircraft, in the pilot's view. Under no circumstances were readings taken outside of the pilot's view as this can jeopardise the safety of the operator. As the helicopter always landed on flat ground, the error due to the gravity observation not being coincident with the GNSS observation is minimal. A small latitude based error of less than 0.05 $\mu m/s^2$ would apply, but this is not seen to be appreciable on a regional gravity survey, so is not corrected for.

At each station, the gravity operator took a minimum of two gravity readings of 20 second duration so that any seismic or wind noise could be detected. Control station readings were set to 60 second duration. Before taking the reading, the operator ensured that the instrument tilt-reading was restricted to less than 5 arc-seconds and after the reading, not higher than 20 arc-seconds. Tilt-testing prior to project commencement showed that the gravity meters performed well even at extreme tilts (better than 0.05 $\mu m/s^2$ at +150/-150 arc-seconds).

If two separate readings did not agree to better than 0.20 $\mu m/s^2$ (0.10 $\mu m/s^2$ for control station readings), then the operator continued taking readings until the tolerance between consecutive readings was achieved. At the conclusion of the gravity reading, the final data display on the gravity meter was analysed to ensure the instrument was performing to specification and that the station observation provided data conforming to the project specifications. The operator also checked that the temperature, standard deviation and rejection values were within required tolerance before recording the reading. At each station, the operator recorded the gravity data digitally in the gravity meter as well as in an Atlas Geophysics Pty Ltd field book so that instrument drift and reading repeatability could be analysed easily whilst in the field. Data recorded at each GSL was assigned a unique station code and station number.

Repeat stations were marked with a biodegradable flagging tape for subsequent reoccupation. When reoccupying stations, the pilot positioned the helicopter as close to the original landing spot as possible (usually better than 0.5m). A very small percentage of the repeat stations were positioned greater than 0.5m from the original location due to soft ground and/or windy conditions, but always on flat ground at the same level as the original observation. All repeat gravity observations were taken in exactly the same location, even if the helicopter landed slightly offset from the original position.

8.3.3 Processing of the Gravity Data

The acquired gravity data were processed using the company's in-house gravity pre-processing and reduction software, AGRIS. This software allows for full data pre-processing, reduction to Bouguer Anomaly, repeatability and statistical analysis, as well as full quality control of the output dataset.

The software is capable of downloading Scintrex CG-3/CG-5 and Lacoste Romberg gravity data. Once downloaded, the gravity data is analysed for consistency and preliminary QC is performed on the data to check that observations meet specification for standard deviation, reading rejection, temperature and tilt values. Once the data is verified, the software averages the multiple readings and performs a merge with the GNSS data (which it has also previously verified) and performs a linear drift correction and earth tide correction. Calculation of Free Air and Bouguer Anomalies is then performed using the contract specified formulae.

The following corrections were applied to the dataset to produce Bouguer Anomaly values for each of the gravity stations. All formulae produce values in μm/s^2.

Instrument scale factor: This correction is used to correct a gravity reading (in dial units) to a relative gravity unit value based on the meter calibration.

$$r_c = 10 \cdot (r \cdot S(r))$$

where,
r_c corrected reading in μm/s^2
r gravity meter reading in dial units
$S(r)$ scale factor (dial units/mGal)

Earth Tide Correction: The earth is subject to variations in gravity due to the gravitational attraction of the Sun and the Moon. These background variations can be corrected for using a predictive formula which utilises the gravity observation position and time of observation. The Scintrex CG5 gravity meter automatically calculates ETC but uses only an approximate position for the gravity observation so is not entirely accurate. For this reason, the Scintrex ETC is subtracted from the reading and a new correction calculated within AGRIS software. The full formula is listed in Appendix G.

$$r_t = r_c + g_{tide}$$

where,
r_t tide corrected reading in μm/s^2
r_c scale factor corrected reading in μm/s^2
g_{tide} Earth Tide Correction (ETC) in μm/s^2

Instrument Drift Correction: Since all gravity meters are mechanical they are all prone to instrument drift. Drift can be caused by mechanical stresses and strains in the spring mechanism as the meter is moved, knocked, reset, subjected to temperature extremes, subjected to vibration, unclamped etc. The most common cause of instrument drift is due to extension of the sensor spring with changes in temperature (obeying Hooke's law). To calculate and correct for daily instrument drift, the difference between the gravity control station readings (closure error) is used to assume the drift and a linear correction is applied.

$$ID = \frac{r_{cs2} - r_{cs1}}{t_{cs2} - t_{cs1}}$$

where,

ID Instrument Drift in µm/s^2 /hour
r_{cs2} control station 2nd reading in µm/s^2
r_{cs1} control station 1st reading in µm/s^2
t_{cs2} control station 2 time
t_{cs1} control station 1 time

Observed Gravity: The preceding corrections are applied to the raw gravity reading to calculate the earth's absolute gravitational attraction at each gravity station. The corrections produced Observed Gravities on the AAGD07 datum.

$$G_o = g_{cs1} + (r_t - r_{cs1}) - (t - t_{cs1}) \cdot ID$$

where,

G_o Observed Gravity in µm/s^2
g_{cs1} control station 1 known observed gravity in µm/s^2
r_t tide corrected reading in µm/s^2
r_{cs1} control station 1 reading in µm/s^2
t reading time
t_{cs1} control station 1 time
ID instrument drift in µm/s^2/hour

Normal Gravity: The normal (or theoretical) gravity value at each gravity station is calculated based on the assumption that the Earth is a homogeneous ellipsoid. The closed form of the 1980 International Gravity Formula is used to approximate the theoretical gravity at each station location and essentially produce a latitude correction. Gravity values vary with latitude as the earth is not a perfect sphere and the polar radius is much smaller than the equatorial radius. The effect of centrifugal acceleration is also different at the poles versus the equator.

$$G_n = 9780326.7715((1 + 0.001931851353(sin^2 l)/(SQRT(1 - 0.0066943800229(sin^2 l)))$$

where,

G_n Theoretical Gravity in gravity units
l GDA94 latitude at the gravity station in decimal degrees

Atmospheric Correction: The gravity effect of the atmosphere above the ellipsoid can be calculated with an atmospheric model and is subtracted from the normal gravity.

$$AC = 8.74 - 0.00099 \cdot h + 0.0000000356 \cdot h^2$$

where,

AC Atmospheric Correction in gravity units
h elevation above the GRS80 ellipsoid in metres

Free Air Correction: Since the gravity field varies inversely with the square of distance, it is necessary to correct for elevation changes from the reference ellipsoid (GRS80). Gravitational attraction decreases as the elevation above the reference ellipsoid increases.

$$FAC = -(3.087691 - 0.004398\, sin^2 l) \cdot h + 7.2125 \cdot 10^{-7} \cdot h^2$$

where,
FAC Free Air Correction in gravity units
l GDA94 latitude at the gravity station in decimal degrees
h elevation above the GRS80 ellipsoid in metres

Bouguer Correction: If a gravity observation is made above the reference ellipsoid, the effect of rock material between the observation and the ellipsoid must be taken into account. The mass of rock makes a positive contribution to the gravity value. The correction is calculated using the closed form equation for the gravity effect of a spherical cap of radius 166.7km, based on a spherical Earth with a mean radius of 6,371.0087714km, height relative the ellipsoid and a rock density of 2.67 t/m^3.

$$BC = 2\pi G\rho((1+\mu)\cdot h - \lambda R)$$

where,
BC Bouguer Correction in gravity units
G gravitational constant = $6.67428 \cdot 10^{-11} m^3 kg^{-1} s^{-2}$
ρ rock density (2.67 t/m^3)
h elevation above the GRS80 ellipsoid in metres
R $(R_o + h)$ the radius of the earth at the station
R_o mean radius of the earth = 6,371.0087714 km (on the GRS80 ellipsoid)
μ & λ are dimensionless coefficients defined by:

$$\mu = ((1/3)\cdot \eta^2 - \eta)\cdot$$

where,
η h/R

$$\lambda = (1/3)\{(d + f\delta + \delta^2)[(f - \delta)^2 + k]^{\frac{1}{2}} + p + m\cdot ln(n/(f - \delta + [(f - \delta)^2 + k]^{\frac{1}{2}})\}$$

where,
d $3\cdot cos^2\alpha - 2$
f $cos\alpha$
k $sin^2\alpha$
p $-6\cdot cos^2\alpha \cdot \sin(\alpha/2) + 4\cdot sin^3(\alpha/2)$
δ (R_o/R)
m $-3\cdot k\cdot f$
n $2\cdot[sin(\alpha/2) - sin^2(\alpha/2)]$
α S/R_o with S = Bullard B Surface radius = 166.735 km

Terrain Correction: The terrain correction accounts for variations in gravity values caused by variations in topography near the observation point. The correction accounts for the attraction of material above the assumed spherical cap and for the over-correction made by the Bouguer correction when in valleys. The terrain correction is positive regardless of whether the local topography consists of a mountain or a valley. Section 8.3.4 contains a more in-depth discussion of the terrain correction process.

Free Air Anomaly: The free air anomaly is the difference between the observed gravity and normal gravity that has been computed for latitude and corrected for the elevation of the gravity station above or below the reference ellipsoid:

$$FAA = G_o - (G_n - AC) - FAC$$

where,

FAA Free Air Anomaly in gravity units
G_o Observed Gravity in gravity units
G_n Normal Gravity in gravity units
AC Atmospheric Correction in gravity units
FAC Free Air Correction in gravity units

Bouguer Anomaly: The Bouguer anomaly is computed from the free air anomaly above by removing the attraction of the spherical cap calculated by the Bouguer correction.

$$BA = FAA - BC$$

where,

BA Bouguer Anomaly in gravity units
FAA Free Air Anomaly in gravity units
BC Bouguer Correction in gravity units

Complete Bouguer Anomaly: This is obtained by adding the terrain correction to the Bouguer anomaly. The Complete Bouguer Anomaly is the most interpretable value derived from a gravity survey as changes in the anomaly can be directly attributed to lateral density contrasts within the geology below the observation point.

$$CBA = BA + TC$$

where,

CBA Complete Bouguer Anomaly in gravity units
BA Bouguer Anomaly in gravity units
TC Terrain Correction in gravity units

8.3.4 Terrain Corrections

Terrain corrections, which account for the variation in gravity due to topography proximal to the gravity station, were computed using a digital elevation model (DEM) and RASTERTC software from Geopotential. RASTERTC software permits the user to input a DEM in the form of a binary grid file, and gravity data in an ASCII file. From this information, the software is capable of calculating extremely accurate terrain corrections. For more detailed information regarding the software and algorithm, the reader is asked to visit the Geopotential website http://geopotential.com/docs/RasterTC/RasterTC.shtml

Elevation data were sourced from the 1 second SRTM Level 2 Derived Smoothed Digital Elevation Model (DEM-S) Version 1.0 which has an equivalent cell size of 30m. Data were extracted to provide a 30km buffer from the extents of the gravity survey.

A comparison against GNSS heights recorded during the gravity survey revealed that the DEM data were sufficiently accurate to be used in regional terrain corrections. The average difference between GNSS height and DEM heights was -2.36 m and the standard deviation of the differences was 2.15 m.

When executing the terrain correction, the following inputs were used with RASTERTC:

R_{MIN} = 30 m
R_{MED} = 250 m
R_{MAX} = 30000 m
Angle = 6 degrees

R_{MIN} was selected to enable correction for topography near to the gravity station and coincided with the grid cell size of the SRTM DEM. R_{MAX} was selected to allow for outer zone correction of severe topography at large distances from the gravity station. R_{MED} was chosen so that the DEM would be sampled at an interval close to the grid cell size of the DEM when using the 6 degree integration angle.

The terrain correction software provides indicators for terrain correction quality and accuracy as part of its output (included on the data USB as Appendix J). The output variables QFINNER and QFOUTER specify the quality factor for each correction made. If these factors have a value of 0, then the user can assume that the terrain correction proceeded successfully. If non-zero values are reported, then the value of the QF factor will provide an indication as to possible problems or inadequacies in the correction.

For the inner zone correction, an indicator of how well the terrain in the immediate vicinity of a gravity station is represented by the available elevation samples is obtained by examining the spatial distribution of the elevation samples. In the radial interval R_{MIN} to R_{MED}, RASTERTC counts the number of samples falling within the 8 octants surrounding the station. If any of these octants are missing elevation samples, that fact is noted, and the tabulated quality factor simply notes how many of octants are missing samples (see Table 5).

For the outer zone correction, a result of 0 means that the correction proceeded successfully. If a portion of the outer-zone terrain is missing from the DEM supplied, the value of QF-Outer will reflect the percent of terrain that was available (rounded to the nearest percent). For example, if QF-Outer is 91, the implication is that 9% of the terrain in the outer zones was missing for some reason, and that the terrain correction calculated for that particular station is too small by some amount.

QF-Inner	Explanation of Error Code
0	Inner-zone terrain calculation OK
1	No elevation samples occur in 1 octant surrounding the gravity station
2	No elevation samples occur in 2 octants surrounding the gravity station
3	No elevation samples occur in 3 octants surrounding the gravity station
4	No elevation samples occur in 4 octants surrounding the gravity station
5	No elevation samples occur in 5 octants surrounding the gravity station
6	No elevation samples occur in 6 octants surrounding the gravity station
7	No elevation samples occur in 7 octants surrounding the gravity station
22	Duplicate elevation nodes encountered while calculating terrain gradients
23	All elevation nodes collinear or triangulation structure corrupted

Table 5: Terrain Correction Error Codes

8.3.5 Quality Control of the Processed Gravity data

Following reduction of the data to Bouguer Anomaly, repeatability and QC procedures were applied to both the positional and gravity observations using AGRIS software. AGRIS checks the following as part of its QC processing:

- Easting Observation Repeatability and Histogram
- Northing Observation Repeatability and Histogram
- Elevation Observation Repeatability and Histogram
- Gravity Observation Repeatability and Histogram
- Gravity SD, Tilt XY, Temperature, Rejection, Reading Variance
- Gravity meter drift / closure
- Gravity meter loop time, drift per hour
- GNSS Dilution of Precision, Coordinate Quality Factor, Standard Error
- Variation of surveyed station location from programmed location

QC procedures were applied to the gravity data on a daily basis and any gravity stations not conforming to contract specifications were repeated by the company at no cost to the client.

8.3.6 Additional Processing, Gridding and Plotting

Complementing the QC procedures is additional daily gridding, imaging and plotting of the elevation and gravity data. Once processed to Bouguer Anomaly and assessed for QC, data are imported into Geosoft Oasis Montaj or ChrisDBF software for gridding at 1/5th the station spacing to produce ERMapper compatible grid files. Resultant grids are contoured, filtered and interpreted using ERMapper and ArcMap software to check that data is smoothly varying and that no spurious anomalies are present. A first vertical, tilt angle and horizontal derivative filter are routinely applied to the data as these filters allow for excellent noise recognition. Once identified, any spurious stations can be field checked by the helicopter crew the following day and repeated if required. During the course of the survey one anomalous station was field checked and found to be valid.

Plotting of the acquired stations on a daily basis allowed for identification of any missed stations which were then gained the following day.

9.0 Results

The Daly Basin Gravity Survey was completed with some difficulty due to steep and rugged terrain, high grass and tall trees. Landing in high, dry grass was very risky, with the helicopter crew exercising extreme caution due to the risk of uncontrollable grass fire. Some fires were started, but quickly extinguished by the crew. Many stations were offset due to safety concerns associated with main rotor or tail rotor strike.

A total of **1,798** new gravity stations were gained during the survey.

Final data have been delivered to a technically excellent standard and are presented both digitally and hardcopy as Appendices to this report.

9.1 Survey Timing and Production Rates

The surveys crew began gravity data acquisition on 13th July 2016 and completed the survey on 31st July 2016. The only survey downtime encountered was that required for the routine 100 hourly maintenance on the helicopters. The downtime was utilised to conduct gravity ties and to provision the logistics bases. On the whole, production was consistent with an average production rate of 120-150 stations per day. Lower production days were mainly due to the requirement to ferry to sections of the grid that were at distance from gazetted roads.

A full production report can be found on the data USB (Appendix J).

9.2 Data Formats

Final point located data for the project have been delivered in ASEG-GDF2 compliant format. Appendix I contains a listing of the definition and description files accompanying the final data.

Raw GNSS and gravity data in their respective native formats have been included on the data USB as Appendix J. Table 6 overleaf summarises the deliverables.

Final Delivered Data	Format	Data USB	Hardcopy
Gravity Database	Point located data ASEG-GDF2	•	
Raw Positional Data	AGRIS format, comma delimited	•	
Raw Gravity Data	Scintrex CG5 format	•	
Raw GNSS Data	Waypoint GPB Binary	•	
Gravity Control Data	Microsoft Excel Format	•	•
Calibration Data	Microsoft Excel Format	•	•
Repeat Data	Microsoft Excel Format	•	•
Terrain Corrections	RASTERTC output file	•	
Final Grids	ERMapper Grids .ers	•	
Final Images	Geotiff Images	•	•
Acquisition Report	PDF .pdf	•	•

Table 6: Final Deliverables

9.3 Data Repeatability: All Observations

The repeatability of both the gravity and GNSS data was excellent. In total, **205** gravity and GNSS repeat stations were collected and analysed. As a percentage, this equates to **9.03%** of the total number of new gravity stations acquired. Repeat stations were acquired so that an even distribution between gravity loops was established and that all loops were interlocked.

Descriptive statistics pertaining to the repeatability are contained in Table 7 and Appendix F contains a tabulation of the actual repeat data for the entire survey.

The standard deviation of the gravity repeat deviations was **0.29 µm/s^2** and the standard deviation of the GNSS derived elevation repeat deviations was **0.035m**. These statistics confirm that the data has exceeded contract specifications.

	Elevation Repeat (mGRS80)	Gravity Repeat (µm/s^2)
Mean	0.002	0.03
Standard Error	0.002	0.02
Median	0.004	0.02
Mode	-0.013	-0.07
Standard Deviation	0.035	0.29
Sample Variance	0.001	0.08
Kurtosis	-0.223	-0.21
Skewness	-0.068	0.14
Range	0.185	1.48
Minimum	-0.100	-0.69
Maximum	0.085	0.79
Sum	0.464	5.81
Count	205	205

Table 7: Repeat Statistics

9.3.1 Repeatability Histograms

Histograms showing the distribution of repeat differences for both the GNSS and gravity observations are shown in Figures 12 and 13.

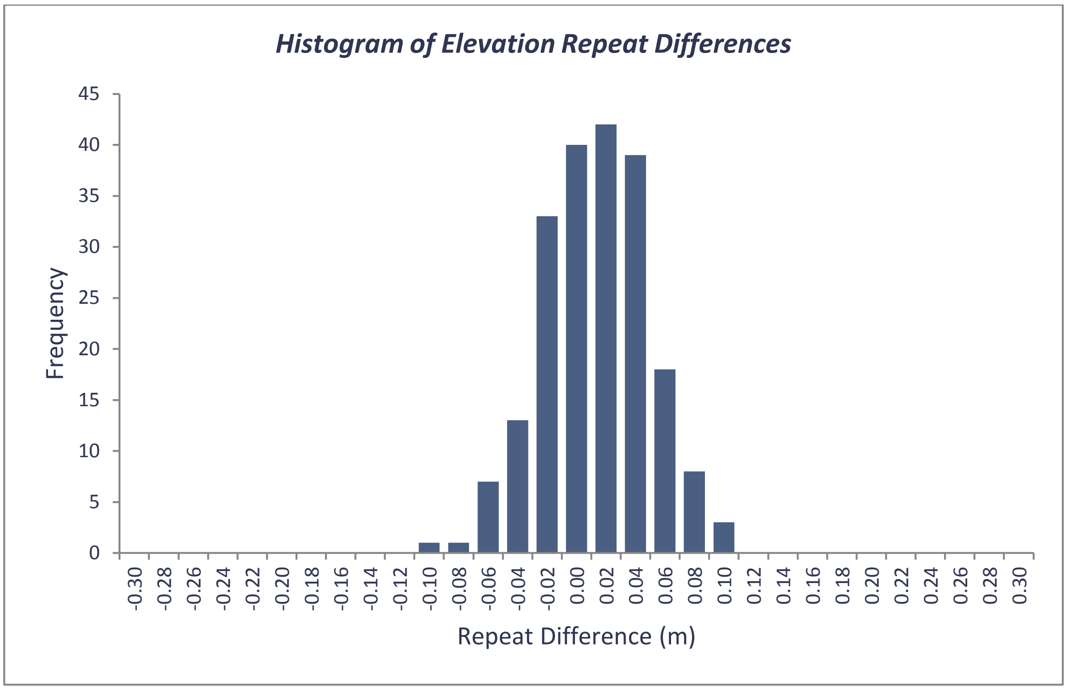


Figure 12: Histogram of GNSS Repeat Differences

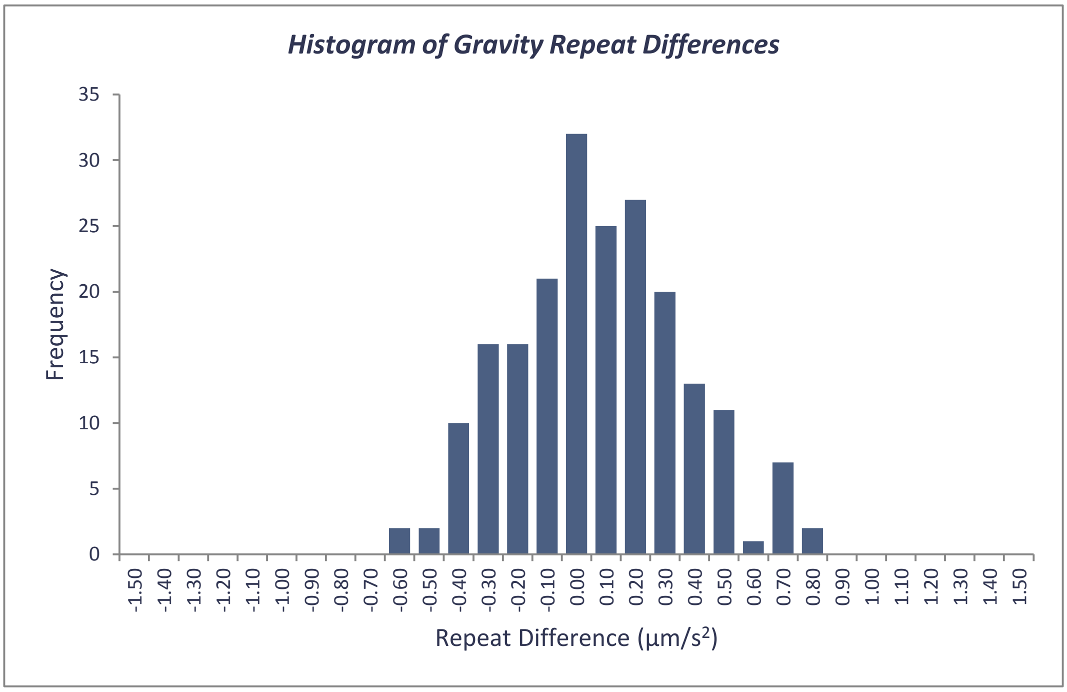


Figure 13: Histogram of Gravity Repeat Differences

9.4 Data Repeatability: Multiple Control Station Observations Only

The repeatability of gravity and GNSS observations made with respect to multiple control stations was also analysed separately to the main database.

Descriptive statistics pertaining to the repeatability are contained in Table 8 and Appendix G contains a tabulation of the actual repeat data controlled from multiple control stations.

The standard deviation of the gravity repeat deviations was **0.42µm/s²** and the standard deviation of the GNSS derived elevation repeat deviations was **0.038m**. These statistics confirm that the data has met and exceeded contract specifications for data controlled from multiple control stations.

	Elevation Repeat (mGRS80)	Gravity Repeat (µm/s²)
Mean	-0.001	0.09
Standard Error	0.004	0.21
Median	0.000	0.02
Mode	0.034	#N/A
Standard Deviation	0.034	0.42
Sample Variance	0.001	0.18
Kurtosis	-0.514	-1.51
Skewness	0.031	0.68
Range	0.154	0.93
Minimum	-0.073	-0.31
Maximum	0.081	0.62
Sum	-0.072	0.34
Count	93	4

Table 8: Repeat Statistics

9.4.1 Multiple Control Station Repeatability Histograms

Histograms showing the distribution of repeat differences for both the GNSS and gravity observations from multiple control stations are shown in Figures 14 and 15.

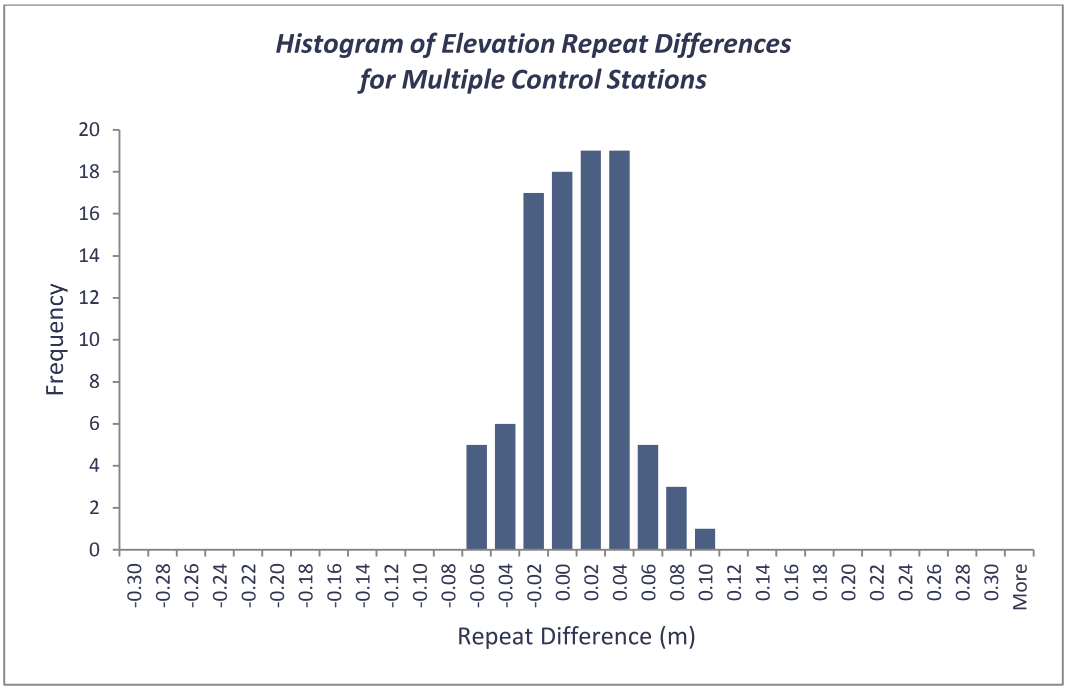


Figure 14: Histogram of GNSS Repeat Differences

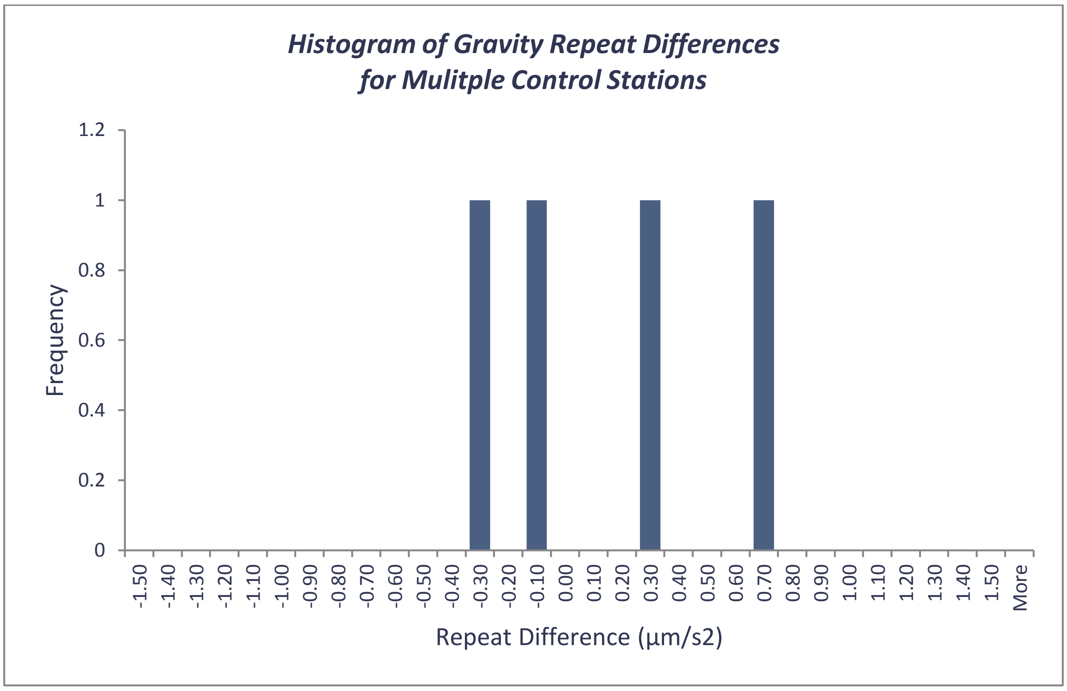


Figure 15: Histogram of Gravity Repeat Differences

9.5 Grids, Images and Plots

Final reduced data have been gridded using ChrisDBF software and a minimum curvature algorithm with multiple loops. All grids are provided in ERMapper compatible .ers format and are in units of $\mu m/s^2$ and m (GRS80).

Grids for GNSS Derived Elevation (GRS80), Complete Spherical Cap Bouguer Anomaly (CSCBA267) and 1st vertical derivative of Complete Bouguer Anomaly (CBA267VD) were produced for this particular project. The grid cell size for all grids is 500m.

The grids produced have been imaged using Geosoft Oasis Montaj mapping and processing software. Five plots of these images have been included with this report to assist in data interpretation (Appendix A). The plots have been included digitally on the data USB in Arcmap GIS compatible TIFF format.

Station Location Plot: The first plot displays the acquired gravity station locations overlayed on a 1:1 million topographic map of the area and surrounds. As evident on the plot, some stations have been moved off the original programmed co-ordinates due to terrain and safety considerations.

GNSS Derived Elevation: This plot displays a pseudocoloured grid of the digital elevation data obtained from the gravity survey (GRS80). A histogram equalisation colour stretch has been applied when pseudocolouring and a sunshade from the north-east has been applied.

Complete Bouguer Anomaly 2.67 Contours: This plot displays a pseudocoloured grid of Complete Bouguer Anomaly calculated with a rock density of 2.67 t/m^3. A histogram equalisation stretch has been applied when pseudocolouring. Overlying the image data are contours created at an appropriate interval.

Complete Bouguer Anomaly 2.67 Sunshade: This plot displays a pseudocoloured grid of Complete Bouguer Anomaly calculated with a rock density of 2.67 t/m^3. A histogram equalisation stretch has been applied when pseudocolouring and a sunshade from the north-east has been applied.

Vertical Derivative Image: This plot displays a pseudocoloured grid of the first vertical derivative of Complete Bouguer Anomaly calculated with a rock density of 2.67 t/m^3. A histogram equalisation stretch has been applied when pseudocolouring and sunshading from the north-east has been applied. This image represents the rate of change of the Complete Bouguer Anomaly and is useful for detecting lineaments and body edges, especially where there are large regional gradients present.

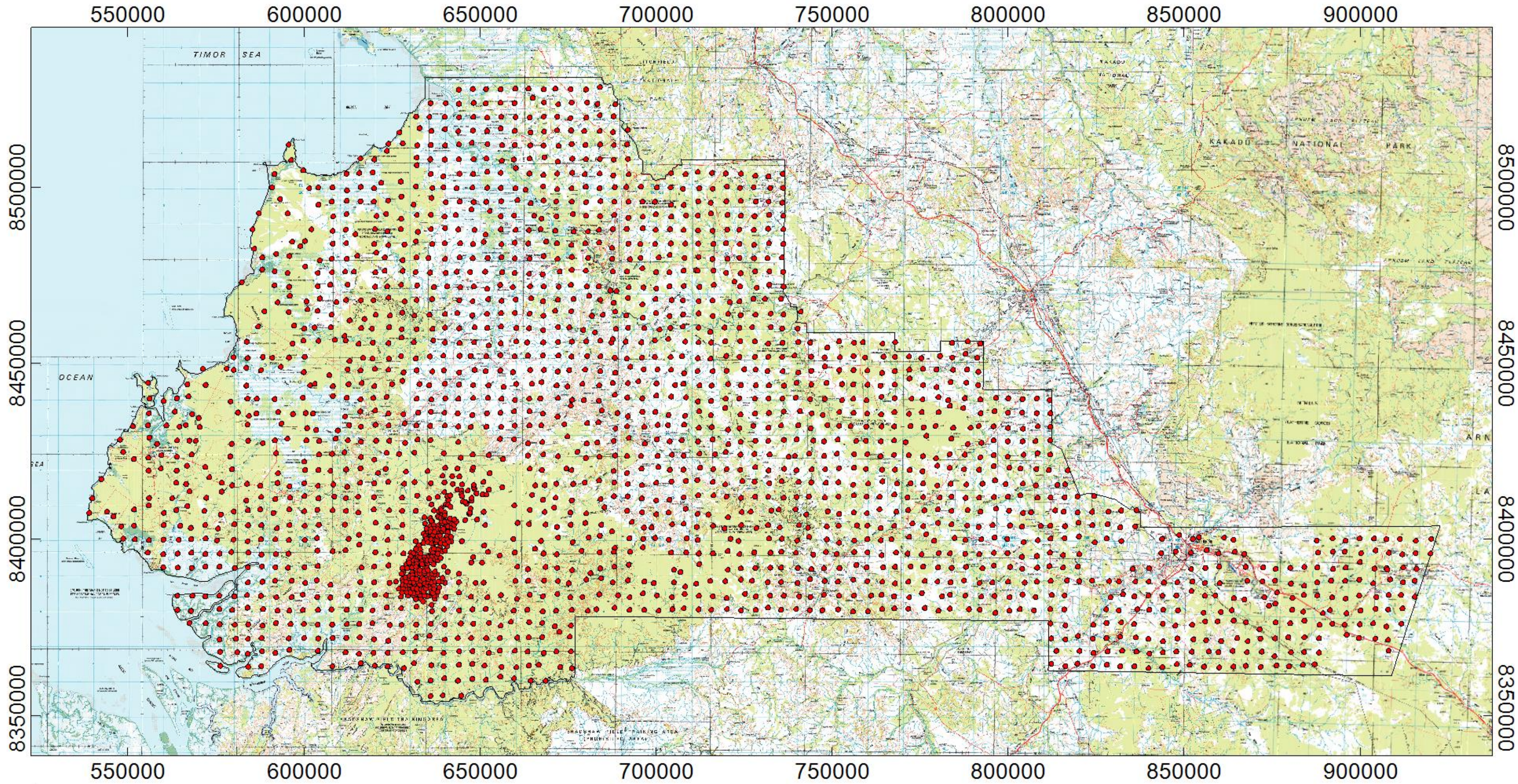
10.0 Conclusion

Atlas Geophysics Pty Ltd is confident that it has delivered high quality data to its client, to a high standard and in the safest way possible.

The company was pleased to be involved in the acquisition and processing of the gravity data collected on this project and look forward to working with Geoscience Australia again in the future.

Leon Mathews
Director

APPENDIX A
Plots and Images



Scale 1:1756000

25000 0 25000 50000

(meters)

GDA94 / MGA zone 52

GEOSCIENCE AUSTRALIA

P2016074 Daly Basin Gravity Survey

Gained Stations

4km x 4km & 1km x 1km Station Spacing

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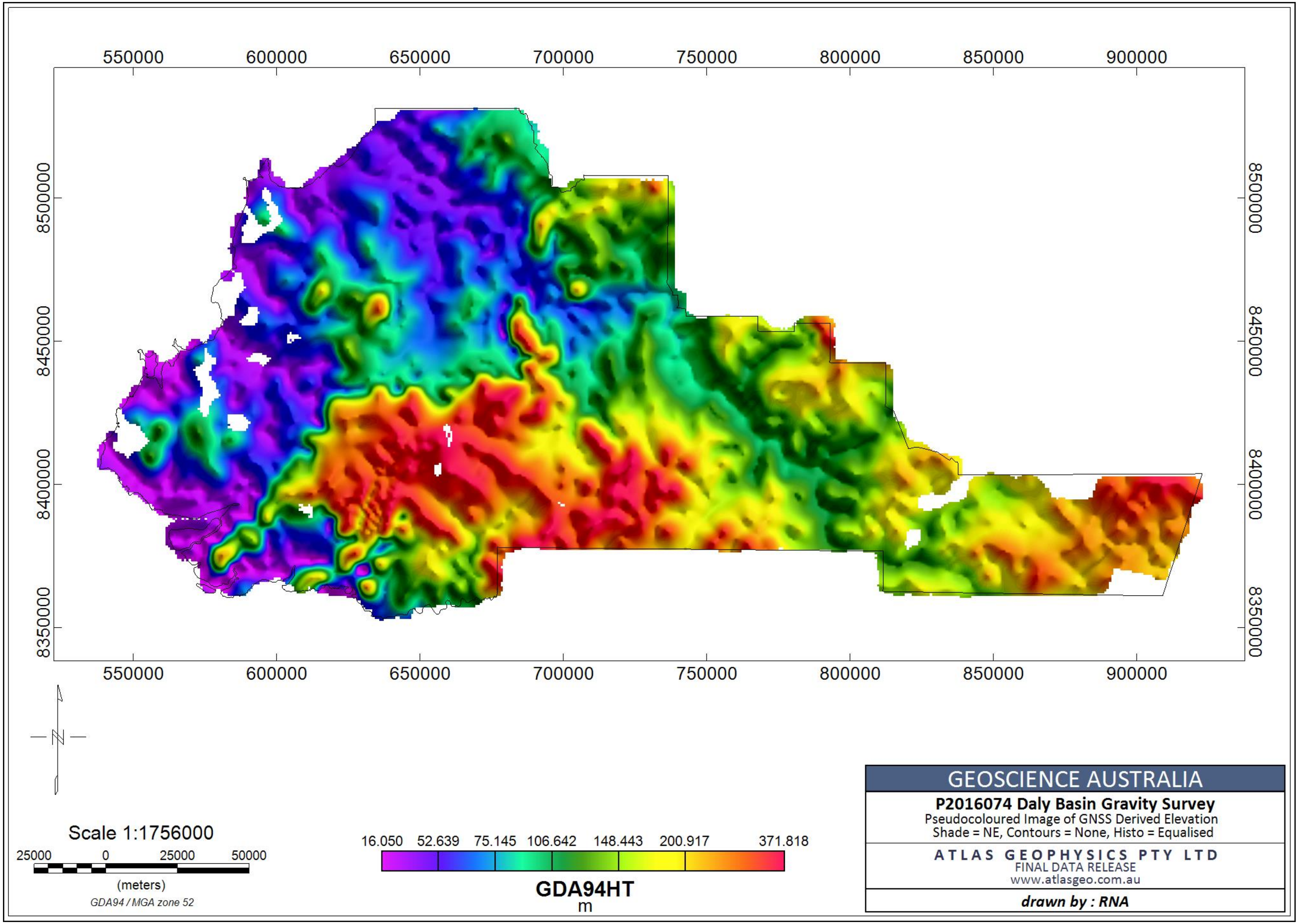
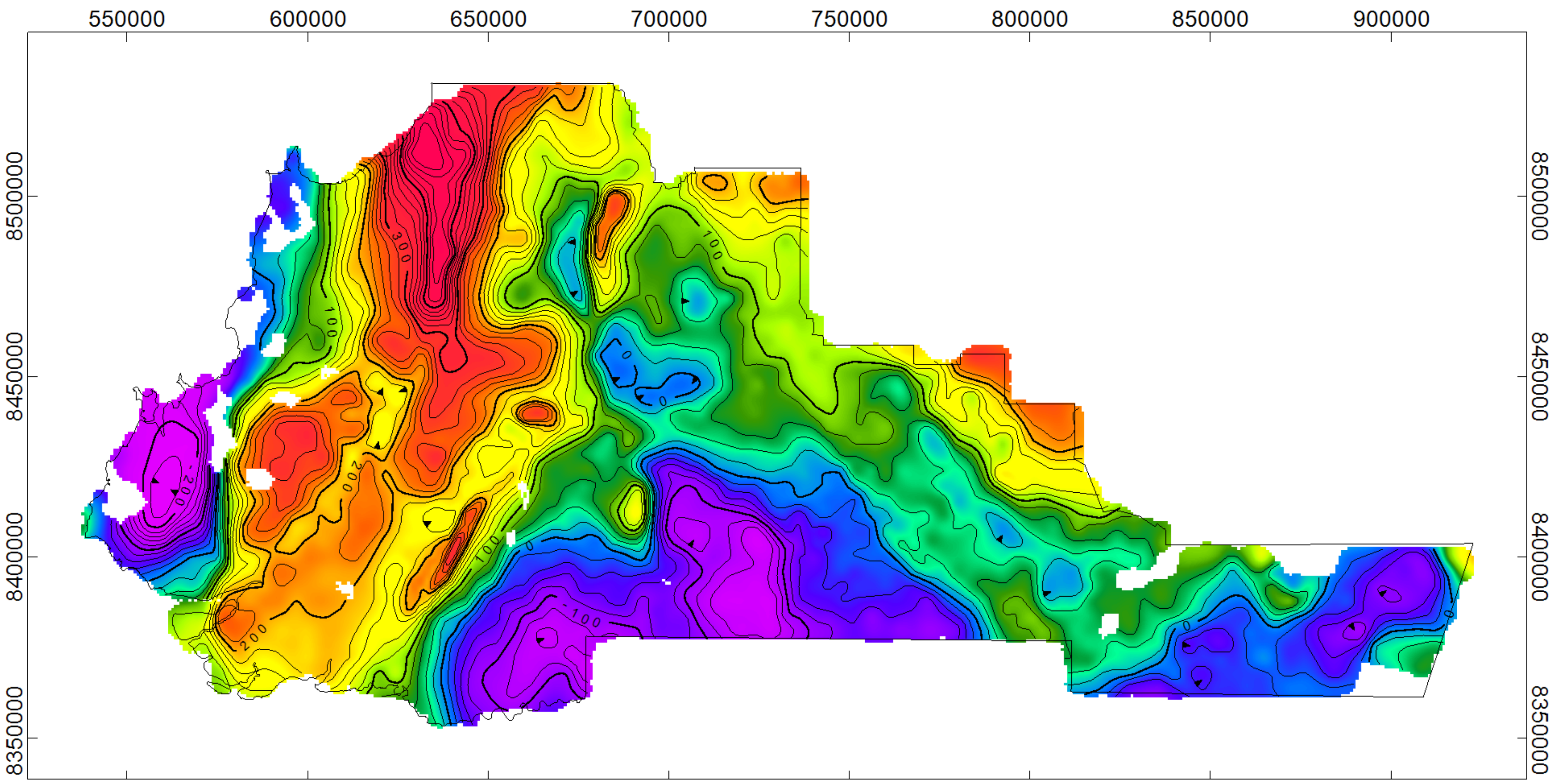
drawn by : RNA


550000
600000
650000
700000
750000
800000
850000
900000
8500000
8450000
8400000
8350000
Scale 1:1756000
25000 0 25000 50000
(meters)
GDA94 / MGA zone 52
16.050 52.639 75.145 106.642 148.443 200.917 371.818
GDA94HT
m
GEOSCIENCE AUSTRALIA
P2016074 Daly Basin Gravity Survey
Pseudocoloured Image of GNSS Derived Elevation
Shade = NE, Contours = None, Histo = Equalised
ATLAS GEOPHYSICS PTY LTD
FINAL DATA RELEASE
www.atlasgeo.com.au
drawn by : RNA



Scale 1:1756000

25000 0 25000 50000

(meters)

GDA94 / MGA zone 52

16.050 52.639 75.145 106.642 148.443 200.917 371.818

CSCBA267

um/s^2

GEOSCIENCE AUSTRALIA

P2016074 Daly Basin Gravity Survey

Pseudocoloured Image of Complete SC Bouguer Anomaly 2.67 t/m^3

Shade = None, Contours = NE, Histo = Equalised

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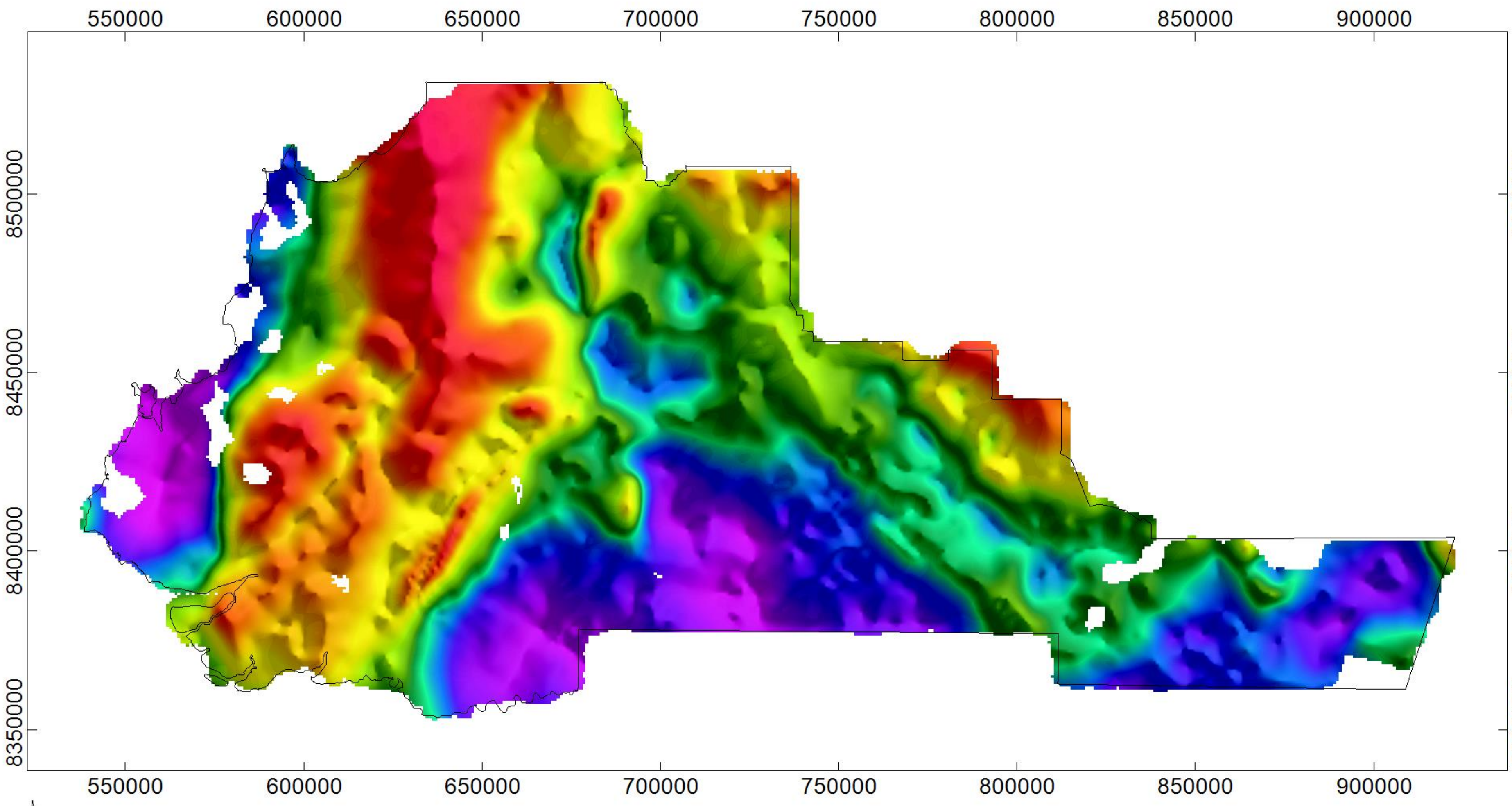
drawn by : RNA



Scale 1:1756000

25000 0 25000 50000

(meters)

GDA94 / MGA zone 52

16.050 52.639 75.145 106.642 148.443 200.917 371.818

CSCBA267
um/s^2

GEOSCIENCE AUSTRALIA

P2016074 Daly Basin Gravity Survey

Pseudocoloured Image of Complete SC Bouguer Anomaly 2.67 t/m^3

Shade = NE, Contours = None, Histo = Equalised

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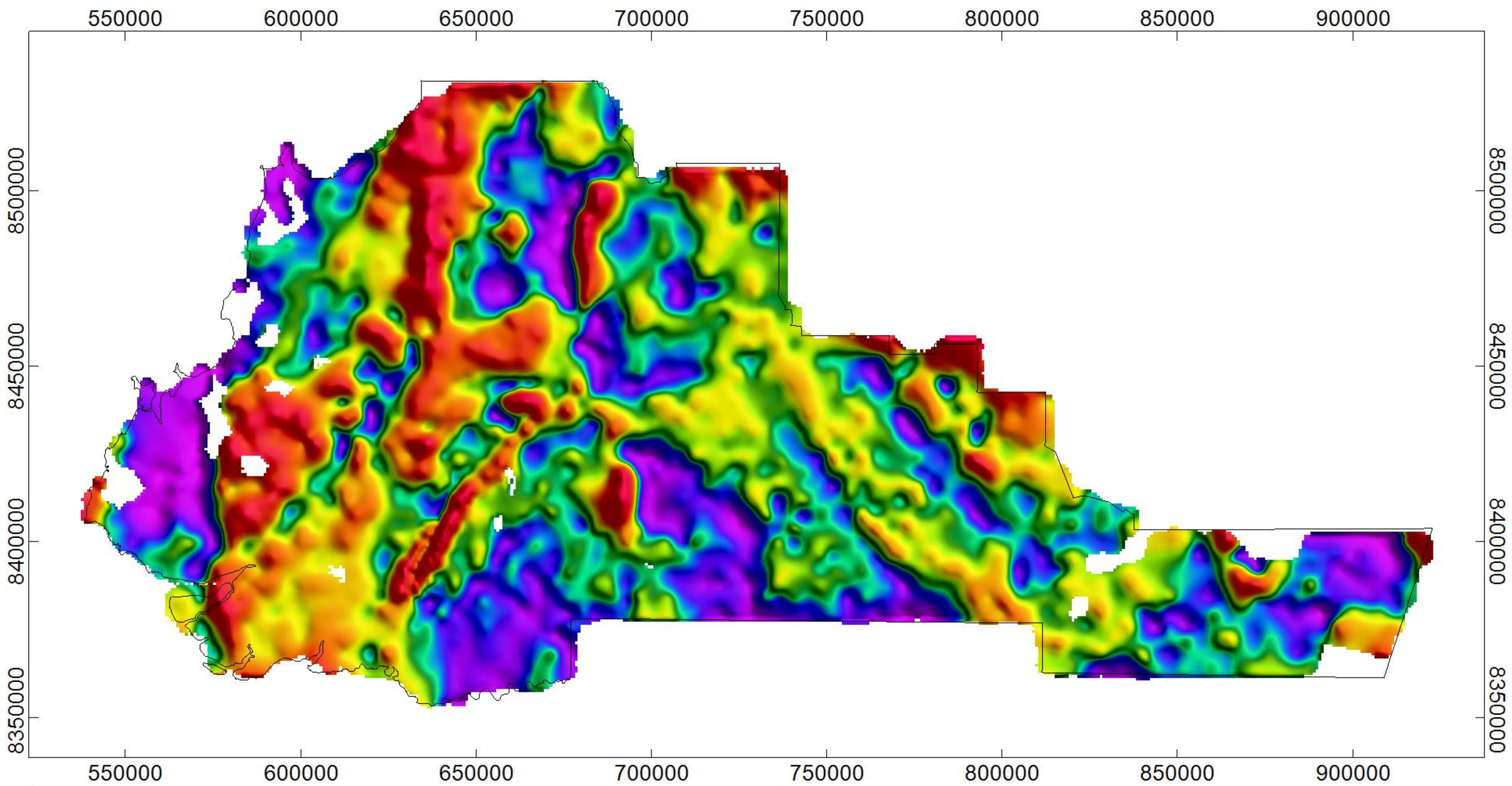
drawn by : RNA



Scale 1:1756000

25000 0 25000 50000

(meters)

GDA94 / MGA zone 52

-0.070 -0.010 -0.005 -0.003 -0.000 0.003 0.006 0.048

1VD

GEOSCIENCE AUSTRALIA

P2016074 Daly Basin Gravity Survey

Pseudocoloured Image of 1VD Complete SC Bouguer Anomaly 2.67 t/m^3
Shade = None, Contours = NE, Histo = Equalised

ATLAS GEOPHYSICS PTY LTD
FINAL DATA RELEASE
www.atlasgeo.com.au

drawn by : RNA

APPENDIX B
Control Station Descriptions

201607400001 (GA 20168000001) – DALY RIVER

GEODETIC COORDS GDA94/GRS80		GRID COORDINATES MGA Z52	
Latitude (DD MM SS)	-13 45 53.27018	*Easting*	685,115.353
Longitude (DD MM SS)	130 42 44.00121	*Northing*	8,477,627.424
Ellipsoidal Height	61.274	*Orthometric Height (AUSGEODI09)*	15.268

OBSERVED GRAVITY		Established 13/07/2016
AAGD07 µm/s²	9783241.97	

Occupation Method/Location Details

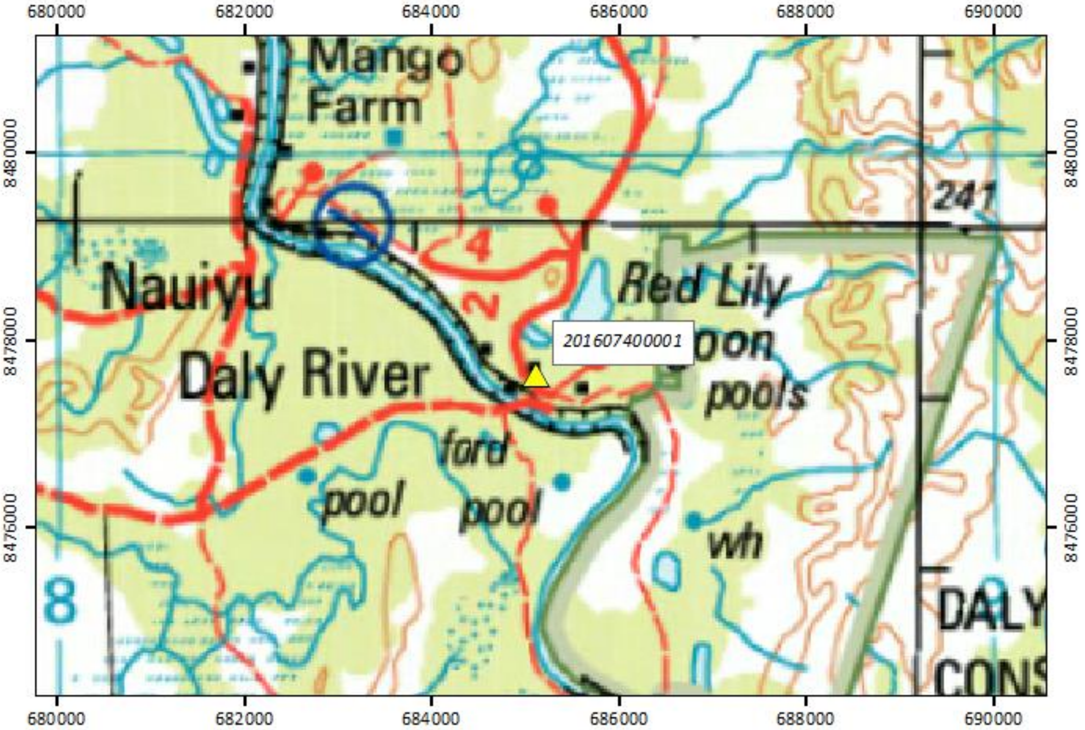
The GNSS control point consists of a dumpy steel star picket driven into the ground to a height of 10cm above ground level. The gravity control point consists of a small concrete slab (30cm square) concreted into the ground, opposite the GNSS control point. The control station is witnessed by an Atlas Geophysics survey plaque attached to a 1.5 metre steel picket placed within 0.5m of both control points.

Gravity Control was established by Atlas Geophysics via multiple ABA loops with the project gravity meter to AFGN station 1991900332 CS1 War Graves Memorial on 25/07/2016. Expected accuracy would be better than 0.1 µm/s².

GNSS Control was established using AUSPOS. Three separate 10 hour sessions were submitted to Geoscience Australia's online processing system, AUSPOS. Returned coordinates were accurate to better than 0.01m.

The station is located in an open area behind the Daly River Police Station and lodging, at the corner of two fence lines. The corner is 110m north of the access road. Permission to access the yard should be sought from the Police before accessing the station.

Photograph of Control Station 201607400001



Location of Control Station 201607400001

Satellite Image of Control Station 201607400001

201607400003 (GA 20168000003) – MANBULLOO

GEODETIC COORDS GDA94/GRS80		GRID COORDINATES MGA Z52	
Latitude (DD MM SS)	-14 30 58.94377	*Easting*	845,109.725
Longitude (DD MM SS)	132 12 5.56967	*Northing*	8,392,745.493
Ellipsoidal Height	147.031	*Orthometric Height (AUSGEODI09)*	N/A (Auton GNSS)
OBSERVED GRAVITY			Established 14/08/2105
AAGD07 µm/s²	9783904.08		

Occupation Method/Location Details

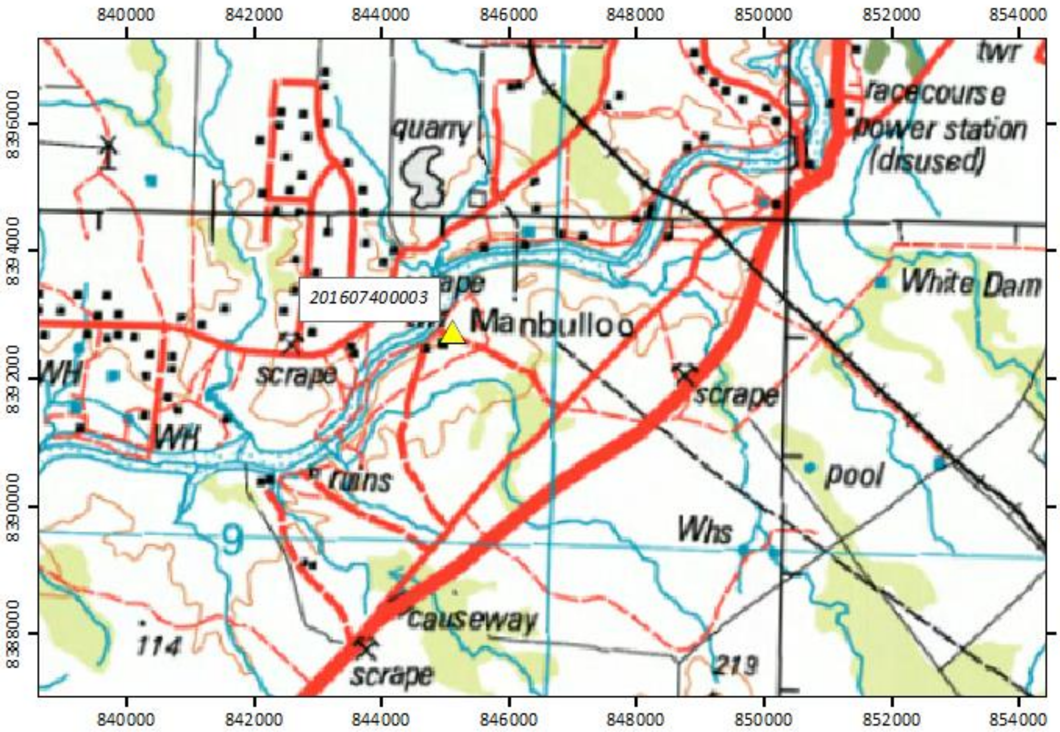
The GNSS control point consists of a dumpy steel star picket driven into the ground to a height of 10cm above ground level. The gravity control point consists of a small concrete slab (30cm square) concreted into the ground, opposite the GNSS control point. The control station is witnessed by an Atlas Geophysics survey plaque attached to a 1.5 metre steel picket placed within 0.5m of both control points.

Gravity Control was established by Atlas Geophysics via multiple ABA loops with the project gravity meter to AFGN station 1980902318 Tindal Airport Carport on 02/08/2016 and 05/08/2016. Expected accuracy would be better than 0.1 µm/s².

GNSS Control was established using AUSPOS. Three separate 10 hour sessions were submitted to Geoscience Australia's online processing system, AUSPOS. Returned coordinates were accurate to better than 0.01m.

Travel 3.2km from Victoria Highway towards Manbulloo homestead. Station is in the property of Gecko Canoeing and Trekking, along a fenceline to the east of the main building.

Photograph of Control Station 201607400003



Location of Control Station 201607400003

Satellite Image of Control Station 201607400003

APPENDIX C
GNSS Control Information

201607400001 Daly River
0001 -13 45 53.27040 130 42 44.00092 61.274 15.268 GDA94
0001 -13 45 53.26986 130 42 44.00132 61.279 15.273 GDA94
0001 -13 45 53.27029 130 42 44.00140 61.270 15.264 GDA94

GDA94AVE
-13 45 53.27018
130 42 44.00121

-13.76479727
130.71222256

GRS80HT
61.274

AHDHT
15.268

N
46.006

MGA52
685115.353
8477627.424

AMG52
684982.638
8477463.064

201607400002 Daly River Backup GNSS Base
0002 -13 45 53.24457 130 42 44.04675 61.255 15.249 GDA94
0002 -13 45 53.24488 130 42 44.04673 61.243 15.237 GDA94

GDA94AVE
-13 45 53.24473
130 42 44.04674

-13.76479020
130.71223521

GRS80HT
61.249

AHDHT
15.243

N
46.006

MGA52
685116.727
8477628.196

AMG52
684984.012
8477463.837

201607400003 Katherine
0003 -14 30 58.94377 132 12 05.56970 147.030 100.565 GDA94
0003 -14 30 58.94376 132 12 05.56963 147.031 100.566 GDA94

GDA94AVE
-14 30 58.94377
132 12 5.56967

-14.51637327
132.20154713

GRS80HT
147.031

AHDHT
100.566

N
46.465

MGA52
845109.725
8392745.493

AMG52
844977.415
8392580.651

201607400101
0101 -13 42 50.45658 130 08 48.22957 50.304 5.204 GDA94
0101 -13 42 50.45657 130 08 48.22956 50.297 5.197 GDA94
0101 -13 42 50.45654 130 08 48.22951 50.290 5.190 GDA94

GDA94AVE
-13 42 50.45656
130 08 48.22955

-13.71401571
130.14673043

GRS80HT
50.297

AHDHT
5.197

N
45.100

MGA52
623995.315
8483607.566

AMG52
623862.396
8483443.282

201607400102
0102 -14 24 27.52360 129 42 31.26373 87.817 46.454 GDA94
0102 -14 24 27.52364 129 42 31.26381 87.817 46.454 GDA94
0102 -14 24 27.52361 129 42 31.26378 87.809 46.446 GDA94

GDA94AVE
-14 24 27.52362
129 42 31.26377

-14.40764545
129.70868438

GRS80HT
87.814

AHDHT
46.451

N
41.363

MGA52
576396.267
8407071.804

AMG52
576263.137
8406907.299

201607400103
0103 -14 28 00.03166 130 28 46.36578 319.516 276.310 GDA94
0103 -14 28 00.03167 130 28 46.36586 319.515 276.309 GDA94
0103 -14 28 00.03175 130 28 46.36586 319.517 276.311 GDA94

GDA94AVE
-14 28 0.03169
130 28 46.36583

-14.46667547
130.47954606

GRS80HT
319.516

AHDHT
276.310

N
43.206

MGA52
659465.250
8400146.262

AMG52
659332.377
8399981.673

201607400104
0104 -14 15 01.70230 131 12 08.60447 148.939 103.794 GDA94
0104 -14 15 01.70229 131 12 08.60445 148.936 103.792 GDA94

GDA94AVE
-14 15 1.70230
131 12 8.60446

-14.25047286
131.20239013

GRS80HT
148.938

AHDHT
103.793

N
45.145

MGA52
737629.744
8423447.699

AMG52
737497.142
8423283.101

201607400105
0105 -14 18 51.20904 131 46 27.51313 127.239 80.784 GDA94
0105 -14 18 51.20907 131 46 27.51317 127.243 80.788 GDA94
0105 -14 18 51.20906 131 46 27.51311 127.232 80.777 GDA94

GDA94AVE
-14 18 51.20906
131 46 27.51314

-14.31422474
131.77430921

GRS80HT
127.238

AHDHT
80.783

N
46.455

MGA52
799291.607
8415729.030

AMG52
799159.190
8415564.328

201607400106
0106 -14 37 59.23816 132 36 43.75704 233.213 186.354 GDA94
0106 -14 37 59.23805 132 36 43.75829 233.214 186.355 GDA94

GDA94AVE
-14 37 59.23811
132 36 43.75767

-14.63312170
132.61215491

GRS80HT
233.214

AHDHT
186.355

N
46.859

MGA52
889214.300
8379149.277

AMG52
889082.100
8378984.321

80HT
233.214

AHDHT
186.355

N
46.859

MGA52
889214.300
8379149.277

AMG52
889082.100
8378984.321

APPENDIX D
Gravity Control Processing and Information

201607400001 GRAVITY CONTROL TIES

1 = 201607400001 Daly River
332 = 1991900332 CS1 War Graves Memorial
Ties carried out by vehicle

METER A2

station	gda94_longitude_dd	gda94_latitude_dd	date_ddmmyyyy	time_hhmmss	dialrdng_mgal	etc_mgal	dial_dc_mgal	metersn
1	130.712222	-13.764797	25/07/2016	09:27:00	2678.564	-0.048	3843.300	40241
1	130.712222	-13.764797	25/07/2016	09:28:00	2678.563	-0.048	3843.300	40241
332	131.114240	-13.230990	25/07/2016	11:22:00	2676.785	-0.047	3833.529	40241
332	131.114240	-13.230990	25/07/2016	11:24:00	2676.785	-0.046	3833.530	40241
1	130.712222	-13.764797	25/07/2016	13:01:00	2678.540	0.006	3843.299	40241
1	130.712222	-13.764797	25/07/2016	13:02:00	2678.541	0.007	3843.300	40241
						DIFF	-9.771	
1	130.712222	-13.764797	25/07/2016	13:01:00	2678.764	0.037	3843.295	40241
1	130.712222	-13.764797	25/07/2016	13:02:00	2678.765	0.037	3843.296	40241
332	131.114240	-13.230990	25/07/2016	14:50:00	2676.993	0.035	3833.507	40241
332	131.114240	-13.230990	25/07/2016	14:51:00	2676.993	0.035	3833.508	40241
1	130.712222	-13.764797	25/07/2016	18:35:00	2678.739	0.032	3843.295	40241
1	130.712222	-13.764797	25/07/2016	18:36:00	2678.738	0.031	3843.295	40241
						DIFF	-9.788	
332	130.469752	-15.644377	25/07/2016	11:23:00	3833.526	0.016	3833.526	40241
332	130.469752	-15.644377	25/07/2016	11:24:00	3833.528	0.017	3833.528	40241
1	130.445873	-15.621072	25/07/2016	13:01:00	3843.299	0.022	3843.299	40241
1	130.445873	-15.621072	25/07/2016	13:02:00	3843.300	0.023	3843.300	40241
332	130.469752	-15.644377	25/07/2016	14:50:00	3833.524	0.030	3833.524	40241
332	130.469752	-15.644377	25/07/2016	14:51:00	3833.526	0.030	3833.526	40241
						DIFF	9.773	check

AVE DIFF	-9.777	
KNOWN 332	978314.420	
CALC 1	978324.197	mGal AAGD07
	9783241.97	**µm/s² AAGD07**

201607400003 GRAVITY CONTROL TIES

1 = 201607400003 Manbulloo
318 = 1980902318 Tindal Airport Carport
Ties carried out by vehicle

METER A2

station	gda94_longitude_dd	gda94_latitude_dd	date_ddmmyyyy	time_hhmmss	dialrdng_mgal	etc_mgal	dial_dc_mgal	metersn
3	132.201555	-14.516361	02/08/2016	15:57:00	2682.176	0.014	3855.859	40241
3	132.201555	-14.516361	02/08/2016	15:58:00	2682.176	0.013	3855.859	40241
2318	132.363970	-14.513120	02/08/2016	17:05:00	2694.511	-0.011	3847.705	40241
2318	132.363970	-14.513120	02/08/2016	17:07:00	2694.511	-0.011	3847.707	40241
3	132.201555	-14.516361	02/08/2016	17:41:00	2682.175	0.073	3855.859	40241
3	132.201555	-14.516361	02/08/2016	17:42:00	2682.176	0.073	3855.859	40241
						DIFF	-8.153	
3	132.201555	-14.516361	05/08/2016	13:39:00	3768.531	0.033	3856.660	40241
3	132.201555	-14.516361	05/08/2016	13:40:00	3768.532	0.033	3856.659	40241
2318	132.363970	-14.513120	05/08/2016	17:11:00	3780.863	-0.024	3848.503	40241
2318	132.363970	-14.513120	05/08/2016	17:12:00	3780.863	-0.024	3848.505	40241
3	132.201555	-14.516361	05/08/2016	19:19:00	3768.508	0.030	3856.659	40241
3	132.201555	-14.516361	05/08/2016	19:20:00	3768.510	0.029	3856.660	40241
						DIFF	-8.155	
						AVE DIFF	-8.154	
						KNOWN 188	978324.680	
						CALC 1	978332.835	mGal AAGD07
							9783328.35	**µm/s² AAGD07**

APPENDIX E
Gravity Meter Calibration Data

P2016074_GA_DALY_BASIN_GRAVITY_SURVEY

PRE SURVEY CALIBRATION DATA

1 = 2010990117 CS1 Guildford Cemetery 9793899.63 µm/s^2 AAGD07

2 = 2010990217 CS2 Helena Valley Primary School **9794483.85 µm/s^2 AAGD07**

STATION	GDA94LONG	GDA94LAT	DATE	TIME	OBSGAAD07_µm/s2	SERIAL
A2 METER						
1	116.049600	-31.924856	30/06/2016	15:48:00	9793899.62	40241
1	116.049600	-31.924856	30/06/2016	15:49:00	9793899.65	40241
2	115.978110	-31.918230	30/06/2016	16:30:00	9794483.82	40241
2	115.978110	-31.918230	30/06/2016	16:31:00	9794483.83	40241
1	116.049600	-31.924856	30/06/2016	17:03:00	9793899.63	40241
1	116.049600	-31.924856	30/06/2016	17:04:00	9793899.63	40241
2	115.978110	-31.918230	30/06/2016	17:32:00	9794483.81	40241
2	115.978110	-31.918230	30/06/2016	17:33:00	9794483.83	40241
1	116.049600	-31.924856	30/06/2016	18:03:00	9793899.65	40241
1	116.049600	-31.924856	30/06/2016	18:04:00	9793899.62	40241
				AVG2	**9794483.82**	

P2016074_GA_DALY_BASIN_GRAVITY_SURVEY

POST SURVEY CALIBRATION DATA

1 = 2010990117 CS1 Guildford Cemetery 9793899.63 µm/s² AAGD07

2 = 2010990217 CS2 Helena Valley Primary School **9794483.85 µm/s² AAGD07**

STATION	GDA94LONG	GDA94LAT	DATE	TIME	OBSGAAD07_µm/s2	SERIAL
A2 METER						
1	116.049600	-31.924856	03/10/2016	10:24:00	9793899.62	40241
1	116.049600	-31.924856	03/10/2016	10:26:00	9793899.61	40241
2	115.978110	-31.918230	03/10/2016	11:01:00	9794483.81	40241
2	115.978110	-31.918230	03/10/2016	11:03:00	9794483.81	40241
1	116.049600	-31.924856	03/10/2016	12:00:00	9793899.63	40241
1	116.049600	-31.924856	03/10/2016	12:03:00	9793899.63	40241
2	115.978110	-31.918230	03/10/2016	12:45:00	9794483.81	40241
2	115.978110	-31.918230	03/10/2016	12:47:00	9794483.82	40241
1	116.049600	-31.924856	03/10/2016	13:24:00	9793899.65	40241
1	116.049600	-31.924856	03/10/2016	13:26:00	9793899.63	40241
				AVG2	**9794483.81**	

APPENDIX F
Repeat Listing: All Observations

STATION	MGAEAST	MGANORTH	REPEAT_ERROR ELEVATION_M	REPEAT_ERROR GRAVITY_µm/s²	DATE_DDMMYY	TIME_HHMMSS	METERSN
20168001001	692565.3	8479591.8	0.051	0.06	13072016	182152	40241
20168001000	687535.5	8479689.5	-0.022	0.29	13072016	182739	40241
20168001017	623982.3	8483616.6	0.000	-0.11	14072016	130152	40241
20168001012	656063.5	8480160.1	-0.013	-0.07	14072016	134653	40241
20168001011	659865.6	8479832.4	-0.038	-0.20	14072016	135131	40241
20168001009	668078.6	8480489.1	-0.013	0.08	14072016	135745	40241
20168001007	676049.4	8480240.4	-0.020	0.13	14072016	140406	40241
20168001006	680704.0	8479984.6	-0.019	0.11	14072016	141050	40241
20168001054	683364.4	8523730.4	-0.057	-0.10	14072016	173245	40241
20168001052	684005.0	8516023.6	-0.089	-0.09	14072016	174825	40241
20168001050	684042.7	8508082.3	-0.031	0.12	14072016	180228	40241
20168001048	683985.6	8499763.7	-0.023	0.07	14072016	181607	40241
20168001052	684003.9	8516022.5	0.068	0.05	15072016	083558	40241
20168001054	683363.1	8523729.2	0.077	-0.02	15072016	085111	40241
20168001052	684004.1	8516022.5	0.013	0.01	15072016	123514	40241
20168001099	687745.3	8515715.0	-0.001	0.14	15072016	124038	40241
20168001097	687988.3	8507892.9	0.012	0.27	15072016	124710	40241
20168001050	684041.3	8508080.9	0.056	-0.07	15072016	125205	40241
20168001095	688298.5	8500061.8	-0.036	0.06	15072016	130239	40241
20168001093	688088.6	8492162.2	0.008	0.42	15072016	131016	40241
20168001091	687452.4	8482800.6	0.004	0.44	15072016	131723	40241
20168001006	680703.9	8479984.6	0.008	-0.36	15072016	134947	40241
20168001007	676049.6	8480240.6	0.020	0.03	15072016	135350	40241
20168001008	672003.3	8479681.0	0.022	-0.23	15072016	135723	40241
20168001009	668078.7	8480489.0	0.046	0.02	15072016	140110	40241
20168001011	659865.7	8479832.3	0.081	0.35	15072016	140611	40241
20168001012	656064.0	8480160.6	0.026	-0.29	15072016	140951	40241
20168001017	623982.1	8483616.6	0.006	0.05	15072016	144913	40241
20168001008	672002.8	8479681.1	0.031	-0.25	15072016	181554	40241
20168001006	680704.0	8479984.5	0.008	0.20	15072016	182142	40241
20168001007	676049.3	8480240.6	-0.007	0.11	16072016	074827	40241
20168001008	672002.9	8479681.3	-0.031	0.25	16072016	075220	40241
20168001218	639631.5	8500038.6	-0.028	0.32	16072016	105543	40241
20168001219	643324.5	8499796.4	-0.029	0.17	16072016	110020	40241
20168001008	672003.2	8479681.0	-0.038	-0.03	16072016	134557	40241
20168001006	680703.9	8479984.3	-0.001	0.25	16072016	135156	40241
20168001001	692565.0	8479592.0	-0.032	0.00	16072016	142259	40241
20168001097	687988.3	8507892.8	-0.037	0.48	16072016	151953	40241
20168001095	688298.5	8500061.6	-0.033	0.37	16072016	152608	40241
20168001263	691559.2	8500124.1	0.085	0.20	16072016	153002	40241
20168001276	712268.1	8499811.0	0.022	-0.01	16072016	174241	40241
20168001275	707639.7	8499595.4	0.049	-0.37	16072016	174820	40241
20168001270	699673.1	8495898.9	-0.045	-0.01	16072016	180210	40241
20168001001	692565.0	8479592.0	-0.008	0.04	16072016	182613	40241
20168001006	680704.4	8479984.4	0.001	-0.07	17072016	073347	40241
20168001007	676049.0	8480240.3	-0.041	-0.36	17072016	073921	40241
20168001008	672002.9	8479681.0	-0.023	-0.41	17072016	074342	40241

STATION	MGAEAST	MGANORTH	REPEAT_ERROR ELEVATION_M	REPEAT_ERROR GRAVITY_µm/s²	DATE_DDMMYY	TIME_HHMMSS	METERSN
20168001009	668078.7	8480488.6	-0.026	-0.45	17072016	074833	40241
20168001011	659865.7	8479832.2	-0.056	-0.15	17072016	080317	40241
20168001317	620206.6	8471791.0	0.015	0.40	17072016	130635	40241
20168001305	659883.8	8464354.9	-0.018	0.11	17072016	135109	40241
20168001304	660107.0	8468157.1	-0.050	-0.14	17072016	135508	40241
20168001000	687535.6	8479689.8	-0.029	0.00	17072016	145155	40241
20168001001	692564.9	8479591.8	-0.067	-0.22	17072016	145641	40241
20168001001	692564.9	8479592.1	0.010	0.18	17072016	182636	40241
20168001000	687535.7	8479689.4	0.002	0.13	17072016	183059	40241
20168001363	684200.3	8468052.7	0.035	0.26	18072016	072625	40241
20168001429	631193.0	8456003.5	0.004	-0.22	18072016	144158	40241
20168001363	684200.1	8468052.8	-0.051	0.15	18072016	155502	40241
20168001363	684200.7	8468053.6	-0.014	0.11	19072016	072720	40241
20168001545	619861.8	8371635.7	0.063	-0.12	19072016	112423	40241
20168001544	619793.9	8367774.1	0.003	-0.46	19072016	113019	40241
20168001531	647825.2	8364618.6	0.050	0.23	19072016	120703	40241
20168001530	651265.4	8364148.2	0.054	0.16	19072016	121104	40241
20168001516	684585.1	8436650.7	-0.050	0.31	19072016	142708	40241
20168001514	683850.4	8443772.0	-0.012	0.41	19072016	143233	40241
20168001511	684100.5	8456473.3	-0.036	0.15	19072016	144016	40241
20168001363	684200.7	8468053.4	-0.020	-0.09	19072016	151420	40241
20168001511	684100.9	8456473.7	-0.022	-0.01	19072016	152155	40241
20168001514	683850.8	8443772.4	-0.013	0.03	19072016	152910	40241
20168001511	684100.4	8456473.7	-0.023	0.34	19072016	182633	40241
20168001363	684200.2	8468053.4	0.015	0.13	19072016	183329	40241
20168001363	684200.4	8468053.1	0.003	-0.13	20072016	072137	40241
20168001450	576386.5	8407063.1	0.015	0.06	20072016	095235	40241
20168001653	564432.6	8399907.1	0.030	0.62	20072016	121428	40241
20168001652	567953.9	8400059.5	0.035	0.72	20072016	121833	40241
20168001698	593580.6	8432925.2	0.035	-0.50	20072016	171151	40241
20168001691	620296.3	8432544.5	0.013	-0.03	20072016	173645	40241
20168001357	660290.4	8460123.8	-0.065	0.07	20072016	181852	40241
20168001304	660106.9	8468157.1	0.068	0.35	20072016	182408	40241
20168001363	684200.5	8468052.9	0.020	-0.46	21072016	072313	40241
20168001511	684100.3	8456473.5	0.028	-0.09	21072016	073018	40241
20168001714	660278.5	8444152.6	-0.044	-0.28	21072016	080333	40241
20168001713	648012.2	8443884.8	0.025	-0.48	21072016	081521	40241
20168001712	635538.7	8443759.9	0.005	-0.32	21072016	082558	40241
20168001711	619975.6	8443517.1	0.024	-0.42	21072016	084327	40241
20168001691	620296.0	8432544.6	-0.035	-0.25	21072016	085602	40241
20168001691	620295.9	8432544.9	0.037	0.27	21072016	133027	40241
20168001779	607985.6	8424279.6	-0.026	0.06	21072016	143808	40241
20168001771	592339.8	8403162.2	0.067	0.19	21072016	150846	40241
20168001517	659468.0	8400135.6	0.005	0.27	21072016	174744	40241
20168001714	660278.6	8444152.2	0.009	0.70	21072016	182254	40241
20168001008	672002.5	8479680.9	-0.018	0.22	22072016	071939	40241
20168001304	660106.7	8468156.7	-0.007	0.62	22072016	072821	40241

STATION	MGAEAST	MGANORTH	REPEAT_ERROR ELEVATION_M	REPEAT_ERROR GRAVITY_µm/s²	DATE_DDMMYY	TIME_HHMMSS	METERSN
20168001357	660290.5	8460124.0	0.061	0.65	22072016	073339	40241
20168001714	660278.6	8444153.0	-0.013	0.79	22072016	074141	40241
20168001713	648012.0	8443884.6	0.034	-0.07	22072016	080023	40241
20168001793	595913.5	8415093.6	0.026	0.57	22072016	094244	40241
20168001811	603999.5	8379927.7	-0.020	-0.04	22072016	102816	40241
20168001811	603999.7	8379927.6	0.046	0.10	22072016	123017	40241
20168001852	608354.9	8415589.4	-0.020	-0.30	22072016	130813	40241
20168001691	620295.7	8432544.7	-0.005	0.13	22072016	135957	40241
20168001779	607985.7	8424279.4	0.009	0.24	22072016	142806	40241
20168001852	608355.2	8415589.6	-0.012	0.25	22072016	143355	40241
20168001511	684100.5	8456474.1	-0.011	0.03	22072016	182145	40241
20168001363	684200.3	8468053.2	0.017	-0.14	22072016	182756	40241
20168001304	660106.9	8468156.8	-0.021	-0.28	23072016	074217	40241
20168001017	623981.7	8483616.3	-0.005	0.10	23072016	082653	40241
20168001017	623982.2	8483616.3	0.012	-0.17	23072016	112828	40241
20168001009	668078.5	8480488.8	-0.014	0.23	23072016	125330	40241
20168001305	659883.7	8464355.1	0.016	-0.03	23072016	130306	40241
20168001357	660290.5	8460123.8	0.028	-0.28	23072016	130711	40241
20168001714	660278.5	8444153.0	-0.027	-0.30	23072016	131526	40241
20168001811	603999.6	8379927.2	-0.020	0.47	23072016	150621	40241
20168002015	636054.2	8416005.0	0.033	-0.22	23072016	180225	40241
20168001713	648012.3	8443884.8	-0.016	0.61	23072016	181640	40241
20168001357	660290.7	8460123.7	-0.013	-0.41	23072016	182457	40241
20168001008	672002.1	8479680.9	0.034	-0.40	23072016	183402	40241
20168001008	672002.6	8479681.0	0.029	-0.08	24072016	071045	40241
20168001363	684200.1	8468053.2	0.005	-0.22	24072016	072303	40241
20168001511	684100.5	8456473.5	0.012	0.05	24072016	072944	40241
20168001514	683850.0	8443772.6	0.007	0.01	24072016	073720	40241
20168002004	659690.0	8436380.3	0.085	0.42	24072016	075302	40241
20168002014	635113.0	8419409.0	0.036	-0.11	24072016	081919	40241
20168002015	636053.9	8416004.5	-0.029	0.37	24072016	082300	40241
20168002015	636054.0	8416004.8	-0.020	0.43	24072016	124004	40241
20168002014	635112.6	8419408.8	0.021	0.47	24072016	124328	40241
20168002131	643830.2	8427687.0	0.000	0.26	24072016	133707	40241
20168002015	636054.3	8416005.4	0.044	0.50	24072016	134545	40241
20168001517	659468.2	8400135.9	-0.042	-0.66	24072016	152152	40241
20168001941	671851.9	8403529.7	0.059	0.32	24072016	154543	40241
20168001514	683849.8	8443772.4	-0.014	0.04	24072016	164243	40241
20168001511	684100.4	8456473.8	-0.029	-0.15	24072016	164937	40241
20168001363	684200.3	8468053.3	-0.033	0.19	24072016	165552	40241
20168001363	684200.4	8468052.9	0.035	-0.39	26072016	092255	40241
20168001511	684100.4	8456473.6	0.041	-0.33	26072016	093058	40241
20168002067	672138.0	8440147.9	-0.069	-0.38	26072016	094048	40241
20168002131	643830.1	8427687.1	-0.057	0.16	26072016	095827	40241
20168002015	636054.2	8416005.1	-0.021	-0.69	26072016	100640	40241
20168002015	636054.0	8416005.1	0.033	-0.47	26072016	134727	40241
20168002131	643830.2	8427687.2	0.042	0.26	26072016	135544	40241

STATION	MGAEAST	MGANORTH	REPEAT_ERROR ELEVATION_M	REPEAT_ERROR GRAVITY_µm/s²	DATE_DDMMYY	TIME_HHMMSS	METERSN
20168001713	648012.5	8443884.7	-0.019	-0.09	26072016	142706	40241
20168002131	643830.1	8427686.8	-0.006	-0.15	26072016	143659	40241
20168002014	635113.0	8419409.0	0.005	-0.04	26072016	145223	40241
20168002015	636054.0	8416004.5	-0.023	0.47	26072016	145610	40241
20168001857	600195.8	8403854.8	0.034	-0.14	26072016	153948	40241
20168001450	576384.3	8407062.9	0.036	-0.12	26072016	160350	40241
20168001857	600195.3	8403854.6	-0.049	0.26	26072016	162153	40241
20168002131	643829.8	8427687.0	-0.004	-0.25	26072016	180337	40241
20168001714	660278.4	8444152.6	0.030	-0.32	26072016	181349	40241
20168001357	660291.0	8460123.4	0.034	0.14	26072016	182152	40241
20168001006	680704.7	8479984.2	0.004	0.28	26072016	183454	40241
20168001007	676049.1	8480240.4	0.026	0.04	27072016	071716	40241
20168001357	660290.8	8460123.7	0.035	-0.23	27072016	072833	40241
20168001714	660278.5	8444152.8	0.039	-0.03	27072016	073656	40241
20168002131	643830.2	8427687.0	0.000	-0.34	27072016	074756	40241
20168002131	643830.2	8427687.0	0.012	-0.01	27072016	132153	40241
20168002067	672137.2	8440147.3	0.043	-0.20	27072016	181456	40241
20168001511	684100.4	8456473.6	0.070	0.01	27072016	182558	40241
20168001363	684200.3	8468053.3	-0.008	0.39	27072016	183219	40241
20168001363	684200.0	8468053.6	0.035	-0.03	28072016	071552	40241
20168001713	648012.8	8443884.7	-0.013	0.36	28072016	142158	40241
20168002004	659689.9	8436380.5	-0.052	-0.47	28072016	142945	40241
20168001940	671897.5	8391898.8	-0.038	0.15	28072016	163005	40241
20168001517	659468.1	8400135.9	0.015	0.13	28072016	180216	40241
20168002067	672137.3	8440147.5	0.021	0.38	28072016	182517	40241
20168001363	684200.4	8468052.8	0.004	0.07	28072016	183730	40241
20168001000	687535.4	8479689.2	0.045	-0.39	29072016	071630	40241
20168002423	712149.7	8395973.4	0.009	-0.17	29072016	125749	40241
20168002422	711943.4	8412539.9	-0.100	-0.27	29072016	130537	40241
20168002421	711937.1	8427823.1	-0.014	-0.16	29072016	131255	40241
20168002419	711748.0	8447858.2	-0.024	0.19	29072016	132145	40241
20168002417	699864.1	8468272.3	0.006	0.11	29072016	133058	40241
20168001000	687535.5	8479689.2	0.014	-0.11	29072016	133836	40241
20168002417	699864.6	8468272.6	0.027	-0.14	29072016	140924	40241
20168002418	712089.1	8464202.3	-0.011	-0.11	29072016	141936	40241
20168002419	711747.9	8447858.5	0.013	-0.01	29072016	181458	40241
20168002418	712089.0	8464202.2	-0.007	0.00	29072016	182237	40241
20168002417	699864.8	8468272.6	-0.075	0.04	29072016	182925	40241
20168002417	699864.8	8468272.6	0.046	0.07	30072016	083822	40241
20168002418	712089.0	8464202.2	-0.014	0.22	30072016	084713	40241
20168002419	711748.0	8447857.9	-0.007	-0.05	30072016	133742	40241
20168002418	712088.9	8464202.3	0.019	-0.04	30072016	134619	40241
20168002417	699864.6	8468272.7	-0.042	0.17	30072016	135332	40241
20168002341	737615.9	8423446.7	-0.024	-0.04	30072016	174828	40241
20168002417	699864.1	8468272.5	-0.030	0.28	30072016	183942	40241
20168002341	737615.7	8423446.4	-0.021	-0.07	31072016	083221	40241
20168002682	767612.6	8428110.8	-0.073	-0.13	31072016	101747	40241

STATION	MGAEAST	MGANORTH	REPEAT_ERROR ELEVATION_M	REPEAT_ERROR GRAVITY_µm/s^2	DATE_DDMMYY	TIME_HHMMSS	METERSN
20168002678	756814.9	8428009.4	-0.061	-0.17	31072016	122103	40241
20168002417	699864.6	8468272.7	0.055	-0.05	31072016	142356	40241
20168002341	737616.1	8423446.6	0.034	0.21	01082016	131842	40241
20168002894	807790.9	8427919.6	0.021	0.61	02082016	101151	40241
20168002912	787717.5	8440105.7	0.015	-0.35	02082016	113526	40241
20168002885	799304.2	8415726.2	0.027	0.20	02082016	133506	40241
20168002885	799304.7	8415726.5	0.033	0.21	03082016	095258	40241
20168002682	767612.4	8428110.5	0.062	-0.18	03082016	103243	40241
20168002678	756815.3	8428009.8	0.048	0.62	03082016	104137	40241
20168002885	799304.5	8415726.3	-0.064	-0.31	03082016	164032	40241
20168003049	816068.2	8411956.6	0.057	0.31	03082016	172242	40241
20168003092	843767.8	8363745.0	0.052	-0.07	04082016	104521	40241
20168003118	832386.0	8368358.1	-0.001	-0.35	04082016	113743	40241
20168003106	880333.0	8367973.2	-0.010	0.48	04082016	131554	40241
20168003149	891380.1	8379917.5	0.005	-0.33	04082016	145835	40241
20168003169	889362.5	8379041.7	0.029	-0.09	04082016	174454	40241
20168003169	889362.2	8379041.4	-0.027	-0.58	05082016	090442	40241

APPENDIX G

Repeat Listing: Multiple Control Station Observations

STATION	MGA94EAST	MGA94NORTH	REPEAT_ERROR ELEVATION_M	REPEAT_ERROR GRAVITY_µm/s^2	DATE_DDMMYY	TIME_HHMMSS	METERSN	GRVBASE	GPSBASE
20168001000	687535.3	8479689.6			13072016	173455	40241	20168000001	20168000001
20168001000	687535.5	8479689.5	-0.022		13072016	182739	40241	20168000001	20168000001
20168001000	687535.6	8479689.8	-0.029		17072016	145155	40241	20168000001	20168000002
20168001000	687535.7	8479689.4	0.002		17072016	183059	40241	20168000001	20168000002
20168001000	687535.4	8479689.2	0.045		29072016	071630	40241	20168000001	20168000001
20168001000	687535.5	8479689.2	0.014		29072016	133836	40241	20168000001	20168000001
20168001001	692565.1	8479592.0			13072016	174358	40241	20168000001	20168000001
20168001001	692565.3	8479591.8	0.051		13072016	182152	40241	20168000001	20168000001
20168001001	692565.0	8479592.0	-0.032		16072016	142259	40241	20168000001	20168000002
20168001001	692565.0	8479592.0	-0.008		16072016	182613	40241	20168000001	20168000002
20168001001	692564.9	8479591.8	-0.067		17072016	145641	40241	20168000001	20168000002
20168001001	692564.9	8479592.1	0.01		17072016	182636	40241	20168000001	20168000002
20168001006	680703.8	8479984.7			14072016	081648	40241	20168000001	20168000001
20168001006	680704.0	8479984.6	-0.019		14072016	141050	40241	20168000001	20168000001
20168001006	680703.9	8479984.6	0.008		15072016	134947	40241	20168000001	20168000001
20168001006	680704.0	8479984.5	0.008		15072016	182142	40241	20168000001	20168000001
20168001006	680703.9	8479984.3	-0.001		16072016	135156	40241	20168000001	20168000002
20168001006	680704.4	8479984.4	0.001		17072016	073347	40241	20168000001	20168000002
20168001006	680704.7	8479984.2	0.004		26072016	183454	40241	20168000001	20168000001
20168001007	676049.1	8480240.6			14072016	082354	40241	20168000001	20168000001
20168001007	676049.4	8480240.4	-0.02		14072016	140406	40241	20168000001	20168000001
20168001007	676049.6	8480240.6	0.02		15072016	135350	40241	20168000001	20168000001
20168001007	676049.3	8480240.6	-0.007		16072016	074827	40241	20168000001	20168000001
20168001007	676049.0	8480240.3	-0.041		17072016	073921	40241	20168000001	20168000002
20168001007	676049.1	8480240.4	0.026		27072016	071716	40241	20168000001	20168000001
20168001008	672002.9	8479681.1			14072016	082945	40241	20168000001	20168000001
20168001008	672003.3	8479681.0	0.022		15072016	135723	40241	20168000001	20168000001
20168001008	672002.8	8479681.1	0.031		15072016	181554	40241	20168000001	20168000001
20168001008	672002.9	8479681.3	-0.031		16072016	075220	40241	20168000001	20168000001
20168001008	672003.2	8479681.0	-0.038		16072016	134557	40241	20168000001	20168000002
20168001008	672002.9	8479681.0	-0.023		17072016	074342	40241	20168000001	20168000002
20168001008	672002.5	8479680.9	-0.018		22072016	071939	40241	20168000001	20168000001
20168001008	672002.1	8479680.9	0.034		23072016	183402	40241	20168000001	20168000001
20168001008	672002.6	8479681.0	0.029		24072016	071045	40241	20168000001	20168000001
20168001009	668078.9	8480488.8			14072016	083517	40241	20168000001	20168000001
20168001009	668078.6	8480489.1	-0.013		14072016	135745	40241	20168000001	20168000001

STATION	MGA94EAST	MGA94NORTH	REPEAT_ERROR ELEVATION_M	REPEAT_ERROR GRAVITY_µm/s²	DATE_DDMMYY	TIME_HHMMSS	METERSN	GRVBASE	GPSBASE
20168001009	668078.7	8480489.0	0.046		15072016	140110	40241	20168000001	20168000001
20168001009	668078.7	8480488.6	-0.026		17072016	074833	40241	20168000001	20168000002
20168001009	668078.5	8480488.8	-0.014		23072016	125330	40241	20168000001	20168000001
20168001011	659865.3	8479832.4			14072016	084352	40241	20168000001	20168000001
20168001011	659865.6	8479832.4	-0.038		14072016	135131	40241	20168000001	20168000001
20168001011	659865.7	8479832.3	0.081		15072016	140611	40241	20168000001	20168000001
20168001011	659865.7	8479832.2	-0.056		17072016	080317	40241	20168000001	20168000002
20168001017	623982.1	8483616.6			14072016	093422	40241	20168000001	20168000001
20168001017	623982.3	8483616.6	0.000		14072016	130152	40241	20168000001	20168000001
20168001017	623982.1	8483616.6	0.006		15072016	144913	40241	20168000001	20168000101
20168001017	623981.7	8483616.3	-0.005		23072016	082653	40241	20168000001	20168000101
20168001017	623982.2	8483616.3	0.012		23072016	112828	40241	20168000001	20168000101
20168001095	688298.5	8500061.8			15072016	080841	40241	20168000001	20168000001
20168001095	688298.5	8500061.8	-0.036		15072016	130239	40241	20168000001	20168000001
20168001095	688298.5	8500061.6	-0.033		16072016	152608	40241	20168000001	20168000002
20168001097	687988.4	8507893.2			15072016	082114	40241	20168000001	20168000001
20168001097	687988.3	8507892.9	0.012		15072016	124710	40241	20168000001	20168000001
20168001097	687988.3	8507892.8	-0.037		16072016	151953	40241	20168000001	20168000002
20168001304	660107.6	8468157.4			17072016	081203	40241	20168000001	20168000002
20168001304	660107.0	8468157.1	-0.050		17072016	135508	40241	20168000001	20168000002
20168001304	660106.9	8468157.1	0.068		20072016	182408	40241	20168000001	20168000001
20168001304	660106.7	8468156.7	-0.007		22072016	072821	40241	20168000001	20168000001
20168001304	660106.9	8468156.8	-0.021		23072016	074217	40241	20168000001	20168000001
20168001305	659883.9	8464355.4			17072016	081946	40241	20168000001	20168000002
20168001305	659883.8	8464354.9	-0.018		17072016	135109	40241	20168000001	20168000002
20168001305	659883.7	8464355.1	0.016		23072016	130306	40241	20168000001	20168000001
20168001357	660290.6	8460124.0			17072016	134703	40241	20168000001	20168000002
20168001357	660290.4	8460123.8	-0.065		20072016	181852	40241	20168000001	20168000001
20168001357	660290.5	8460124.0	0.061		22072016	073339	40241	20168000001	20168000001
20168001357	660290.5	8460123.8	0.028		23072016	130711	40241	20168000001	20168000001
20168001357	660290.7	8460123.7	-0.013		23072016	182457	40241	20168000001	20168000001
20168001357	660291.0	8460123.4	0.034		26072016	182152	40241	20168000001	20168000001
20168001357	660290.8	8460123.7	0.035		27072016	072833	40241	20168000001	20168000001

STATION	MGA94EAST	MGA94NORTH	REPEAT_ERROR ELEVATION_M	REPEAT_ERROR GRAVITY_µm/s²	DATE_DDMMYY	TIME_HHMMSS	METERSN	GRVBASE	GPSBASE
20168001363	684200.1	8468053.3			17072016	142202	40241	20168000001	20168000002
20168001363	684200.3	8468052.7	0.035		18072016	072625	40241	20168000001	20168000001
20168001363	684200.1	8468052.8	-0.051		18072016	155502	40241	20168000001	20168000001
20168001363	684200.7	8468053.6	-0.014		19072016	072720	40241	20168000001	20168000001
20168001363	684200.7	8468053.4	-0.020		19072016	151420	40241	20168000001	20168000001
20168001363	684200.2	8468053.4	0.015		19072016	183329	40241	20168000001	20168000001
20168001363	684200.4	8468053.1	0.003		20072016	072137	40241	20168000001	20168000001
20168001363	684200.5	8468052.9	0.020		21072016	072313	40241	20168000001	20168000001
20168001363	684200.3	8468053.2	0.017		22072016	182756	40241	20168000001	20168000001
20168001363	684200.1	8468053.2	0.005		24072016	072303	40241	20168000001	20168000001
20168001363	684200.3	8468053.3	-0.033		24072016	165552	40241	20168000001	20168000001
20168001363	684200.4	8468052.9	0.035		26072016	092255	40241	20168000001	20168000001
20168001363	684200.3	8468053.3	-0.008		27072016	183219	40241	20168000001	20168000001
20168001363	684200.0	8468053.6	0.035		28072016	071552	40241	20168000001	20168000001
20168001363	684200.4	8468052.8	0.004		28072016	183730	40241	20168000001	20168000001
20168001714	660278.3	8444153.1			20072016	181111	40241	20168000001	20168000001
20168001714	660278.5	8444152.6	-0.044		21072016	080333	40241	20168000001	20168000001
20168001714	660278.6	8444152.2	0.009		21072016	182254	40241	20168000001	20168000103
20168001714	660278.6	8444153.0	-0.013		22072016	074141	40241	20168000001	20168000001
20168001714	660278.5	8444153.0	-0.027		23072016	131526	40241	20168000001	20168000001
20168001714	660278.4	8444152.6	0.030		26072016	181349	40241	20168000001	20168000001
20168001714	660278.5	8444152.8	0.039		27072016	073656	40241	20168000001	20168000001
20168001857	600195.7	8403854.7			22072016	095534	40241	20168000001	20168000102
20168001857	600195.8	8403854.8	0.034		26072016	153948	40241	20168000001	20168000102
20168001857	600195.3	8403854.6	-0.049		26072016	162153	40241	20168000001	20168000103
20168002341	737615.3	8423446.5			28072016	083643	40241	20168000001	20168000104
20168002341	737615.9	8423446.7	-0.024		30072016	174828	40241	20168000001	20168000104
20168002341	737615.7	8423446.4	-0.021		31072016	083221	40241	20168000001	20168000104
20168002341	737616.1	8423446.6	0.034		01082016	131842	40241	20168000001	20168000001
20168002419	711748.1	8447858.1			29072016	074540	40241	20168000001	20168000001
20168002419	711748.0	8447858.2	-0.024		29072016	132145	40241	20168000001	20168000104
20168002419	711747.9	8447858.5	0.013		29072016	181458	40241	20168000001	20168000104
20168002419	711748.0	8447857.9	-0.007		30072016	133742	40241	20168000001	20168000104
20168002678	756815.0	8428009.5			31072016	085440	40241	20168000001	20168000104
20168002678	756814.9	8428009.4	-0.061		31072016	122103	40241	20168000001	20168000104
20168002678	756815.3	8428009.8	0.048	0.62	03082016	104137	40241	20168000003	20168000105

STATION	MGA94EAST	MGA94NORTH	REPEAT_ERROR ELEVATION_M	REPEAT_ERROR GRAVITY_µm/s²	DATE_DDMMYY	TIME_HHMMSS	METERSN	GRVBASE	GPSBASE
20168002682	767612.7	8428110.6			31072016	090918	40241	20168000001	20168000104
20168002682	767612.6	8428110.8	-0.073		31072016	101747	40241	20168000001	20168000104
20168002682	767612.4	8428110.5	0.062	-0.18	03082016	103243	40241	20168000003	20168000105
20168002885	799304.6	8415726.6			02082016	090534	40241	20168000001	20168000105
20168002885	799304.2	8415726.2	0.027		02082016	133506	40241	20168000001	20168000105
20168002885	799304.7	8415726.5	0.033	0.21	03082016	095258	40241	20168000003	20168000105
20168002885	799304.5	8415726.3	-0.064	-0.31	03082016	164032	40241	20168000003	20168000003
20168003049	816066.4	8411956.0			03082016	160906	40241	20168000003	20168000105
20168003049	816068.2	8411956.6	0.057		03082016	172242	40241	20168000003	20168000003
20168003106	880333.2	8367973.3			04082016	100713	40241	20168000003	20168000003
20168003106	880333.0	8367973.2	-0.010		04082016	131554	40241	20168000003	20168000106

APPENDIX H
Longman's Earth Tide Correction Formula

```
input dLat (latitude)
input dLon (longitude)
input dDate (date)
*Date broken down into year, month and date
input dTime (time)

array pClndr[12]={0,31,59,90,120,151,181,212,243,273,304,334}
lYr=year
lMo=month
lDa=day

ny=(lYr-1900)
days=(dTime/24.0+lDa-1+pClndr[lMo-1])
lLeap=(ny/4)
if(lLeap/2=ny and lMo<3)then lLeap=lLeap-1
lDay=(ny*365+lLeap+lDa+pClndr[lMo-1])
dcent = (ny*365.0+lLeap+days+0.5)/36525)
dhrs = (ny*365.0+lLeap+days+0.5)*24.0)
ds = (dcent*8399.7092 99+4.72002 3434+(dcent*dcent)*4.40696e-5)
dp=(dcent*71.01800936+5.835124713-(dcent*dcent)*1.80545e-4-dcent*2.1817e-
7*(dcent*dcent)
dh=(dcent*628.3319509+4.88162792+(dcent*dcent)*5.27962e-6)
doln=(4.523588564-dcent*33.757153303+(dcent*dcent)*3.6749e-5)
dps=(dcent*0.0300052 6416+4.908229461+(dcent*dcent)*7.902463e-6)
des=(0.01675104-dcent*4.18e-5-(dcent*dcent)*1.26e-7)
dsoln=(sin(doln))
dci=(0.91369-cos(doln)*0.03569)
dsi=(sqrt(1.0-(dci*dci))
dsn=(dsoln*0.08968/dsi)
dcn=(sqrt(1.0-(dsn*dsn))
dtit=(dsoln*0.39798/(dsi*cos(doln)*dcn+1.0dsoln*0.91739*dsn))
det=(atan(dtit)*2.0)
if (det<0.0)then det=det+6.2831852)

dolm1=(ds-doln+det+sin(ds-dp)*0.1097 9944)
dolm=(dolm1+sin((ds-dp)*2.0)*0.00376 7474+sin(ds-
dh*2.0+dp)*0.0154002+sin((ds-dh)*2.0)*0.00769395)
dha=((dTime*15.0-180)*0.01745329 2519 9+dLon/57.2957795 13)
dchi=(dha+dh-atan(dsn/dcn))
dal=(dLat/57.295779513)
dct=(sin(dal)*dsi*sin(dolm)+cos(dal)*((dci+1.0)*cos(dolm-dchi)+(1.0-
dci)*cos(dolm+dchi))/2.0)
dda=(cos(ds-dp)*0.14325+2.60144+cos((ds-dp)*2.0)*0.0078644+cos(ds-
dh*2.0+dp)*0.0200918+cos((ds-dh)*2.0)*0.0146006)
dr=(6.378388/sqrt((1.0-((cos(dal)*cos(dal))*0.0067 6902+1.0)
r_1=(dda)
r_2=(dct)
r_3=(dr)
r_4=(dda)
r_5=(dda*dda)
r_6=(dct)
dgm=(dr80.49049*dda*(r_1*r_1)*((r_2*r_2)*3.0-1.0)+(r_3*r_3)*7.4e-
4*(r_5*r_5)*dct*((r_6*r_6)*5.0-3.0))
dols=(dh+des*2.0*sin(dh-dps))
dchis=(dha+dh)
dds=((des*cos(dh-dps)+1.0)*0.668881/(1.0-(des*des))
dcf=(sin(dal)*0.39798*sin(dols)+cos(dal)*(cos(dols-
```

APPENDIX I
Data Formats and Metadata

```
DEFN   ST=RECD,RT=COMM;RT:A4;COMMENTS:A76
DEFN 1 ST=RECD,RT=;PROJECT:F7.0:NULL=-9999.,NAME=PROJECT
DEFN 2 ST=RECD,RT=;STATION:F12.0:NULL=-999999999.,NAME=STATION
DEFN 3 ST=RECD,RT=;LATITUDE:F11.6:NULL=-99.999999,NAME=LATITUDE
DEFN 4 ST=RECD,RT=;LONGITUD:F12.6:NULL=-999.999999,NAME=LONGITUDE
DEFN 5 ST=RECD,RT=;EAST:F9.1:NULL=-99999.9,NAME=EASTING
DEFN 6 ST=RECD,RT=;NORTH:F10.1:NULL=-999999.9,NAME=NORTHING
DEFN 7 ST=RECD,RT=;ELLIPSHTGRS80:F9.3:NULL=-999.999,NAME=ELLIPSHTGDA94
DEFN 8 ST=RECD,RT=;NAG09:F9.3:NULL=-999.999,NAME=NAG09
DEFN 9 ST=RECD,RT=;GRNDELEVATION:F9.3:NULL=-999.999,NAME=GRNDELEVATION
DEFN 10 ST=RECD,RT=;OBSGAAGD07:F12.2:NULL=-9999999.99,NAME=OBSGAAGD07
DEFN 11 ST=RECD,RT=;HTGM:F9.3:NULL=-999.999,NAME=HTGM
DEFN 12 ST=RECD,RT=;TCINNER:F7.2:NULL=-99.99,NAME=TCINNER
DEFN 13 ST=RECD,RT=;TCQFINNER:F4.0:NULL=-9.,NAME=TCQFINNER
DEFN 14 ST=RECD,RT=;TCOUTER:F7.2:NULL=-99.99,NAME=TCOUTER
DEFN 15 ST=RECD,RT=;TCQFOUTER:F4.0:NULL=-9.,NAME=TCQFOUTER
DEFN 16 ST=RECD,RT=;TCTOTAL:F7.2:NULL=-99.99,NAME=TCTOTAL
DEFN 17 ST=RECD,RT=;EFAA:F10.2:NULL=-99999.99,NAME=EFAA
DEFN 18 ST=RECD,RT=;SCBA267:F10.2:NULL=-99999.99,NAME=SCBA267
DEFN 19 ST=RECD,RT=;CSCBA267:F10.2:NULL=-99999.99,NAME=CSCBA267
DEFN 20 ST=RECD,RT=;HORIZDIST:F9.2:NULL=-9999.99,NAME=HORIZDIST
DEFN 21 ST=RECD,RT=;GRVBASE:F13.0:NULL=-9999999999.,NAME=GRVBASE
DEFN 22 ST=RECD,RT=;GPSBASE:F13.0:NULL=-9999999999.,NAME=GPSBASE
DEFN 23 ST=RECD,RT=;TIME:A9,NAME=TIME
DEFN 24 ST=RECD,RT=;DATE:A9,NAME=DATE
DEFN 25 ST=RECD,RT=;MGAZONE:F4.0:NULL=-9.,NAME=MGAZONE
DEFN 26 ST=RECD,RT=;GMTYPESN:A20,NAME=GMTYPESN
DEFN 27 ST=RECD,RT=;STATIONDESC:F20.0:NULL=-99999999999999999.,NAME=STATIONDESC
DEFN 28 ST=RECD,RT=;COMMENTS:F20.0:NULL=-99999999999999999.,NAME=COMMENTS;END DEFN
DEFN 1 ST=RECD,RT=PROJ; RT:A4
DEFN 1 ST=RECD,RT=PROJ; RT:A4
DEFN 2 ST=RECD,RT=PROJ; PROJNAME:A30: COMMENT=GDA94 / MGA zone 52
DEFN 3 ST=RECD,RT=PROJ; ELLPSNAM:A30: COMMENT=GRS 1980
DEFN 4 ST=RECD,RT=PROJ; MAJ_AXIS: D12.1: UNIT=m, COMMENT=6378137.000000
DEFN 5 ST=RECD,RT=PROJ; ECCENT: D12.9: COMMENT=298.257222
DEFN 6 ST=RECD,RT=PROJ; PRIMEMER: F10.1: UNIT=deg, COMMENT=0.000000
DEFN 7 ST=RECD,RT=PROJ; PROJMETH: A30: COMMENT=Transverse Mercator
DEFN 8 ST=RECD,RT=PROJ; PARAM1: D14.0: COMMENT=      0.000000
DEFN 9 ST=RECD,RT=PROJ; PARAM2: D14.0: COMMENT=    129.000000
DEFN 10 ST=RECD,RT=PROJ; PARAM3: D14.0: COMMENT=      0.999600
DEFN 11 ST=RECD,RT=PROJ; PARAM4: D14.0: COMMENT= 500000.000000
DEFN 12 ST=RECD,RT=PROJ; PARAM5: D14.0: COMMENT=10000000.00000
DEFN 13 ST=RECD,RT=PROJ; PARAM6: D14.0:
DEFN 14 ST=RECD,RT=PROJ; PARAM7: D14.0:
DEFN 15 ST=RECD,RT=PROJ; END DEFN
```

```
COMM ATLAS GEOPHYSICS PTY LTD ASEG-GDF2 FORMAT FILE
COMM WWW.ATLASGEO.COM.AU
COMM INFO@ATLASGEO.COM.AU
COMM
COMM ATLAS PROJECT NUMBER               P2016074
COMM GA PROJECT NUMBER                  201680
COMM CLIENT                             GA
COMM PROJECT AREA                       DALY BASIN GRAVITY SURVEY
COMM START DATE                         13072016
COMM END DATE                           31072016
COMM PROCESSED BY                       LR MATHEWS
COMM
COMM VESSEL                             HELICOPTER ROBINSON R44
COMM OPERATORS                          GEOSCIENCE AUSTRALIA / GA
COMM OBSERVERS                          AT,CH
COMM
COMM MIN SPACING                        4000m,2000m,1000m
COMM MAX SPACING                        4000m,2000m,1000m
COMM LAYOUT                             CELL CENTRE
COMM
COMM GRAVITY STATIONS                   1798
COMM
COMM GEODETIC DATUM                     GDA94
COMM PROJECTION                         MGA52
COMM HORIZ ACCURACY                     0.05 m
COMM
COMM VERTICAL DATUM                     GDA94
COMM VERTICAL ACCURACY                  0.04 m
COMM
COMM GRAVITY DATUM                      AAGD07
COMM GRAVITY ACCURACY                   0.28 µm/s^2
COMM
COMM GRAVITY INSTRUMENT                 SCINTREX CG5
COMM GRAVITY SN                         40241
COMM GPS INSTRUMENT                     LEICA GPS1200
COMM GPS METHOD                         PPK
COMM
COMM GPS BASE                           20168000001-20168000003,20168000101-20168000106
COMM GRV BASE                           20168000001,20168000003
COMM CTRL TIE STATION                   1991900332,1980902318
COMM
COMM PROCESSING
COMM DRIFT CORRECTION
COMM ETC CORRECTION                     LONGMAN
COMM NORMAL GRAVITY                     9780326.7715*((1+0.001931851353*(SIN(B3*(PI()/180)))^2)/(SQRT(1-0.0066943800229*(SIN(B3*(PI()/180)))^2)))
COMM ATMOSPHERIC CORRECTION             8.74-0.00099*F3+0.0000000356*F3^2
COMM FREE AIR CORRECTION                -(3.087691-0.004398*SIN(LAT)^2)*ELLIPSHT+0.00000072125*ELLIPSHT^2
COMM SCAP BOUGUER CORRECTION            2*PI*Gp((1+µ)*ELLIPSHT-LAMBDA*R) for p=2.67 t/m^3
COMM TERRAIN CORRECTION METHOD          RASTERTC
COMM
COMM SOFTWARE                           AGRIS(IN HOUSE), WAYPOINT860, CHRISDBF, ERMAPPER, RASTERTC
COMM
COMM
COMM DETAILED COLUMN DESCRIPTIONS
COMM COLUMN NAME                        COLUMN DESCRIPTION                                          UNITS
COMM
COMM PROJECT                            GA PROJECT NUMBER                                           NONE
COMM STATION                            GA STATION NUMBER                                           NONE
COMM LATITUDE                           COORDINATE LATITUDE GDA94                                   DECIMAL DEGREES
COMM LONGITUDE                          COORDINATE LONGITUDE GDA94                                  DECIMAL DEGREES
COMM EASTING                            COORDINATE EASTING MGA/GDA94                                M
COMM NORTHING                           COORDINATE NORTHING MGA/GDA94                               M
COMM ELLIPSHTGRS80                      COORDINATE ELEVATION ELLIPSOIDAL GRS80                      M
COMM NAG09                              GEOID ELLIPSOID SEPARATION AUSGEOID09                       M
COMM GRNDELEVATION                      GROUND LEVEL ELEVATION                                      M
COMM OBSGAAGD07GU                       OBSERVED GRAVITY AAGD07                                     µm/s^2
COMM HTGM                               STATION HEIGHT OF GRAVITY METER                             M
COMM TCINNER267                         INNER ZONE TERRAIN CORRECTION 2.67 t/m^3                    µm/s^2
COMM TCQFINNER                          QUALITY FACTOR OF INNER ZONE TERRAIN CORRECTION             NONE
COMM TCOUTER267                         OUTER ZONE TERRAIN CORRECTION 2.67 t/m^3                    µm/s^2
COMM TCQFOUTER                          QUALITY FACTOR OF OUTER ZONE TERRAIN CORRECTION             NONE
COMM TCTOTAL267                         TOTAL TERRAIN CORRECTION  2.67 t/m^3                        µm/s^2
COMM EFAA                               ELLIPSOIDAL FREE AIR ANOMALY                                µm/s^2
COMM SCBA267                            SPHERICAL CAP BOUGUER ANOMALY 2.67 t/m^3                    µm/s^2
COMM CSCBA267                           COMPLETE SPHERICAL CAP BOUGUER ANOMALY 2.67 t/m^3           µm/s^2
COMM HORIZDIST                          HORIZONTAL DISTANCE FROM PROGRAMMED STATION                 M
COMM GRVBASE                            GRAVITY BASE STATION REFERENCED TO                          NONE
COMM GPSBASE                            GPS BASE STATION REFERENCED TO                              NONE
COMM TIME                               TIME OF GRAVITY OBSERVATION                                 NONE
COMM DATE                               DATE OF GRAVITY OBSERVATION                                 NONE
COMM MGAZONE                            MGA ZONE NUMBER                                             NONE
COMM GMTYPESN                           GRAVITY METER TYPE SERIAL                                   NONE
COMM STATIONDESC                        STATION DESC                                                NONE
COMM COMMENTS                           COMMENTS                                                    NONE
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