

GPCR2013_01

Atlas Geophysics Report Number R2013001

North West Tasmania Gravity Survey

Mineral Resources Tasmania

Report completed by:



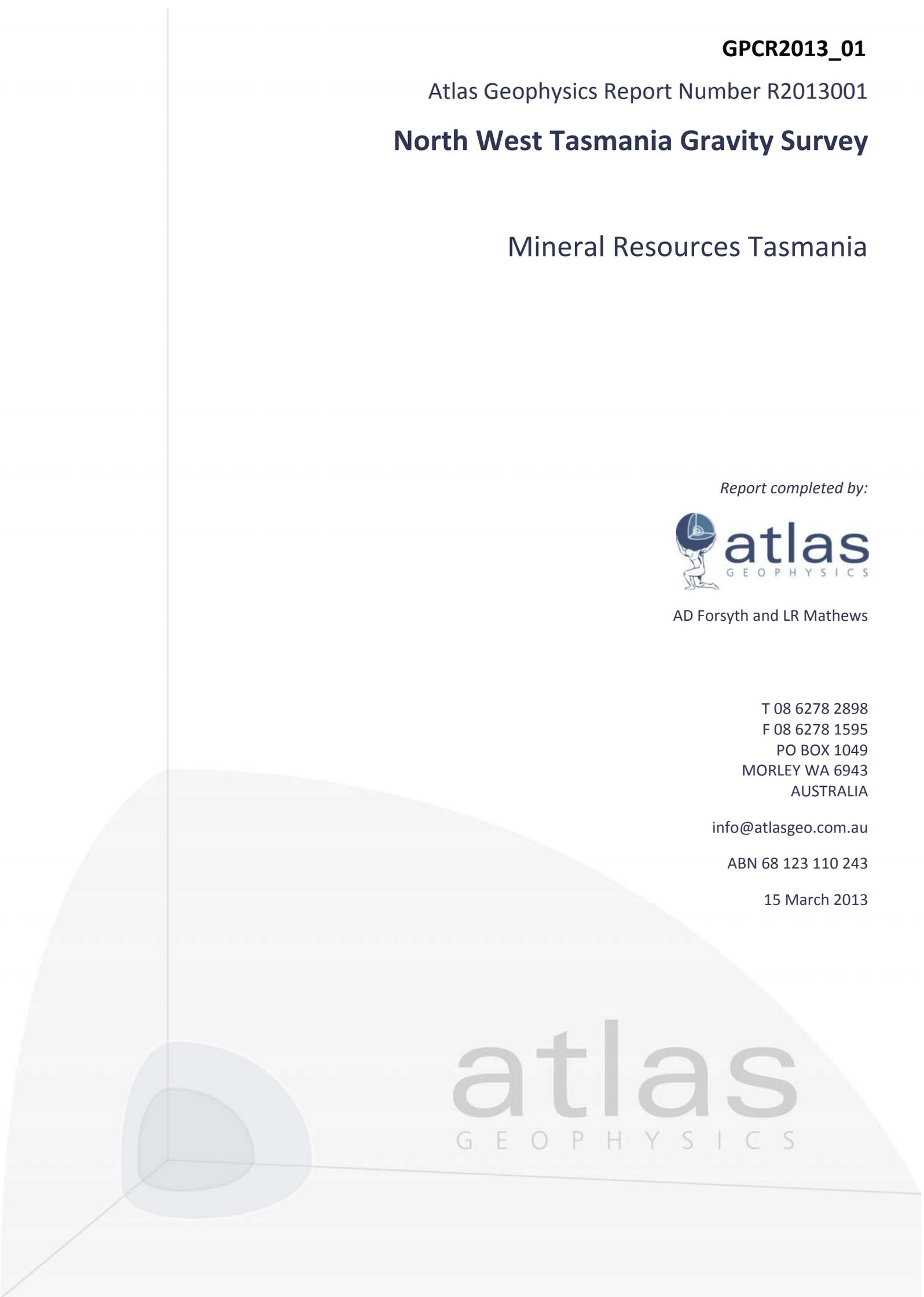
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G E O P H Y S I C S

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- Appendix C GPS Control Information
- Appendix D Gravity Control Processing and Information
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- Appendix F Data Formats
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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 15 years 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 Occupational Health and 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 P2013001 required the acquisition and processing of **1,200** new regional gravity stations on behalf of Mineral Resources Tasmania (MRT). The gravity survey is referred to as the “North West Tasmania Gravity Survey”.

The survey area covered a large portion of north-western Tasmania with survey operations based out of two logistical bases at Smithton and Waratah.

Atlas Geophysics Pty Ltd completed the acquisition of the dataset using primarily vehicle-borne gravity methods with two separate survey crews. Some stations inaccessible by vehicle were acquired on foot.

The survey commenced on 25th January 2013. Acquisition was completed on 26th February 2013.

2.1 Location, Access and Terrain

The gravity survey spanned a large area in the north-west of Tasmania up to 80km wide and 100km in length (Figure 1). The survey area incorporated several forest and nature reserves, plus vast sections of State Forest. Some stations (mostly south of Smithton) were located in open farmland. A long traverse was also surveyed between Port Latta and Savage River mine, along the Savage River slurry pipeline.

As most of the survey was located in forested areas, the crew often encountered very heavily wooded sections with very tall trees and very dense canopy. This often necessitated longer than normal GPS occupation times. Terrain varied, with easy to negotiate flat and open farmland in the north, and moderate to extremely steep relief in the south.

Access was mostly good with predominantly gazetted roads and forestry tracks used for survey. Some forestry tracks were inaccessible due to fallen logs and/or overgrown vegetation and others were heavily degraded and not negotiable by four wheel drive vehicle. Some stations in the Rocky Cape National Park and in around Savage River were acquired on foot as there was no vehicular access and data coverage here was important.

2.2 Survey Configuration

Gravity acquisition was conducted using four wheel drive vehicles taking measurements along gazetted roads and forestry access tracks at approximately one kilometre separations. Some selected traverses utilised a 500m station spacing.

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



Figure 1 : Location of North West Tasmania Gravity Survey

3.0 Personnel

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 25 years experience in the acquisition, processing and quality analysis 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 15 years and has directly overseen the acquisition and processing of over 1,000,000 gravity stations.

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

All final data processing, QA, 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:

Crew 01

Sam Giles

Project Field Supervisor

Crew02

Thomas Ostersen

Field Geophysicist

Phillip Saul

Field Technician

4.0 Equipment and Instrumentation

4.1 Glonass/GPS Receiver Equipment

Leading edge dual-frequency GPS 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 GPS technologies.

The use of Glonass technology in addition to GPS 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 Leica GPS1200 geodetic grade receivers were utilised to conduct the survey. Two receivers per vehicle were used as post-processed kinematic (PPK) rovers with the other receivers used as base stations for logging static data on multiple control stations.

4.2 Gravity Instrumentation

Complementing the company's GNSS/GPS 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 overleaf lists the gravity meters used on the project.

Gravity Meter Type	Gravity Meter Code	Gravity Meter Serial Number
Scintrex CG5	A8	40826
Scintrex CG5	A5	40361

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
- Two Iridium satellite phones for long distance communications and scheduled calls
- Personal Protective Equipment for all personnel
- Batteries and battery chargers
- Survey consumables
- Tools, engineering and maintenance equipment for vehicle servicing
- First aid and survival kits
- Tyres and recovery equipment
- Two satellite tracking and communication devices.

Leica GPS1200

Fast, accurate, rugged and reliable

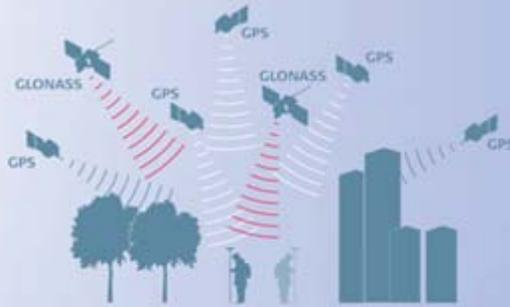


GNSS technology

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).

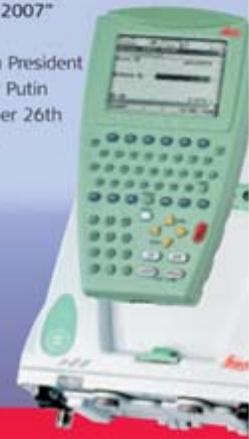


GLONASS

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

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.

WORKING TOGETHER
 FUNCTION
 LEICA SYSTEM 1200

Figure 3: Leica GPS1200 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	Nominal 12 VDC.			
Consumption	5.2 W receiver + controller + antenna			ATX1230: 2.4 W, RX1250 1.1 W
Event Input and PPS	Optional:	Optional:	Optional:	
	1 PPS output port	1 PPS output port	1 PPS output port	
	2 event input ports	2 event input ports	2 event input ports	
Standard antenna	SmartTrack AX1202	SmartTrack AX1202	SmartTrack AX1201	SmartTrack ATX1230
Built in groundplane	Built in groundplane	Built in groundplane	Built in groundplane	Built in groundplane

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.	Temperature	Operation: Receiver -40°C to +65°C
Plug-in Li-Ion batteries	Power receiver + controller + SmartTrack antenna for about 15 hours (for data logging).	ISO9022	Antennas -40°C to +70°C
Same for GPS and TPS	Power receiver + controller + SmartTrack antenna + low power radio modem or phone for about 10 hours (for RTK/DGPS).	MIL-STD-810F	Controllers -30°C to +65°C
	Power SmartAntenna + RX1250 controller for about 5 hours (for RTK/DGPS)		Storage: Receiver -40°C to +80°C
External power	External power input 10.5 V to 28 V.		Antennas -55°C to +85°C
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).		Controllers -40°C to +80°C
	Carbon fiber pole with SmartTrack antenna and RX1210 controller: 1.80 kg.	Humidity	Receiver, antennas and controllers
	All on pole: carbon fiber pole with SmartAntenna, RX1250 controller and plug-in batteries: 2.84 kg.	ISO9022, MIL-STD-810F	Up to 100% humidity.
		Protection against water, dust and sand	Receiver, antennas and controllers:
		IP67, MIL-STD-810F	Waterproof to 1m temporary submersion.
		Shock/drop onto hard surface	Dust tight
			Receiver: withstands 1m drop onto hard surface.
			Antennas: withstand 1.5m drop onto hard surface.
		Tumble over on pole	Receiver, antennas and controllers:
			withstand fall if pole topples over.
		Vibrations	Receiver, antennas and controllers:
		ISO9022	withstand vibrations on large construction machines. No loss of lock.
		MIL-STD-810F	

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 Lithium-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 temperature 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 Vehicles

Two rental four wheel drive vehicles were used to conduct the survey.

The field crew carried out daily pre-start checks on all vehicles and these have been documented in Atlas Geophysics pre-start log books.

6.0 Accommodation

The crew were accommodated and messed at Grace's Cottage in Smithton and Bischoff Hotel in Waratah.

7.0 Communications, Internet and Scheduled Calls

The primary method of communication for the field crews was via mobile phones and Iridium satellite phones. The crew sent scheduled check-ins to the WA operations base three times daily.

Internet connections for client contact and data server access were established using a Telstra Turbo Gateway NextG internet modem.

8.0 Survey Methodology

All gravity data were acquired using Atlas Geophysics Pty Ltd vehicle-borne techniques with the exception of a few traverses that were walked. These techniques, which involve concurrent GPS and gravity acquisition, allow for rapid acquisition of very high quality data.

8.1 Gravity and GPS Control Establishment

The survey was controlled using 16 primary GPS control stations and two primary gravity stations (Table 2). The gravity control stations were ideally located near to each of the logistical bases and the GPS control stations were located to minimise baseline length.

At each primary GPS control station, a metal pin of 15cm length was driven into ground level to mark the location of the station. To minimise impact on the environment, the stations were not witnessed with a plaque, tag or picket.

Gravity control stations were placed on permanent features, and to avoid being unsightly, not marked with a plaque.

Digital photos and accurate GPS coordinates can be used to recover the control stations. The details of all primary gravity control stations have been recorded on Atlas Geophysics Pty Ltd control station summary sheets. The sheets include the geodetic coordinates, observed gravity value, station description and a digital photo of the station. The sheets are contained in Appendix B.

Control Station ID	Lat / Long / Ht (GDA94, GRS80)	Observed Gravity (ISOGAL65 mGal)
201300100001	-40 50 36.7 145 07 19.9 N/A	980275.022
201300100002	-41 26 41.7680 145 31 42.4760 N/A	980182.659
201300100100	-40 57 49.2327 144 56 17.4534 36.833	N/A
201300100101	-41 4 48.1415 144 59 9.8700 45.239	N/A
201300100103	-40 56 56.6658 145 18 38.5308 60.550	N/A
201300100108	-40 57 53.0581 145 24 6.7449 160.314	N/A
201300100111	-41 5 36.9275 145 13 4.4909 220.578	N/A
201300100116	-41 17 35.7013 145 6 2.4394 286.660	N/A
201300100118	-41 28 14.4142 145 20 30.8213 310.624	N/A
201300100122	-41 42 58.9009 145 4 33.4954 181.720	N/A
201300100204	-41 10 43.3910 144 43 23.5229 85.222	N/A
201300100210	-41 3 36.7708 145 28 26.8263 335.745	N/A
201300100214	-41 31 23.0834 145 12 48.5529 360.407	N/A
201300100216	-41 38 42.6355 145 5 7.1465 63.108	N/A
201300100218	-40 58 23.6925 145 34 2.4389 114.477	N/A
201300100221	-41 10 12.7967 145 18 20.6308 410.260	N/A
201300100222	-41 9 46.8508 145 26 20.5526 181.742	N/A
201300100224	-41 11 9.0620 145 26 52.6910 193.898	N/A

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

8.1.1 GPS Control

Primary GPS control was established for all control stations except the gravity control stations (where autonomous GPS was used) 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 GPS control was used as a backup to assist verification of field measurements under challenging GPS conditions and to restrict GPS baseline length to less than 20km. In the field, whilst the survey was underway, coordinates for these stations were obtained using static base-line processing to the primary control station over a minimum five hour period.

Upon final processing, coordinates for all primary and secondary control stations were obtained using the 5 second static GPS data logged at each station whilst the gravity survey was underway. The static data for each of the control stations used during processing 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.

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 GPS measurement at each primary control station giving an accuracy of better than 1m 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 GPS 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 is contained in Appendix C.

8.1.2 Gravity Control

Primary gravity control stations were established at the logistical bases of Smithton and Waratah. Once tied to the [Australian Fundamental Gravity Network](#) (AFGN), the gravity control stations allowed all field gravity observations to be tied to both the ISO GAL65 and Australian Absolute Gravity Datum 2007 (AAGD07) datums.

An accurate observed or absolute gravity value for the control stations was established via "ABABA" ties with the project gravity meters to a nearby 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 0.01 mGal (or 0.1 $\mu\text{m/s}^2$).

Control Station ID	AFGN station tied to	Date of ties
201300100001 <i>Grace's Cottage, Smithton</i>	Smithton Airstrip 1964919142	9/02/2013
201300100002 <i>Bischoff Hotel, Waratah</i>	Devonport Airport Terminal 1985911141 Smithton Airstrip 1964919142	13/02/2013 26/02/2013

Table 3: Gravity control ties

It should be noted that a 0.07 mGal error was identified in the cross control station repeats and this is thought to be due to the relative difference between the Smithton and Devonport AFGN stations being different for the ISOGAL65 and AAGD07 datums (see Table 4). The error may have been introduced when a least squares adjustment was carried out by Geoscience Australia upon conversion of ISOGAL65 to AAGD07 values. It is suggested that new absolute readings be taken at the two AFGN stations. To enable quick integration to the Mineral Resources Tasmania gravity database, two separate final gravity databases have been supplied: one using the ISOGAL65 datum and the other using AAGD07.

Control Station ID	Observed Gravity (mGal)		
	ISOGAL65	ISOGAL84	AAGD07
1985911141 <i>Devonport Airport</i>	980284.39	980270.92	980270.84
1964919142 <i>Smithton Airstrip</i>	980276.05	980262.65	980262.57
Difference (mGal)	8.34	8.27	8.27

Table 4: AFGN station differences

8.2 GPS Data Acquisition, Processing and Quality Analysis

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

8.2.1 GPS-Glonass Acquisition

Each gravity station location (GSL) was positioned using navigation grade receivers running a mobile map display. At each station, the driver ensured the vehicle was always positioned safely off the road and never on a blind corner or hill crest. The vehicle was, where possible, positioned so that maximum sky coverage was achieved to minimise GPS cycle slips and record the cleanest data possible. At times, gravity station spacing was adjusted to obtain a better view of the sky and increase GPS performance.

For the kinematic vehicle operations, two separate GPS-Glonass receivers were used to allow for solution comparison when GPS conditions were challenging. Both receivers were carried in the cab of the vehicle, with one sensor mounted on a tall, fixed length aluminium pole secured to the rear tray and the other on the roof of the vehicle using a magnetic mount. When operating on foot, a single receiver was carried in a backpack with the sensor sitting atop a fixed length aluminium pole (2m).

Phase data were logged at five second epochs onto Compact Flashcards (CF) for later downloading and post-processing. Occupation times were commensurate with the time of day, number of satellites visible, Dilution of Precision (DOP) and GPS baseline length. Generally, a minimum 10 minute window was used, but some stations required in excess of 30 minutes because of poor satellite visibility and/or cycle slips.

Static data were also concurrently logged at the primary and secondary GPS control stations to allow for later kinematic processing. Where possible, static control stations were positioned in open areas such as farmland or cleared areas for maximum GPS satellite coverage.

8.2.2 GPS-Glonass Processing

The acquired raw GPS-Glonass data were processed nightly using [Novatel Waypoint Grafnav v8.40](#) post-processing software (Figure 6). GrafNav is a fully-featured kinematic and static GPS/Glonass post-processing package that uses Waypoint's robust GPS/Glonass processing carrier phase kinematic (CPK) filter engine. The software is capable of processing raw kinematic GPS/Glonass data from most GPS/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 GPS 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 8.40, 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 GPS 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.

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.

GPS + GLONASS – The GrafNav kernel has the ability to also process GPS+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.

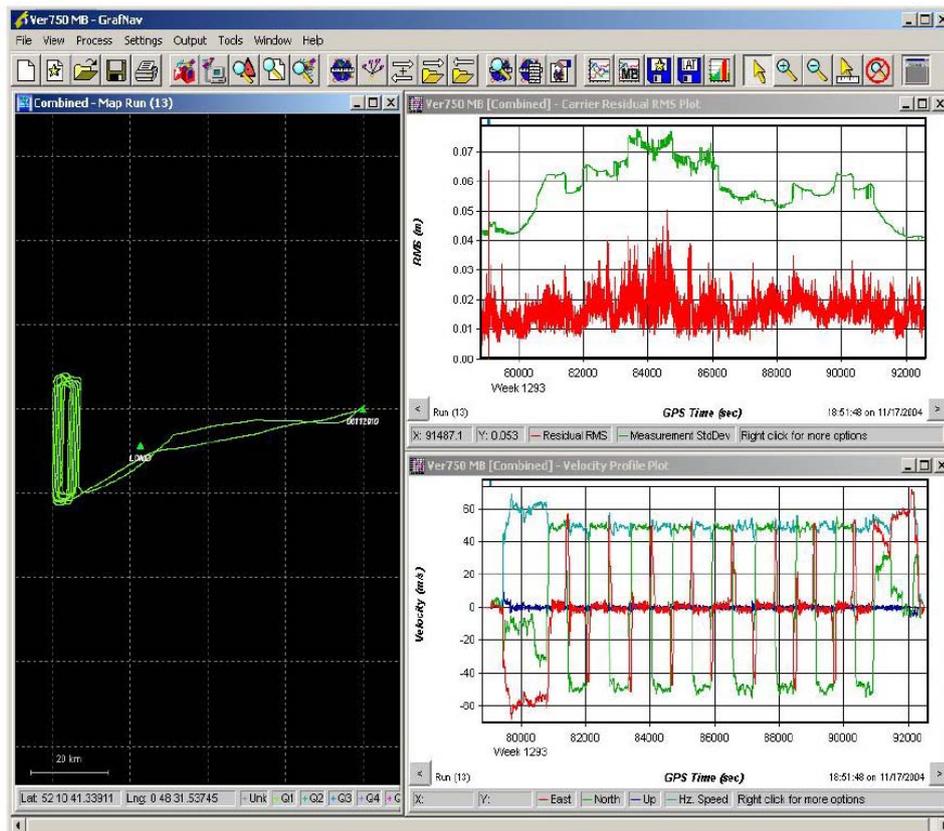


Figure 6: Waypoint Grafnav Processing Software

Once each station was processed to give a solution for the WGS84 position and elevation at ground level (i.e. corrected for sensor height), conversion between GPS-Glonass 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 GPS-derived WGS84 coordinates using a Universal Transverse Mercator (UTM) projection with zone 55S. For legacy purposes, AMG66 coordinates were calculated from the MGA94 coordinates using program GDA. For more information about WGS84, GDA94, MGA94 and AMG66 coordinates, the reader is asked to visit the Geoscience Australia website <http://www.ga.gov.au/geodesy/datums/gda.jsp>.

Elevations above the Australian Height Datum (AHD) were modelled using Waypoint 8.40 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 GPS derived WGS84/GRS80 ellipsoidal height (Figure 7).

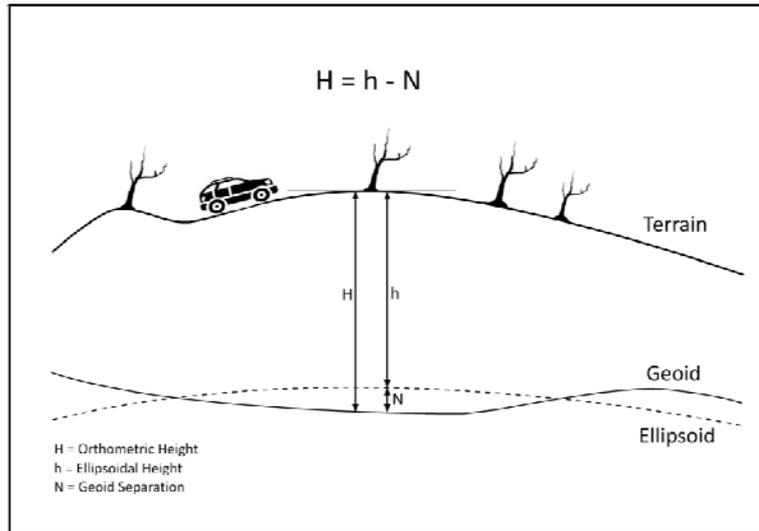


Figure 7: Geoid-Ellipsoid Separation

8.2.3 GPS/Glonass Quality Analysis

Due to the difficult GPS conditions endured for most of the project, rigorous quality analysis procedures were required to ensure the accuracy of the GPS solution. This was done using Waypoint Grafnav's built in QA tools. Some of the Waypoint tools used on this project include:

Combined Separation Plot: This plot shows the difference between the forward and reverse solutions (Figure 8). 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 survey would indicate that the data is of high quality.

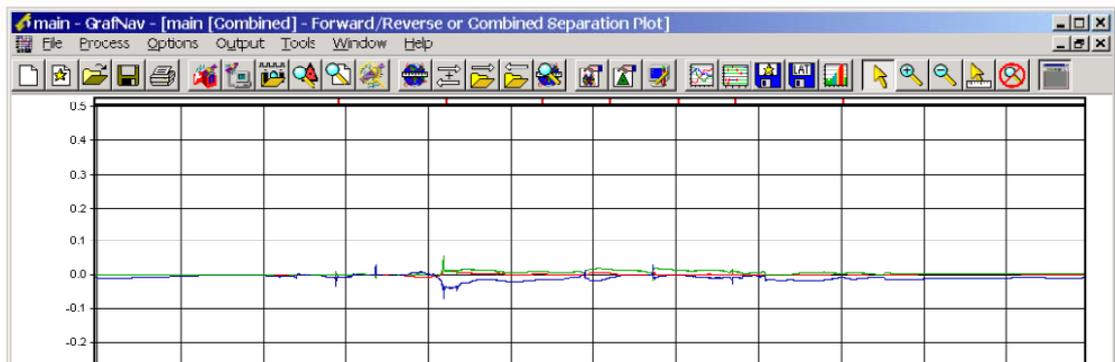


Figure 8: Combined Separation Plot

Float or Fixed Ambiguity Status Plot: This plot shows if the final solution is float or fixed (Figure 9). 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. No Float solutions were used on this project – all solutions were fixed.

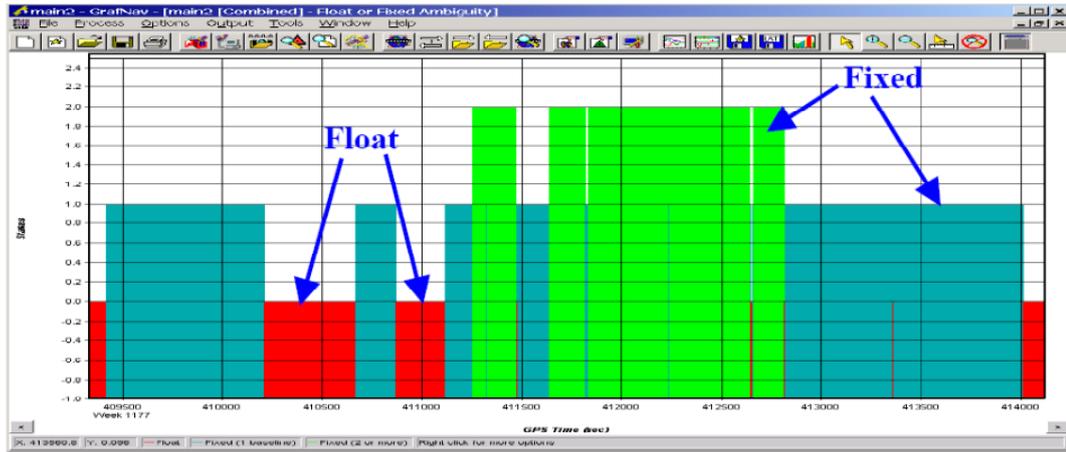


Figure 9: Float or Fixed Ambiguity Status Plot

Quality Factor Plot: This plot shows the quality of the final solution (Figure 10). There are five different quality factors plotted and these factors are also output in the Atlas Geophysics Pty Ltd GPS data file.

- Quality 1 – Fixed Integer (Green)
- Quality 2 – Stable Float (Aqua)
- Quality 3 – Converging Float (Blue)
- Quality 4 – DGPS 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.

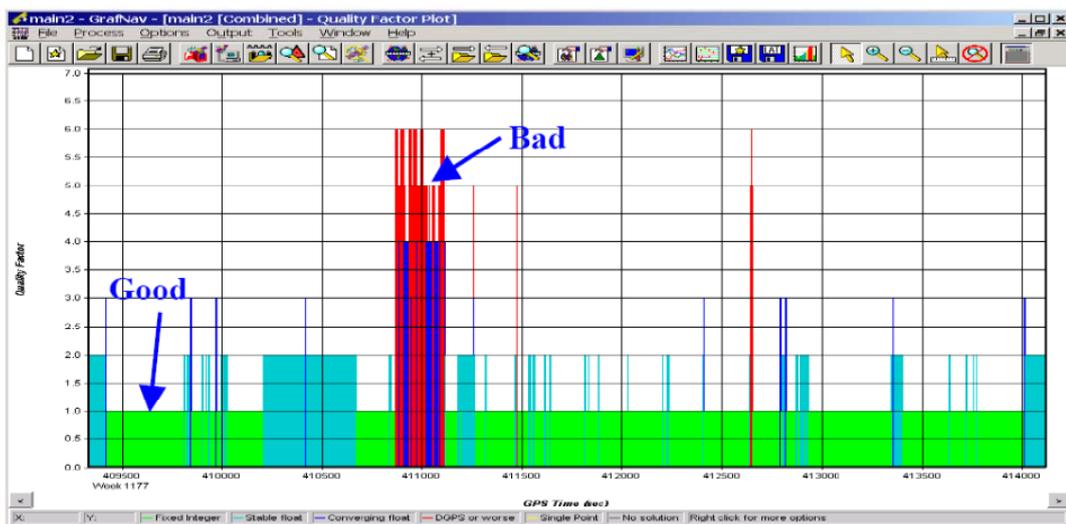


Figure 10: Quality factor plot

Complementing Waypoint GrafNav QA tools is the company's own in-house GPS quality analysis 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. If

a particular station failed to meet QA specifications, then it was reprocessed using all permutations of possible base/rover baseline combinations until it did. If QA specifications were not met after this process was exhausted, then the station was repeated at no cost to the client.

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.

8.3 Gravity Data Acquisition, Processing and Quality Analysis

Gravity data were gained using the company's high accuracy vehicle-borne techniques. The company's own in-house reduction and QA 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 Meters

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

Weekly tilt-tests and cycles were conducted to ensure the meters 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 GPS-Glonass data using Scintrex CG5 gravity meters. Data were acquired in a single loop controlled by observations at the gravity control stations. Each loop contained a minimum of one repeated readings so that an interlocking network of closed loops was formed. A total of **5.58%** repeats were acquired for quality control purposes.

When acquiring gravity data using a vehicle, the driver, after safely navigating to the station, parked the vehicle alongside the road in a safe position, with headlights on, rotating beacon flashing, park brake applied and vehicle engine off. Once safe to do so, the observer disembarked the vehicle on the verge or shoulder side and took the gravity reading alongside the vehicle, underneath the GPS observation point (Photo 1). At all times, the vehicle was parked on flat, level ground. Under no circumstances, did the observer acquire a reading in front of, or behind the vehicle.



Photo 1: Vehicle-borne Gravity Acquisition

When acquiring data on foot, the GPS operator safely navigated to the station using the GPS receiver's stake-out function. The gravity operator followed the GPS operator to the station and took readings at the base of the GPS survey staff, on flat, level ground.

At each station, the gravity operator took a minimum of two gravity readings of 60 seconds duration so that any seismic or wind noise could be detected. Control station readings were also 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 0.01 mGal at +150/-150 arc-seconds).

If two separate readings did not agree to better than 0.02 mGal (0.01 mGal 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 gravity station location was assigned a unique station code and station number.

Repeat stations were marked with a biodegradable flagging tape and water based marker paint for subsequent reoccupation. When reoccupying a station, the crews positioned the

vehicle/walking staff as close to the original position as possible (usually better than 0.5m). All repeat gravity observations were taken in exactly the same location.

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 analysis of the output dataset.

The software is capable of downloading Scintrex CG3/CG5 and Lacoste Romberg gravity data. Once downloaded, the gravity data is analysed for consistency and preliminary QA 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 GPS 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 $\mu\text{m/s}^2$. To convert to mGal units, divide by 10.

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 gravity units
 r gravity meter reading in dial units
 $S(r)$ scale factor (dial units/milliGal)

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.

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

where,

r_t tide corrected reading in gravity units
 r_c scale factor corrected reading in gravity units
 g_{tide} Earth Tide Correction (ETC) in gravity units

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 gu/hour
 r_{cs2} control station 2nd reading in gravity units
 r_{cs1} control station 1st reading in gravity units
 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, ISOGAL84 and ISOGAL65 gravity datums.

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

where,

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

Theoretical Gravity 1980: The theoretical (or normal) 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.

$$G_{t80} = 9780326.7715((1 + 0.001931851353(\sin^2 l))/(SQRT(1 - 0.0066943800229(\sin^2 l))))$$

where,

G_{t80} Theoretical Gravity 1980 in gravity units
 l GDA94 latitude at the gravity station in decimal degrees

Theoretical Gravity 1967: The theoretical (or normal) gravity value at each gravity station is calculated based on the assumption that the Earth is a homogeneous ellipsoid. The 1967 variant of the 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.

$$G_{t67} = (9780318.456 \cdot (1 + 0.005278895 \cdot \sin^2(l) + 0.000023462 \cdot \sin^4(l)))$$

where,

G_{t67} Theoretical Gravity 1967 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 theoretical 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

Ellipsoidal 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.

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

where,

$EFAC$ Ellipsoidal Free Air Correction in gravity units

l GDA94 latitude at the gravity station in decimal degrees

h elevation above the GRS80 ellipsoid in metres

Geoidal 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 geoid (AHD). Gravitational attraction decreases as the elevation above the reference geoid increases.

$$GFAC = (3.08768 - 0.00440 \sin^2(l)) \cdot h - 0.000001442 \cdot h^2$$

where,

$GFAC$ Free Air Correction in gravity units

l GDA94 latitude at the gravity station in decimal degrees

h elevation above the reference geoid (AHD) in metres

Spherical Cap 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 rock densities of 2.67, 2.40 and 2.20 tm^{-3} (gm/cc).

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

where,

SCBC Spherical Cap Bouguer Correction in gravity units

G gravitational constant = $6.67428 \cdot 10^{-11} \text{m}^3 \text{kg}^{-1} \text{s}^{-2}$

ρ rock density (2.67, 2.40 and 2.20 gm/cc)

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:

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

where,

$$\eta = h/R$$

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

where,

$$d = 3 \cdot \cos^2 \alpha - 2$$

$$f = \cos \alpha$$

$$k = \sin^2 \alpha$$

$$p = -6 \cdot \cos^2 \alpha \cdot \sin(\alpha/2) + 4 \cdot \sin^3(\alpha/2)$$

$$\delta = (R_o/R)$$

$$m = -3 \cdot k \cdot f$$

$$n = 2 \cdot [\sin(\alpha/2) - \sin^2(\alpha/2)]$$

$$\alpha = S/R_o \text{ with } S = \text{Bullard B Surface radius} = 166.735 \text{ km}$$

Geoidal Bouguer Correction: If a gravity observation is made above the reference geoid, 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 slab of rock makes a positive contribution to the gravity value. Rock densities of 2.67, 2.40 and 2.20 (gm/cc) were used in the correction.

$$GBC = 0.4191 \cdot \rho \cdot h$$

where,

GBC Geoidal Bouguer Correction in gravity units

ρ rock density (2.67, 2.40 and 2.20 gm/cc)

h elevation above the reference geoid (AHD) in m

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 Bouguer slab 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. Terrain corrections were not applied on this project as they are expected to be carried out by the client.

Ellipsoidal Free Air Anomaly: The Ellipsoidal Free Air Anomaly is the difference between the observed gravity and theoretical gravity that has been computed for latitude and corrected for the elevation of the gravity station above or below the reference ellipsoid.

$$EFAA = G_{oAAGD07} - (G_{t80} - AC) - EFAC$$

where,

EFAA Ellipsoidal Free Air Anomaly in gravity units

G_o Observed Gravity in gravity units

G_{t80} Theoretical Gravity 1980 in gravity units

AC Atmospheric Correction in gravity units

EFAC Ellipsoidal Free Air Correction in gravity units

Geoidal Free Air Anomaly: The Geoidal Free Air Anomaly is the difference between the observed gravity and theoretical gravity that has been computed for latitude and corrected for the elevation of the gravity station above or below the reference geoid.

$$GFAA = G_{oISOGAL84} - G_{t67} + GFAC$$

where,

GFAA Free Air Anomaly in gravity units

G_o Observed Gravity on the ISOGAL84 datum in gravity units

G_{t67} Theoretical Gravity 1967 in gravity units

GFAC Geoidal Free Air Correction in gravity units

Spherical Cap Bouguer Anomaly: The Spherical Cap Bouguer Anomaly is computed from the Ellipsoidal Free Air Anomaly above by removing the attraction of the spherical cap calculated by the Spherical Cap Bouguer Correction.

$$SCBA = EFAA - SCBC$$

where,

SCBA Spherical Cap Bouguer Anomaly in gravity units

EFAA Ellipsoidal Free Air Anomaly in gravity units

SCBC Bouguer Correction in gravity units

Geoidal Bouguer Anomaly: The Geoidal Bouguer Anomaly is computed from the Geoidal Free Air Anomaly above by removing the attraction of the slab calculated by the Geoidal Bouguer Correction.

$$GBA = GFAA - GBC$$

where,

GBA Geoidal Bouguer Anomaly in gravity units

GFAA Geoidal Free Air Anomaly in gravity units

GBC Geoidal Bouguer Correction in gravity units

Complete Bouguer Anomaly: This is obtained by adding the terrain correction to the Bouguer Anomaly (Spherical Cap or Geoidal). 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 Quality Analysis of the Processed Gravity data

Following reduction of the data to Bouguer Anomaly, repeatability and QA procedures were applied to both the positional and gravity observations using AGRIS software. AGRIS checks the following as part of its QA 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
- GPS Dilution of Precision, Coordinate Quality Factor, Standard Error
- Variation of surveyed station location from programmed location

QA 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.

8.3.5 Additional Processing, Gridding and Plotting

Complementing the QA procedures is additional daily gridding, imaging and plotting of the elevation and gravity data. Once processed to Bouguer Anomaly and assessed for QA, data are imported into Geosoft Oasis Montaj or ChrisDBF software for gridding at 1/4th 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 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 North West Tasmania Gravity Survey was completed with a degree of difficulty as a result of the limited access into some areas and the poor GPS satellite coverage in forested areas.

A total of **1,200** new gravity stations were acquired and processed 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 survey crew began gravity data acquisition on Friday 25th January 2013 with survey cessation on Tuesday 26th February 2013.

Survey production was variable and influenced by several factors including: poor or non-existent access (e.g. locked gates, blocked roads, overgrown tracks), poor track conditions, large distances from the logistical bases, and heavily wooded areas with dense tree canopy. It was the dense canopy that hindered production most, with GPS performance significantly compromised due to reduced satellite coverage and the extra occupation times required for GPS ambiguity resolution. In relatively open areas, the crews acquired 30-50 stations per day per crew and in more challenging areas much lower production was achieved. A full production report can be found on the data DVD (Appendix G).

9.2 Data Formats

Final point located data for the project have been delivered in Atlas standard format (with reductions on the AAGD07 and ISOGAL84 gravity datum) and in Mineral Resources Tasmania CSV format (with reductions on the ISOGAL65 datum only).

Raw GPS-GNSS and gravity data in their respective native formats have been included on the data DVD as Appendix J. Table 5 overleaf summarises the deliverables.

Final Delivered Data	Format	Data DVD	Hardcopy
Gravity Database	Atlas and MRT Format	•	
Raw Positional Data	AGRIS format, comma delimited	•	
Raw Gravity Data	Scintrex CG5 format	•	
Gravity Control Data	Microsoft Excel Format	•	•
Final Grids	ERMapper Grids .ers	•	
Final Images	Geotiff	•	•
Acquisition Report	PDF .pdf	•	•

Table 5: Final Deliverables

9.3 Data Repeatability: All Observations

The repeatability of both the gravity and GPS data was excellent. In total, **67** gravity and GPS repeat stations were collected and analysed. As a percentage, this equates to **5.58%** 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 6.

The standard deviation of the gravity repeat deviations was **0.023 mGal** and the standard deviation of the GPS derived elevation repeat deviations was **0.039m**. These statistics confirm that the data has met and exceeded contract specifications.

FIELD	MEAN	SD	MINIMUM	MAXIMUM
DIFFEASTM	-0.160	0.586	-3.994	0.606
DIFFNORTHM	-0.104	0.852	-6.624	0.940
DIFFHTM	0.003	0.039	-0.102	0.123
DIFFOBSGMGAL	0.008	0.023	-0.072	0.044
DIFFOBSGGU	0.080	0.226	-0.720	0.440

Table 6: Repeat Statistics

9.3.1 Repeatability Histograms

Histograms showing the distribution of repeat differences for both the GPS and gravity observations are shown in Figures 11 and 12.

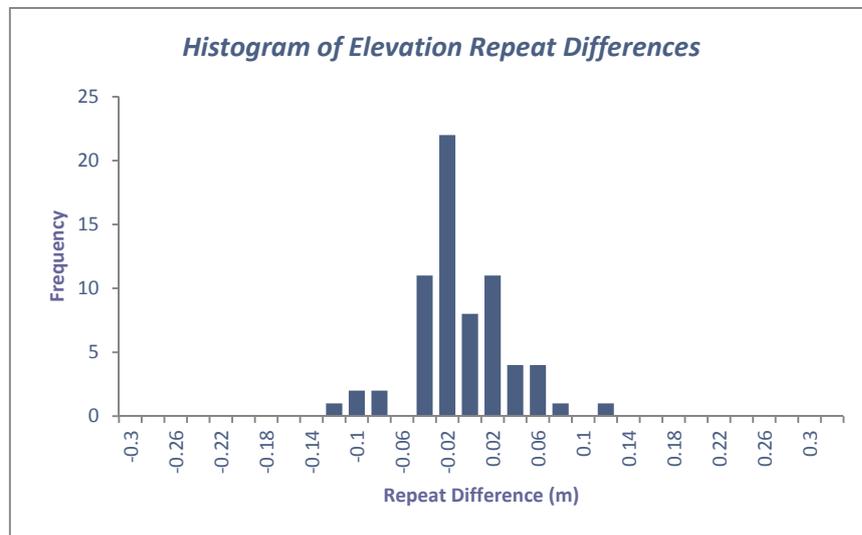


Figure 11: Histogram of GPS Repeat Differences

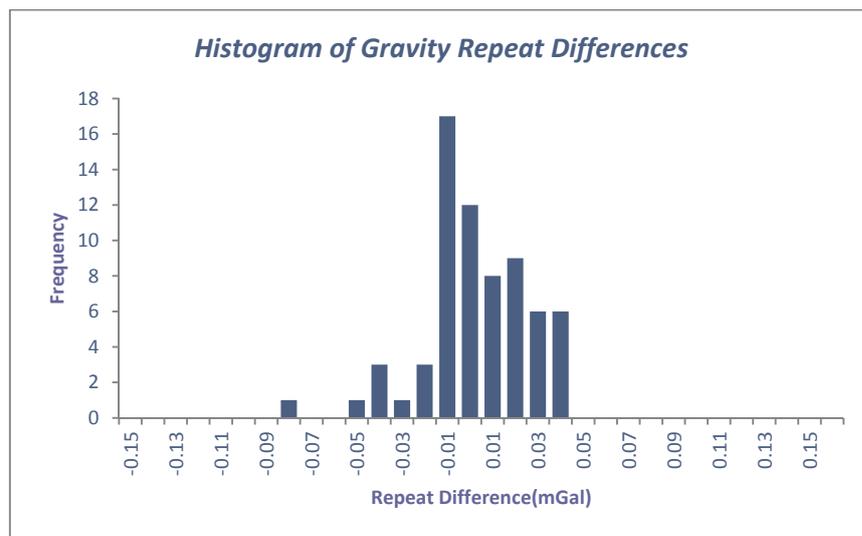


Figure 12: Histogram of Gravity Repeat Differences

9.4 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 mGal and m (AHD).

Grids for GPS Derived Elevation (AHD), Geoidal Bouguer Anomaly (GBA267MGAL) and 1st vertical derivative of Complete Bouguer Anomaly (GBA267VD) were produced for this particular project. The grid cell size for all grids is 250m.

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 DVD in Arcmap GIS compatible TIFF format.

Station Location Plot: The first plot displays the acquired gravity station locations overlaid 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.

GPS Derived Elevation: This plot displays a pseudocoloured grid of the digital elevation data obtained from the gravity survey (AHD). A histogram equalisation colour stretch has been applied when pseudocolouring.

Geoidal Bouguer Anomaly 2.67 Contours: This plot displays a pseudocoloured grid of Geoidal Bouguer Anomaly calculated with a rock density of 2.67 gm/cc. A histogram equalisation stretch has been applied when pseudocolouring.

Vertical Derivative Image: This plot displays a pseudocoloured grid of the first vertical derivative of Geoidal Bouguer Anomaly calculated with a rock density of gm/cc.

10.0 Project Safety

There were no incidents or accidents to report during the project.

Weekly toolbox meetings were held to discuss project safety and address any staff member concerns. A Hazard Identification and Risk Assessment (HIRA) was carried out for all new tasks not covered under Atlas Geophysics Standard Operating Procedures (SOP's) or in the company's Health Safety and Environment (HSE) manual.

11.0 Conclusion

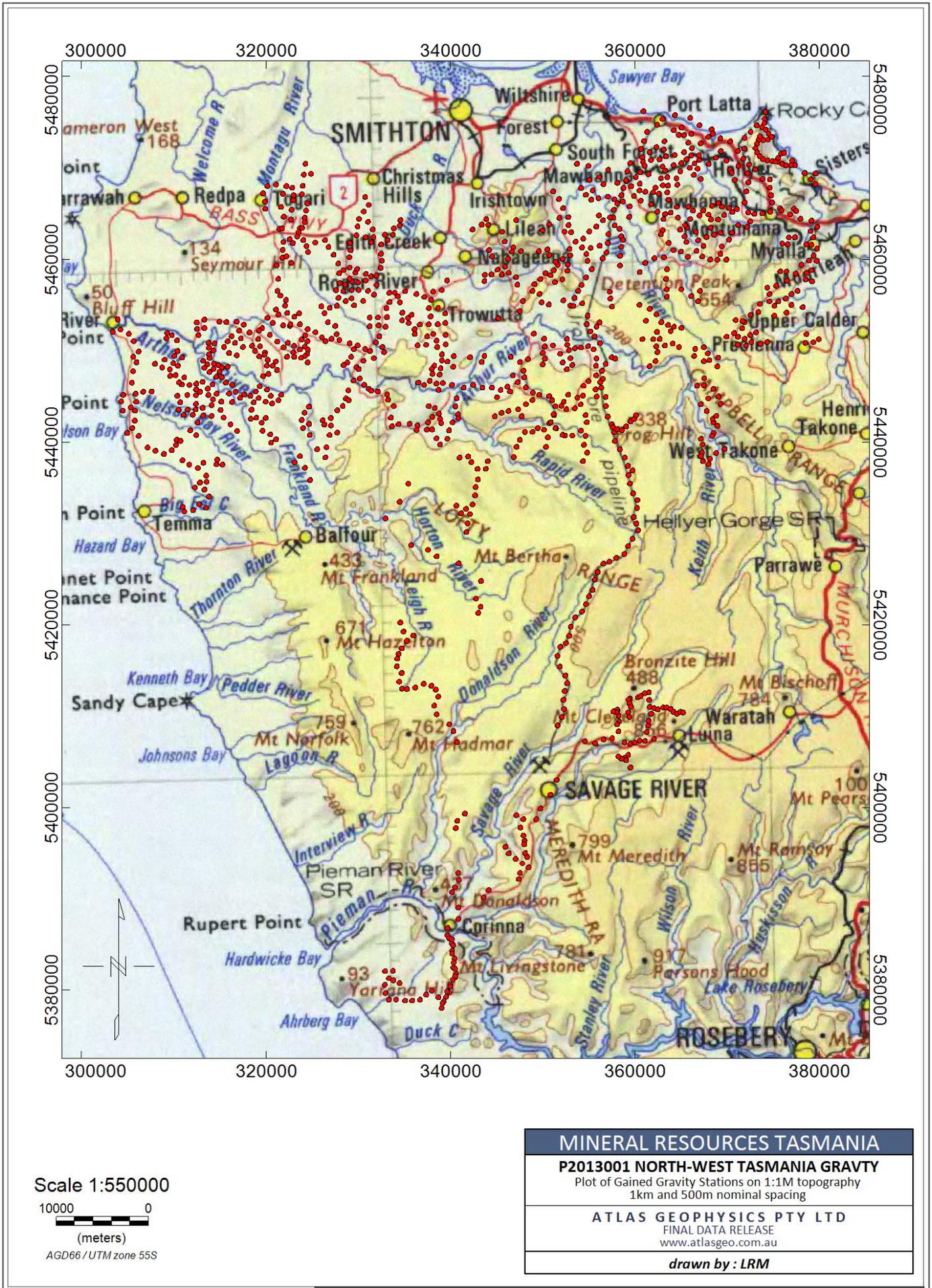
Atlas Geophysics Pty Ltd is confident that it has delivered high quality data to its client, to a high standard and in the safest way possible.

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 Mineral Resources Tasmania again in the future.



Leon Mathews
Director

APPENDIX A
Plots and Images

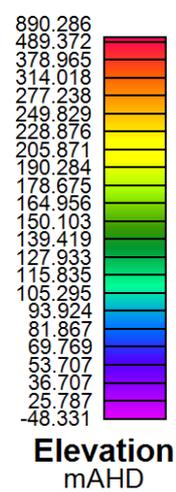
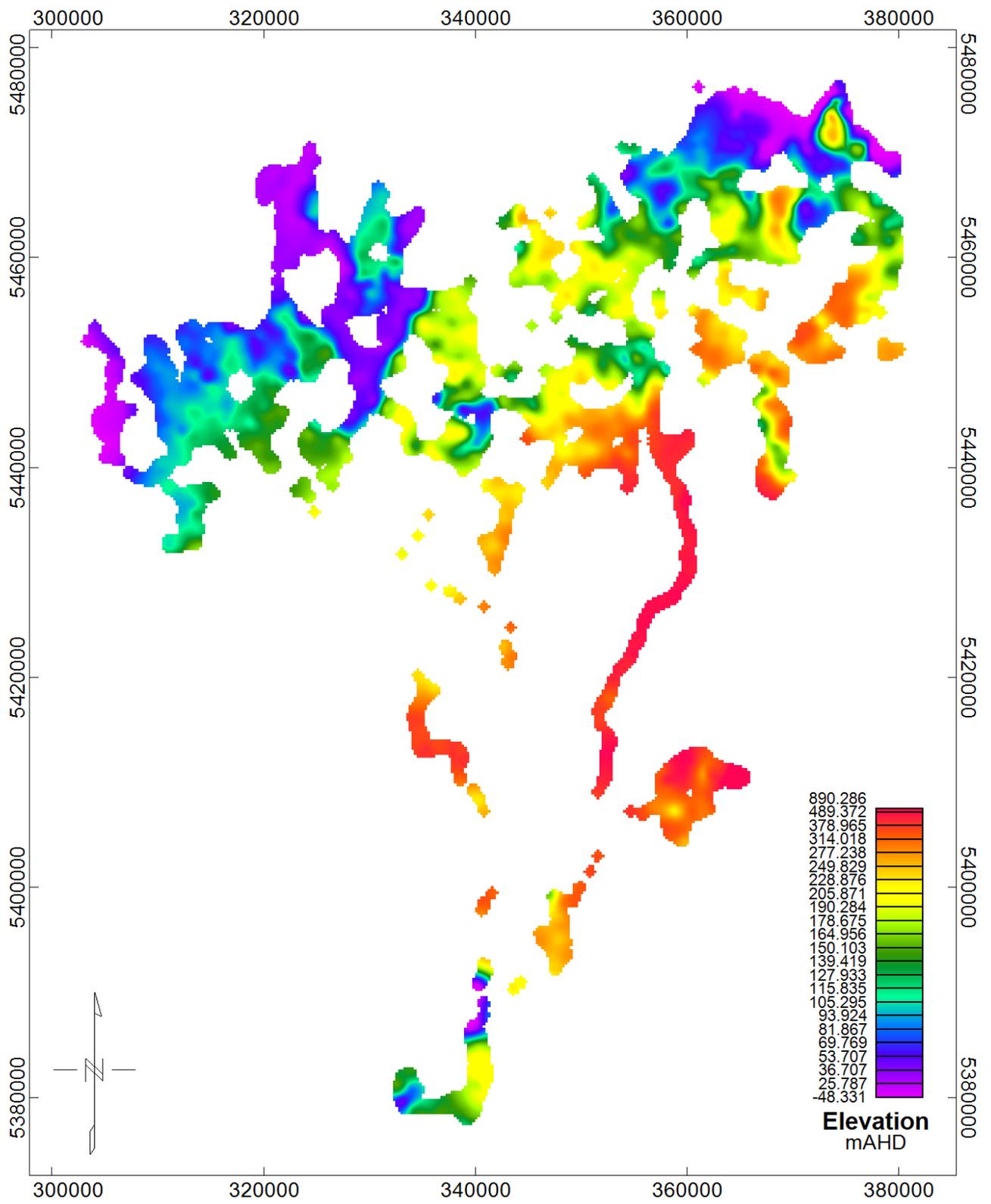


MINERAL RESOURCES TASMANIA	
P2013001 NORTH-WEST TASMANIA GRAVITY	
Plot of Gained Gravity Stations on 1:1M topography 1km and 500m nominal spacing	
ATLAS GEOPHYSICS PTY LTD FINAL DATA RELEASE www.atlasgeo.com.au	
drawn by : LRM	

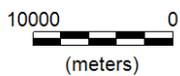
Scale 1:550000

10000 0
 (meters)

AGD66 / UTM zone 55S

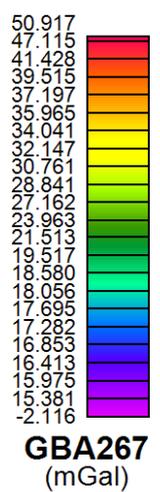
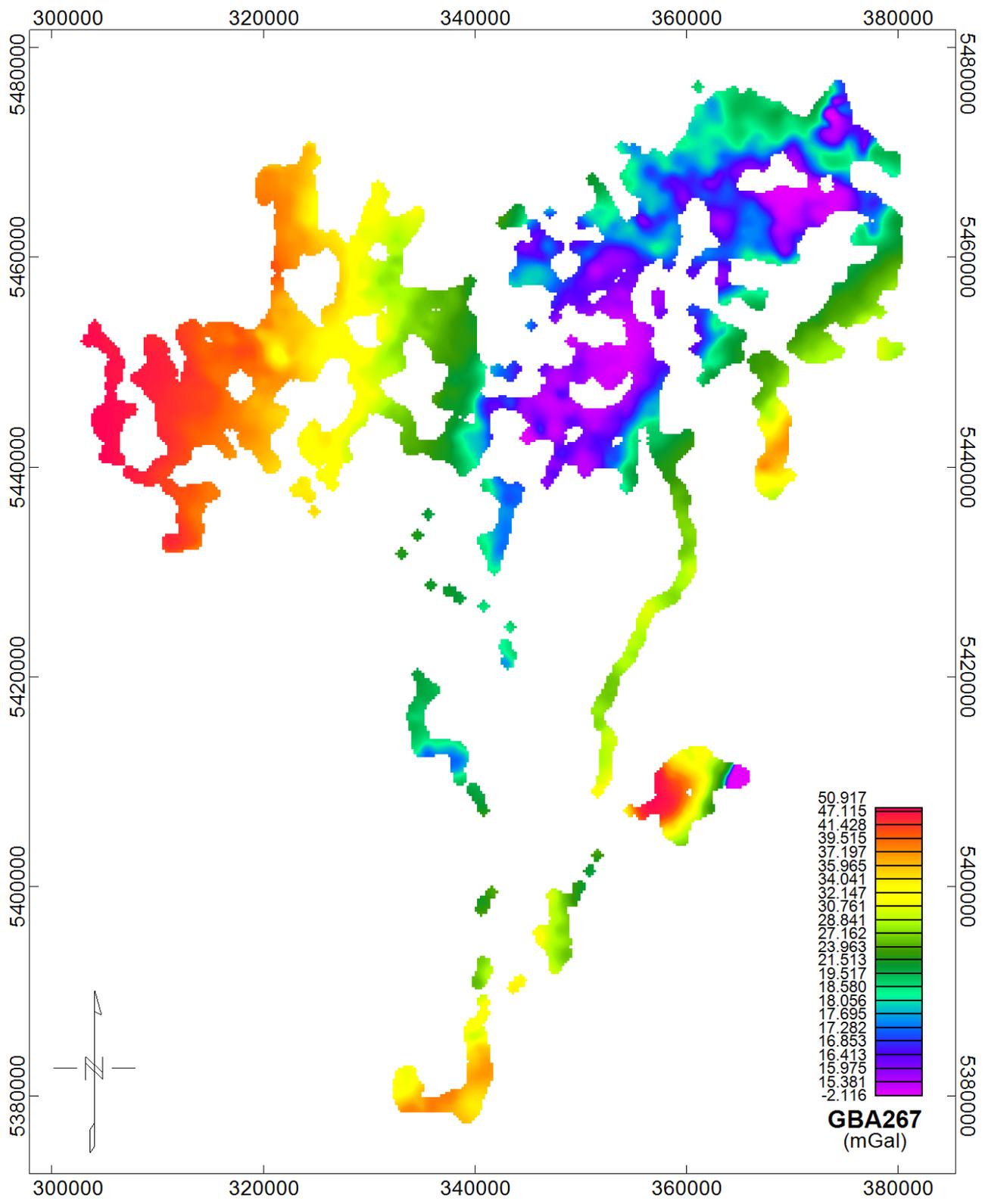


Scale 1:550000



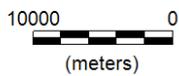
AGD66 / UTM zone 55S

MINERAL RESOURCES TASMANIA
P2013001 NORTH-WEST TASMANIA GRAVITY Pseudocoloured Image of GPS Derived Elevation (mAHd) Shade = None, Contours = None, Histo = Equalised
ATLAS GEOPHYSICS PTY LTD FINAL DATA RELEASE www.atlasgeo.com.au
<i>drawn by : LRM</i>



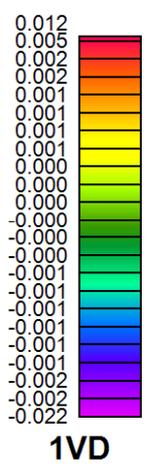
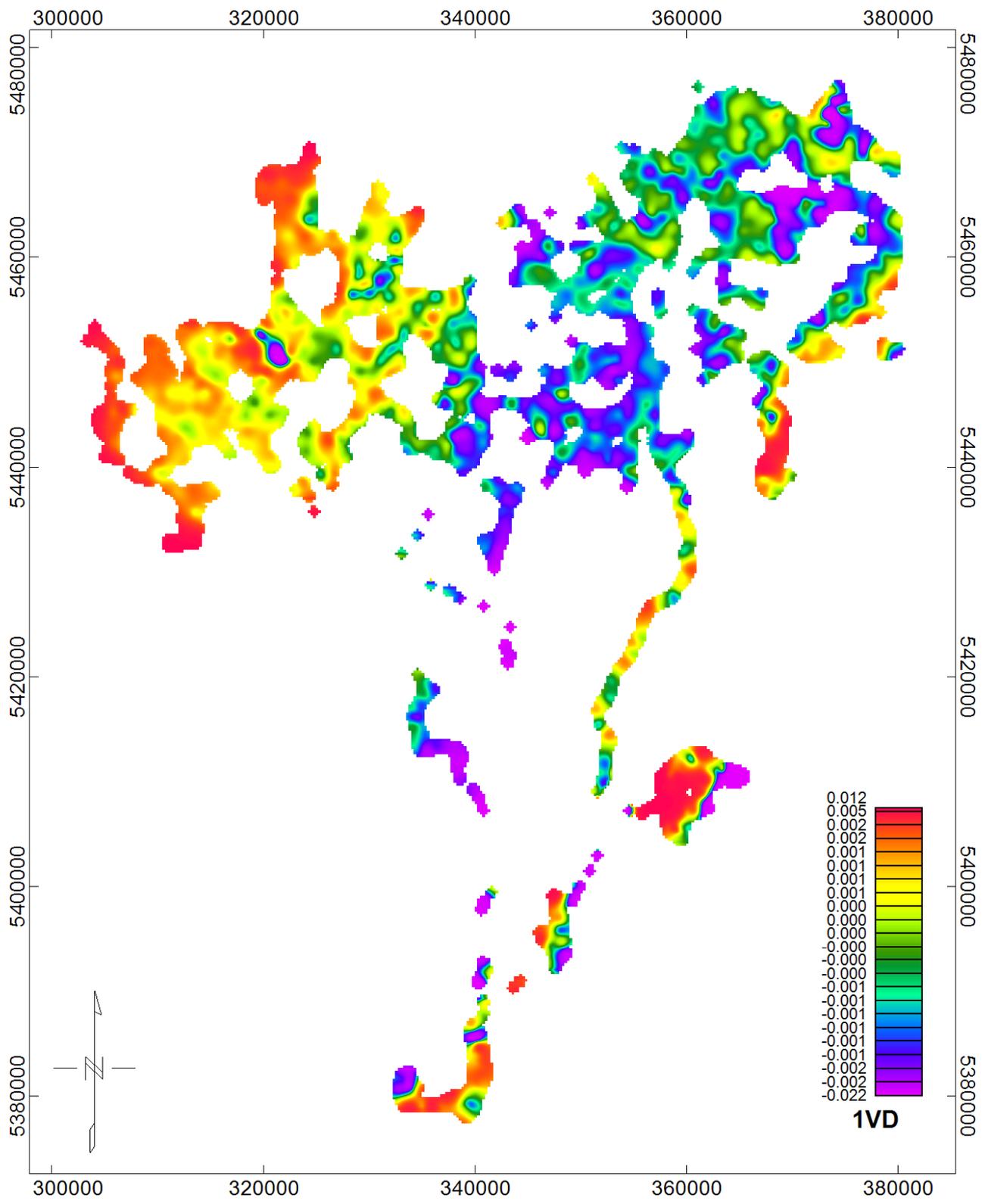
GBA267
(mGal)

Scale 1:550000

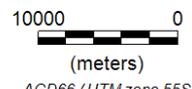


AGD66 / UTM zone 55S

MINERAL RESOURCES TASMANIA	
P2013001 NORTH-WEST TASMANIA GRAVITY	
Pseudocoloured Image of Geoidal Bouguer Anomaly 2.67 gm/cc Shade = None, Contours = None, Histo = Equalised	
ATLAS GEOPHYSICS PTY LTD	
FINAL DATA RELEASE www.atlasgeo.com.au	
<i>drawn by : LRM</i>	



Scale 1:550000



AGD66 / UTM zone 55S

MINERAL RESOURCES TASMANIA	
P2013001 NORTH-WEST TASMANIA GRAVITY	
Pseudocoloured Image of 1VD Geoidal Bouguer Anomaly 2.67 gm/cc Shade = None, Contours = None, Histo = Equalised	
ATLAS GEOPHYSICS PTY LTD	
FINAL DATA RELEASE www.atlasgeo.com.au	
<i>drawn by : LRM</i>	

APPENDIX B
Control Station Descriptions

201300100001 – Grace’s Cottage, Smithton

GDA94/GRS80		MGA Z55		AMG Z55	
<i>Latitude</i>	-40 50 36.7	<i>Easting</i>	341,696	<i>Easting</i>	341,585
<i>Longitude</i>	145 07 19.9	<i>Northing</i>	5,476,915	<i>Northing</i>	5,476,732
<i>Ellipsoidal Height</i>	N/A	<i>Orthometric Height</i>	N/A	<i>Orthometric Height</i>	N/A

OBSERVED GRAVITY

<i>AAGD07 mGal</i>	980261.544
<i>ISOGAL65 mGal</i>	980275.022

Occupation Method/Location Details

This gravity control station has not been established at a new permanent monument, rather it has been located on an existing concrete pad on the small front verandah at Grace’s Cottage. The station sits adjacent to the front door, against the wall of the building.

Gravity Control was established by Atlas Geophysics via multiple ABA loops with the project gravity meters to the Smithton Airstrip AFGN station 1964919142 on 9th February 2013. Expected accuracy would be better than 0.01 mGal.

GPS Control was not established. A handheld Garmin GPS was used to record autonomous coordinates. No elevation was recorded.

Grace’s Cottage is located at 33 Gibson Street in Smithton, Tasmania. A small park is located just west of the cottage.



Photograph of Control Station 201300100001

201300100002 – Waratah Water Wheel

GDA94/GRS80		MGA Z55		AMG Z55	
<i>Latitude</i>	-41 26 41.7	<i>Easting</i>	377,075	<i>Easting</i>	376,965
<i>Longitude</i>	145 31 42.4	<i>Northing</i>	5,410,804	<i>Northing</i>	5,410,620
<i>Ellipsoidal Height</i>	N/A	<i>Orthometric Height</i>	N/A	<i>Orthometric Height</i>	N/A

OBSERVED GRAVITY

<i>AAGD07 mGal</i>	980169.111
<i>ISO GAL65 mGal</i>	980182.659

Occupation Method/Location Details

This gravity control station has not been established at a new permanent monument, rather it has been located on the corner of a concrete pad next to a water wheel/mill in Waratah.

Gravity Control was established by Atlas Geophysics via ABA loops with the project meters to AFGN station 1985911141 at the Devonport airport terminal on 13th February 2013 and 22nd February 2013. Expected accuracy would be better than 0.1 mGal.

GPS Control was not established. A handheld Garmin GPS was used to get autonomous coordinates. No elevation was recorded.

The water mill is easily accessible via an asphalt car park off Smith or Crosby Street, Waratah. A large lake sits just east of the car park.



Photograph of Control Station 201300100002

APPENDIX C
GPS Control Information

201300100100
1000 -40 57 49.23267 144 56 17.45343 36.833 39.342 GDA94

GDA94AVE
-40 57 49.2327
144 56 17.4534

-40.96367575
144.93818150

GRS80HT
36.833

AHDHT
39.342

N
-2.509

MGA55
326497.410
5463228.201

AMG55
326383.988
5463044.945

201300100101
1010 -41 04 48.14153 144 59 09.86995 45.239 47.790 GDA94

GDA94AVE
-41 4 48.1415
144 59 9.8700

-41.08003931
144.98607500

GRS80HT
45.239

AHDHT
47.790

N
-2.551

MGA55
330826.061
5450403.593

AMG55
330712.649
5450220.380

201300100103
1030 -40 56 56.66575 145 18 38.53076 60.550 62.491 GDA94

GDA94AVE
-40 56 56.6658
145 18 38.5308

-40.94907383
145.31070300

GRS80HT
60.550

AHDHT
62.491

N
-1.941

MGA55
357815.294
5465522.246

AMG55
357701.784
5465339.035

201300100108
1080 -40 57 53.05811 145 24 06.74485 160.314 162.087 GDA94

GDA94AVE
-40 57 53.0581
145 24 6.7449

-40.96473836
145.40187358

GRS80HT
160.314

AHDHT
162.087

N
-1.773

MGA55
365521.033
5463927.576

AMG55
365407.503
5463744.380

201300100111
1110 -41 05 36.92754 145 13 04.49086 220.578 222.644 GDA94

GDA94AVE
-41 5 36.9275
145 13 4.4909

-41.09359097
145.21791414

GRS80HT
220.578

AHDHT
222.644

N
-2.066

MGA55
350332.725
5449323.212

AMG55
350219.261
5449140.033

201300100116
1160 -41 17 35.70129 145 06 02.43944 286.660 289.099 GDA94

GDA94AVE
-41 17 35.7013
145 6 2.4394

-41.29325036
145.10067761

GRS80HT
286.660

AHDHT
289.099

N
-2.439

MGA55
340970.337
5426948.748

AMG55
340856.934
5426765.617

201300100118
1180 -41 28 14.41418 145 20 30.82133 310.624 312.625 GDA94

GDA94AVE
-41 28 14.4142
145 20 30.8213

-41.47067061
145.34189481

GRS80HT
310.624

AHDHT
312.625

N
-2.001

MGA55
361545.113
5407664.971

AMG55
361431.682
5407481.929

201300100122
1220 -41 42 58.90085 145 04 33.49538 181.720 185.627 GDA94

GDA94AVE
-41 42 58.9009
145 4 33.4954

-41.71636136
145.07597094

GRS80HT
181.720

AHDHT
185.627

N
-3.907

MGA55
339947.335
5379926.440

AMG55
339834.013
5379743.447

201300100204
2040 -41 10 43.39098 144 43 23.52290 85.222 88.543 GDA94

GDA94AVE
-41 10 43.3910
144 43 23.5229

-41.17871972
144.72320081

GRS80HT
85.222

AHDHT
88.543

N
-3.321

MGA55
309029.078
5438904.090

AMG55
308915.746
5438720.871

201300100210
2100 -41 03 36.77075 145 28 26.82633 335.745 337.231 GDA94

GDA94AVE
-41 3 36.7708
145 28 26.8263

-41.06021411
145.47411842

GRS80HT
335.745

AHDHT
337.231

N
-1.486

MGA55
371785.773
5453436.994

AMG55
371672.243
5453253.837

201300100214
2140 -41 31 23.08344 145 12 48.55289 360.407 363.059 GDA94

GDA94AVE
-41 31 23.0834
145 12 48.5529

-41.52307872
145.21348692

GRS80HT
360.407

AHDHT
363.059

N
-2.652

MGA55
350942.646
5401632.799

AMG55
350829.256
5401449.759

201300100216
2160 -41 38 42.63552 145 05 07.14652 63.108 66.712 GDA94

GDA94AVE
-41 38 42.6355
145 5 7.1465

-41.64517653
145.08531847

GRS80HT
63.108

AHDHT
66.712

N
-3.604

MGA55
340549.254
5387847.429

AMG55
340435.917
5387664.412

201300100218
2180 -40 58 23.69245 145 34 02.43894 114.477 116.034 GDA94

GDA94AVE
-40 58 23.6925
145 34 2.4389

-40.97324792
145.56734414

GRS80HT
114.477

AHDHT
116.034

N
-1.557

MGA55
379460.959
5463224.397

AMG55
379347.393
5463041.225

201300100221
2210 -41 10 12.79668 145 18 20.63081 410.260 411.978 GDA94

GDA94AVE
-41 10 12.7967
145 18 20.6308

-41.17022131
145.30573078

GRS80HT
410.260

AHDHT
411.978

N
-1.718

MGA55
357873.780
5440962.929

AMG55
357760.307
5440779.785

201300100222
2220 -41 09 46.85078 145 26 20.55255 181.742 183.180 GDA94

GDA94AVE
-41 9 46.8508
145 26 20.5526

-41.16301411
145.43904239

GRS80HT
181.742

AHDHT
183.180

N
-1.438

MGA55
369042.854
5441972.251

AMG55
368929.349
5441789.122

201300100224
2240 -41 11 09.06201 145 26 52.69101 193.898 195.296 GDA94

GDA94AVE
-41 11 9.0620
145 26 52.6910

-41.18585056
145.44796972

GRS80HT
193.898

AHDHT
195.296

N
-1.398

MGA55
369837.065
5439450.382

AMG55
369723.561
5439267.261

APPENDIX D
Gravity Control Processing and Information

201300100001 GRAVITY TIES

1 = 201300100001 Grace's Cottage Smithton
 9142 = 1964919142 Smithton Airport Terminal
 Ties carried out by vehicle

METER A5

station	gda94_longitude_dd	gda94_latitude_dd	date_ddmmyyyy	time_hhmmss	dialrdng_mgal	etc_mgal	obsg_mgal	metersn
1	145.083000	-40.830000	09/02/2013	06:36:23	4767.043	-0.091	980000.000	40361
1	145.083000	-40.830000	09/02/2013	06:37:29	4767.043	-0.091	980000.001	40361
9142	145.122194	-40.843528	09/02/2013	06:54:11	4768.054	-0.085	980001.026	40361
9142	145.122194	-40.843528	09/02/2013	06:55:17	4768.054	-0.084	980001.027	40361
1	145.083000	-40.830000	09/02/2013	07:09:42	4767.013	-0.078	980000.000	40361
1	145.083000	-40.830000	09/02/2013	07:09:42	4767.013	-0.078	980000.000	40361
1	145.083000	-40.830000	09/02/2013	07:10:48	4767.016	-0.077	980000.004	40361
9142	145.122194	-40.843528	09/02/2013	07:30:18	4768.022	-0.066	980001.026	40361
9142	145.122194	-40.843528	09/02/2013	07:31:24	4768.025	-0.066	980001.030	40361
1	145.083000	-40.830000	09/02/2013	07:45:16	4766.982	-0.057	979999.999	40361
1	145.083000	-40.830000	09/02/2013	07:46:22	4766.982	-0.056	980000.000	40361

METER A8

station	gda94_longitude_dd	gda94_latitude_dd	date_ddmmyyyy	time_hhmmss	dialrdng_mgal	etc_mgal	obsg_mgal	metersn
1	145.083000	-40.830000	09/02/2013	06:26:08	4161.410	-0.094	980000.000	40826
1	145.083000	-40.830000	09/02/2013	06:27:14	4161.405	-0.094	979999.995	40826
9142	145.122194	-40.843528	09/02/2013	06:54:46	4162.426	-0.085	980001.027	40826
9142	145.122194	-40.843528	09/02/2013	06:55:52	4162.426	-0.084	980001.027	40826
1	145.083000	-40.830000	09/02/2013	07:16:16	4161.388	-0.075	980000.000	40826
1	145.083000	-40.830000	09/02/2013	07:16:16	4161.388	-0.075	980000.000	40826
1	145.083000	-40.830000	09/02/2013	07:17:22	4161.385	-0.074	979999.998	40826
9142	145.122194	-40.843528	09/02/2013	07:30:35	4162.408	-0.066	980001.029	40826
9142	145.122194	-40.843528	09/02/2013	07:32:55	4162.406	-0.065	980001.029	40826
1	145.083000	-40.830000	09/02/2013	07:53:08	4161.360	-0.052	979999.998	40826
1	145.083000	-40.830000	09/02/2013	07:54:14	4161.361	-0.051	980000.000	40826

AVG 9142	980001.028
DIFF 9142_1	1.028
KNOWN 9142 AAGD07	980262.572
KNOWN 9142 ISOGAL65	980276.050
CALC 1 AAGD07	980261.544
CALC 1 ISOGAL65	980275.022

201300100002 GRAVITY TIES

1 = 201300100001 Grace's Cottage Smithton
 2 = 201300100002 Waratah Water Wheel
 9142 = 1964919142 Smithton Airport Terminal
 1141 = 1985911141 Devonport Airport Terminal
 Ties carried out by vehicle

METER A5

station	gda94_longitude_dd	gda94_latitude_dd	date_ddmmyyyy	time_hhmmss	dialrdng_mgal	etc_mgal	obsg_mgal	metersn
2	145.528465	-41.444936	13/02/2013	14:11:23	4676.893	0.054	980000.000	40361
2	145.528465	-41.444936	13/02/2013	14:12:59	4676.893	0.054	980000.000	40361
1141	146.426360	-41.171830	13/02/2013	16:28:55	4778.611	0.035	980101.712	40361
1141	146.426360	-41.171830	13/02/2013	16:30:01	4778.612	0.035	980101.712	40361
2	145.528465	-41.444936	13/02/2013	18:08:25	4676.946	-0.020	980000.000	40361
2	145.528465	-41.444936	13/02/2013	18:08:25	4676.946	-0.020	980000.000	40361

METER A8

station	gda94_longitude_dd	gda94_latitude_dd	date_ddmmyyyy	time_hhmmss	dialrdng_mgal	etc_mgal	obsg_mgal	metersn
2	145.528465	-41.444936	13/02/2013	14:26:43	4072.704	0.056	980000.000	40826
2	145.528465	-41.444936	13/02/2013	14:27:57	4072.706	0.056	980000.002	40826
1141	146.426360	-41.171830	13/02/2013	16:29:58	4174.450	0.035	980101.732	40826
1141	146.426360	-41.171830	13/02/2013	16:31:12	4174.450	0.034	980101.732	40826
2	145.528465	-41.444936	13/02/2013	17:59:58	4072.762	-0.015	980000.000	40826
2	145.528465	-41.444936	13/02/2013	17:59:58	4072.762	-0.015	980000.000	40826
2	145.528465	-41.444936	22/02/2013	07:09:30	4080.568	-0.007	980000.000	40826
2	145.528465	-41.444936	22/02/2013	07:10:56	4080.570	-0.006	980000.003	40826
1141	146.426360	-41.171830	22/02/2013	08:45:48	4182.252	0.049	980101.749	40826
1141	146.426360	-41.171830	22/02/2013	08:46:54	4182.249	0.050	980101.747	40826
2	145.528465	-41.444936	22/02/2013	10:35:10	4080.450	0.092	980000.000	40826
2	145.528465	-41.444936	22/02/2013	10:35:10	4080.450	0.092	980000.000	40826

AVG 1141 980101.731
 DIFF 1141_1 101.731
 KNOWN 1141 AAGD07 980270.842
 KNOWN 1141 ISOGAL65 980284.390
CALC 1 AAGD07 980169.111
CALC 1 ISOGAL65 980182.659

Check to Smithton A/S

2	145.528465	-41.444936	26/02/2013	07:07:32	4084.112	-0.093	980000.000	40826
2	145.528465	-41.444936	26/02/2013	07:08:38	4084.111	-0.093	979999.999	40826
9142	145.122194	-40.843528	26/02/2013	16:26:36	4177.436	0.013	980093.474	40826
9142	145.122194	-40.843528	26/02/2013	16:27:42	4177.437	0.012	980093.475	40826
2	145.528465	-41.444936	26/02/2013	18:42:29	4084.041	-0.078	980000.000	40826
2	145.528465	-41.444936	26/02/2013	18:43:34	4084.041	-0.078	980000.000	40826

AVG 1	980093.475	
DIFF 2_1	93.475	
KNOWN 9142 AAGD07	980262.572	
KNOWN 9142 ISOGAL65	980276.050	<i>diff mGal</i>
CALC 1 AAGD07	980169.098	-0.014
CALC 1 ISOGAL65	980182.576	-0.084

APPENDIX E
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*8399.709299+4.720023434+(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*0.03000526416+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)*0.10979944)
dolm=(dolm1+sin((ds-dp)*2.0)*0.003767474+sin(ds-dh*2.0+dp)*0.0154002+sin((ds-dh)*2.0)*0.00769395)
dha=((dTime*15.0-180)*0.0174532925199+dLon/57.295779513)
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))*0.00676902+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 F
Data Format

ATLAS FORMAT

Field Header	Field Description	Format	Units
PROJECT	Atlas Geophysics Project Number	A9	None
STATION	Unique Station ID	I8	None
STATIONCODE	Unique Station Code	A13	None
LINE	Line ID	I8	None
TYPE	Observation Type : Base, Field or Repeat	A8	None
MGAEAST	Coordinate Easting MGA94/GDA94	F11.3	m
MGANORTH	Coordinate Northing MGA94/GDA94	F12.3	m
ZONE	MGA Zone Number	F8.0	NA
GDA94LAT	Coordinate Latitude GDA94	F15.10	DD
GDA94LONG	Coordinate Longitude GDA94	F15.10	DD
ORTHOHTM	Coordinate Elevation Orthometric	F9.3	m
GRS80HTM	Coordinate Elevation Ellipsoidal	F9.3	m
NAG09	Geoid Separation AUSGEOID09	F8.3	m
AMG84EAST	Coordinate Easting AMG84	F11.3	m
AMG84NORTH	Coordinate Northing AMG84	F12.3	m
DATE	Observation Date	I8	None
TIME	Observation Time	I8	None
DIALMGAL	Gravity Dial Reading	F9.3	mGal
ETCMGAL	Earth Tide Correction (Longman)	F8.3	mGal
SCALE	Scale Factor Applied to Dial Reading	F9.6	None
OBSG84MGAL	Observed Gravity ISOGAL84	F11.3	mGal
OBSG84GU	Observed Gravity ISOGAL84	F11.2	gu
OBSGAAGD07GU	Observed Gravity AAGD07	F13.2	gu
OBSGAAGD007MGAL	Observed Gravity AAGD07	F16.3	mGal
DRIFTMGAL	Drift Applied to Dial Readings	F10.3	mGal
TGRAV67GU	Theoretical Gravity 1967	F11.2	gu
TGRAV67MGAL	Theoretical Gravity 1967	F12.3	mGal
TGRAV80GU	Theoretical Gravity 1980	F11.2	gu
GFACGU	Geoidal Free Air Correction	F8.2	gu
GFACMGAL	Geoidal Free Air Correction	F9.3	mGal
GFAAGU	Geoidal Free Air Anomaly	F8.2	gu
GFAAMGAL	Geoidal Free Air Anomaly	F9.3	mGal
GBC267GU	Geoidal Bouguer Correction 2.67 tm ⁻³	F9.2	gu
GBC240GU	Geoidal Bouguer Correction 2.40 tm ⁻³	F9.2	gu
GBC220GU	Geoidal Bouguer Correction 2.20 tm ⁻³	F9.2	gu
GBC267MGAL	Geoidal Bouguer Correction 2.67 tm ⁻³	F11.3	mGal
GBC240MGAL	Geoidal Bouguer Correction 2.40 tm ⁻³	F11.3	mGal
GBC220MGAL	Geoidal Bouguer Correction 2.20 tm ⁻³	F11.3	mGal
GBA267GU	Geoidal Bouguer Anomaly 2.67 tm ⁻³	F9.2	gu
GBA240GU	Geoidal Bouguer Anomaly 2.40 tm ⁻³	F9.2	gu
GBA220GU	Geoidal Bouguer Anomaly 2.20 tm ⁻³	F9.2	gu
GBA267MGAL	Geoidal Bouguer Anomaly 2.67 tm ⁻³	F11.3	mGal
GBA240MGAL	Geoidal Bouguer Anomaly 2.40 tm ⁻³	F11.3	mGal
GBA220MGAL	Geoidal Bouguer Anomaly 2.20 tm ⁻³	F11.3	mGal
TGRAV80ACGU	Theoretical Gravity 1980 Atmospheric Corrected	F11.2	gu
EFACGU	Ellipsoidal Free Air Correction	F9.2	gu
EFAAGU	Ellipsoidal Free Air Anomaly	F8.2	gu
SCBC267GU	Spherical Cap Bouguer Correction 2.67 tm ⁻³	F10.2	gu
SCBC240GU	Spherical Cap Bouguer Correction 2.40 tm ⁻³	F10.2	gu
SCBC220GU	Spherical Cap Bouguer Correction 2.20 tm ⁻³	F10.2	gu
SCBA267GU	Spherical Cap Bouguer Anomaly 2.67 tm ⁻³	F10.2	gu
SCBA240GU	Spherical Cap Bouguer Anomaly 2.40 tm ⁻³	F10.2	gu
SCBA220GU	Spherical Cap Bouguer Anomaly 2.20 tm ⁻³	F10.2	gu
SCBA267MGAL	Spherical Cap Bouguer Anomaly 2.67 tm ⁻³	F12.3	mGal
SCBA240MGAL	Spherical Cap Bouguer Anomaly 2.40 tm ⁻³	F12.3	mGal
SCBA220MGAL	Spherical Cap Bouguer Anomaly 2.20 tm ⁻³	F12.3	mGal
TCINNERGU	Inner Terrain Correction	F8.2	gu
TCINNERMGAL	Inner Terrain Correction	F8.3	mGal
QFINNER	Quality Factor Inner TC	I2	None
TCOUTERGU	Outer Terrain Correction	F8.2	gu
TCOUTERMGAL	Outer Terrain Correction	F8.3	mGal
QFOUTER	Quality Factor Outer TC	F2	None
TCTOTALGU	Total Terrain Correction	F8.2	gu
TCTOTALMGAL	Total Terrain Correction	F8.3	mGal
CGBA267GU	Complete Geoidal Bouguer Anomaly 2.67 tm ⁻³	F11.3	gu
CGBA267MGAL	Complete Geoidal Bouguer Anomaly 2.67 tm ⁻³	F11.3	mGal
CSCBA267GU	Complete Spherical Cap Bouguer Anomaly 2.67 tm ⁻³	F12.2	gu
CSCBA267MGAL	Complete Spherical Cap Bouguer Anomaly 2.67 tm ⁻³	F12.2	mGal
DIFFEASTM	Repeat Error for Easting Observation	F8.3	m
DIFFNORTHM	Repeat Error for Northing Observation	F8.3	m
DIFFHTM	Repeat Error for Elevation Observation	F8.3	m
DIFFOBSGMGAL	Repeat Error for Observed Gravity	F8.3	mGal
DIFFOBSGGU	Repeat Error for Observed Gravity	F8.2	gu
METERSN	Serial Number of Gravity Instrument	I8	None
CLOSUREGU	Loop Closure in gu	F8.2	gu
CLOSUREMGAL	Loop Closure in mGal	F8.3	mGal
GRVBASE	Gravity Base	A11	None
GPSBASE	GPS Base	A11	None

MRT FORMAT

Field Header	Field Description	Format	Units
STATION	Unique Station ID	I8	None
ZONE	UTM Zone Number	F8.0	NA
AMGEAST	Coordinate Easting AMG66	F11.3	m
AMGNORTH	Coordinate Northing AMG66	F12.3	m
ORTHOHTM	Coordinate Elevation Orthometric	F9.3	m
OBSG65MGAL	Observed Gravity ISOGAL65	F11.3	mGal
GBA267MGAL	Geoidal Bouguer Anomaly 2.67 gm/cc	F11.3	mGal
MGAEAST	Coordinate Easting MGA94/GDA94	F11.3	m
MGANORTH	Coordinate Northing MGA94/GDA94	F12.3	m
GDA94LAT	Coordinate Latitude GDA94	F15.10	DD
GDA94LONG	Coordinate Longitude GDA94	F15.10	DD
GRS80HTM	Coordinate Elevation Ellipsoidal	F9.3	m
NAG09	Geoid Separation AUSGEOID09	F8.3	m
DATE	Observation Date	I8	None
TIME	Observation Time	I8	None
GRVBASE	Gravity Base	A11	None
GPSBASE	GPS Base	A11	None