Birrindudu Detailed Gravity Survey, NT 2005

Logistics Report

Project 200580

Prepared by Fugro Ground Geophysics

August 2005

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1. INTRODUCTION

1.1 GENERAL

During the period May 9 to June 18 (2005), Fugro Ground Geophysics (FGG) conducted a GPS positioned regional gravity survey on behalf of Geoscience Australia (GA). The survey was located near Birrindudu Station, on the Western Australia – Northern Territory border (figure 1).

The survey involved observation of 3728 stations at 2km by 2km intervals and covered the 1:250 000 Birrindudu Map Sheet (SE 52-11). Negotiations for land access were conducted by the Northern Territory Geological Survey (NTGS) with some areas of the map sheet being excluded (figure 2).

Observations of relative gravity measurements were made using Scintrex CG-3 Autograv Gravity Meters while positioning information was acquired using Ashtech dual frequency geodetic receivers operating in post processed kinematic (*OTF* – on the fly) mode. Gravity stations were located using autonomous GPS and positioned on the ground as close as possible to the pre-planned location depending upon finding a suitable site for landing.

The survey was completed using helicopter support and in order to maximise the daily flying time two crews (1 pilot and 1 operator per crew) were utilised. Each crew operated for approximately half a day with the change over occurring around midday during the helicopter refuelling. Three pilots were utilised on a rotational basis each day in order to comply with flight time regulations.

The survey area terrain was predominantly open with low to moderate vegetation, becoming more undulating in the north-west of the grid.

Figure 1. Birrindudu Gravity Survey – Survey Area Location

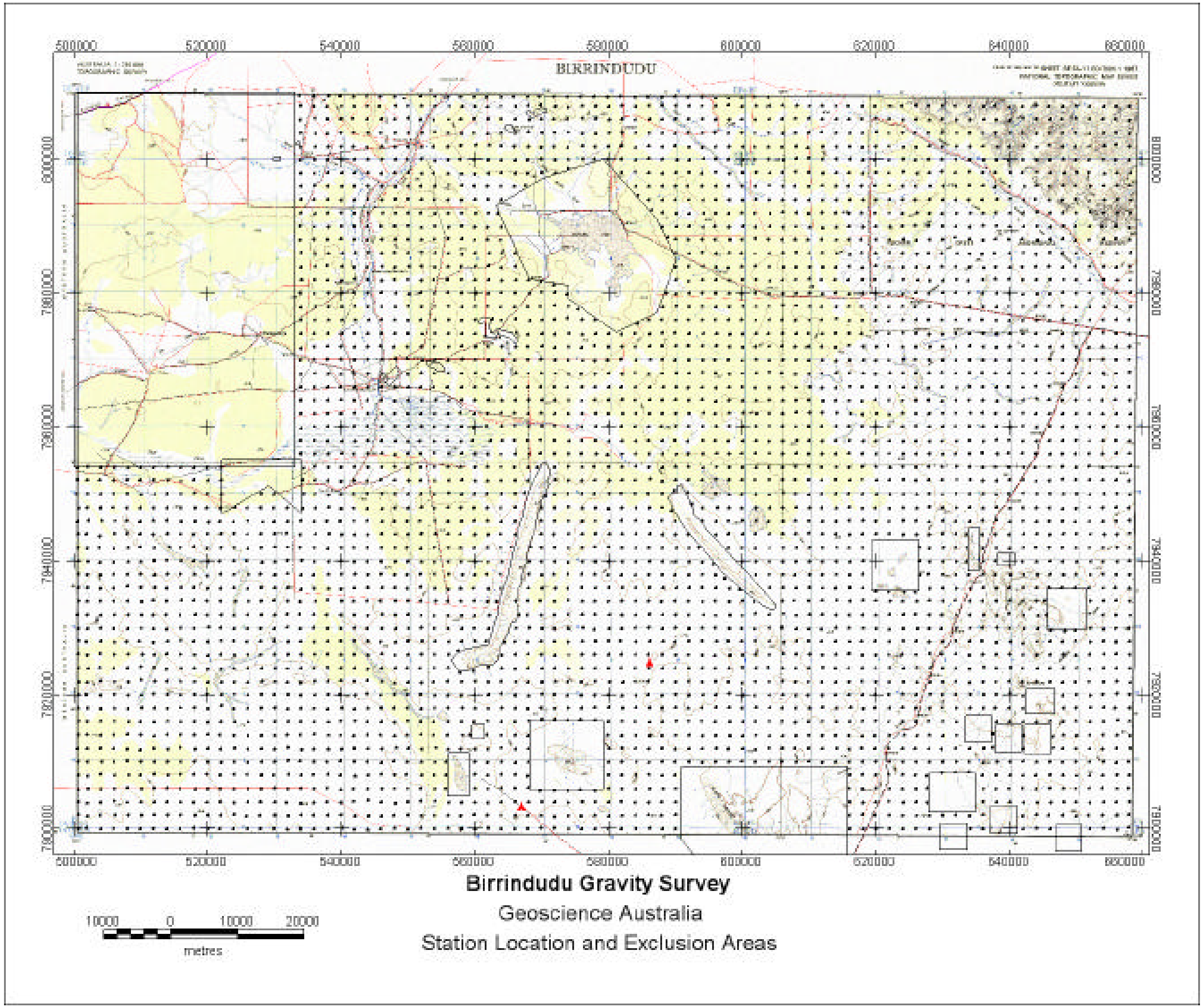


Figure 2. Birrindudu Gravity Survey – Station Locations

1.2 EQUIPMENT AND PERSONNEL

The following FGG personnel were on-site during field operations:

GRAVITY/GPS PERSONNEL

PERSONNEL	POSITION
Gregory Kunda	Crew Chief / Data Processor / Gravity Observer
Keith Clinton	Gravity Observer
Laurie Murphy	Gravity Observer
Jack Larsen (Heliwork)	Pilot
David Creed (Heliwork)	Pilot
Pat Maher (Heliwork)	Pilot
Craig Iesley (Heliwork)	Pilot

FGG supplied the following equipment for the survey:

Num	HARDWARE
4	Scintrex CG-3/M gravity meters
1	LaCoste & Romberg gravity meter
5	Ashtech Z-Surveyor dual frequency GPS receivers
2	Ashtech Z12 dual frequency GPS receivers
3	Garmin GPS for navigation
3	Robinson R44 helicopters (on a rotational basis)
2	Inclinometers (Suunto PM-5)
1	Leica Disto-meter
4	Telit Global Star satellite telephones
2	Toyota Landcruiser 4 X 4 utility vehicles
1	Computer / printer / modem
	Safety equipment / first aid and survival kits
	Camp equipment (tents / messing / power)
	SOFTWARE
	GRAVI Gravity Processing software
	Geosoft – Oasis Montaj
	PNav – Ashtech post processing software

The field crew and all operations were based out of Birrindudu Station for the duration of the survey.

1.2.1 Gravity Meter Calibration

In order to ensure the accuracy of the gravity meters used on the survey, the calibration factor (GCAL1) was checked by making observations on the Perth (Mundairing) calibration range upon the completion of the survey. Observations of gravity differences were made between stations 7391.0217 (Mt Gungin) and 8090.0317 (Mundairing Wier Pumping Station) which has a published difference of 541.8μms^{-2}. Errors in the observed difference between these stations for each meter were -0.23μms^{-2} (9808440), -0.16μms^{-2} (9002133), 0.05μms^{-2} (9507283) and -0.08μms^{-2} (9610353) all well within the contractual requirement of 0.5μms^{-2}. No adjustments have been made to the survey data based on these results. Results of these tests are contained in Appendix C of this report.

2. SURVEY PROCEDURE AND SPECIFICATIONS

2.1 DATA ACQUISITION

The survey consisted of a total of 3728 stations which were acquired at the following parameters:

PARAMETER	Grid
Line Spacing	2km
Station Spacing Number of Stations	2km 3728
Number of Repeats	225 (Gravity) 205 (GPS)
Navigation	Real time GPS (autonomous)
Surveying	Dual frequency GPS
Survey Method	OTF Kinematic

2.2 NAVIGATION

Station location and helicopter navigation were completed using real time GPS (non-corrected). Coordinates for each station were up-loaded daily to the helicopter's Garmin GPS receiver, which displayed a steering indicator and the distance to the next station. The pilot followed the steering indicator until the distance to the station was less than 100 metres, at which point a search for a suitable landing site would commence. Because of the varying nature of the vegetation and topography present in parts of the survey area, it was not always possible to land safely at the designated location. In these cases, the pilot attempted to land as close as was safely possible.

2.3 READING OFFSET

The GPS antenna was located approximately mid-way along the tail boom of the helicopter to enable it as clear view as possible for continuous satellite tracking. As this position is outside of the field of view of the pilot and would mean working dangerously close to the tail rotor, the actual reading position for the gravity meter was located at right angles to the helicopter. In order to correct for this offset and comply with the requirement that all stations must be located with a 1m accuracy (X-Y position), measurements of offset between the reading position and the antenna were made at each station. The offset distance was measured using a Leica disto-meter with a reading accuracy of better than 1cm, and the offset direction was measured using a standard Sunnto compass (KB-14/360) with a reading accuracy of better than 1°. From these measurements and using simple geometry the components of east and north could be computed and the position of the gravity meter determined relative to the GPS antenna (to better than 1m accuracy). All reading sites were chosen to be as flat as possible to minimise elevation differences between the antenna and the reading site (<10cm).

2.4 GRAVITY SURVEYING

During surveying, measurements of relative gravity were made using Scintrex CG-3 and CG-3M Autograv gravity meters. At each station, readings were averaged for a duration of 30 seconds with a minimum of 2 readings taken having a difference of less than 0.3μms^{-2}. During processing multiple gravity readings taken at each station were averaged.

All gravity surveying consisted of measuring data in independent, closed loops which started and finished at base 200580.9901. This was due to the fact the crew were based at Birrindudu Station (the site at which 200580.9901 was located) for the duration of the survey and it was convenient to start and end loops at this point. Loop duration was generally around 10 – 12 hours but in order to ensure data quality was high, a minimum of 5% of stations were repeated with both internal and external repeat readings taken.

Field notes were recorded by the operator at each station which included the station identifier (line and station number), relative gravity reading, time, measurements of distance and direction offset of the gravity meter from the GPS antenna and inclinometer measurements for Hammer Zones B and C if required. Digital data was recorded by the gravity meter which was downloaded at the end of each day and checked against field notes to ensure consistency.

Whenever possible gravity stations were located as far away as practical from abrupt changes in elevation in order to limit the effect of terrain on the gravity meter.

2.4.1 Datum Control

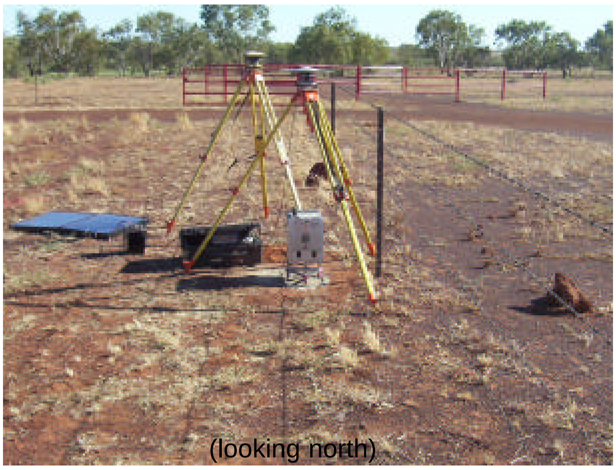
A primary gravity base station (200580.9901) was established at Birrindudu Station for the purpose of datum and drift control. This base station is located immediately west of an existing fence post (star picket), and marked with a flat topped concrete monument embedded with a brass plate stamped with the station number (figure 3). Base station 200580.9901 was tied to the Australian Fundamental Gravity Network (AFGN) by several A-B-A loops using multiple gravity meters. The tie was made to GA base station 6491.0129 at the Halls Creek Airport Terminal. Details for this base station can be found in Appendix E. Because of the large distance between the stations (a travel time of some 8 hours return trip) it was not possible to complete any more than one loop per day but to improve accuracy and confirm the reliability of the value for 200580.9901, several ties were done over a number of days using different gravity meters.

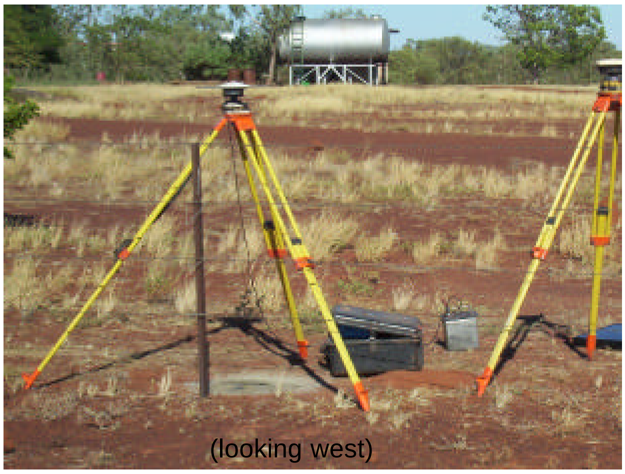
Results of the ties observed to the AFGN network using all gravity meters are shown below as is the final observed gravity value for 200580.9901 as used for final processing.

Tie	Observed Diff. (mGal)	Observed Grav. @ AFGN Stn (μms^{-2})	Calc. Observed Grav (μms^{-2})	Date of Observation	Meter used for Observation
200580.9901 – 6491.0129	+4.08	9784473.02	9784468.94	13/05/2005	9002133
200580.9901 – 6491.0129	+4.32	9784473.02	9784468.70	13/06/2005	9507283
200580.9901 – 6491.0129	+3.97	9784473.02	9784469.05	13/06/2005	9002133
200580.9901 – 6491.0129	+4.18	9784473.02	9784468.84	23/06/2005	9002133
200580.9901 – 6491.0129	+4.31	9784473.02	9784468.71	23/06/2005	9610353
200580.9901 – 6491.0129	+3.99	9784473.02	9784469.03	23/06/2005	9808440
		Average value:	9784468.88 μms^{-2}	$\pm$ 0.11μms^{-2}	

The ties shown above were completed with all gravity meters used on the survey.

Station ID:	200580.9901	Station Name:	Birrindudu Station			Date:	13/05/2005
HORIZONTAL DETAIL		VERTICAL DETAIL		MARK DETAIL		GRAVITY DETAIL	
Easting:	545479.780	Elevation:	369.48m	Mark Type:	Primary Base	Obs Gravity:	9784468.88
Northing:	7966801.900	N-Value:	29.86m	Witness Mark:	Star Picket		
Zone:	52	(Geoid98)		Witness Plate:	N/A		
Latitude:	-18° 23' 17.8078"			Monument Type:	Concrete block		
Longitude:	129° 25' 50.0167				Brass plate		
Datum:	GDA94	Datum:	AHD71	Plaque Stamped:	200580.9901	Datum:	IGSN71
Order:	1	Order:	3				(Isogal 84)
Method:	AUSPOS	Method:	GPS	Map Sheet: Birrindudu (SE 52-11)		Units:	μms^{-2}


(looking north)


(looking west)

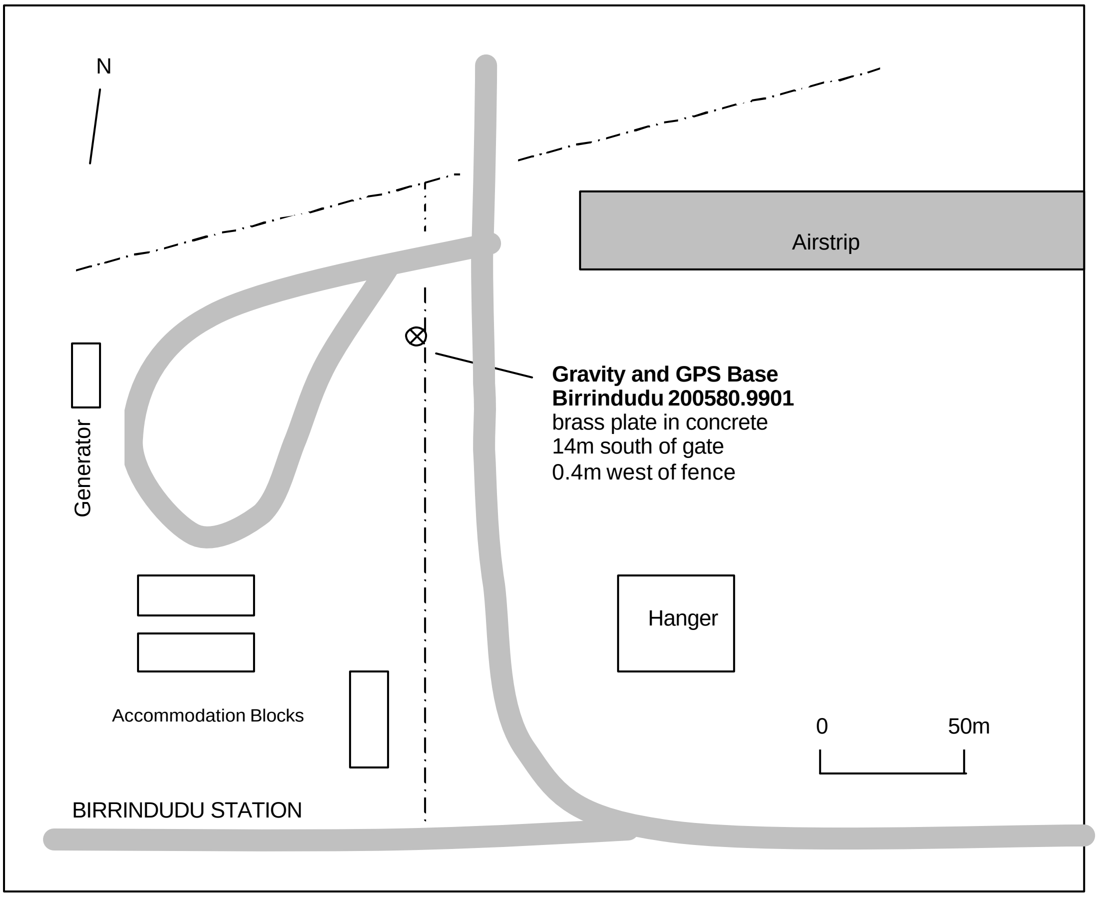


Figure 3. Primary Gravity Base Station 200580.9901

2.4.2 Drift Control

Drift has two components, a cyclic component due to the time varying gravitational effects of the sun and moon, and an approximately linear component due to instrumental drift. The tidal effects are removed using Longman's algorithm which calculates the tidal correction to a resolution of 0.1μms^{-2}. As the remaining drift is predominantly linear, gravity loop times can be extended to cover the full day.

This offers a number of advantages :

- Loops are directly tied to the primary base reducing accumulated errors generated from tying to secondary bases.
- Removes the need to set up a series of temporary bases along the survey line.
- Instrument drift rate is often less than reading error, even for long duration loops.

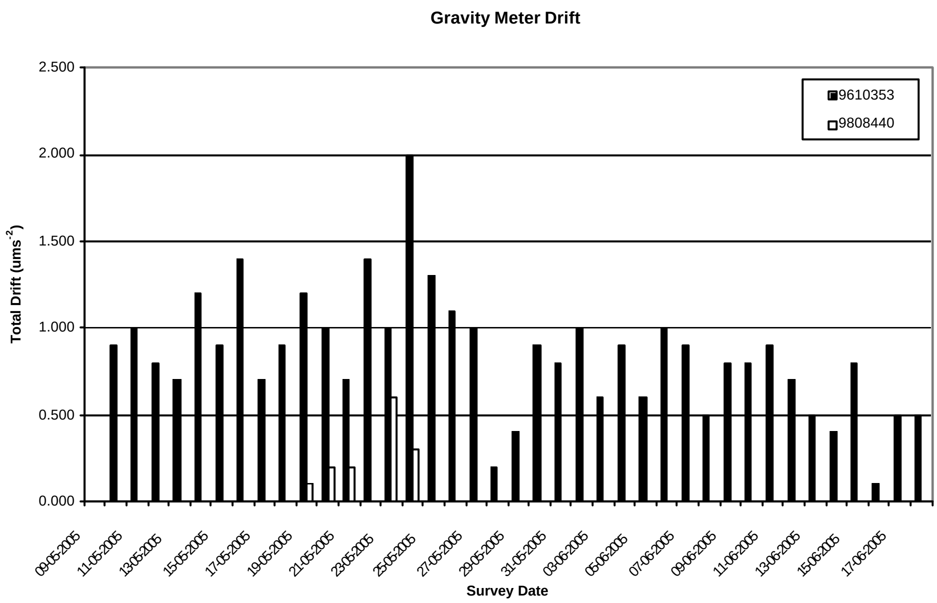


Figure 4. Instrument Drift Characteristics

Because the long term instrument drift of the CG-3 is extremely stable and linear (and larger than a conventional steel spring), a correction in real time (by the gravity meter software) is made leaving only a small residual which is determined using the daily base in and out readings. Whilst this feature is useful in most cases, when the value entered into the software is incorrect the result can be an apparently high drift or changes can occur in the drift rate from day to day if the value is changed in the software during the survey. Because the software only applies this correction linearly, neither of these problems affect the relative accuracy or precision of the loop data. Demonstration of the linearity of the drift can be seen by analysing the repeats within each loop.

2.4.3 Gravity Repeats

An operational procedure that includes at least 5% repeats provides both quality control and confirmation of the linearity of the mechanical drift. The repeats can also be used as secondary bases to isolate and reduce the amount of field data recovery in the instances where excessive tares have occurred. A total of 225 (6%) stations were repeated with an overall standard deviation of 0.21 μms^{-2}. The error distribution of the repeat readings is shown below.

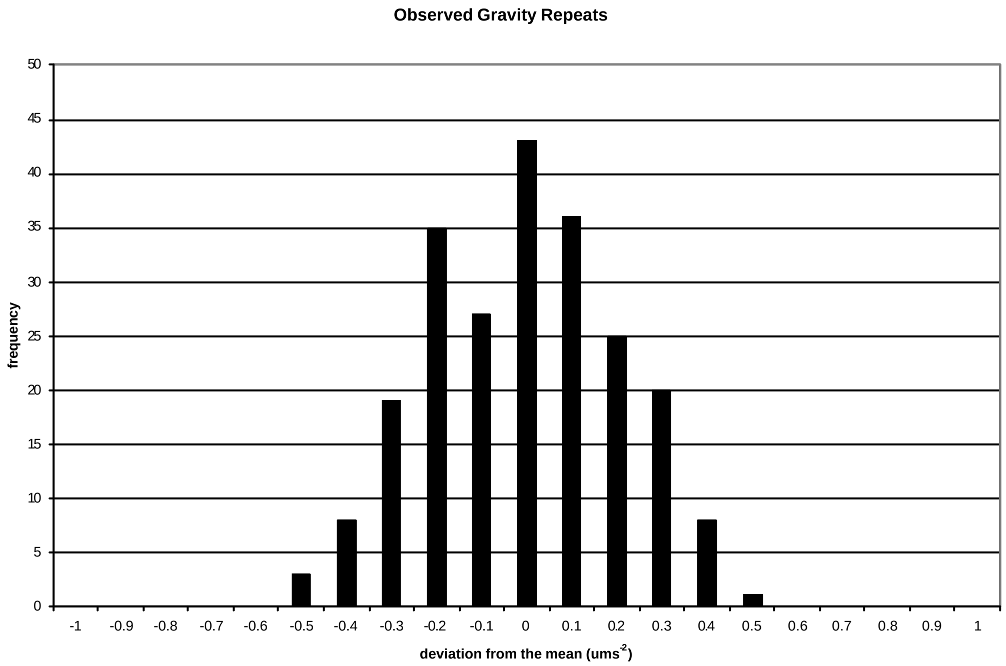


Figure 5. Observed Gravity Repeats

Repeat stations were marked using pin flags so that they could be easily identified and reoccupied.

2.5 GPS SURVEYING

FGG surveyed all gravity stations with GPS utilising Ashtech Z-Surveyors and Z-12 dual frequency geodetic receivers. Data was recorded continuously during the day at 5 second intervals and stored on either internal memory (Z-12) or removable PCMCIA cards (Z-Surveyor) and downloaded at the completion of each day.

In order to minimise the loss of survey data in the event of a hardware failure, two GPS receivers were used to log data in the helicopter at all times (logging simultaneously) in addition to two GPS receivers running concurrently at each field base station site.

2.5.1 Control Point Establishment

39 stations were established in order to provide positioning control during the survey. The primary GPS base station was located coincident with gravity base 200580.9901 (Birrindudu Station) and this station was used to establish all local field bases. In general, a receiver positioned at GPS base 200580.9901 logged each day in order to establish the local field base which was set out by the helicopter crew in the morning. For processing purposes, the local field base was used to correct the helicopter rover data in order to limit the baseline length (base – rover separation) to less than 30km. Base station 200580.9901 was then used to derive coordinates for the local field base via a static tie with approximately 8 – 10 hours of data providing extremely stable and reliable solutions. External repeats between loops established from different GPS base stations also demonstrate compatibility and consistency between the GPS base stations. Field bases were marked with a pin flag and established only for short term (one day) use.

Survey control station 200580.9901 was established using long baseline processing (AUSPOS). This facility is provided by GA, and uses the Australian Regional GPS Network (ARGN) base stations situated around Australia. The data processing is accurate to 10-20mm in the horizontal and 20-30mm in vertical ellipsoidal height provided sufficient data is observed at the field base. Files from logging on the 09-05-05 (5.5hrs) and 13-05-05 (10.5hrs) at 200580.9901 were submitted for processing with differences of 6mm in the easting, 0mm in the northing and 11mm in the elevation.

Because coordinates from the AUSPOS processing are generated in ITRF/GDA94, simply applying the Ausgeoid98 N-value to survey stations processed differentially from a base using these coordinates would result in an absolute error of around 0.3–0.5m in the AHD elevation (but this error would be consistent over the survey area making the relative error between stations much smaller). In order to improve the absolute error at each field station (to less than 0.1m) base station 200580.9901 was tied to the Northern Territory Survey Control Network at Benchmark FH 31. This benchmark is 3rd order and provided a means for tieing the survey to an accurate AHD reference datum providing 3rd order accuracy to the AHD elevations at each field station (relative to the accuracy/reliability of the original

AHD value at the benchmark). This benchmark was situated approximately 25km west of Birrindudu Station.

The preliminary tie to BM FH31 showed an absolute difference of 0.6m between the supplied 3rd order AHD and that calculated using AUSPOS derived base coordinates for 200580.9901. This difference is due only to the absolute error in the Ausgeoid98 grid in the area, which was used to derive AHD values initially. As a result, the base coordinates for 200580.9901 along with all field stations were adjusted for this difference.

Coordinates for the GPS control stations used during the survey are contained in the following table. Only station 200580.9901 was marked with a concrete monument for recovery, the other stations are marked only with a pin flag at the location of the GPS antenna.

		GDA94 (Zone 52)					Ausgeoid98	AHD71
Field_ID	Station_No	East	North	Lat	Long	h	N	H
257A	200580.9901	545479.78	7966801.90	-18.3882799	129.4305602	399.34	29.86	369.48
F02B	200580.8001	556014.95	7969977.88	-18.3593239	129.5302068	426.39	30.33	396.07
F03A	200580.8002	553971.25	7979980.38	-18.2689744	129.5105977	421.27	30.52	390.75
F04A	200580.8003	554574.25	7992021.72	-18.1601286	129.5159816	436.03	30.87	405.16
F05A	200580.8004	554097.44	7996016.99	-18.1240308	129.5113687	429.30	30.96	398.34
F06A	200580.8005	557658.82	7963659.35	-18.4163860	129.5459461	401.56	30.22	371.35
F07A	200580.8006	575991.46	7963905.34	-18.4135847	129.7195117	406.56	30.69	375.87
F08B	200580.8007	575959.98	7971860.74	-18.3416884	129.7189156	467.74	30.91	436.83
F09B	200580.8008	574045.71	7978060.71	-18.2857226	129.7005738	435.16	31.04	404.12
F10A	200580.8009	552019.16	7948045.83	-18.5576445	129.4929514	432.38	29.67	402.71
F11A	200580.8010	601913.99	7985893.78	-18.2137862	129.9638318	472.88	31.73	441.16
F12A	200580.8011	551975.41	7941916.41	-18.6130417	129.4926961	446.27	29.51	416.76
F13A	200580.8012	568023.41	8004110.56	-18.0504867	129.6427353	453.16	31.63	421.53
F14A	200580.8013	548061.05	7925928.33	-18.7576307	129.4559776	452.97	28.91	424.06
F15A	200580.8014	604110.58	7997958.77	-18.1046475	129.9839926	466.24	32.09	434.16
F16A	200580.8015	545856.28	7919969.77	-18.8115318	129.4351986	417.93	28.64	389.28
F17A	200580.8016	594101.93	7953895.16	-18.5033212	129.8914405	420.38	30.69	389.69
F18A	200580.8017	521952.13	7947913.10	-18.5593731	129.2080297	396.13	28.75	367.38
F19A	200580.8018	548007.13	7915873.74	-18.8485012	129.4557106	425.06	28.58	396.49
F20A	200580.8019	510045.00	7936104.13	-18.6661939	129.0952512	417.78	28.16	389.62
F22B	200580.8020	549974.30	7903995.40	-18.9558047	129.4746862	444.98	28.30	416.68
F23A	200580.8021	507984.40	7923969.55	-18.7758745	129.0757605	451.03	27.77	423.25
F24A	200580.8022	613992.05	8003985.31	-18.0496866	130.0770427	450.45	32.31	418.14
F25A	200580.8023	639906.24	7999951.96	-18.0846136	130.3221197	400.13	32.27	367.86
F26A	200580.8024	637973.55	7992053.31	-18.1561114	130.3043877	389.86	31.98	357.88
F27A	200580.8025	638111.68	7979976.18	-18.2652325	130.3065069	412.24	31.55	380.69
F28A	200580.8026	637967.56	7967995.06	-18.3735029	130.3059558	410.01	31.15	378.86
F29A	200580.8027	638060.97	7958094.25	-18.4629594	130.3075155	397.08	30.82	366.26
F30A	200580.8028	638026.69	7948060.87	-18.5536212	130.3078795	432.03	30.51	401.52
F31A	200580.8029	638043.95	7935951.68	-18.6630350	130.3088794	446.78	30.17	416.61

F32A	200580.8030	638008.95	7923993.05	-18.7710906	130.3093791	404.66	29.80	374.86
F33A	200580.8031	638002.35	7907962.21	-18.9159371	130.3104400	463.26	29.28	433.98
F34A	200580.8032	609925.09	7912042.31	-18.8807582	130.0436329	517.26	29.63	487.63
F35A	200580.8033	584016.41	7913981.46	-18.8644519	129.7975924	459.85	29.40	430.45
F36A	200580.8034	513901.89	7923844.49	-18.7769735	129.1319098	433.14	27.91	405.23
F37A	200580.8035	600065.70	7925937.08	-18.7556983	129.9493324	484.80	29.97	454.83
F38A	200580.8036	524071.24	7925916.15	-18.7581571	129.2283772	434.12	28.22	405.90
F39A	200580.8037	593932.13	7946027.62	-18.5744281	129.8902003	444.66	30.48	414.18
F40A	200580.8038	595939.98	7934012.77	-18.6829143	129.9098046	469.76	30.18	439.58
FH31	(NT_Surveys)	500049.66	7973439.20	-18.3287773	129.0004700	399.63	28.68	370.95

Station FH31 is Benchmark FH31 with a supplied 3rd order AHD elevation but scaled horizontal coordinates (+/- 500m). From the GPS observations made during this survey 1st order X and Y coordinates have been generated and are shown in the table above. GPS field base stations have been number in the range 200580.8001 – 200580.8038. Figure 6 shows the GPS base station network established during the survey.

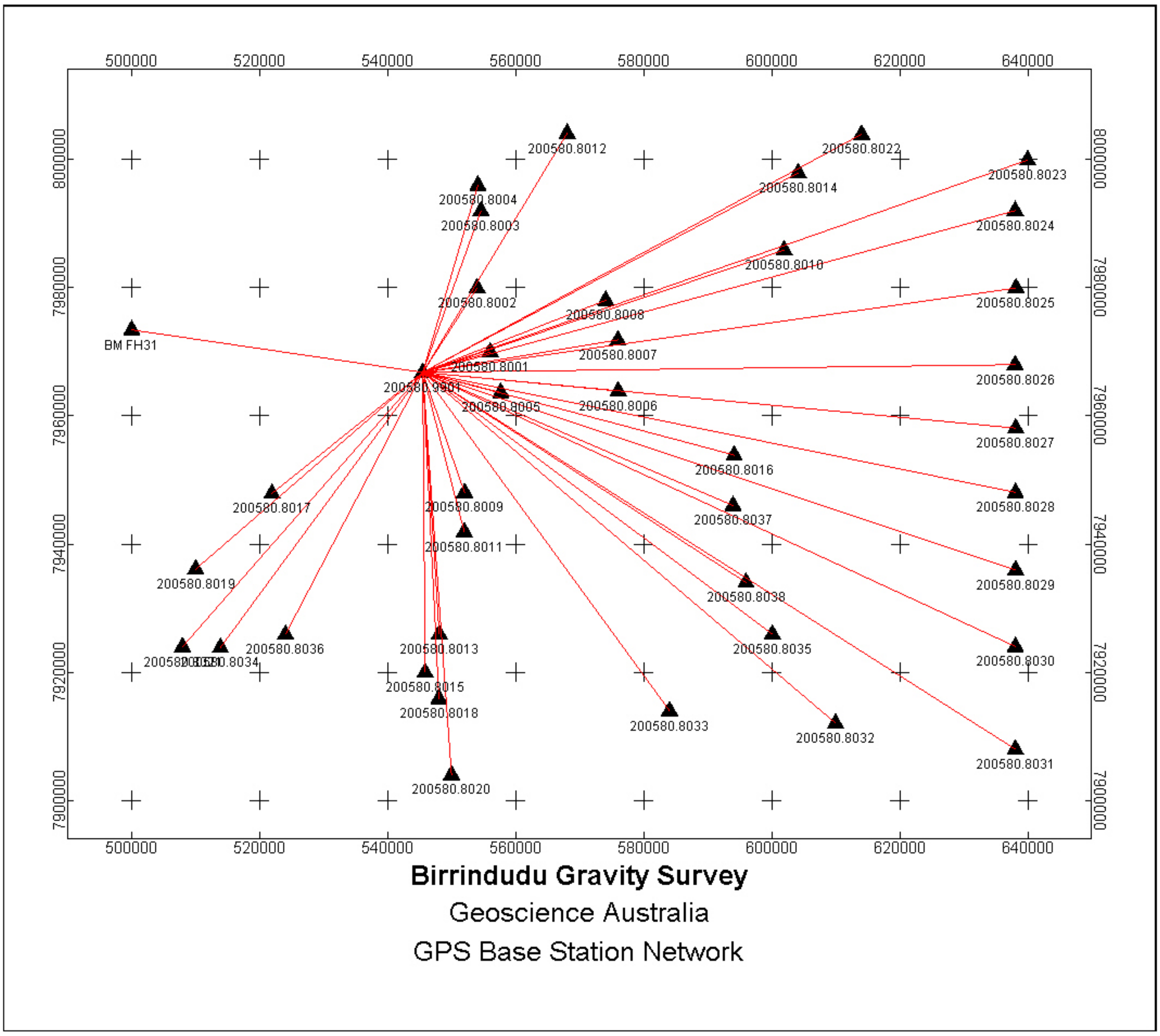


Figure 6. GPS Base Station Network

2.5.2 GPS Repeats

In order to demonstrate the repeatability and reliability of the GPS data, 205 (5.5%) repeats were observed with an overall standard deviation of 0.04m. The error distribution is shown as follows.

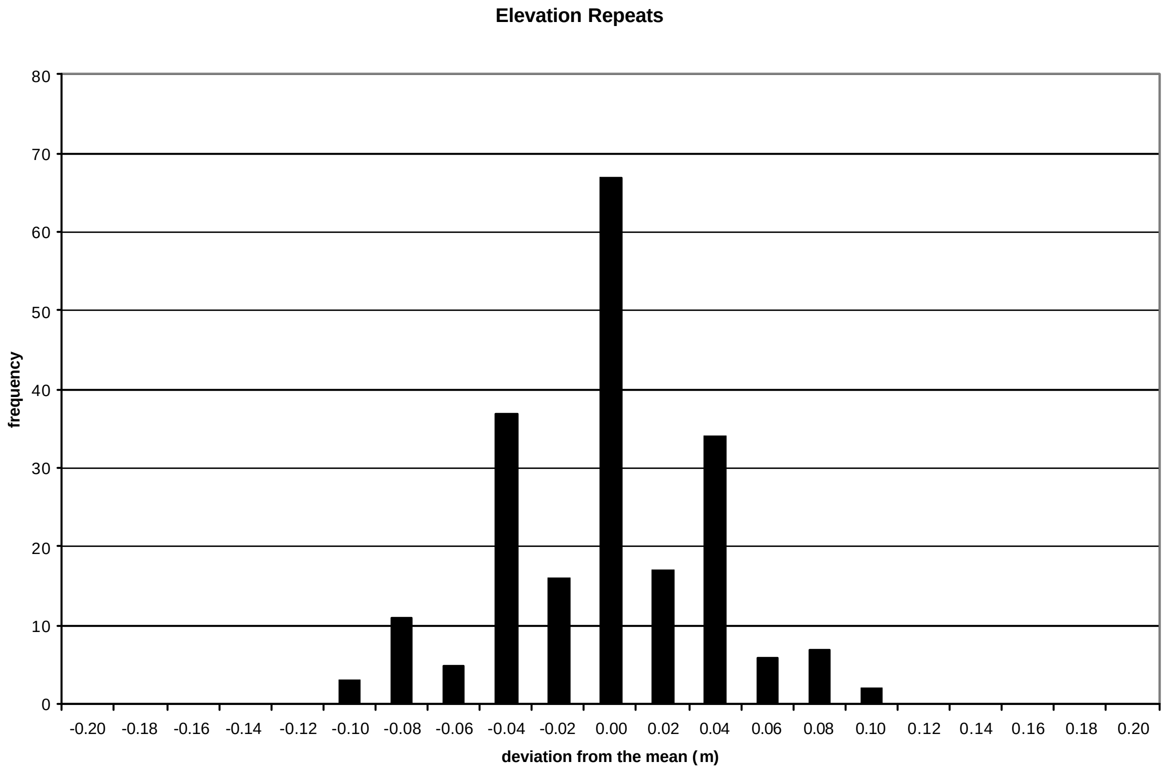


Figure 7. Elevation Repeats

3. DATA PROCESSING

3.1 OBSERVED GRAVITY

The following corrections are applied to the raw gravity data to obtain observed gravity (g_o):

Instrument correction: Not required for Scintrex CG3 gravimeters as all necessary factors are applied internally.

Tidal correction: To correct for the differential gravitational effects of the moon and sun. Longman's polynomial approximation of tidal effect is applied to the base-out, base-in readings before the loop drift rate is calculated and is also applied to each station within the loop. The Longman's formulae are published in the Journal of Geophysical Research, Vol 64, No 12.

Mechanical drift: removed with the assumption that the drift between base-out and base-in is linear. This is a valid assumption when the non-linear components (tidal) have been removed before the drift rate is calculated and the meter has not suffered significant tares during the course of the loop.

The following equation summarises theses corrections to obtain observed gravity:

$$g_o = g_{stn} + C_{tide} - C_{drift} - g_{base-out} + g_{0(base)}$$

where:

g_o=	observed gravity
g_{stn}=	raw gravity reading at each station
C_{tide}=	tidal effect
$g_{0(base)}$	absolute value of gravity at the base

$$C_{drift} = (g_{base-out} - g_{base-in})/(t_{base-out} - t_{base-in}) \times t_{stn}$$

$g_{base-out}$, $g_{base-in}$	are base readings at start and end of loops
$t_{base-out}$, $t_{base-in}$	are base times at start and end of loops

3.2 BOUGUER GRAVITY

Bouguer gravity is calculated using equation:

$$G_b = G_o - G_t + C_{fa} - C_b + C_t$$

where

G_o=	observed gravity described above
G_t=	theoretical gravity calculated from the station's latitude.
C_{fa}=	free air correction
C_b=2pG?h	Bouguer correction, G=universal gravity constant, ?=density
C_t=	terrain correction

Latitude Correction - To correct observed gravity for the effects of the differential centrifugal acceleration due to the reduction in angular velocity at the surface of the earth with latitude (this acceleration is at its maximum at the equator where the observed gravity will be at its minimum). This correction is solely a function of latitude (f) obtained from survey co-ordinates.

For this survey the 1967 gravity formula is used to calculate the theoretical gravity g_t (using updated constants as supplied in GA Deed 2004/1163 – Schedule 3; Section 1.4 *Gravity Data Processing*)

$$g_t = 9780318.456 \times (1 + 0.005278895 \times \sin^2 (f) - 0.000023462 \times \sin^4 (f))$$

Free Air Correction - To correct for the fact that gravity decreases (as the square of the distance) from the elevation datum. This correction is a function of station elevation above the datum and the formula used was

$$FAC = (3.08768 – 0.00440\sin^2 (f))*h – 0.000001442*h^2 \ \mu ms^{-2}/metre.$$

Bouguer Correction - Corrects for the gravitational attraction of the rock between the station and elevation datum. This correction is dependent on elevation and the rock density and is approximately 2pG?h = 0.4191? μms^{-2}/meter. For this survey, a density of 2.67 gms/cc was used for the Bouguer corrections.

Terrain Correction - Corrects for the effects of surrounding topographic features which deviates from the infinite slab that is implicit in the Bouguer correction. Quite small hills close to the reading site can have significant effects on gravity. Major features can have effects in excess of 20 km from the reading site.

3.3 TERRAIN CORRECTIONS

Due to the variation in terrain of the north-eastern section of the survey area (comprising both near meter and under meter terrain effects) terrain corrections were applied using Shuttle Radar Topography Mission (SRTM) data. Terrain correction calculations were completed using in-house software for a Bouguer Density of 2.67gm/cc. SRTM data is a 3' x 3' grid (approx 90m x 90m) with a vertical precision of about 15m. Corrections calculated with this data were applied a minimum of 100m from the point to minimise the effects of elevation errors on the station, with corrections for Hammer zones B and C determined from in-field inclinometer readings. Inclinometer readings are converted to height differences between each Hammer Sector and the gravity observation point and the Hammer formula is then used to derive sector terrain corrections from sector height differences.

The SRTM data was re-sampled to 45m to provide an improved approximation of the terrain gradient. Each gridded cell is treated as a prism with height $\Delta h =$ terrain height at the cell – gravity observation height and positioned using the vector distance between the gravity measured at the centre of the gridded cell and the gravity observation point.

The gravity effect of each prism up to a maximum of 10km is calculated and summed to derive the total terrain correction. The 10m limit is considered an appropriate maximum distance for calculating the terrain correction for each gravity station as Δh never exceeds 250m over the survey area.

To minimise level shifts between the SRTM and gravity survey elevation datum, a best fit height adjustment was calculated and applied after comparing gravity station heights that were located close to the SRTM cell centres in low gradient areas. Although the quoted accuracy of the SRTM data is 15m, the typical accuracy after adjustment in this case was less than 5m (in low gradient areas).

3.4 GPS

3.4.1 ELLIPSOID-GEOID SEPARATION

All elevation data in the field was processed on the GDA94 datum and then converted to Australian Height Datum (AHD) values using Ausgeoid 98 values. This was performed using in-house (GPSGrav) software. The calculation takes the form:

$$H_{orthometric} = h_{ellipsoidal} - N$$

Where $h_{ellipsoidal}$ – is the GDA94 elevation
$H_{orthometric}$ – is the AHD elevation
N is the AusGeoid98 geoid-ellipsoid separation value

3.5 OFFICE REPROCESSING

As a standard procedure, all data is routinely checked throughout the survey, and undergoes a final checking process via a reprocessing sequence if required subsequent to the completion of the survey.

The following data integrity checks were made:

All data entry of raw gravity are checked against field books

GPS and Gravity Base station ties are checked and reprocessed

4. ERROR ANALYSIS

The total probable error in the final Bouguer Gravity data, e_{bg}, is calculated using: (from Appendix F)

$$e_{bg}{}^2 = e_g{}^2 + e_{gt}{}^2 + (c*e_h)^2$$

where

e_g is the error in the observed gravity

e_{gt} is the error in the theoretical gravity value used

e_h is the error in the elevation value

c=(3.08768-2p?G)

where G=6.67x10^{-8} (dyne cm^2)/g Universal Gravity Constant

?=2.67 g/cc

c=1.967 µms^{-2}/metre

From preceding sections

e_g = 0. 21 x 0.707 = 0.1485 µms^{-2}

e_h = 0.040 x 0.707 = 0.0283 metres

e_{gt} = 0.0081 sin(2 x latitude) µms^{-2}/metre x northing error

= 0.001 µms^{-2}

It follows that the probable Bouguer error for the survey

$e_{bg}{}^2$ = 0.1485^2 + 0.001^2 + (0.0283 x 1.967)^2

e_{bg} = 0.15 µms^{-2}

5. DATA PRODUCTS

5.1 FIELD DATA PRODUCTS

Preliminary field data was sent during the survey and upon completion of the field work to GA. Data was sent in the form of located TIFF images with a weekly report on operations and survey progress.

5.2 FINAL DATA PRODUCTS

Verification images of terrain corrected Bouguer Gravity at a density of 2.67gm/cc as well as a map of AHD elevation can be found in Appendix G. Final digital data is contained on a CD appended to this report.

5.2.1 Final Data Format

The final data is supplied in a ASEG-GDF format including definition and projection files. All horizontal coordinate data has been supplied in GDA94, elevation data in AHD71 and gravity data in μms^{-2} on the AFGN (Isogal84). Bouguer Gravity data have been terrain corrected.

For and on behalf of Fugro Ground Geophysics

Peter Johnson
Operations Manager
Fugro Ground Geophysics

APPENDIX A

GRAVITY LOOP STATISTICS

GRAVITY LOOP STATISTICS

LOOP	DATE	READ	REPT	DRIFT	METER	G FACT	BASEOUT	BASEIN
101	09-05-2005	15	1	0.000	9610353	1.00000	200580.9901	200580.9901
102	10-05-2005	84	3	0.900	9610353	1.00000	200580.9901	200580.9901
103	11-05-2005	97	4	1.000	9610353	1.00000	200580.9901	200580.9901
104	12-05-2005	106	3	0.800	9610353	1.00000	200580.9901	200580.9901
105	13-05-2005	100	2	0.700	9610353	1.00000	200580.9901	200580.9901
106	14-05-2005	101	3	1.200	9610353	1.00000	200580.9901	200580.9901
107	15-05-2005	106	4	0.900	9610353	1.00000	200580.9901	200580.9901
108	16-05-2005	103	5	1.400	9610353	1.00000	200580.9901	200580.9901
109	17-05-2005	79	4	0.700	9610353	1.00000	200580.9901	200580.9901
110	18-05-2005	89	2	0.900	9610353	1.00000	200580.9901	200580.9901
111	19-05-2005	85	4	1.200	9610353	1.00000	200580.9901	200580.9901
211	20-05-2005	3	0	0.100	9610353	1.00000	200580.9901	200580.9901
112B	20-05-2005	13	0	0.200	9808440	1.00000	200580.9901	200580.9901
112A	20-05-2005	100	10	1.000	9610353	1.00000	200580.9901	200580.9901
113B	21-05-2005	4	0	0.200	9808440	1.00000	200580.9901	200580.9901
113A	21-05-2005	107	7	0.700	9610353	1.00000	200580.9901	200580.9901
114	22-05-2005	102	5	1.400	9610353	1.00000	200580.9901	200580.9901
215	23-05-2005	16	1	0.600	9808440	1.00000	200580.9901	200580.9901
115	23-05-2005	86	8	1.000	9610353	1.00000	200580.9901	200580.9901
216	24-05-2005	5	1	0.300	9808440	1.00000	200580.9901	200580.9901
116	24-05-2005	99	5	2.000	9610353	1.00000	200580.9901	200580.9901
117	25-05-2005	109	6	1.300	9610353	1.00000	200580.9901	200580.9901
118	26-05-2005	104	6	1.100	9610353	1.00000	200580.9901	200580.9901
119	27-05-2005	91	4	1.000	9610353	1.00000	200580.9901	200580.9901
120	28-05-2005	42	2	0.200	9610353	1.00000	200580.9901	200580.9901
121	29-05-2005	35	2	0.400	9610353	1.00000	200580.9901	200580.9901
122	30-05-2005	101	6	0.900	9610353	1.00000	200580.9901	200580.9901
123	31-05-2005	112	6	0.800	9610353	1.00000	200580.9901	200580.9901
124	02-06-2005	104	5	1.000	9610353	1.00000	200580.9901	200580.9901
125	03-06-2005	99	9	0.600	9610353	1.00000	200580.9901	200580.9901
126	04-06-2005	111	9	0.900	9610353	1.00000	200580.9901	200580.9901
127	05-06-2005	114	6	0.600	9610353	1.00000	200580.9901	200580.9901
128	06-06-2005	112	9	1.000	9610353	1.00000	200580.9901	200580.9901
129	07-06-2005	110	9	0.900	9610353	1.00000	200580.9901	200580.9901
130	08-06-2005	110	7	0.500	9610353	1.00000	200580.9901	200580.9901
131	09-06-2005	114	6	0.800	9610353	1.00000	200580.9901	200580.9901
132	10-06-2005	114	5	0.800	9610353	1.00000	200580.9901	200580.9901
133	11-06-2005	112	6	0.900	9610353	1.00000	200580.9901	200580.9901
134	12-06-2005	118	6	0.700	9610353	1.00000	200580.9901	200580.9901
135	13-06-2005	112	5	0.500	9610353	1.00000	200580.9901	200580.9901

LOOP	DATE	READ	REPT	DRIFT	METER	G FACT	BASEOUT	BASEIN
136	14-06-2005	96	7	0.400	9610353	1.00000	200580.9901	200580.9901
137	15-06-2005	108	8	0.800	9610353	1.00000	200580.9901	200580.9901
138	16-06-2005	106	5	0.100	9610353	1.00000	200580.9901	200580.9901
139	17-06-2005	120	7	0.500	9610353	1.00000	200580.9901	200580.9901
140	18-06-2005	100	9	0.500	9610353	1.00000	200580.9901	200580.9901

Notes:

1. Loop number is in format **cdd** where **c** is crew number, **dd** is day number
2. **DATE** is date of loop acquisition in format **dd-mm-yyyy**
3. **READ** is number of stations observed within the loop
4. **REPT** is number of repeats contained within the loop
5. **DRIFT** is total meter drift for the loop in μms^{-2}
6. **METER** is the gravity meter serial number used to observe loop
7. **G-FACTOR** is calibration constant for loop meter (1.00000 for CG-3)
8. **BASEOUT / BASEIN** are loop gravity base station used (morning / afternoon)
9. All loops have a minimum 1 repeat reading. Those in the table above which show 0 have been reported in other loops

APPENDIX B

SURVEY METADATA

Name:	Birrindudu Gravity Survey
Start Date:	May 9, 2005
End Date:	June 18, 2005
Operators:	Geoscience Australia & Northern Territory Geological Survey
Contractor:	Fugro Ground Geophysics Pty Ltd
Processors:	Gregory Kunda & Ray Lockwood
Software:	PNAV (GPS post processing), GRAVI (GPS/Gravity data file merging and manipulation, and terrain corrections), Geosoft Oasis Montaj (imaging / flight planning)
Vessel Type:	Helicopter – *Robinson R44*
Geodetic Datum:	Geocentric Datum of Australia 1994
Projection:	Map Grid of Australia (Zone 52)
Horizontal Accuracy:	< 0.1m
Location Method:	real time GPS (non-corrected)
Gravity Station Spacing Minimum:	nominal 2km x 2km
Gravity Station Spacing Maximum:	nominal 2km x 2km
Gravity Stations:	3728
Elevation Accuracy:	< 0.1m
Elevation Datum:	AHD71
Gravity Accuracy:	< 0.5μms^{-2}
Gravity Datum:	IGSN71
Terrain Correction:	using in-house software (based on using prisms to approximate terrain and compute terrain effect)
Computation Method:	
Layout:	combination traverse & cell centre method
Equipment Details:	Ashtech Z-Surveyors: s/n UZ01196, UZ01197, UZ01198, UZ02540, UZ01097 Ashtech Z-12: s/n 04998, 02272 Scintrex CG-3/M Gravity Meters: s/n 9610353, 9808440, 9002133, 9507283
Gravity Observers:	Gregory Kunda, Keith Clinton & Laurie Murphy
Fundamental Gravity:	Halls Creek Airport Terminal – **6491.0129**
Base Station Ties:	A – B – A; Completed on 13/05/05 & 23/06/05 using 4 gravity meters
Any Other Information:	

APPENDIX C

GRAVITY METER CALIBRATION RANGE RESULTS

Notes:

1. Calibration range testing was completed between GA stations 7391.0217 (Mt Gungin) and 8090.0317 (Weir Pumping Station)
2. All values shown are differences only in gravity between the range stations (not observed gravity values) in μms^{-2}

Fugro Ground Geophysics Gravity Reduction Report: Calibration Range Data

Base station for current loop: 7391.0217
Observed gravity at base: 0.00
Gravity Data units: μms^{-2}
Survey date: 11/07/05
Current date: 12/07/05
Gravity meter serial number: **9808440**
Gravity meter operator(s): 1

STATION	OBSGRAV	TIME	DATE	GRAVREF	METERNO
8090.0317	541.50	14:05:04	110705	7391.0217	9808440
8090.0317	541.65	15:05:40	110705	7391.0217	9808440
Average Value:	541.57 μms^{-2}				
Max Repeat Error:	0.15 μms^{-2}				
Std Dev:	0.13 μms^{-2}				
Obs. difference:	541.57 μms^{-2}				
**Published Value:	541.80 μms^{-2}				
Error:	-0.23 μms^{-2}				

Calibration constant error = 0.04%

```
----------------------------------------------------------------------------------------------------------
Fugro Ground Geophysics Gravity Reduction Report: Calibration Range Data

Base station for current loop: 7391.0217
     Observed gravity at base: 0.00
           Gravity Data units: µms-2
                  Survey date: 11/07/05
                 Current date: 12/07/05
  Gravity meter serial number: 9002133
    Gravity meter operator(s): 1
----------------------------------------------------------------------------------------------------------
           STATION      OBSGRAV       TIME    DATE     GRAVREF     METERNO
         8090.0317       541.68   14:02:38  110705   7391.0217     9002133
         8090.0317       541.61   15:04:07  110705   7391.0217     9002133
    Average Value:       541.64 µms-2
 Max Repeat Error:         0.07 µms-2
          Std Dev:         0.13 µms-2
  Obs. difference:       541.64 µms-2
**Published Value:       541.80 µms-2
                   ------------
            Error:        -0.16 µms-2
                   ------------

Calibration constant error = 0.03%
```

Fugro Ground Geophysics Gravity Reduction Report: Calibration Range Data

Base station for current loop: 7391.0217
Observed gravity at base: 0.00
Gravity Data units: μms^{-2}
Survey date: 11/07/05
Current date: 12/07/05
Gravity meter serial number: **9507283**
Gravity meter operator(s): 1

STATION	OBSGRAV	TIME	DATE	GRAVREF	METERNO
8090.0317	541.88	14:02:35	110705	7391.0217	9507283
8090.0317	541.82	15:04:21	110705	7391.0217	9507283

Average Value:	541.85 μms^{-2}
Max Repeat Error:	0.06 μms^{-2}
Std Dev:	0.00 μms^{-2}
Obs. difference:	541.85 μms^{-2}
**Published Value:	541.80 μms^{-2}
Error:	0.05 μms^{-2}

Calibration constant error = 0.01%

```
----------------------------------------------------------------------------------------------------
Fugro Ground Geophysics Gravity Reduction Report: Calibration Range Data

Base station for current loop: 7391.0217
     Observed gravity at base: 0.00
           Gravity Data units: μms-2
                  Survey date: 11/07/05
                 Current date: 12/07/05
  Gravity meter serial number: 9610353
    Gravity meter operator(s): 1
----------------------------------------------------------------------------------------------------
           STATION      OBSGRAV       TIME    DATE     GRAVREF     METERNO
         8090.0317       541.64   14:02:18  110705   7391.0217     9610353
         8090.0317       541.79   15:03:40  110705   7391.0217     9610353
    Average Value:       541.72 μms-2
 Max Repeat Error:         0.15 μms-2
          Std Dev:         0.13 μms-2
  Obs. difference:       541.72 μms-2
**Published Value:       541.80 μms-2
                   ------------
           Error:        -0.08 μms-2
                   ------------

Calibration constant error = 0.01%
```

APPENDIX D

GRAVITY REPEAT STATION LISTING

Notes:

1. Listing is based on line/station identifiers. To convert to GA number format add line & station together with prefix “200580.” (ie line 44, station 30 is 200580.4430)
2. Loop is in the format **CCDD** where CC is crew number and DD is survey day number (day number is a serial day count since the start of the survey with day 1 being Monday, 09/05/05)
3. **All gravity data is in milligals**
4. Deviation from mean is the standard deviation of all readings taken at the station

GRAVITY REPEATS - Deviation from the Mean

Line	Station	Loop Time	Obs_Grav	Dev from Mean
11	14	0123/15.10	978447.941	0.000
11	14	0136/10.46	978447.940	-0.001
AVG	978447.941	STD 0.001	505882	7900007
11	22	0122/16.49	978436.978	0.009
11	22	0136/11.23	978436.961	-0.009
AVG	978436.970	STD 0.012	521865	7899932
11	75	0133/16.17	978494.358	-0.017
11	75	0134/08.43	978494.381	0.006
11	75	0145/15.38	978494.385	0.010
AVG	978494.375	STD 0.015	628062	7899971
12	71	0134/09.04	978473.271	-0.004
12	71	0145/15.27	978473.280	0.004
AVG	978473.275	STD 0.006	619907	7902027
13	36	0122/07.31	978459.446	0.039
13	36	0122/10.47	978459.377	-0.030
13	36	0122/14.07	978459.429	0.022
13	36	0122/15.41	978459.380	-0.027
13	36	0122/17.05	978459.402	-0.005
AVG	978459.407	STD 0.030	549975	7904009
13	72	0145/15.09	978476.186	0.003
13	72	0145/15.48	978476.180	-0.003
AVG	978476.183	STD 0.004	621879	7904122
14	21	0136/17.17	978433.154	-0.030
14	21	0138/13.47	978433.214	0.030
AVG	978433.184	STD 0.042	520013	7905948
14	26	0136/16.54	978447.076	-0.005
14	26	0138/10.32	978447.087	0.005
AVG	978447.082	STD 0.008	530021	7906025
14	45	0116/08.59	978487.763	0.027
14	45	0122/09.18	978487.708	-0.027
AVG	978487.735	STD 0.039	568019	7906140
14	51	0135/08.00	978478.813	0.010
14	51	0135/09.49	978478.792	-0.010
AVG	978478.802	STD 0.015	580004	7906036
14	89	0133/13.28	978464.239	-0.007
14	89	0133/14.56	978464.254	0.008
AVG	978464.246	STD 0.011	656106	7905999
15	80	0133/07.46	978454.802	0.027
15	80	0133/10.38	978454.794	0.019
15	80	0133/12.42	978454.774	-0.001
15	80	0133/16.53	978454.730	-0.045
AVG	978454.775	STD 0.032	637997	7907981

```
Line       Station Loop  Time    Obs_Grav  Dev from Mean

16             36 0119/16.08 978460.604      0.026
16             36 0122/11.22 978460.551     -0.026
AVG  978460.578 STD     0.037  549904 7909951

16             57 0134/14.04 978467.087     -0.023
16             57 0135/11.13 978467.134      0.023
AVG  978467.110 STD     0.033  592065 7910030

16             69 0134/07.55 978465.647      0.007
16             69 0134/11.10 978465.634     -0.007
AVG  978465.640 STD     0.009  615979 7910025

17             66 0134/07.32 978460.758      0.036
17             66 0134/13.24 978460.723      0.001
17             66 0134/17.19 978460.686     -0.036
AVG  978460.722 STD     0.036  609910 7912035

17             77 0133/11.10 978456.226      0.019
17             77 0134/11.50 978456.188     -0.019
AVG  978456.207 STD     0.027  631909 7912018

18             12 0120/09.47 978441.404      0.023
18             12 0123/08.13 978441.357     -0.023
AVG  978441.380 STD     0.033  501950 7914118

18             27 0119/12.43 978455.899      0.019
18             27 0119/15.11 978455.861     -0.019
AVG  978455.880 STD     0.027  531939 7914065

18             53 0135/07.28 978467.021      0.018
18             53 0135/13.11 978466.999     -0.004
18             53 0135/17.18 978466.990     -0.013
AVG  978467.003 STD     0.016  584013 7913996

19             16 0123/15.58 978448.651      0.022
19             16 0136/07.57 978448.608     -0.022
AVG  978448.630 STD     0.030  509929 7915984

19             35 0119/07.35 978458.777      0.015
19             35 0119/16.17 978458.746     -0.015
AVG  978458.762 STD     0.022  548012 7915892

19             45 0116/09.27 978475.253      0.023
19             45 0216/09.32 978475.207     -0.023
AVG  978475.230 STD     0.033  568081 7916102

19             90 0132/14.34 978463.099     -0.034
19             90 0133/08.52 978463.168      0.034
AVG  978463.133 STD     0.049  658020 7916043

20             17 0123/17.10 978448.734      0.021
20             17 0136/07.48 978448.693     -0.021
AVG  978448.714 STD     0.029  512072 7917979
```

```
Line       Station Loop  Time    Obs_Grav  Dev from Mean

20             72 0132/16.41 978488.157     -0.036
20             72 0133/11.55 978488.230      0.037
20             72 0134/16.49 978488.149     -0.044
20             72 0137/10.44 978488.236      0.043
AVG  978488.193 STD     0.046  622057 7918001

21             34 0116/07.26 978458.205      0.047
21             34 0116/14.03 978458.145     -0.013
21             34 0116/16.45 978458.121     -0.036
21             34 0119/08.54 978458.159      0.002
AVG  978458.157 STD     0.035  545878 7919979

21             35 0114/16.48 978461.205     -0.040
21             35 0116/07.34 978461.284      0.039
AVG  978461.245 STD     0.056  547960 7920050

21             48 0114/15.20 978466.565     -0.007
21             48 0135/16.44 978466.553     -0.019
21             48 0216/09.54 978466.597      0.025
AVG  978466.572 STD     0.023  573871 7919905

22             27 0119/09.35 978448.403      0.018
22             27 0119/11.47 978448.368     -0.018
AVG  978448.386 STD     0.025  531999 7921891

22             44 0114/09.14 978477.401      0.038
22             44 0114/14.55 978477.324     -0.038
AVG  978477.363 STD     0.054  566087 7921997

22             54 0135/17.10 978468.350     -0.024
22             54 0137/08.10 978468.399      0.024
AVG  978468.374 STD     0.035  585885 7922043

23             15 0123/07.26 978442.118      0.009
23             15 0123/09.59 978442.098     -0.012
23             15 0123/13.47 978442.094     -0.015
23             15 0123/17.17 978442.128      0.019
AVG  978442.110 STD     0.016  507981 7923984

23             18 0136/07.26 978446.945      0.003
23             18 0136/13.02 978446.947      0.005
23             18 0136/17.28 978446.935     -0.007
AVG  978446.942 STD     0.006  513897 7923858

23             48 0114/09.40 978466.382      0.002
23             48 0137/08.43 978466.378     -0.002
AVG  978466.380 STD     0.003  573980 7923927

23             72 0132/08.24 978477.809     -0.025
23             72 0137/11.26 978477.859      0.025
AVG  978477.834 STD     0.035  622034 7924051

23             80 0132/07.33 978463.987      0.009
23             80 0132/10.45 978463.992      0.014
23             80 0132/17.10 978463.955     -0.023
AVG  978463.978 STD     0.020  638001 7924007
```

Line	Station	Loop	Time	Obs_Grav	Dev from Mean
23	90	0132/09.50		978468.390	0.004
23	90	0132/13.32		978468.381	-0.004
AVG	978468.386 STD	0.006	658023 7923980		
24	23	0138/07.16		978446.768	-0.008
24	23	0138/12.45		978446.777	0.001
24	23	0138/16.15		978446.782	0.006
AVG	978446.776 STD	0.007	524077 7925901		
24	35	0114/07.35		978462.102	0.044
24	35	0114/13.59		978462.037	-0.021
24	35	0114/16.57		978462.034	-0.024
AVG	978462.058 STD	0.038	548047 7925934		
24	61	0137/07.26		978453.656	0.011
24	61	0137/09.46		978453.689	0.044
24	61	0137/14.07		978453.613	-0.032
24	61	0137/17.21		978453.622	-0.023
AVG	978453.645 STD	0.035	600049 7925933		
25	56	0137/14.35		978473.373	-0.015
25	56	0140/15.40		978473.404	0.015
AVG	978473.389 STD	0.022	589935 7927914		
25	72	0132/12.04		978466.067	0.034
25	72	0137/16.00		978465.999	-0.034
AVG	978466.033 STD	0.048	622012 7927949		
25	79	0131/16.59		978460.658	-0.031
25	79	0132/11.00		978460.719	0.031
AVG	978460.689 STD	0.043	635845 7928060		
25	90	0131/16.07		978465.138	-0.020
25	90	0132/09.59		978465.177	0.020
AVG	978465.157 STD	0.028	657981 7927985		
27	37	112A/17.57		978470.468	-0.007
27	37	112B/18.00		978470.426	-0.049
27	37	0114/10.60		978470.489	0.014
27	37	0116/11.20		978470.518	0.043
AVG	978470.475 STD	0.039	551979 7931925		
27	48	112A/17.04		978459.521	0.017
27	48	112B/17.08		978459.479	-0.025
27	48	0140/14.21		978459.512	0.008
AVG	978459.504 STD	0.022	573970 7932058		
27	90	0131/08.52		978463.340	0.047
27	90	0131/15.58		978463.247	-0.047
AVG	978463.293 STD	0.066	658051 7931919		

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Line       Station Loop  Time    Obs_Grav  Dev from Mean

28              59 0140/07.26 978471.586     -0.017
28              59 0140/09.17 978471.607      0.004
28              59 0140/10.50 978471.633      0.030
28              59 0140/13.24 978471.579     -0.024
28              59 0140/15.47 978471.610      0.007
AVG  978471.603 STD     0.021  595927 7934006

28              72 0131/12.01 978455.186      0.003
28              72 0131/14.28 978455.157     -0.026
28              72 0140/12.19 978455.206      0.023
AVG  978455.183 STD     0.025  622116 7933956

29              16 0120/07.25 978456.124      0.004
29              16 0123/10.49 978456.133      0.014
29              16 0123/13.05 978456.103     -0.016
29              16 0136/14.22 978456.118     -0.002
AVG  978456.120 STD     0.013  510036 7936088

29              20 0123/12.40 978451.393     -0.002
29              20 0138/15.19 978451.398      0.002
AVG  978451.396 STD     0.004  517915 7936077

29              42 112A/15.29 978466.318      0.021
29              42 112B/15.32 978466.276     -0.021
AVG  978466.297 STD     0.030  562055 7935890

29              48 112B/14.31 978463.520     -0.021
29              48 0140/10.03 978463.561      0.021
AVG  978463.541 STD     0.029  573943 7935956

29              80 0131/07.33 978447.170      0.032
29              80 0131/09.55 978447.167      0.029
29              80 0131/12.53 978447.117     -0.021
29              80 0131/17.08 978447.099     -0.039
AVG  978447.138 STD     0.036  638029 7935948

30              30 112A/12.45 978466.982     -0.004
30              30 112B/12.48 978466.949     -0.037
30              30 0114/11.43 978467.027      0.041
AVG  978466.986 STD     0.039  538080 7938033

30              59 0139/16.34 978472.452     -0.024
30              59 0140/07.36 978472.500      0.024
AVG  978472.476 STD     0.034  595983 7937947

31              48 112A/09.08 978467.613      0.013
31              48 112B/14.19 978467.607      0.007
31              48 0139/15.49 978467.581     -0.019
AVG  978467.600 STD     0.017  573964 7939878

32              16 0118/17.31 978454.170     -0.040
32              16 0120/07.46 978454.206     -0.004
32              16 0120/11.37 978454.255      0.045
AVG  978454.210 STD     0.043  509882 7942092
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Line	Station	Loop	Time	Obs_Grav	Dev from Mean
32	27	0116/	12.09	978468.485	0.020
32	27	0118/	16.28	978468.446	-0.020
AVG	978468.465	STD	0.028	532023	7942084
32	37	112A/	07.32	978461.122	-0.042
32	37	112A/	11.14	978461.193	0.029
32	37	112A/	18.09	978461.188	0.024
32	37	112B/	18.12	978461.154	-0.010
AVG	978461.164	STD	0.033	551962	7941927
32	74	0130/	16.27	978444.392	-0.019
32	74	0131/	10.34	978444.429	0.019
AVG	978444.410	STD	0.026	626461	7942031
33	90	0130/	13.43	978456.647	0.002
33	90	0130/	15.04	978456.643	-0.002
AVG	978456.645	STD	0.003	658018	7944107
34	58	0139/	07.18	978462.364	-0.018
34	58	0139/	09.02	978462.384	0.002
34	58	0139/	11.18	978462.390	0.009
34	58	0139/	16.41	978462.388	0.007
AVG	978462.382	STD	0.012	593938	7946043
34	71	0139/	10.06	978441.241	0.007
34	71	0139/	14.06	978441.227	-0.007
AVG	978441.234	STD	0.010	620017	7945992
35	11	0118/	11.29	978446.319	-0.009
35	11	0118/	14.48	978446.338	0.009
AVG	978446.329	STD	0.013	500687	7947933
35	22	0118/	08.10	978458.685	-0.027
35	22	0118/	12.26	978458.724	0.012
35	22	0118/	17.42	978458.726	0.014
AVG	978458.712	STD	0.023	521939	7947926
35	28	0110/	09.35	978464.101	0.011
35	28	0110/	13.42	978464.086	-0.004
35	28	112A/	12.07	978464.117	0.027
35	28	0118/	13.20	978464.056	-0.034
AVG	978464.090	STD	0.026	534320	7947905
35	80	0130/	07.31	978442.071	0.012
35	80	0130/	09.17	978442.086	0.026
35	80	0130/	10.44	978442.055	-0.004
35	80	0130/	16.37	978442.026	-0.034
AVG	978442.059	STD	0.026	638036	7948051
35	90	0130/	08.18	978454.083	0.021
35	90	0130/	13.34	978454.041	-0.021
AVG	978454.062	STD	0.030	657886	7948003

Line	Station	Loop Time	Obs_Grav	Dev from Mean
36	48	0110/11.22	978462.646	0.042
36	48	0110/15.15	978462.605	0.001
36	48	112A/08.45	978462.581	-0.023
36	48	0117/12.50	978462.591	-0.013
36	48	0139/08.21	978462.597	-0.007
AVG	978462.604 STD	0.025	573928 7950000	
36	71	0117/14.45	978440.639	-0.002
36	71	0130/10.02	978440.655	0.014
36	71	0139/10.16	978440.629	-0.012
AVG	978440.641 STD	0.013	620103 7949944	
37	22	0118/08.23	978453.666	-0.024
37	22	0118/10.25	978453.714	0.024
AVG	978453.690 STD	0.034	522040 7951994	
37	89	0129/16.13	978448.200	-0.034
37	89	0130/08.34	978448.269	0.034
AVG	978448.235 STD	0.049	655967 7952003	
38	58	0117/07.30	978456.923	0.014
38	58	0117/09.55	978456.922	0.013
38	58	0117/16.39	978456.881	-0.028
AVG	978456.909 STD	0.024	594083 7953906	
38	71	0117/08.51	978446.109	0.016
38	71	0117/14.36	978446.093	-0.000
38	71	0129/11.43	978446.078	-0.015
AVG	978446.093 STD	0.016	620052 7954028	
39	48	0106/16.57	978469.124	-0.019
39	48	0117/10.42	978469.162	0.019
39	48	0121/15.30	978469.142	-0.001
AVG	978469.143 STD	0.019	574038 7956011	
39	72	0129/11.38	978443.093	0.018
39	72	0129/14.51	978443.057	-0.018
AVG	978443.075 STD	0.025	621979 7956045	
40	48	0106/13.35	978468.388	-0.013
40	48	0106/17.05	978468.422	0.021
40	48	0121/15.24	978468.392	-0.009
AVG	978468.401 STD	0.019	574140 7957929	
40	71	0107/09.50	978450.405	0.009
40	71	0117/08.43	978450.417	0.021
40	71	0129/11.33	978450.366	-0.030
AVG	978450.396 STD	0.027	620036 7957932	
40	80	0129/07.40	978444.761	0.026
40	80	0129/09.20	978444.755	0.020
40	80	0129/12.37	978444.729	-0.006
40	80	0129/16.27	978444.696	-0.039
AVG	978444.735 STD	0.030	638076 7958094	

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Line       Station Loop  Time    Obs_Grav  Dev from Mean

42             48 0106/08.52 978464.294      0.020
42             48 0106/13.25 978464.264     -0.010
42             48 0107/16.03 978464.264     -0.010
AVG  978464.274 STD     0.017  574015 7961939

42             71 0107/09.39 978449.707      0.001
42             71 0107/14.14 978449.709      0.003
42             71 0129/10.03 978449.702     -0.004
AVG  978449.706 STD     0.004  620142 7962001

42             78 0128/16.22 978443.527     -0.013
42             78 0129/09.33 978443.553      0.013
AVG  978443.540 STD     0.018  634125 7962055

42             90 0128/14.06 978455.551     -0.005
42             90 0129/08.32 978455.561      0.005
AVG  978455.556 STD     0.007  658090 7961919

43             28 0101/16.57 978438.187     -0.010
43             28 0106/10.27 978438.207      0.010
AVG  978438.197 STD     0.014  534002 7963985

43             49 0107/07.37 978463.444     -0.008
43             49 0107/17.02 978463.460      0.008
AVG  978463.452 STD     0.011  575978 7963928

43             59 0107/08.35 978447.516     -0.005
43             59 0107/15.09 978447.527      0.005
AVG  978447.522 STD     0.008  595996 7963844

44             31 0101/16.34 978438.443     -0.002
44             31 0101/17.22 978438.447      0.002
AVG  978438.445 STD     0.003  539944 7966013

44             90 0128/08.25 978455.940      0.004
44             90 0128/13.55 978455.931     -0.004
AVG  978455.935 STD     0.006  657915 7966033

45             53 0107/16.32 978452.154      0.009
45             53 0108/15.24 978452.136     -0.009
AVG  978452.145 STD     0.013  583924 7968111

45             65 0108/10.39 978444.734      0.016
45             65 0108/14.16 978444.702     -0.016
AVG  978444.718 STD     0.023  607943 7967912

45             71 0108/09.54 978443.041     -0.004
45             71 0128/15.46 978443.049      0.004
AVG  978443.045 STD     0.006  619982 7967932

45             80 0128/07.36 978440.888      0.038
45             80 0128/10.22 978440.871      0.021
45             80 0128/13.04 978440.823     -0.027
45             80 0128/15.06 978440.850      0.000
45             80 0128/16.37 978440.817     -0.033
AVG  978440.850 STD     0.030  637946 7967998
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Line	Station	Loop	Time	Obs_Grav	Dev from Mean
46	28	0102/11.25	978433.287	-0.005	
46	28	0102/17.40	978433.298	0.005	
AVG	978433.292	STD	0.008	533937	7970002
46	39	0102/08.26	978449.932	-0.004	
46	39	0102/10.15	978449.939	0.004	
AVG	978449.936	STD	0.005	555996	7969938
46	48	0102/09.17	978450.423	-0.027	
46	48	0102/14.27	978450.465	0.015	
46	48	0108/15.47	978450.463	0.013	
AVG	978450.450	STD	0.024	573996	7969957
47	49	0108/07.42	978445.140	0.014	
47	49	0108/17.32	978445.113	-0.014	
AVG	978445.127	STD	0.019	575949	7971859
47	60	0108/08.45	978451.556	0.020	
47	60	0108/16.49	978451.517	-0.020	
AVG	978451.536	STD	0.028	598052	7971995
47	71	0108/09.41	978436.523	0.002	
47	71	0109/09.21	978436.544	0.023	
47	71	0128/11.30	978436.495	-0.026	
AVG	978436.521	STD	0.025	620086	7972009
48	28	0102/17.18	978432.904	-0.027	
48	28	0103/10.59	978432.958	0.027	
AVG	978432.931	STD	0.038	534026	7974000
48	48	0102/14.48	978447.711	-0.011	
48	48	0103/08.55	978447.733	0.011	
AVG	978447.722	STD	0.016	574095	7974027
48	90	0127/14.19	978453.997	-0.013	
48	90	0128/09.29	978454.023	0.013	
AVG	978454.010	STD	0.018	657996	7973922
49	63	0108/17.16	978443.590	-0.031	
49	63	0109/08.42	978443.652	0.031	
AVG	978443.621	STD	0.044	604042	7976012
50	28	0103/10.48	978434.194	0.014	
50	28	0103/15.53	978434.167	-0.014	
AVG	978434.181	STD	0.019	534037	7977887
50	48	0103/09.06	978449.829	0.016	
50	48	0103/13.25	978449.821	0.008	
50	48	0109/07.36	978449.788	-0.025	
AVG	978449.813	STD	0.022	574032	7978069
50	71	0109/10.28	978432.265	0.046	
50	71	0127/12.34	978432.184	-0.035	
50	71	0128/11.48	978432.209	-0.010	
AVG	978432.219	STD	0.041	620042	7978007

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Line       Station Loop  Time    Obs_Grav  Dev from Mean

51              64 0109/11.07 978437.685      0.014
51              64 0109/13.08 978437.658     -0.014
AVG  978437.672 STD     0.019  606042 7979899

51              80 0127/07.43 978438.106      0.005
51              80 0127/10.13 978438.105      0.004
51              80 0127/13.22 978438.088     -0.013
51              80 0127/16.38 978438.105      0.004
AVG  978438.101 STD     0.009  638103 7979990

52              44 0103/14.04 978445.801     -0.007
52              44 0104/08.36 978445.814      0.007
AVG  978445.807 STD     0.009  566142 7982006

53              34 0104/07.36 978432.603     -0.020
53              34 0104/09.34 978432.642      0.020
AVG  978432.623 STD     0.028  546111 7984057

53              71 0109/13.54 978433.607     -0.014
53              71 0111/09.13 978433.628      0.007
53              71 0127/11.50 978433.627      0.006
AVG  978433.621 STD     0.012  620009 7984138

54              62 0111/08.15 978437.069      0.036
54              62 0111/11.28 978437.004     -0.029
54              62 0111/17.29 978437.025     -0.008
AVG  978437.033 STD     0.033  601902 7985907

54              71 0111/09.02 978431.606      0.023
54              71 0111/15.53 978431.567     -0.016
54              71 0126/15.55 978431.575     -0.008
AVG  978431.583 STD     0.021  619996 7985951

54              90 0126/14.17 978444.991      0.000
54              90 0127/08.39 978444.990     -0.001
AVG  978444.991 STD     0.001  658140 7986094

55              77 0126/13.06 978433.157     -0.002
55              77 0126/15.27 978433.161      0.002
AVG  978433.159 STD     0.003  631807 7988312

56              71 0111/16.03 978428.503      0.010
56              71 0126/12.27 978428.482     -0.010
AVG  978428.492 STD     0.015  620023 7989970

56              90 0126/10.08 978447.323      0.020
56              90 0126/14.07 978447.283     -0.020
AVG  978447.303 STD     0.028  657942 7989813

57              67 0111/17.13 978425.127     -0.031
57              67 0115/08.20 978425.189      0.031
AVG  978425.158 STD     0.044  611953 7992035

57              80 0126/07.55 978440.180      0.028
57              80 0126/10.55 978440.146     -0.006
57              80 0126/17.12 978440.129     -0.023
AVG  978440.152 STD     0.026  637972 7992065
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Line       Station Loop  Time    Obs_Grav   Dev from Mean

58              37 0104/13.49 978435.968     -0.004
58              37 0104/15.35 978435.975      0.004
AVG  978435.971 STD     0.005  552060 7994056

58              53 113A/15.23 978430.705     -0.019
58              53 0115/11.03 978430.742      0.019
AVG  978430.723 STD     0.026  584383 7994652

58              71 0115/08.43 978428.648      0.008
58              71 0126/11.50 978428.633     -0.007

AVG  978428.640 STD     0.011  619984 7993993

58              90 0125/15.20 978449.823     -0.026
58              90 0126/09.56 978449.876      0.026
AVG  978449.850 STD     0.037  658159 7993909

59              38 0104/17.24 978437.885     -0.012
59              38 0105/09.47 978437.908      0.012
AVG  978437.897 STD     0.016  554070 7996000

59              63 0115/07.51 978435.539     -0.020
59              63 0115/10.05 978435.579      0.020
AVG  978435.559 STD     0.028  604036 7996102


59              74 0125/12.35 978430.690     -0.025
59              74 0126/08.36 978430.741      0.025
AVG  978430.715 STD     0.036  625914 7995997

60              63 0115/07.44 978433.320     -0.014
60              63 0115/13.50 978433.352      0.018
60              63 0215/17.20 978433.331     -0.003
AVG  978433.334 STD     0.016  604093 7997971

60              71 0115/09.23 978421.011      0.017
60              71 0115/14.47 978420.978     -0.016
60              71 0125/11.58 978420.994     -0.000
AVG  978420.994 STD     0.017  620003 7998039

61              49 0105/08.39 978439.187     -0.019
61              49 113A/08.10 978439.215      0.009
61              49 113A/14.09 978439.217      0.011
AVG  978439.206 STD     0.017  576123 8000111

61              55 113A/16.40 978437.466     -0.010
61              55 0115/13.03 978437.489      0.013
61              55 0115/16.46 978437.504      0.027
61              55 0215/16.43 978437.447     -0.030
AVG  978437.476 STD     0.025  587943 8000009

61              73 0124/16.25 978424.677     -0.023
61              73 0125/11.43 978424.723      0.023
AVG  978424.700 STD     0.033  624039 8000056
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Line       Station Loop  Time    Obs_Grav  Dev from Mean

61             81 0125/07.46 978442.389      0.013
61             81 0125/11.05 978442.405      0.029
61             81 0125/13.14 978442.354     -0.022
61             81 0125/16.20 978442.355     -0.021
AVG  978442.376 STD     0.025  639891 7999955

62             33 0105/12.59 978430.144      0.000
62             33 0105/15.11 978430.144      0.000
AVG  978430.144 STD     0.000  543899 8001857

62             71 0115/15.12 978423.658      0.018
62             71 0124/16.39 978423.623     -0.018
AVG  978423.640 STD     0.025  619983 8002017

62             82 0124/15.40 978445.628     -0.038
62             82 0125/10.60 978445.705      0.038
AVG  978445.667 STD     0.054  642081 8002078

63             38 0105/16.50 978436.755     -0.026
63             38 113A/10.11 978436.808      0.026
AVG  978436.782 STD     0.037  554034 8004127

63             45 113A/07.40 978433.647      0.011
63             45 113A/17.16 978433.616     -0.020
63             45 113B/17.22 978433.646      0.010
AVG  978433.636 STD     0.018  568026 8004126

63             68 0124/08.03 978425.122      0.027
63             68 0124/12.46 978425.097      0.002
63             68 0124/16.45 978425.066     -0.029
AVG  978425.095 STD     0.028  613984 8003996

63             71 0124/08.21 978425.040      0.026
63             71 0124/14.46 978424.987     -0.026
AVG  978425.014 STD     0.037  620080 8004084

63             90 0125/08.45 978454.339     -0.030
63             90 0125/10.18 978454.402      0.033
63             90 0125/14.06 978454.367     -0.002
AVG  978454.369 STD     0.032  657948 8003927

64             82 0124/13.56 978455.220     -0.004
64             82 0125/09.39 978455.229      0.004
AVG  978455.225 STD     0.006  642018 8006120

66             37 0105/16.25 978432.704      0.004
66             37 113A/12.45 978432.697     -0.004
AVG  978432.701 STD     0.005  551924 8009540

66             53 113A/15.60 978433.997     -0.046
66             53 113B/16.05 978434.089      0.046
AVG  978434.043 STD     0.065  583943 8009389

66             55 113A/17.04 978435.293     -0.016
66             55 0124/10.13 978435.326      0.016
AVG  978435.309 STD     0.023  587943 8009336
```

APPENDIX E

AFGN BASE 6491.0129 (HALLS CREEK) – STATION DESCRIPTION

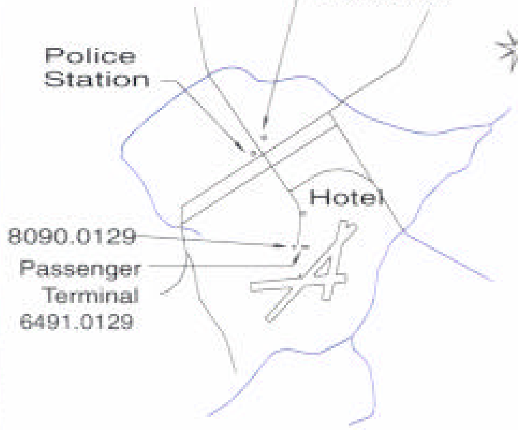
STATION NAME: **Halls Creek W.A.**

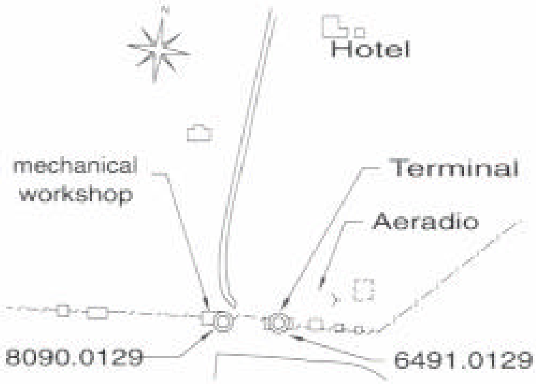
STATION CODE: **6491.0129**

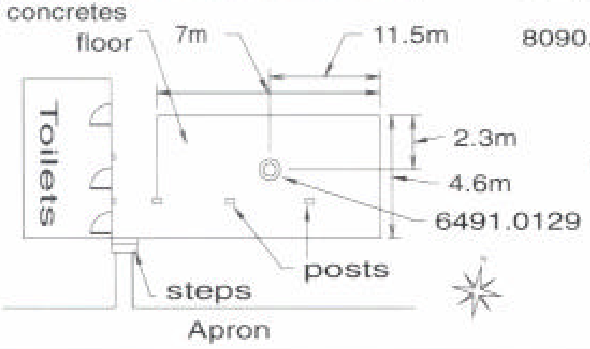
LOCATION	DESCRIBED / RECOVERED BY	OBSERVED GRAVITY (μms^{-2})	DATE
Passenger Waiting Terminal	J.W.W. *Redrawn by P Wynne*	9784473.0	1993

DESCRIPTION: Station Class:

STATION TYPE:
POSITION: S 18 14' 12" E 127 40' 06"
Position Source: Australian Gravity Base-station Network: 1980 Survey
ELEVATION: 409.61 m
Elevation Source: Australian Gravity Base-station Network: 1980 Survey







Station No. 6491.0129 Halls Ck

Sheet 1 of 3

AGSO
AUSTRALIAN GEOLOGICAL SURVEY ORGANISATION

GRAVITY STATIONS
AUSTRALIAN NATIONAL GRAVITY NETWORK

APPENDIX F

STATISTICAL ANALYSIS AND ERROR CALCULATION

STATISTICAL ANALYSIS AND ERROR CALCULATION

Assuming all of the factors contributing to the final Bouguer gravity are mutually independent, then the expected error in the final Bouguer gravity is the square root of the sum of the squares of the error in each factor, ie

$$E_{BG}^2 = E_{OBS}^2 + E_{gv}^2 + (C \times E_h^2) + E_{gT}^2$$

This assumption is not absolutely valid, since a small amount of cross-correlation does exist (for instance, an error in the vertical will affect the terrain correction if measured elevations rather than grid elevations are used to calculate the terrain correction). These cross-correlations will, however, be generally small, so the above error calculation will yield results that are very close to the true values.

In order to quantitatively measure the so-called expected error, it is necessary to define the confidence limit. This gives some meaning to the term expected error (or, put more positively, expected accuracy) by making the following statement possible:

X percent of the measured values will be accurate to within ±Y

For our purposes, we have defined the confidence limit to be 1 sigma, or roughly 67%, hence, we are after the error range (ie ±0.3 μms^{-2}) that will allow us to confidently state that 67% of the data satisfies this criterion. We could have chosen a 2 sigma limit, in which our expected error would have been larger, since our confidence limit would be about 95%. Similarly, we could have gone for a 50% confidence limit, which would have resulted in a smaller expected error. By choosing the 1 sigma limit, we are conforming to a fairly widely accepted industry standard.

The solution of the error equation for the final Bouguer gravity reduces to collecting enough data to determine the 1 sigma confidence limit of each of the factors in the equation. This is done by repeating enough samples to derive a statistically significant error limit. For simplicity, we will look at the probable error in observed gravity. The calculation of the probable errors in the other factors is analogous.

To derive the probable error in the observed gravity, stations are revisited and the gravity reading is taken again. Each reading at a station is compared with the mean of all readings taken at that station. For example, a station with three readings would yield three deviations from the mean value. It is believed that this method yields a much better statistical analysis of the data. Once all the deviations for a survey have been calculated, they are plotted on a histogram. The repeat differences will fit a normal distribution curve with a mean (zero in theory, very close to zero in practice) and a standard deviation (sigma). Statistically, 67% of the repeat differences will fall within ±1 sigma of the mean.

According to our definition:

$$E_{RPT\ DIFF} = \pm \text{ sigma}$$

In other words, the expected repeatability of an observed gravity reading is ± sigma.

It is very important to realise that expected repeatability is not the expected accuracy of an individual reading. The expected repeatability and expected accuracy of the individual reading are only the same if the repeat reading has an expected error of zero. This follows logically from our definition of expected error, as the square root of the sum of the squares of the expected error of each independent factor (see the formula for expected error of final Bouguer gravity). There may be other small cross-correlations (ie the observer may look up the previous reading to speed up the repeat reading), but, for our purposes, we assume they are totally independent.

Thus

$$E_{RPT.DIFF}^2 = E_{RPT\ RDG}^2 + E_{FIRST\ RDG}^2$$

But we assume:

$$E_{RPT\ RDG} = E_{FIRST\ RDG}$$

(This assumption is a good one: you expect to be able to read a gravimeter on the same spot with the same precision at different times).

Therefore:

$$E_{RPT\ RDG}^2 = 2 \times E_{FIRST\ RDG}^2$$

or

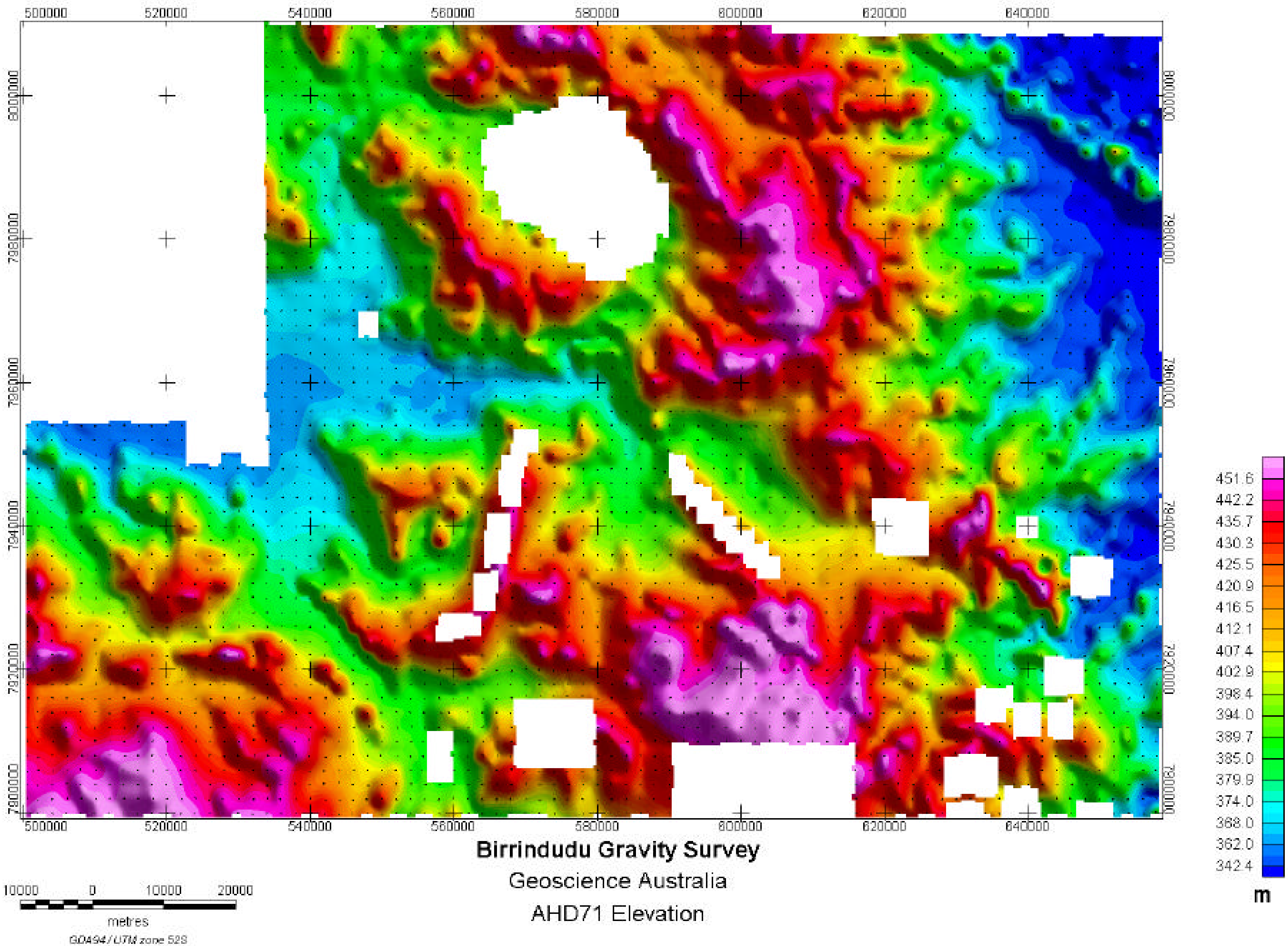
$$E_{FIRST\ RDG} = 0.707 \times \text{Sigma}$$

The expected error of an individual observed gravity value is equal to 0.707 times the expected repeatability.

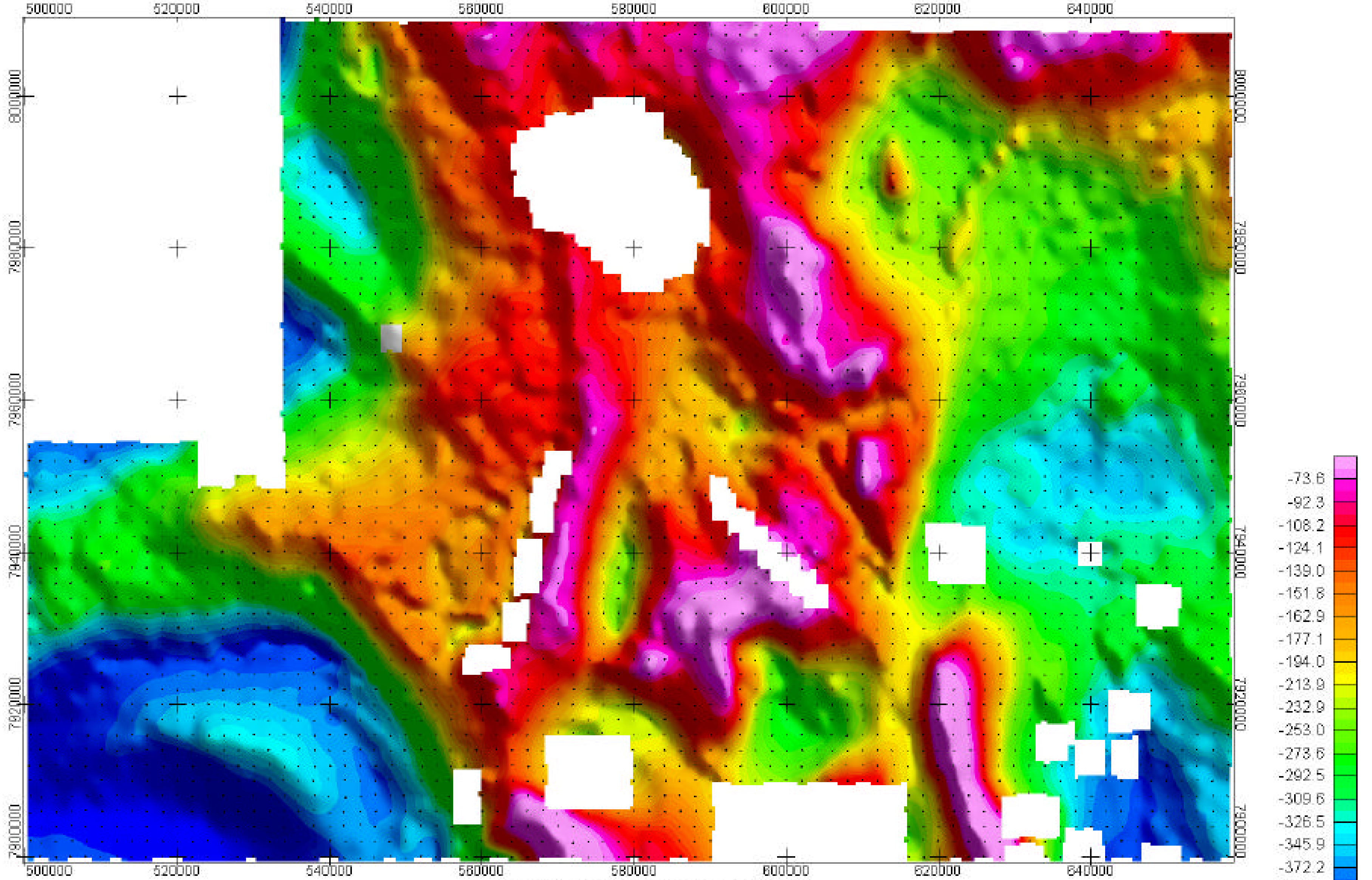
The above calculation for observed gravity is carried through for each factor in the final Bouguer value and the end result is a 67% confidence limit of final Bouguer gravity which we have defined as expected accuracy.

APPENDIX G

VERIFICATION IMAGES



Birrindudu Gravity Survey
Geoscience Australia
AHD71 Elevation



Birrindudu Gravity Survey

Geoscience Australia

Complete Bouguer Anomaly (2.67gm/cc)