AUSQUEST
HELICOPTER GRAVITY SURVEYS 2007

Queensland Prospects

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1. INTRODUCTION

A precision GPS-Gravity survey was carried out on behalf of AUSQUEST between the 13th of October and the 2nd of December 2007. A total of 876 new gravity stations were surveyed across four targeted areas located in the Channel Country of Western Queensland.

Gravity data were acquired using a Scintrex CG-3 automated gravity meter. Position and level data were obtained using Leica 1230GG geodetic grade GPS receivers collecting GPS and GLONASS positional information. All receivers were operating in post-processed kinematic mode. Data was acquired using Daishsat helicopter-borne survey methods.

Gravity data were reduced using standard reductions on the ISOGAL84 gravity network. GPS data were reduced to MGA coordinates with levels expressed as metres above the Australian Height Datum.

Photo 1: Typical terrain in the survey area.

2. SURVEY OVERVIEW

The four survey targets were based on gravity anomalies identified by AusQuest from a government regional gravity survey carried out by Daishsat in 2007 (Mt Isa E).

The survey areas located in Queensland were Bedourie 1, Bedourie 2, Bedourie 3 & Bedourie 4. The survey crew was based at Bedourie for this part of the survey. The terrain encountered over these survey areas varied from densely vegetated channel country through to flat open grazing country punctuated by impinging sand dunes.

Gravity surveying was conducted on variety of station spacing's ranging from a 1.0km square grid configuration down to a 400m diagonal grid. Appendix A contains a plot of the final station locations. Appendix C contains the specifications for the survey.

Photo 2: Typical terrain in the survey area.

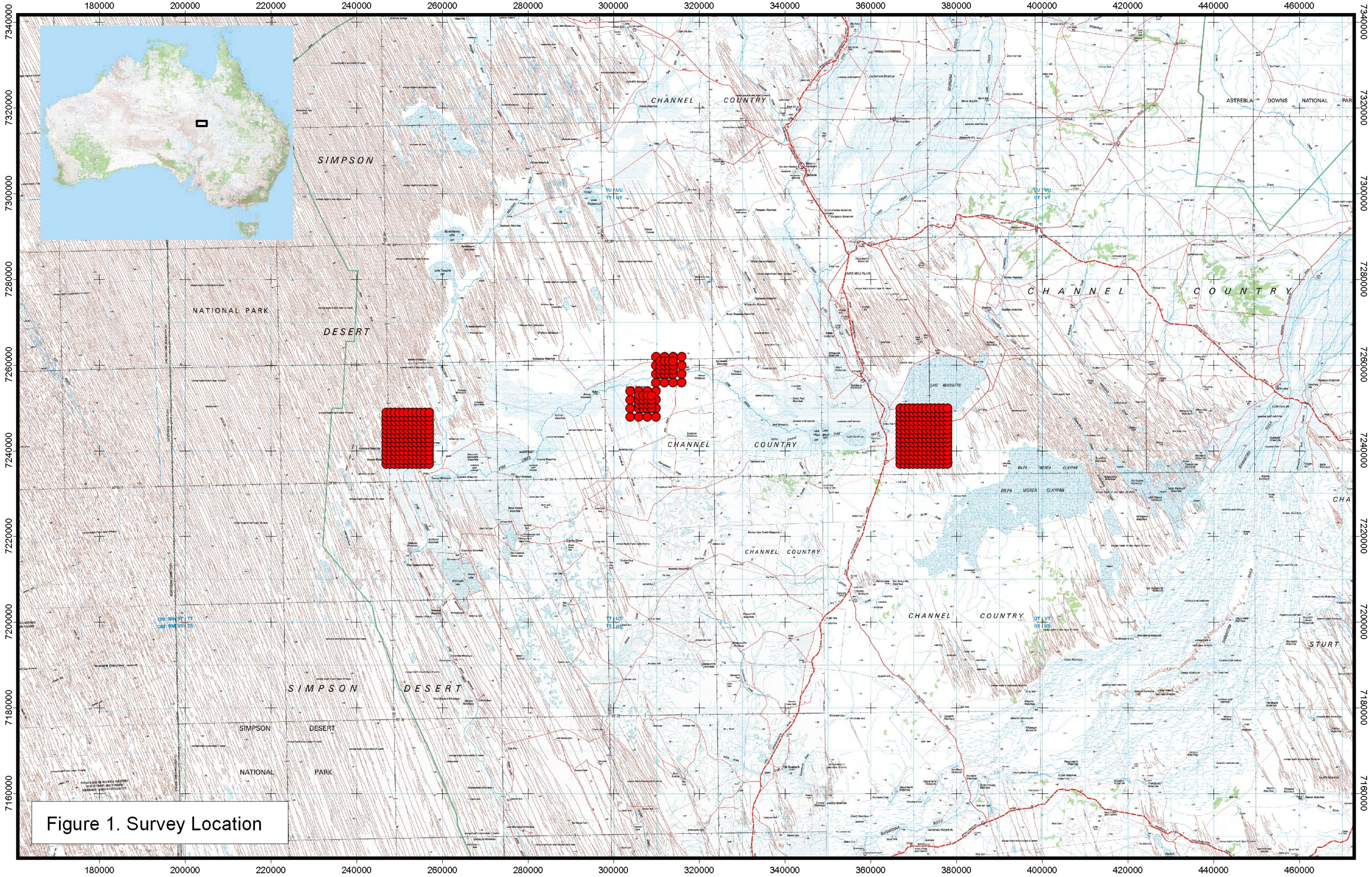


Figure 1. Survey Location

3. PERSONNEL AND EQUIPMENT

3.1 Personnel

The supervisors in charge of the project were Nick Moir and Andrew McCarthy. The supervisors were responsible for daily management of the job and for nightly data processing to ensure quality and integrity. Gravity and GPS measurements were carried out by:

Nick Moir
Mark Rosewall
Matt Hunter

Support personnel in Jervois:

Michael Hunter

Three Helicopter pilots were used for the project

Joanna Murphy
Carl Herpse
Rick Keese

Final data reduction, inspection and reporting were performed by the company Geophysicist, Grant Coopes.

3.2 Survey equipment

The following survey equipment was utilised on the gravity survey:

- Scintrex CG-3 digital gravity metes (G and S meters)
- Leica 1230 dual frequency GPS receivers with GLONASS capability
- Notebook computers for data processing and backup
- Garmin 296 GPS receivers for helicopter navigation
- Garmin Handheld GPS receivers for vehicle navigation
- Various chargers, solar cells and batteries

3.3 Vehicles

Due to the type of terrain and remote locations, 4WD Landcruisers and 4WD Isuzu Trucks were utilized as support vehicles for the surveys. To maintain the high Daishsat safety record, vehicles were fitted with a range of safety equipment including:

- One 20l jerry can of water
- Dual fuel tanks
- Two spare tyres
- UHF radio and satellite phone with car kit
- Self-recovery equipment including winches, snatch straps chains etc.
- Tyre pliers to effect tyre repairs in the field
- Tools and spares to enable field repairs as necessary
- Survival kits with EPIRB emergency locator beacons
- Trans track satellite vehicle monitoring and reporting systems

3.4 Helicopter

Due to the scale, remote location and limited access to the survey areas the most efficient method of transport between stations is by helicopter.
Daishsat utilizes Robinson R-44 Helicopters, a medium size utility helicopter with good maneuverability and proven reliability in harsh operating conditions typical of gravity survey operations.

Photo 3: Robinson R-44 Helicopter VH-HEM and gravity acquisition.

3.5 Accommodation

The crews were accommodated as close as practical to the survey areas with crews using accommodation provided by the Bedourie Roadhouse and Bedourie Hotel.

3.6 Communications

The survey crew and support vehicles were equipped with hand-held Iridium satellite phones as well as UHF and VHF transceivers. “Omnitrack” satellite based tracking was used on all vehicles, Helicopters and Aircraft to enable asset monitoring via a web interface.

Scheduled communications were made by the crew to the communications centre at the base camp at hourly intervals. Communication with the Perth and Murray Bridge offices was ongoing for the duration of the job.

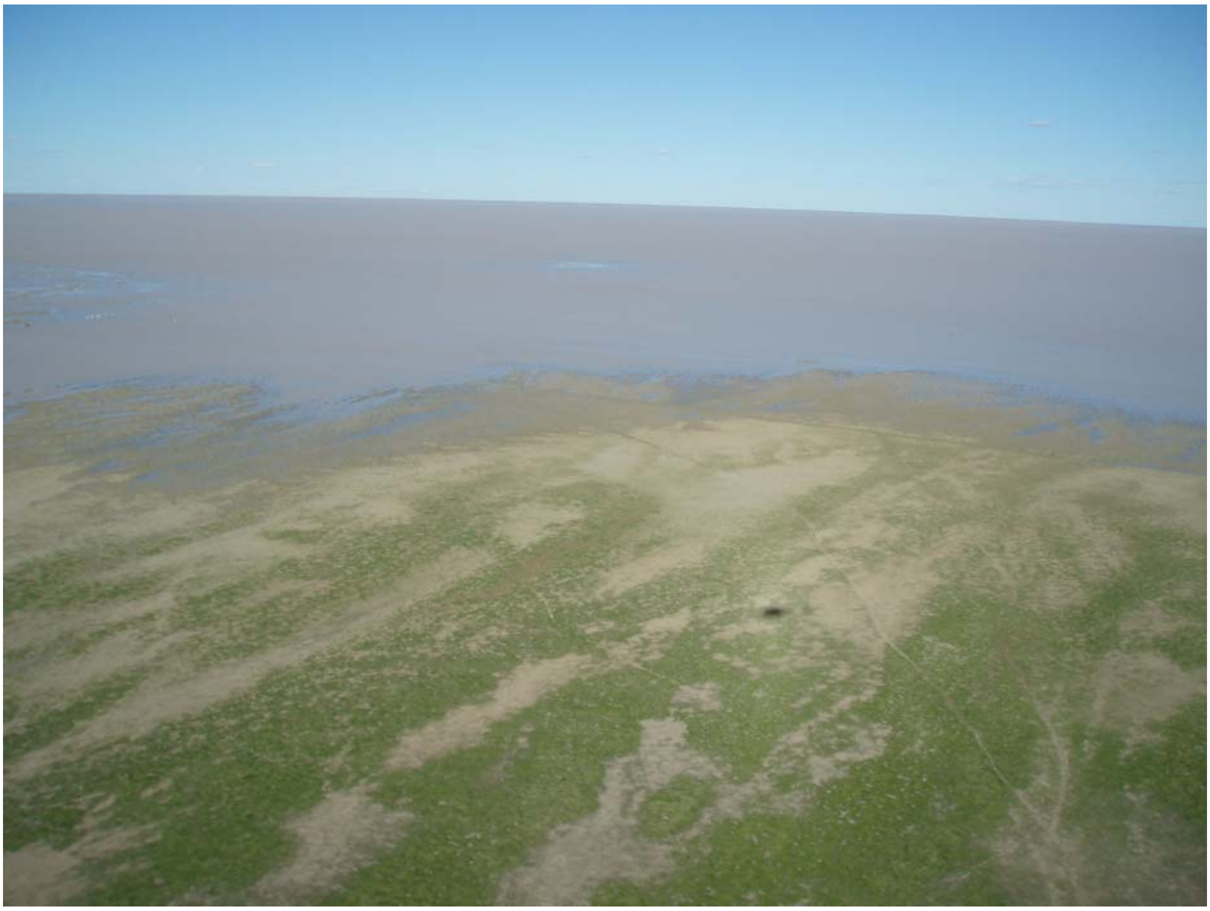


Photo 4: View from VH HZH looking east towards Lake Machattie.

4. GPS SURVEYING AND PROCESSING

4.1 Set out of the grid

This was done concurrently with the gravity data acquisition using navigation grade receivers operating in autonomous mode. Where possible, the readings were taken as close to the ideal coordinates as possible. As the receivers were operating in autonomous mode, set out accuracy was usually better than 10m.

Raw kinematic GPS data were logged by a twin dual-frequency Leica 1230GG receivers inside the helicopter cabin, with the GPS antennas mounted on the tail boom. Static GPS data were logged at the base station using two Leica System 1230GG GPS receivers for later post-processing. The Leica 1230GG is a new generation GPS receiver making use of both the traditional US GPS satellite constellation and the newly available GLONASS satellite constellations for higher positional accuracy and reduced periods of poor satellite coverage.

Repeat stations were placed throughout the surveys to monitor any variations in positional accuracy. Repeats are placed with a washer tied with flagging and marked with the station number was used for future identification. At each station, the station number, position and RL were recorded digitally by the crew.

4.2 Survey datum and control

The gravity surveying, and hence any gravity reductions, used the Australian Height Datum (AHD) as the reference datum. New GPS/Gravity base stations were established at each of the three bases using three days worth of static data and connections to ITRF stations using Geoscience Australia's online GPS processing system, AUSPOS. For more information on this system, please visit the Geoscience Australia website at http://www.ga.gov.au/geodesy/sgc/wwwgps/. Final deviations of better than 5mm were obtained for x, y and z, for all occupations. Appendix D contains the GPS base station information.

4.3 Processing of the position and level data

The raw GPS data were recorded onto the CF memory cards of the GPS receivers. The data were downloaded nightly onto laptop computer for post processing using Waypoint Grafnav v7.80.

Waypoint combines the processing components, GrafNav and GrafNet, in a complete package.

GrafNav processes data for one baseline (e.g. one base and one remote). GrafNav is normally used for kinematic data which it is extremely well suited for. It can also process single static baselines. Receiver types can be mixed and matched via the use of a common format. This component of Waypoint was used for processing the kinematic data acquired each day.

GrafNav and GrafNet share the same processing engine that has been under continuous development since its original inception by Waypoint in 1992. The core of this robust engine is its carrier phase kinematic (CPK) Kalman filter. Some of the major advantages of Waypoint's kernel are:

Fast processing - The GrafNav kernel is one of the fastest on the market. It will process ~0.8 epochs per MHz per second on a Pentium II.
Robust Kalman filter - From experience with processing GPS data from fast jets and NASA sounding rockets, the processing kernel has become extremely robust. Efforts have been made to account for all of the various data error possibilities given the different types of GPS receivers that GrafNav/GrafNet can handle.
Reliable OTF - Waypoint's on-the-fly (OTF) algorithm, called Kinematic Ambiguity Resolution (KAR), has had years of development and stresses reliability. Variations are implemented for both single and dual frequencies, and numerous options are available to control this powerful feature
Accurate Static Processing - Three modes of static processing are implemented in the processing kernel. Fixed static is the most accurate. A quick static solution is also available as an alternative, while the float and iono-free float solution is useful for long baselines.
Dual Frequency - Full dual frequency support comes with GrafNav/GrafNet. For ambiguity resolution, this entails wide/narrow lane solutions for KAR, fixed static and quick static. Ionospheric processing is very important with the peak of the ionosphere's cycle occurring in 2000. The GrafNav kernel implements two ionospheric processing modes including the iono-free and relative models. The relative model is especially useful for airborne applications where initialization is near the base station, and this method is much less susceptible to L2 phase cycle slips.
Forward and Reverse - Processing can be performed in both the forward and reverse directions. Both GrafNav and GrafNet also have the ability to combine these two solutions to obtain a globally optimum one.
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 about of code has been added specifically for the detection and removal of Doppler errors.
Long Baseline - Because precise ephemeris and dual frequency processing is supported; long baselines accuracies can be as good as 0.1 PPM.

For more information about Waypoint processing software, and in particular, Grafnav, please visit the Waypoint http://www.waypnt.com/grafnav_d.html.

Simple transformations to MGA and AHD were done using the GPS derived WGS84 positions.

MGA94 coordinates were obtained by simply projecting the GPS-derived WGS84 coordinates using a UTM projection with zones 53S & 54S. For all practicable purposes, the WGS84 geodetic coordinates are equivalent to GDA94 geodetic coordinates, so no transformation is necessary. For more information about GDA94 and MGA94, please visit http://www.ga.gov.au/geodesy/datums/gda.jsp.
AHD heights were calculated via Waypoint software using the latest geoid model for Australia, AUSGEOID98. Information about the geoid and the modeling process used to extract separations (N values) can be found at http://www.ga.gov.au/geodesy/ausgeoid/. To obtain AHD heights, the modeled N value is subtracted from the GPS derived WGS84 ellipsoidal height (Figure 2).

$$H_{AHD}=h_{WGS84}-N$$

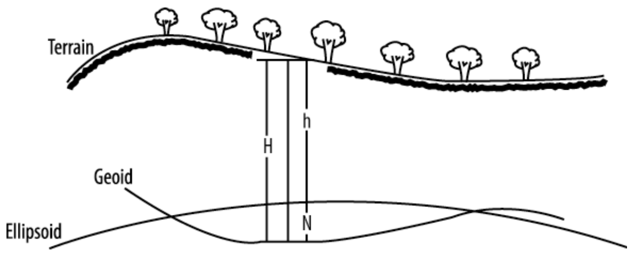


Figure: 2: Geoid-Ellipsoid separation

4.4 GPS Performance

Performance from the 1230GG receivers was excellent. There were no stations that required repeating due to GPS failure or poor coordinate quality.

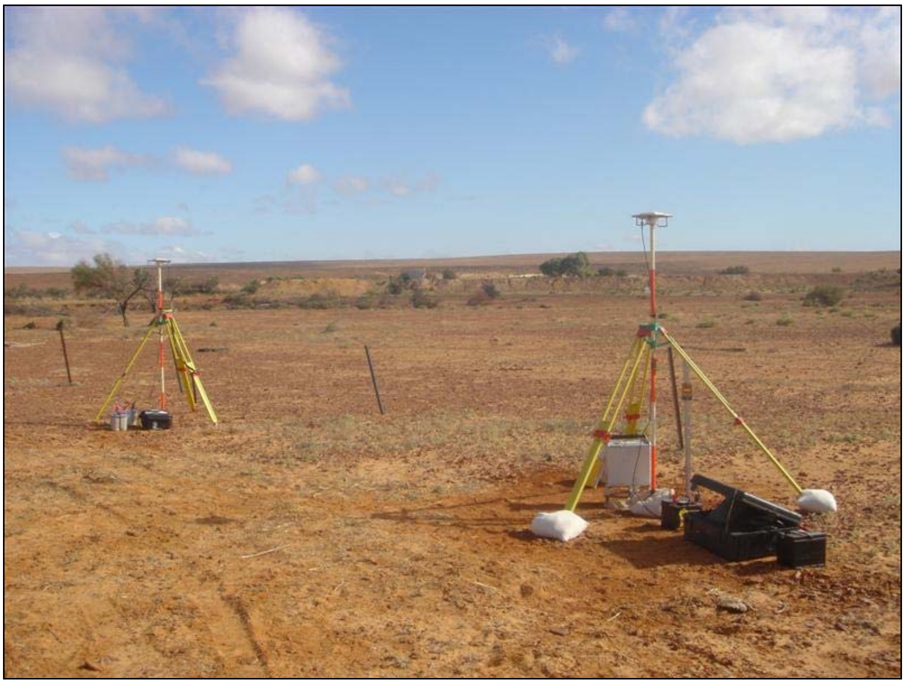


Photo 4: Post process GPS base setup with CG-3 gravimeter.

5. GRAVITY SURVEYING AND PROCESSING

5.1 Gravity data acquisition

Gravity observations were made concurrently with the GPS measurements. Two observations were made for each station, with each observation consisting of a 20-second or greater stacking time. Multiple observations were made at each station so that any seismic or instrumental noise could be immediately detected. The tolerance between readings was set at 0.05 of a dial reading (0.05 mGals). Vertical and horizontal levels were restricted to 5 arc seconds at all times. At each station, the station number, time and two gravity readings (in dial units) were recorded in DAISHSAT carbon-copy gravity field books. The Scintrex meters also automatically record the station, time and readings digitally to allow for downloading to computer.

5.2 Gravity base station

A gravity base station was used for calculation of absolute gravity and drift determination. Details of the gravity bases are contained in Appendix D. When in the field, a base station reading was taken in the morning before observing and at evening after the last observation. When taking a base station reading, the observed gravity values were stacked over 60 seconds to ensure accuracy. Observations were repeated until the readings repeated to 0.010 of a dial reading or less.

The surveys conducted in Queensland used a single gravity base station located at the rear of the Bedourie Roadhouse. This base was established by Daishsat during a previous regional survey conducted for Geoscience Australia in 2007.

All bases used are known to be of a high quality with existing position and gravity values known to Daishsat.

5.3 Gravity data processing

Raw gravity data were processed on a daily basis to check for quality and integrity. This interim process produced a set of Bouguer Anomaly values which were contoured and imaged to provide a check for any anomalous readings that would need repeating. Geosoft GRAVRED software was used for the gravity reduction in the field. Other software used on this project includes Arcview, ChrisDBF, Waypoint and Oasis Montaj. The formulae used for final processing are listed below:

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

Tidal correction: This correction was used to correct for background variations due to changes in the relative position of the moon and sun. The Scintrex calculated ETC was removed and a new ETC calculated using Geosoft Formulae and the surveyed GPS latitude. The formulae used are too complex to list here.

Instrument Drift: Since gravity meters are mechanical, they are prone to drift (extension of the spring with heat, obeying Hooke's law). If two base readings are taken one can assume that the drift between the two readings is linear and can therefore be calculated. The drift and tidal corrected value is referred to as the *observed gravity*.

Normal Gravity: The theoretical value of gravity was calculated using the 1967 variant of the International Gravity Formula and used to latitude correct the observed gravity.

$$Gn=9{,}780{,}318.456*(1+0.005\ 278\ 895*\sin^2\phi+0.000\ 023\ 462*\sin^4\phi)$$

where ϕ represents degrees of latitude;

Free-Air Correction: Since gravity varies inversely with the square of distance, it is necessary to correct for changes in elevation between stations to reduce field readings to a datum surface (in this case, AHD).

$(3.08768 – 0.00440 \sin^2\phi)*h – 0.000001442*h^2\ \mu ms^{-2}$ per metre

Bouguer Correction: This correction accounts for the attraction of material between the station and datum plane that is ignored in the free-air calculation. A value of 2.67 tm^3 was used in the correction.

$0.4191*\rho\ \mu ms^{-2}$ per metre

where ρ = density 2.67 tm^3

Free Air Anomaly: This is obtained by applying the free air correction (FAC) to the observed gravity reading.

$$FAA=G_{OBSG84}-Gn+FAC$$

Bouguer Anomaly: This is obtained when all the preceding reductions or corrections have been applied to the observed gravity reading.

$$BA267=G_{OBSG84}-Gn+FAC-BC$$

5.4 Gravity meter calibration and scale factors

The gravity meter used had previously been calibrated over a number of calibration ranges in WA and SA. A derived scale factor from these calibrations is shown below:

Serial No. (S) **9711410** Scale Factor **1.00000**

6. RESULTS

Raw and processed GPS and gravity data are contained on CDROM as Appendix E. Hardcopy plots of station location and coloured images are contained in Appendix A.

6.1 Stations Surveyed and Survey Progress

In total, 876 new stations were acquired during the survey. Of these 876 stations 52 were revisited to ensure data integrity across the survey.

A brief production summary for the survey is show in Table 1 below.

Generally, production was excellent with the crew averaging over 110 stations per day. Due to CASA regulations restricting duty hours for pilots, some time was lost from direct production although the crews used this downtime to conduct helicopter and equipment maintenance and review the acquired data.

Hot conditions typical of early summer in the desert and channel country caused the crew some concern with temperatures in the mid 40's adversely affecting the performance of both crew members and helicopters.
Production was slowed in some areas where dense vegetation and inundated areas made it a little slower to find safe landing sites. In some instances where it was thought too confined and therefore unsafe to land, stations were moved from the proposed location and in some cases omitted from the survey.

There was no downtime due to geophysical or GPS equipment failure.

Ausquest Gravity Surveys 2007		
Gravity stations acquired (including repeats)	**928**	stations
Gravity station repeats	**52**	6.5%
New gravity stations acquired	**876**	stations
Total accidents	**0**	accidents
Total hours lost from accidents	**0**	hours

Table 1: Gravity Production Summary

6.2 Data Repeatability

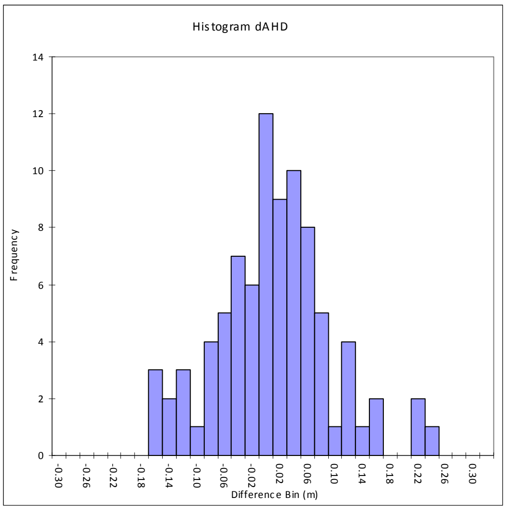
Analysis of the repeat data shows that measurement repeatability is very good for both GPS and gravity observations. Appendix B contains histograms and summary statistics from the analysis. Based on the repeat data, one can assume the following typical accuracies for the observables:

Z position observation: < 0.083 m
Gravity observation: < 0.031 mGals

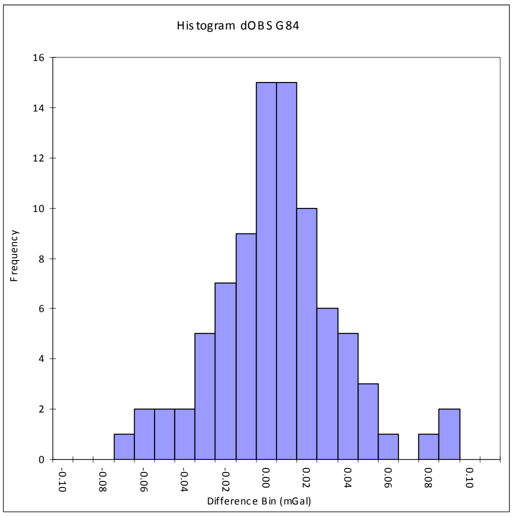
APPENDIX B

Repeat Tabulation and Analysis

Histogram dAHD



Histogram dOBSG84



Summary Statistics

Summary Table	*dAHD*	*dOBSG*
Mean	0.001	0.000
Standard Error	0.009	0.003
Median	0.002	0.000
Mode	-0.013	0.007
Standard Deviation	0.083	0.031
Sample Variance	0.007	0.001
Kurtosis	0.396	0.862
Skewness	0.227	0.256
Range	0.399	0.162
Minimum	-0.177	-0.073
Maximum	0.222	0.089
Sum	0.116	0.012
Count	**86**	**86**

APPENDIX C
Survey Specifications

Queensland Gravity Surveys

Client	AUSQUEST
Survey Name	Bedourie
Operators	AM, MR, NM, MH, MH- Pilots JM, CH, RK
Techniques Employed	GPS, Gravity
Station Spacing	1.0km & 0.5km
Line Spacing	1.0km & 0.5km
Gravity Meter	Scintrex CG-3M (G-meter) 408278
GPS	Leica 1230GG Base & Rovers
Number of Points Surveyed	1331
Gravity Base	Daishsat Base 20064400015, 2006800075, 2006800080
Date of Survey	22nd November to 3rd December 2007

APPENDIX D
Base Station Information

Daishsat Base 20064400015 – Bedourie Roadhouse

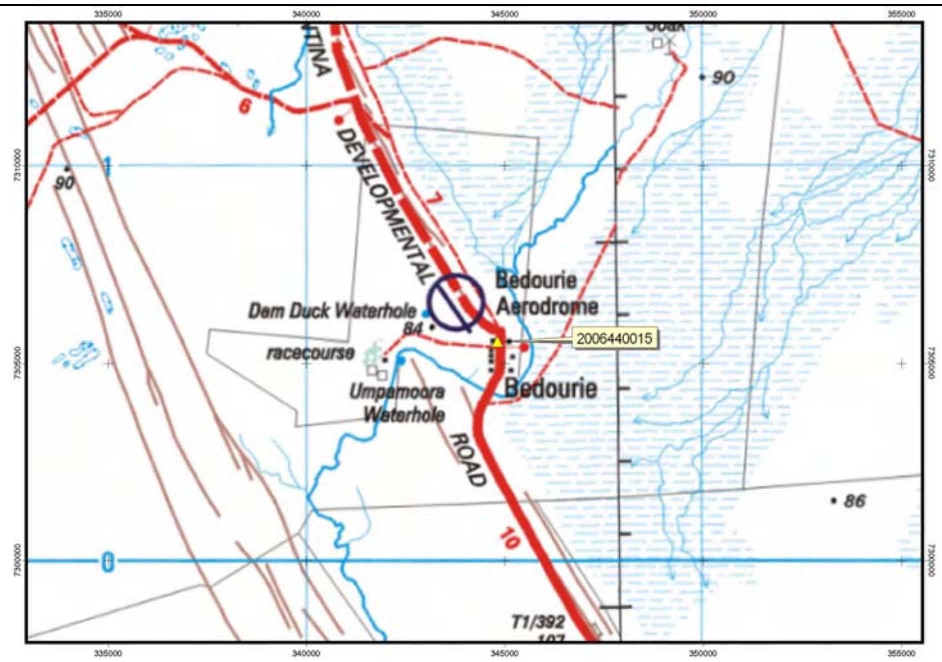
MGA94		GDA94	
EASTING (m)	344 814.411	LATITUDE (DMS)	24 21 20.4942 S
NORTHING (m)	7 305 537.845	LONGITUDE (DMS)	139 28 12.4933 E
ZONE (UTM)	54	GDAHT (m)	117.353
HEIGHT (AHD, m)	88.414	N (AUSGEOID98, m)	28.939
OBSERVED GRAVITY		**SURVEYED BY**	
9789016.07gu ISOGAL84		GPS – Surveyed using three consecutive days submitted to GA's AUSPOS service. IGS final orbits used in solution. Gravity – Tied to AGSO Base 1980900156 at Boulia Airport using ABABA ties with two meters.	

MISCELLANEOUS DETAILS

This station consists of a small star picket protruding approximately 150mm above ground level, and is witnessed by a large star picket with a Daishsat Witness Plate attached ~ 0.3m to the right. A circular concrete slab is also located beside these star pickets and is the gravity base.

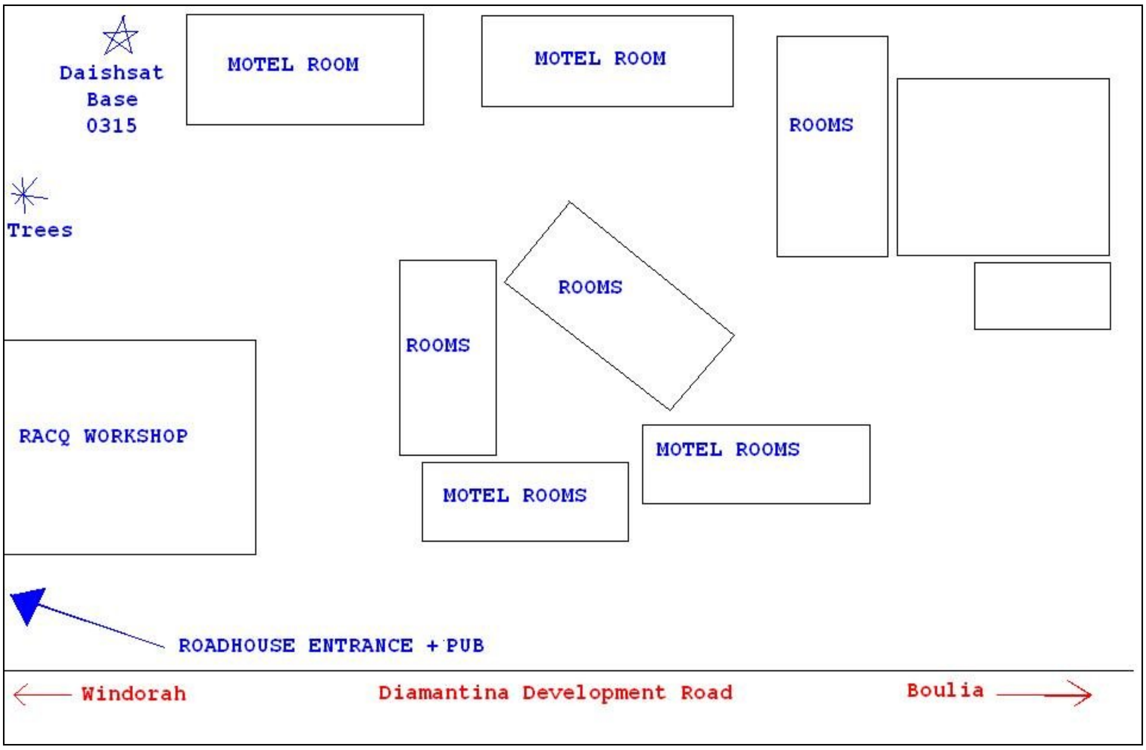
The base is located out the back of the Simpson Desert Oasis Roadhouse, in Bedourie. The Roadhouse is on the western side of the main north-south road running through the town. From the highway the base is 70 meters west of the southern corner of the roadhouse mechanics shed.

The township of Bedourie is 190km south of Boulia. A single lane highway runs between Boulia and Bedourie, and continues south to Birdsville. The Simpson Desert Roadhouse is on the western side of the highway.



Location Map

Base Station Photograph



Locality Sketch (not to scale)