

Surveying and Spatial Information Regulation 2017: GNSS and Plan Requirements

Simon Hine

Office of the Surveyor-General
Spatial Services, NSW Department of Finance, Services & Innovation
Simon.Hine@finance.nsw.gov.au

Les Gardner

Office of the Surveyor-General
Spatial Services, NSW Department of Finance, Services & Innovation
Les.Gardner@finance.nsw.gov.au

ABSTRACT

The Surveying and Spatial Information Regulation 2017 (“the Regulation”) came into force on 1 September 2017 and, in certain circumstances, allowed for the usage of approved Global Navigation Satellite System (GNSS) methods to determine the Map Grid of Australia (MGA) position and MGA orientation of a survey. This paper summarises, from a practical perspective, what should be shown on a survey plan to comply with those clauses of the Regulation that apply to GNSS methods and the datum line of orientation of a survey. Examples illustrating what should and should not be shown on a survey plan for compliance with the Regulation are given.

KEYWORDS: *Regulation, GNSS, datum line, position, orientation.*

1 INTRODUCTION

The horizontal datum of a survey plan is a fundamental requirement that defines the orientation of the survey with respect to a known reference frame. Depending on the regulations within the jurisdiction that apply to that survey plan, the horizontal datum requirements might also define the position of the survey with respect to a known reference frame. Establishing a datum, whether horizontal or vertical, is paramount to the reliability, traceability and spatial enablement of a survey (e.g. Janssen, 2009, 2017).

Historically, the majority of survey plans lodged with the New South Wales Registrar-General over the last 180 years or so have not adopted a horizontal datum line orientation aligned with a State or Federal reference frame or map projection. Instead, the datum line orientations adopted have included, amongst others, bearings from magnetic compass observations, bearings from astronomical observations and bearings from survey plans on public record. Typically, the orientation historically adopted is that of a bearing from magnetic compass observations or a bearing from a survey plan on public record that has adopted a bearing from magnetic compass observations.

A datum line orientation, including an orientation that is aligned with a State or Federal reference frame or map projection, does not solely spatially enable the survey. In order to spatially enable the survey, position information is required (i.e. coordinates of the datum line terminals within a State or Federal reference frame or map projection). The position

information should be stated on the survey plan so that the plan is spatially enabled without reference to any external databases, spatial information systems or other plans. That is, the survey plan should be spatially autonomous requiring very little, if any, further research by the end user. Not only are the majority of survey plans lodged with the NSW Registrar-General over the last 180 years or so not aligned with a State or Federal reference frame or map projection, neither do they have position information, thus the spatial enablement of those plans usually requires some considerable research and processing by the end user.

It is estimated that 95% of all current data contains geographical references (Perkins, 2010). As the spatial enablement of society has increased and continues to increase via the use of Global Navigation Satellite System (GNSS) enabled technology coupled with readily available mobile data connection, there is a greater expectation that data available to society will also be spatially enabled. Notably, the United Nations (UN) Resolution 69/266 has recognised “the economic and scientific importance of and the growing demand for an accurate and stable global geodetic reference frame for the Earth ... as the basis and reference in location and height for geospatial information” (UN, 2015). The ANZLIC Spatial Information Council, a “peak government body in Australia and New Zealand responsible for spatial information” (ANZLIC, 2018a) has introduced the Foundation Spatial Data Framework (FSDF) initiative which “is a change program on Australia’s ‘common asset’ of location information” (ANZLIC, 2018b) that “provides a common reference for the assembly and maintenance of Australian and New Zealand foundation level spatial data in order to serve the widest possible variety of users” (ANZLIC, 2018c). The FSDF has 10 themes, including ‘Positioning’ and ‘Elevation and Depth’, i.e. the fundamental elements required for spatial enablement of data. The NSW state control survey is an example of a dataset contributing to both the FSDF initiative and implementation of UN Resolution 69/266.

To respond to the societal and governmental expectation that publically available data should be spatially enabled, the Surveying and Spatial Information Regulation 2017 (NSW Legislation, 2017) (hereinafter referred to as “the Regulation”) that applies within New South Wales introduced reforms for greater spatial enablement of survey plans. Those reforms require the datum line of orientation for the majority of survey plans to be aligned to the Map Grid of Australia (MGA) and report an MGA position to, at a minimum, Class D standard. In particular, *all* rural surveys and the majority of urban surveys must have an MGA orientation and MGA position.

An MGA orientation and MGA position of the datum line can, under the Regulation, be achieved by two methods:

1. Connection to established survey marks of the state control survey, or
2. Use of an approved GNSS method.

Method number 2, i.e. use of an approved GNSS method, has resulted in a number of queries to the Office of the Surveyor-General regarding the correct implementation of such methods and the information to be shown on a survey plan when using an approved GNSS method for datum line orientation and position. Answers to those queries received have often included the explanation of certain geodetic concepts and their application to cadastral surveying. Traditionally, there has been little crossover between cadastral surveying (“that enables people to readily and confidently identify the location and extent of all rights, restrictions and responsibilities related to land and real property” (ICSM, 2015)) and geodetic surveying (that measures and represents the size and shape of the earth). This has, on occasion, caused confusion in practitioners of either of the above branches of surveying as to the methods and

techniques employed by the other. This confusion has latterly been brought into sharp relief by the ready availability of GNSS equipment, being geodetic surveying equipment that natively operates in a geodetic reference frame. The readily available GNSS equipment has been adopted by a majority of cadastral surveyors for use in cadastral surveys that historically, and as regulated, are expressed as bearings and distances on a local horizontal plane projection, being a non-geodetic projection.

In order to address the queries received by the Office of the Surveyor-General from cadastral surveyors, this paper describes certain geodetic concepts, tools available to cadastral surveyors for calculation of geodetic elements, the cases when approved GNSS methods for datum line purposes are to be used, use of approved GNSS methods for datum line purposes and their application to survey plan requirements under the Regulation, with reference to case studies of survey plans.

2 GEODETIC ELEMENTS REQUIRED FOR SURVEY PLANS

2.1 Grid Bearing

Clause 12 of the Regulation is the clause that regulates the adoption of datum lines of orientation for a survey plan. Clause 12, for many cases that might apply to a survey, states a requirement to adopt a grid bearing derived from MGA coordinates for orientation of the datum line.

2.1.1 Grid Bearing Concept

A line observed between two points on the earth's surface can be expressed as a line representing the shortest distance between two points on an ellipsoid, where the ellipsoid might be an equipotential ellipsoid that best represent the earth's size, shape and gravity field (Moritz, 2000) – that shortest line on the ellipsoid is called a geodesic.

For the Geocentric Datum of Australia 1994 (GDA94), the ellipsoid is the GRS80 reference ellipsoid that uses the International Terrestrial Reference Frame 1992 (ITRF92) as the reference frame. For the Geocentric Datum of Australia 2020 (GDA2020), the ellipsoid is also the GRS80 reference ellipsoid. However, GDA2020 uses a different reference frame being the International Terrestrial Reference Frame 2014 (ITRF2014), i.e. GDA94 and GDA2020 use the same reference ellipsoid, GRS80, but the ellipsoid is in slightly different positions for each of the two datums (e.g. Janssen, 2017). The ellipsoidal coordinates for a survey mark will therefore be different depending on what datum (GDA94 or GDA2020) the coordinates are expressed in. It should be noted that the majority of the ellipsoidal coordinate difference between GDA94 and GDA2020 is due to tectonic plate movement.

When a geodesic on the GRS80 reference ellipsoid for either GDA94 or GDA2020 is projected onto MGA, which is a Universal Transverse Mercator (UTM) projection, the geodesic projects as an arc. As an example, a cadastral surveyor working in NSW uses a total station to measure a line between two permanent survey marks, PM#1 and PM#2. The measured line, expressed as a geodesic on the reference ellipsoid (GRS80) for the GDA94 datum and then projected onto MGA will appear on the projection plane as an arc (Figure 1). If GNSS methods were used instead to measure the line, and that line were expressed as a geodesic (noting, though, that measured 3-dimensional GNSS vectors are not usually

expressed as geodesics in measurement processing), the measured line still appears on the projection plane as an arc.

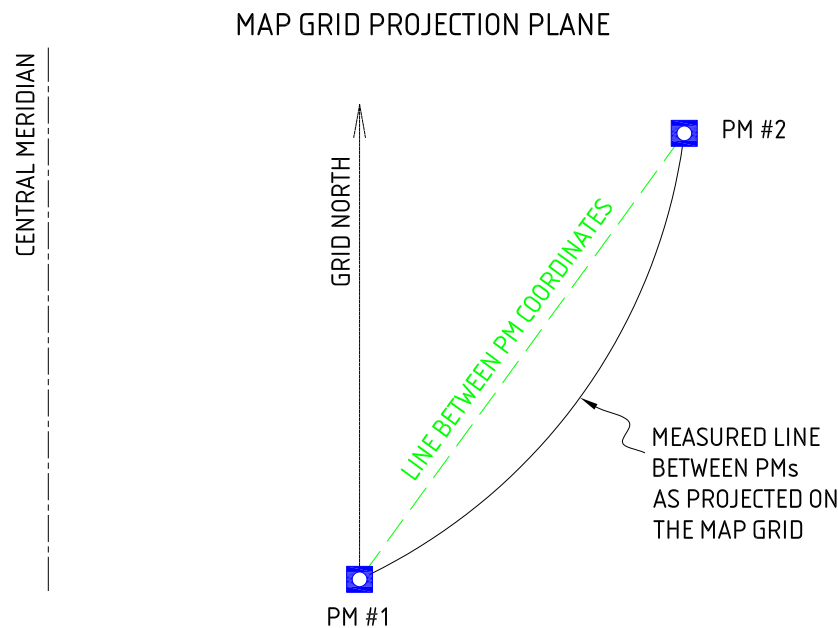


Figure 1: Measured line as projected.

As well as the Laplace correction, used for converting observed astronomical and gyro azimuths to geodetic azimuths (Featherstone and Rüeger, 2000), there are small corrections that apply to a direction measured by total station or theodolite when expressing the measured line as a geodesic on the reference ellipsoid. These corrections are the deflection correction, the skew normal correction and the correction from the normal section direction to the geodesic direction.

The deflection correction accounts for the deflection of the vertical due to the difference between the plumbline (the normal to the geoid) and the normal to the ellipsoid (ICSM, 2014). This gravimetric correction applies only to theodolite or total station direction observations as they use the plumbline as their measurement reference. The skew normal correction accounts for the fact that the ellipsoidal normals at each end of the line are not parallel (ICSM, 2014). The correction from a normal section direction to a geodesic direction accounts for the geodesic, in general, lying between the reciprocal normal section curves (Deakin, 2010).

Referring to the work of Deakin (2010), an example of an observed line from Buninyong to Smeaton, a geodesic distance of approximately 39.8 km, shows the deflection correction to be -0.020 seconds of arc, the skew normal correction to be +0.012 seconds of arc and the correction from the normal section direction to the geodesic direction to be -0.001 seconds of arc.

Within Australia, the GDA2020 technical manual reports that the maximum deflection of the vertical in terms of GDA94 and GDA2020 is of the order of 20 seconds of arc, which might result in a correction to an observed direction approaching half a second of arc (ICSM, 2018a). Featherstone and Rüeger (2000) reported a correction to a direction of 7.25 seconds of arc when reducing a line of geodetic zenith angle 45° (i.e. very large height difference) to the GRS80 ellipsoid using GDA94 position and AUSGeoid98 deflections of the vertical.

For the vast majority of cadastral surveys (i.e. traverse lines less than 10 km), the deflection correction, skew normal correction and the correction from a normal section direction to a geodesic direction are negligible and can be ignored (Deakin, 2010), though very steep lines might require application of the deflection correction.

If the above corrections are considered negligible, the direction as observed in the field for the line PM#1 to PM#2 is the tangent to the arc (the measured line as projected) at PM#1. Similarly, for PM#2 to PM#1 the observed direction is the tangent to the arc at PM#2 (Figure 2).

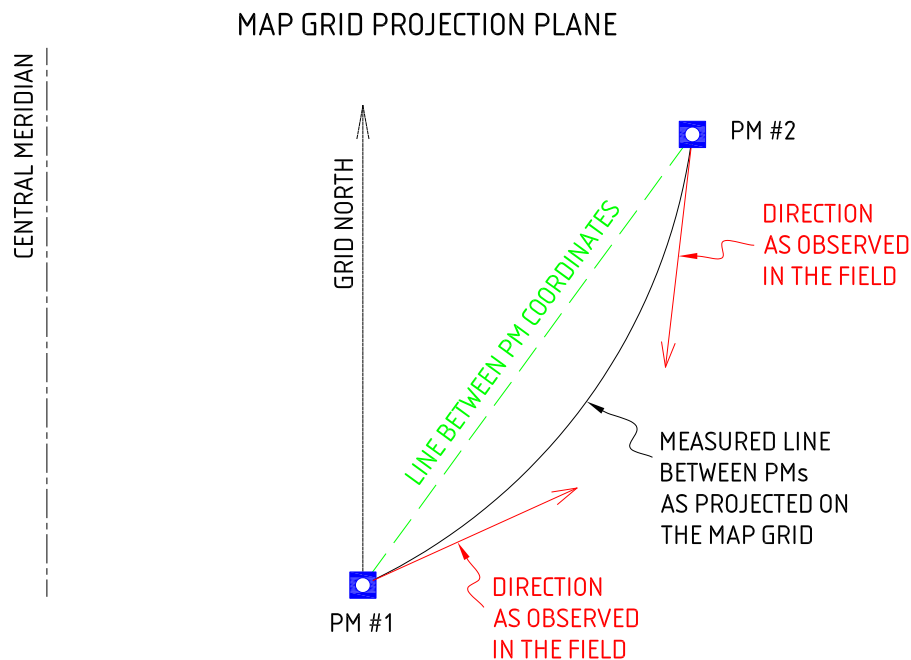


Figure 2: Observed directions on the projection plane.

The grid bearing of a measured line is the clockwise angle between grid north and the tangent to the arc (the measured line as projected) at either terminal of the arc (Figure 3).

The clockwise angle, on the projection plane, between grid north and the straight line between the projected coordinates for PM#1 and PM#2 is called the plane bearing (Figure 4).

The difference between the plane bearing and the grid bearing is known as the arc-to-chord correction (Figure 5).

CENTRAL MERIDIAN

MAP GRID PROJECTION PLANE

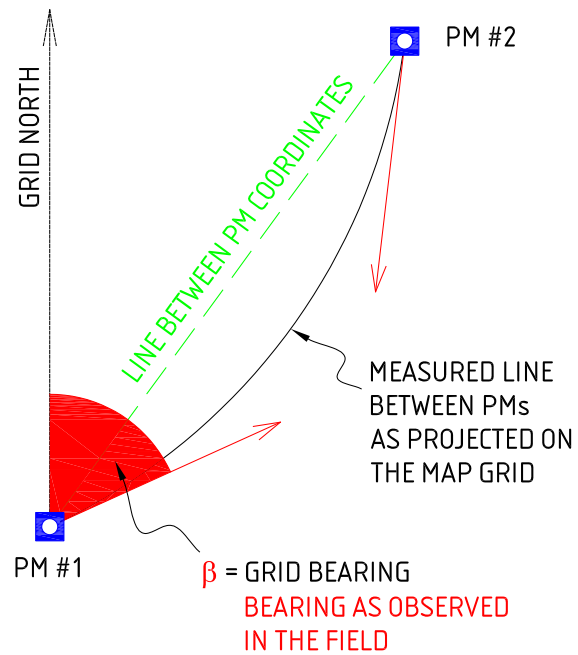


Figure 3: Grid bearing.

CENTRAL MERIDIAN

MAP GRID PROJECTION PLANE

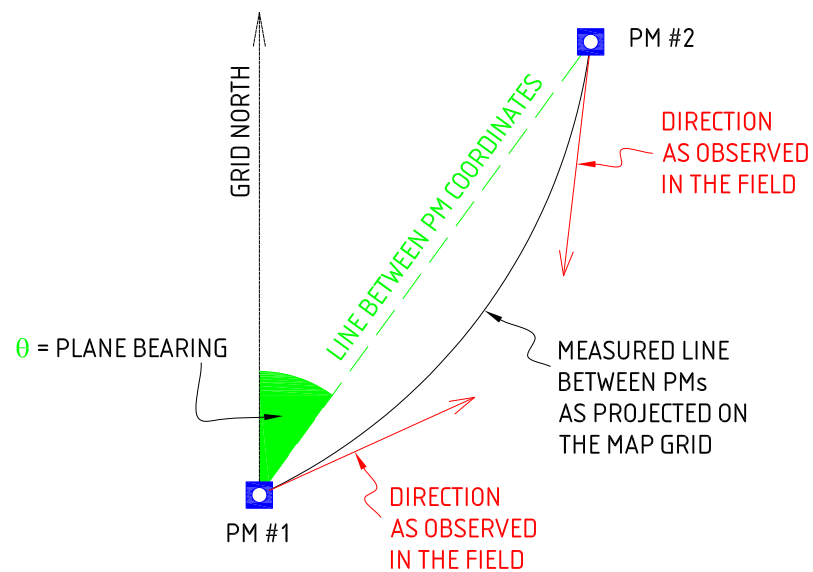


Figure 4: Plane bearing.

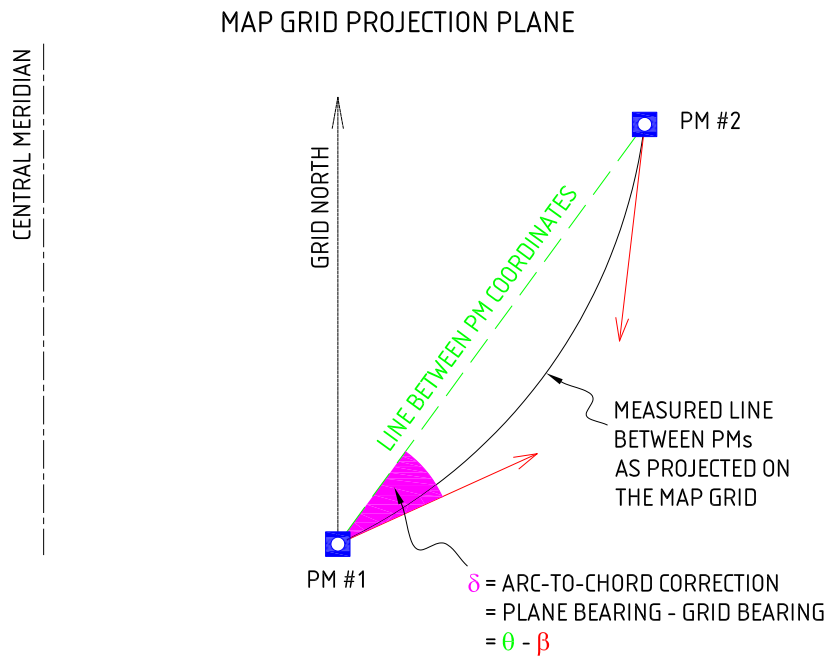


Figure 5: Arc-to-chord correction.

As a ‘rule of thumb’, when determining visually what direction and extent to which an arc, representing a measured line as projected on MGA, will ‘bow out’ on the projection plane (i.e. the direction and extent of the concavity of the arc), it is useful to consider a fictitious wind that blows from the central meridian of the projection zone towards the straight line between the projected coordinates of the line’s terminals. If that straight line is thought of as a sail, then it will always bow out away from the central meridian (Figure 6). Also, the closer that straight line is aligned to the north-south direction and the longer it is, the greater the line will bow out. Lines that are aligned perfectly east-west on the projection plane and those lines perfectly coincident with the central meridian will have an arc-to-chord correction of zero. The magnitude of the arc-to-chord correction is also dependent on where in the projection zone the line is situated. For example, close to the edges of the projection zone, the arc-to-chord correction will be larger.

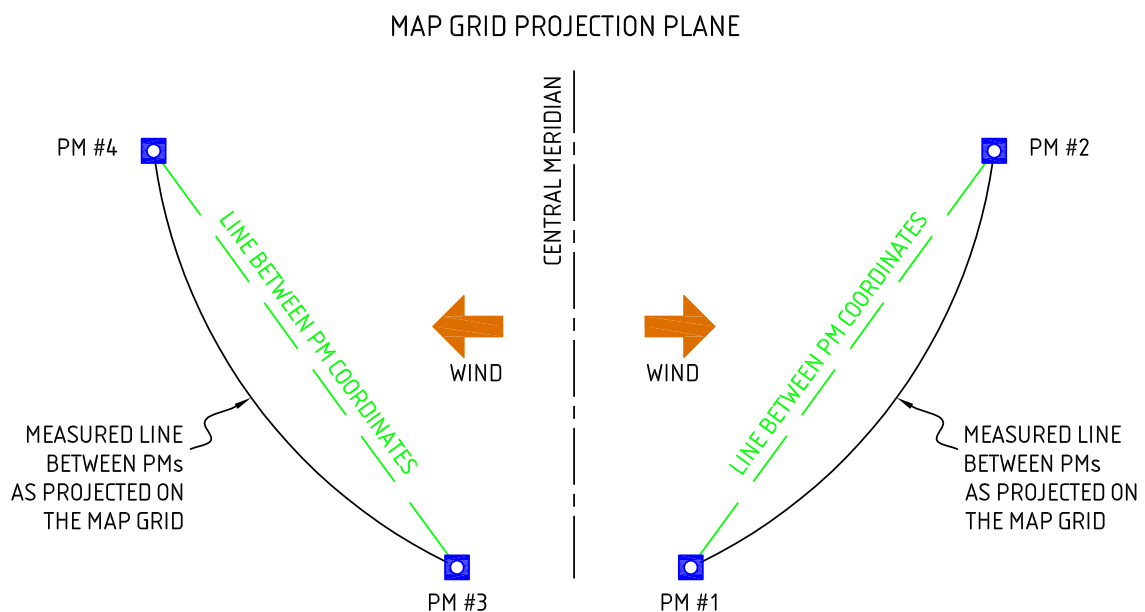


Figure 6: Visualising a measured line as projected.

Essentially, a geodesic joining two points will almost always project as a curved line lying on the side of the straight line joining the two projected terminals where the projection scale factor is greater (NMC, 1986). However, there is an exception to the rule of thumb as described above. In the case where the central meridian divides a line such that one part of the line is less than one-third of the total line length, the visualisation approach for determination of the sign of the arc-to-chord correction will fail. The sign of the arc-to-chord correction is then determined by the concavity of the longer part of the line (NMC, 1986) (Figure 7).

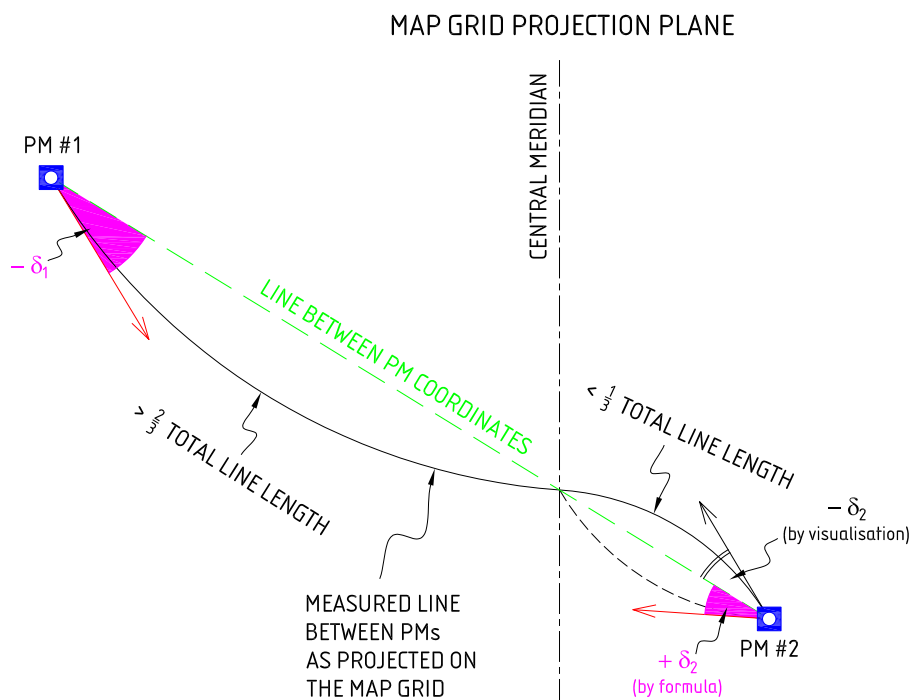


Figure 7: Exception to visualising the arc-to-chord correction.

Summarising the concept of a grid bearing:

- A line measured on the earth's surface will be projected on the MGA projection as an arc.
- The grid bearing is the bearing of the tangent to that arc at a terminal of the arc.

2.1.2 Adoption of a Grid Bearing by a Survey Plan

It can be noted from Figures 4 & 5 that the forward grid bearing and reverse grid bearing for a measured line as projected will not, in most cases, differ by exactly 180°. Survey plans under the Regulation show bearings in a local plane projection where the forward and reverse bearings will differ by exactly 180°. Therefore, the requirement of the Regulation, in specific cases, for the datum line of a survey plan to adopt a grid bearing derived from the MGA coordinates of two marks will align the survey plan exactly with MGA for one terminal of the datum line only (the 'occupied' datum line terminal for the calculated grid bearing). This outcome is due to the distortions that exist between the MGA projection surface, being a UTM projection, and the local horizontal plane projection on which survey plans under the Regulation are placed. For the vast majority of cadastral surveys, being surveys of limited extent, any differences in alignment with MGA over the survey plan extent are very small and can be considered negligible in a cadastral context.

2.1.3 Calculation of a Grid Bearing

The currently available Excel spreadsheet GRIDCALC.XLS, provided by the Intergovernmental Committee on Surveying and Mapping (ICSM) enables the easy calculation of grid bearings from projected coordinates. GRIDCALC.XLS can be accessed as follows:

1. Download a copy of the GDA94 technical manual (ICSM, 2014).
2. Chapter 6 on page 23 displays a link “Excel spreadsheet – Grid calculations” by which a user can download GRIDCALC.XLS.

It is recommended that users familiarise themselves with the ‘Parameters’ tab to ensure that the correct parameters for the required ellipsoid and map projection are set. It should be set to MGA by default. The user should then navigate to the ‘Grid coord > Bearing & Ell Dist’ tab.

The user is required to input the Easting, Northing and projection zone of two points on the projection plane, and receives as output an ellipsoidal distance, a plane distance (the distance of the straight line between the projected coordinates on the map grid projection plane), grid bearings, arc-to-chord corrections and the line scale factor (Figures 8 & 9). Note that the line scale factor is *not* the Combined Scale Factor, which is discussed in section 2.2. The line scale factor is the ratio of a plane distance to the corresponding ellipsoidal distance (NMC, 1986; ICSM, 2014, 2018a).

Grid Bearing and Ellipsoidal Distance from Grid Coordinates				MGA
	Name	East (E)	North (N)	Zone
From (1)	PM #1	737,283.595	6,291,260.090	55
To (2)	PM #2	737,694.224	6,291,635.411	55
Ellipsoidal Distance (s)	556.147			
Plane Distance (L)	556.311			
Grid Bearing (β_1)	47°	34'	20.24"	
Grid Bearing (β_2)	227°	34'	19.78"	
				KEY
				User input
				Result
Arc to Chord correction (δ_1)	-0.23"			
Arc to Chord correction (δ_2)	0.23"			
Line scale factor (K)	1.000 295 40			

Figure 8: GRIDCALC.XLS output – standard example.

Grid Bearing and Ellipsoidal Distance from Grid Coordinates				MGA
	Name	East (E)	North (N)	Zone
From (1)	PM 55644	222,007.144	6,287,455.333	56
To (2)	PM 79821	221,391.685	6,303,291.852	56
Ellipsoidal Distance (s)	15839.683			
Plane Distance (L)	15848.474			
Grid Bearing (β_1)	357°	46'	16.71"	
Grid Bearing (β_2)	177°	46'	39.11"	
				KEY
				User input
				Result
Arc to Chord correction (δ_1)	11.20"			
Arc to Chord correction (δ_2)	-11.21"			
Line scale factor (K)	1.000 554 99			

Figure 9: GRIDCALC.XLS output – edge of zone example.

Figure 8 shows a standard example of a line that might well be adopted as the orientation of the datum line for a cadastral survey within NSW. Note that the arc-to-chord correction for this case would be considered negligible in the context of a cadastral survey. However, other arc-to-chord corrections for lines of differing length, orientation and position within a projection zone might well be significant in the context of a cadastral survey. Such an example on the edge of the projection zone is given in Figure 9.

2.2 Combined Scale Factor

Clause 70 of the Regulation is the clause that regulates the particulars of the coordinate schedule that must be shown on the survey plan. It is the coordinate schedule that is fundamental to the autonomous spatial enablement of the plan discussed in section 1. Clause 70(2)(h) of the Regulation requires the Combined Scale Factor to be shown

2.2.1 Combined Scale Factor Concept

Clause 59(2) of the Regulation requires a survey plan to state distances as “horizontal plane distances at ground level” (NSW Legislation, 2017), otherwise known as level terrain distances (ICSM, 2018a) or, simply, ground distances.

For other purposes, a reduced slope distance can also be expressed as a ground distance, an ellipsoidal distance, a grid distance or a plane distance (Figures 10 & 11):

- A ground distance is a reduced slope distance projected onto a local horizontal plane at mean ground level.
- An ellipsoidal distance is the distance on the ellipsoid along either a normal section or a geodesic. The difference between the normal section and geodesic distances is considered negligible, and amounts to less than 20 mm in 3,000 km (NMC, 1986; ICSM, 2014).

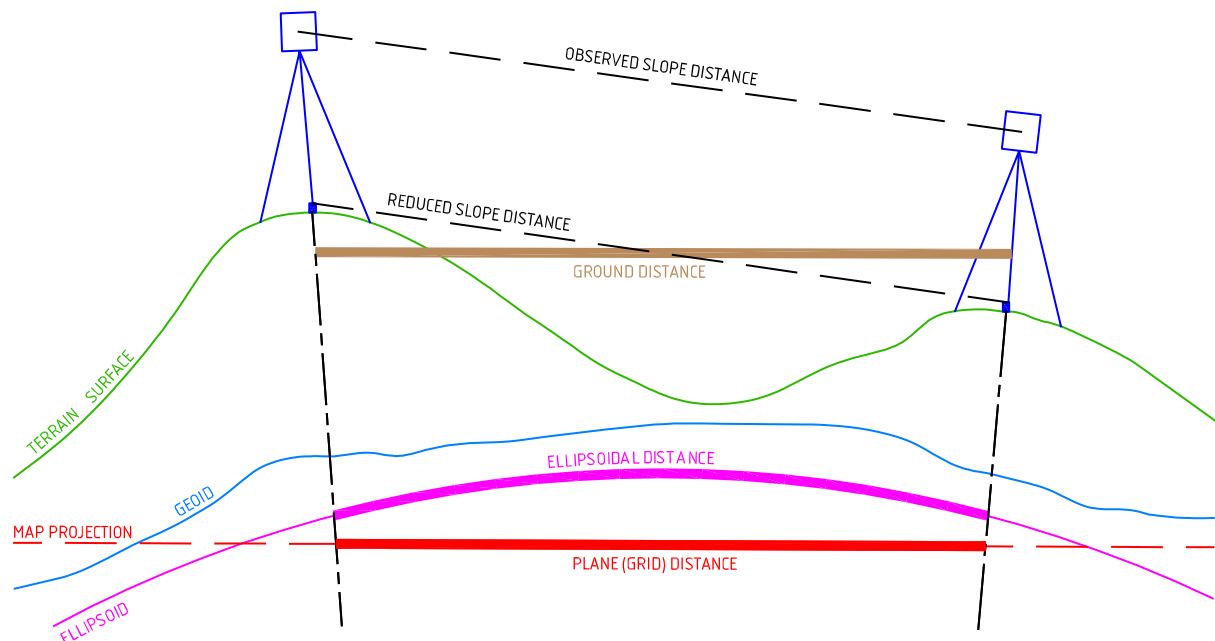


Figure 10: Distance types.

- A grid distance is the length measured on the map grid projection along the arc of a projected geodesic.

- A plane distance is the length of the straight line on the projection between the terminals of the arc of a projected geodesic. The difference in length between the plane distance and grid distance is nearly always negligible (NMC, 1986; ICSM, 2014, 2018a). Mahdi (2006) reported a line where a difference of approximately 1 mm was calculated between a 105 km projected geodesic length and its chord on a UTM projection.

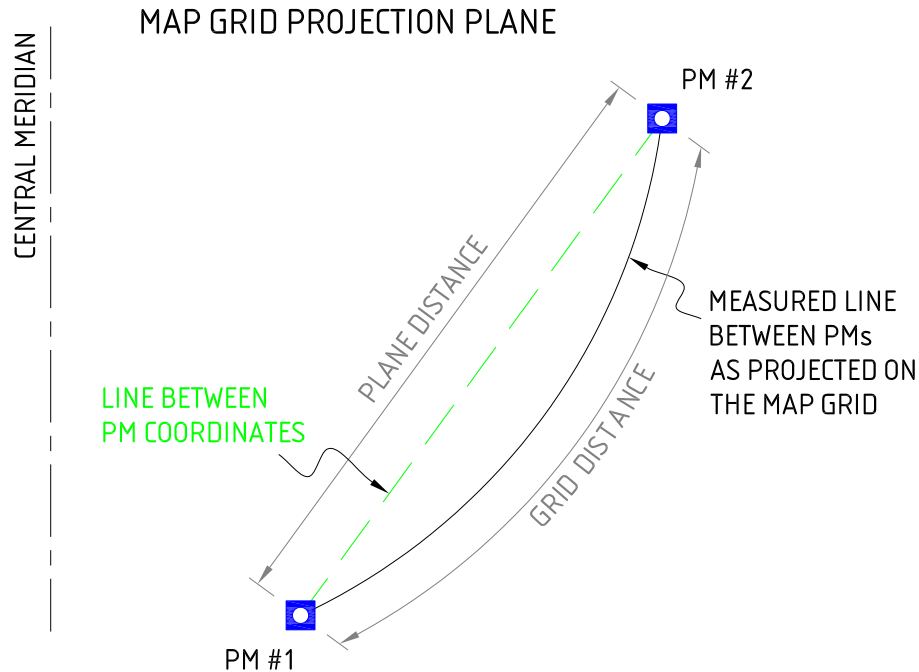


Figure 11: Plane distance and grid distance.

The Combined Scale Factor (CSF) is, as the name suggests, a combination of scale factors that describes the ratio of the plane (grid) distance to the ground distance. The CSF can be calculated for either a line or a point. The basic equation for the CSF (line) is:

$$\text{Combined Scale Factor (line)} = \text{Height Factor (line)} \times \text{line scale factor} \quad (1)$$

In Equation 1, the height factor, for surveys of limited extent, is used to reduce the ground distance to the ellipsoidal distance. The line scale factor is used to reduce the ellipsoidal distance to the plane (grid) distance.

Strictly speaking, the height factor describes the reduction of a ground distance to an ellipsoidal chord distance (NMC, 1986; Deakin, 2006). However, for surveys of limited extent (i.e. the majority of cadastral surveys), the ellipsoidal chord-to-arc correction is considered negligible and thus the height factor is then considered to be the reduction from the ground distance to the ellipsoidal distance. The CSF for a line in a survey of limited extent is described diagrammatically in Figure 12.

For an ellipsoidal chord distance of 5 km, the ellipsoidal chord-to-arc correction is of the order of +0.1 mm (Deakin, 2006), and for an ellipsoidal chord distance of 15 km, it is of the order of +3 mm. Surveyors wanting to derive an accurate CSF (line) for long lines and surveys of large extent might need to consider the inclusion of an ellipsoidal chord-to-arc correction.

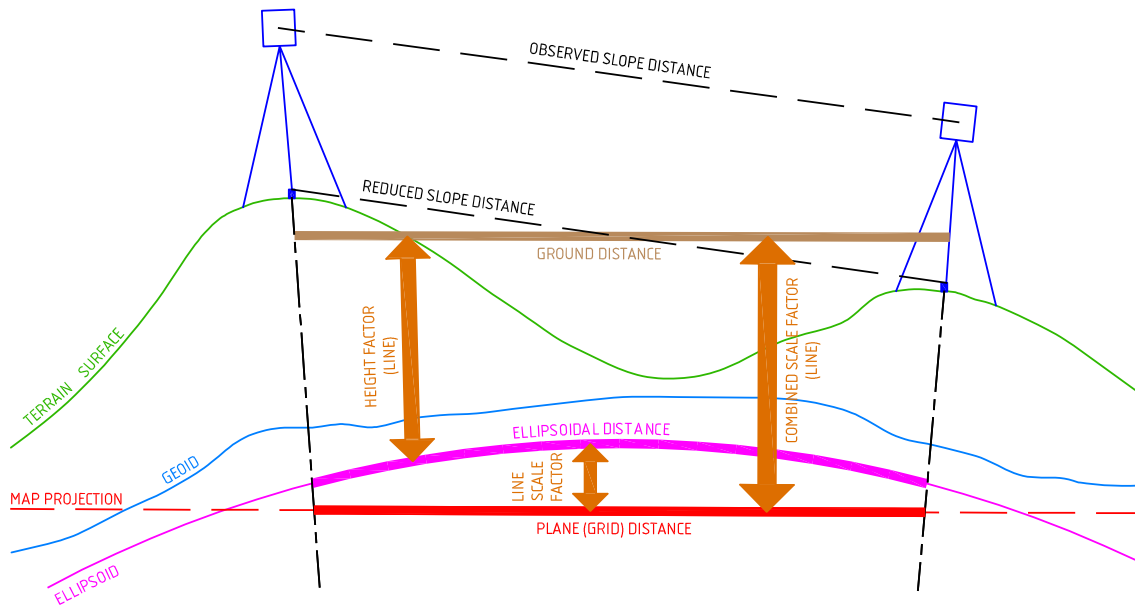


Figure 12: Combined Scale Factor (line) for surveys of limited extent.

The CSF can also be calculated for a point. The CSF for a point describes the ratio of an infinitesimal plane (grid) distance to an infinitesimal ground distance (Figures 13 & 14). The basic equation for the CSF (point) is:

$$\text{Combined Scale Factor (point)} = \text{Height Factor(point)} \times \text{point scale factor} \quad (2)$$

In Equation 2, the height factor for the CSF (point) is used to reduce the infinitesimal ground distance to an infinitesimal ellipsoidal distance. The point scale factor is used to reduce the infinitesimal ellipsoidal distance to the infinitesimal plane (grid) distance.

Strictly speaking, the height factor in Equation 2 describes the reduction of a ground distance to an ellipsoidal chord distance. However, for a point, as the infinitesimal ellipsoidal chord approaches a length of zero, it will be of the same length as the infinitesimal ellipsoidal arc distance. Thus, for a point, the ellipsoidal chord-to-arc correction will be zero.

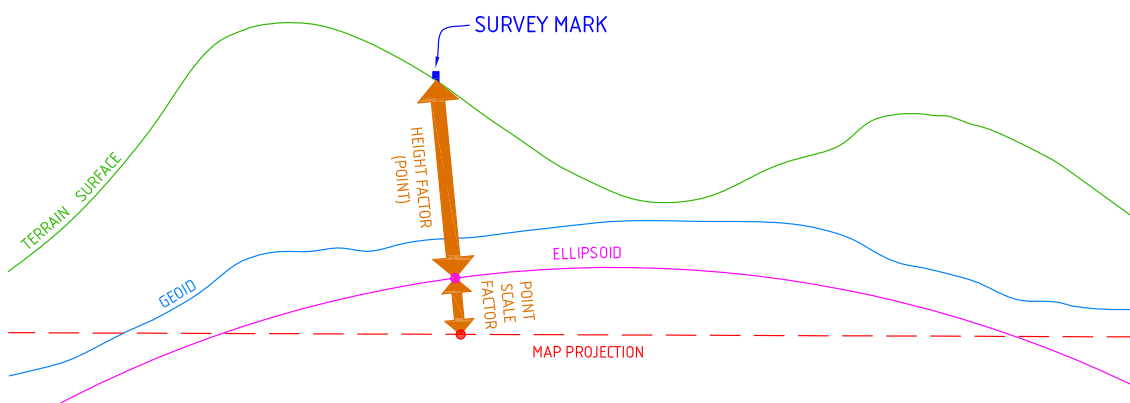


Figure 13: Components of the Combined Scale Factor (point).

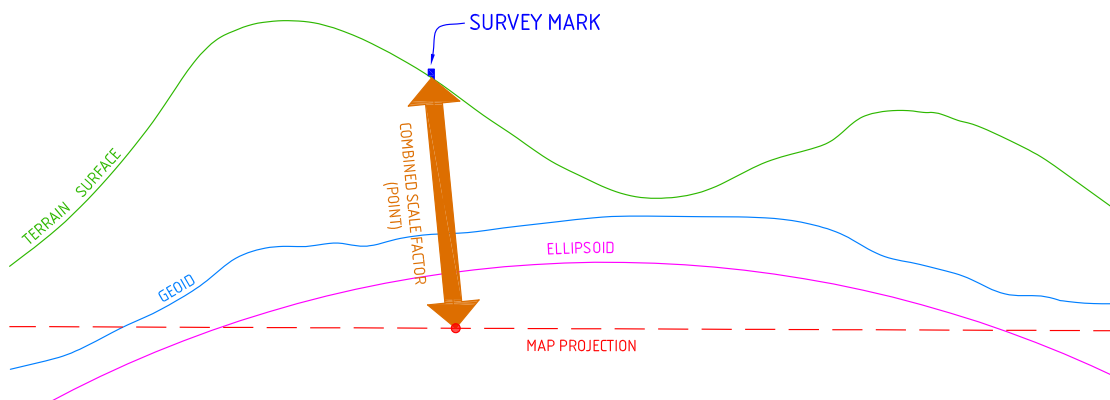


Figure 14: Combined Scale Factor (point).

2.2.2 Calculation of the Combined Scale Factor

Calculation of the Combined Scale Factor (Point)

To calculate an individual CSF (point) for MGA, an Excel spreadsheet CSF.XLS is provided by DFSI Spatial Services that enables easy calculation of the CSF (point) for MGA. It can be accessed as follows:

1. Navigate to the 'Conversion Software' section of DFSI Spatial Services' webpage (DFSI Spatial Services, 2018).
2. Under 'MGA Combined Scale Factor', use the 'Download a spreadsheet' link to download CSF.XLS.

The user is required to input the Easting, Australian Height Datum (AHD) value and geoid-ellipsoid separation (N-value) for the point (Figure 15). Users should be aware that any error in either the AHD value or the N-value will lead to an error in the CSF (point). If the combined error of the AHD value and the N-value is 6 m, the error in the CSF (point) will be approximately 1 ppm.

COMBINED SCALE FACTOR for MGA (GDA 94)

Easting (m)	Height(m)	N	CSF
222007.144	887.296	25.798	1.000409

Figure 15: CSF.XLS – Combined Scale Factor (point).

CSF.XLS uses the same equations for the CSF (point) as the Survey Control Information Management System (SCIMS), the coordinate database for the NSW survey control survey network, and will therefore give the same result as that reported by SCIMS (Figures 15 & 16).

MARK NAME STATUS	COORDINATES AND HEIGHTS				CLASS	ORDER	PU	SOURCE	CSF CONVERGENCE AUSGEOID09
PM 55644	MGA	222007.144	6287455.333	56	A	2	n/a	230288	1.000409
	GDA94	-33° 30' 58.90620"		150° 00' 25.60563"					-1° 39' 13.17"
	AHD71	887.296			LB	L2	n/a	209733	25.798

Figure 16: Part of the SCIMS report for PM55644.

The height factor and point scale factor equations used by CSF.XLS and SCIMS are shown in Equation 3 and are derived from Bomford (1980) and the Australian Geodetic Datum technical manual (NMC, 1986).

Using Equation 2 for MGA:

$$\text{Combined Scale Factor (point)} = \left(1 - \frac{h}{R + h}\right) \times (0.9996 + 1.2323 E'^2 10^{-14}) \quad (3)$$

Also:

$$h = H + N \quad (4)$$

and:

$$E' = E - 500,000 \quad (5)$$

where:

E' = Easting measured from a central meridian, positive eastwards

E = False Easting (as reported by SCIMS)

h = ellipsoidal height

H = orthometric (AHD71) height

N = geoid-ellipsoid separation

R = radius of curvature

In the above terms, E is the Easting as reported by SCIMS and is the Easting measured from the false origin. A suggested value for R in NSW is 6,370,100 m (NMC, 1986). The mid-latitude value of the geometric mean radius for NSW on the GRS80 ellipsoid is approximately 6,369,800 m.

The accuracy of the CSF (point) calculation relies upon the accuracy of the Easting, AHD value and N -value of the point. Generally, an accurate N -value has been the more difficult value for cadastral surveyors to determine. Cadastral surveyors in NSW have several sources by which an accurate N -value can be determined:

- SCIMS report.
- AUSPOS report.
- Geoscience Australia website.
- ICSM website.

As can be seen in Figure 16, a SCIMS report for a mark will list the N -value with respect to the geoid model applicable to the datum (GDA). Figure 16 shows the AUSGeoid09 N -value for PM55644 as 25.798 m. Note, however, that the SCIMS report also lists the CSF (point), being 1.000409 for PM55644.

AUSPOS is a free online GPS processing facility provided by Geoscience Australia, available for static GPS observations (GA, 2018b). Figure 17 shows an extract of an AUSPOS report, which may have been used as a terminal of a datum line, giving sufficient information by which an N -value can be calculated. The use of AUSPOS for datum line orientation is further discussed in Surveyor-General's Direction No. 7 (DFSI Spatial Services, 2017).

3.3 MGA Grid, GRS80 Ellipsoid, GDA94

Station	East (m)	North (m)	Zone	Ellipsoidal Height (m)	Derived AHD (m)
0402	556935.957	6728431.135	55	156.924	128.106

Figure 17: Extract of an AUSPOS report.

Referring to Figure 17, the N-value for the point observed in the AUSPOS report is calculated as the (Ellipsoidal Height) – (Derived AHD). Note that the ‘Derived AHD’ height is not, in a strict legal sense, the height of the point relative to the AHD71 datum as is reported by SCIMS. It is an orthometric height derived from the ellipsoidal height using the appropriate AUSGeoid model and can be considered to represent AHD71, for AUSGeoid09 in conjunction with GDA94, to an accuracy of approximately 0.1 m or better throughout NSW (Janssen and Watson, 2011) and for AUSGeoid2020 in conjunction with GDA2020 to an accuracy of approximately 0.05 m or better throughout NSW (Janssen and Watson, 2018).

Geoscience Australia provides an online calculation tool for determining the N-values of various AUSGeoid models (GA, 2018a) (Figures 18 & 19). The geoid model required is specified, the latitude and longitude of the point, referred to the appropriate datum (GDA94, GDA2020) is entered, a height (ellipsoidal or AHD) is entered and the result computed. The example shown in Figure 19 returns an AUSGeoid09 N-value of 25.799 m for the latitude and longitude entered.

Compute an AUSGeoid value online
Batch Processing

Enter your data in the fields below.

AUSGeoid98 extents are: Latitude [-8 and -46] Longitude [108 and 160].
AUSGeoid09 extents are: Latitude [-8 and -46] Longitude [108 and 160].
AUSGeoid2020 extents are: Latitude [-8 and -61] Longitude [93 and 174].

Note: Only GDA94 coordinates should be used with AUSGeoid98 and AUSGeoid09. Only GDA2020 coordinates should be used with AUSGeoid2020.

AUSGeoid:
AUSGeoid09

GDA94/2020 Latitude: **GDA94/2020 Longitude:**
-33.5163628333 150.007112675
e.g., -35.5000000 145.5000000

☒ Decimal Degrees
☐ Degrees Minutes Seconds

Height (m):
887.296
e.g., 12.345

☒ Ellipsoidal
☒ AHD

compute reset

Figure 18: Geoscience Australia’s online AUSGeoid calculation tool – input form.

Calculation Results

AUSGeoid file used:	AUSGeoid09
Latitude (decimal degrees):	-33.5163628333
Longitude (decimal degrees):	150.007112675
AHD height (m):	887.296
Ellipsoidal height (m):	913.095
AUSGeoid value (m):	25.799
AUSGeoid uncertainty (m):	-
Deflection prime meridian (seconds):	-5.00
Deflection prime vertical (seconds):	0.14

Figure 19: Geoscience Australia's online AUSGeoid calculation tool – results.

As an alternative, ICSM provides geoid interpolation software 'GeodInt' (ICSM, 2018b) (Figures 20 & 21). GeodInt requires a WINTER DAT format or NTv2 GSB format geoid grid file. Instructions on how to download an NTv2 GSB format geoid grid file can be found on Geoscience Australia's AUSGeoid webpage (GA, 2018a) (Figure 22).

- [GeoidInterpolation.zip](#) V1.03 December 2011 (0.6 MB)

Latest version of geoid interpolation program. Requires geoid grid file in either WINTER DAT format or NTv2 gsb format. Offers interactive and file interpolation modes and the ability to create a single NTv2 file from a grid file in the legacy AUSGeoid DAT file format. Software documentation is provided.

(Users who experience problems running this software for the first time should install the Microsoft Visual C++ 2008 Libraries.)

Figure 20: GeodInt download (ICSM, 2018b).

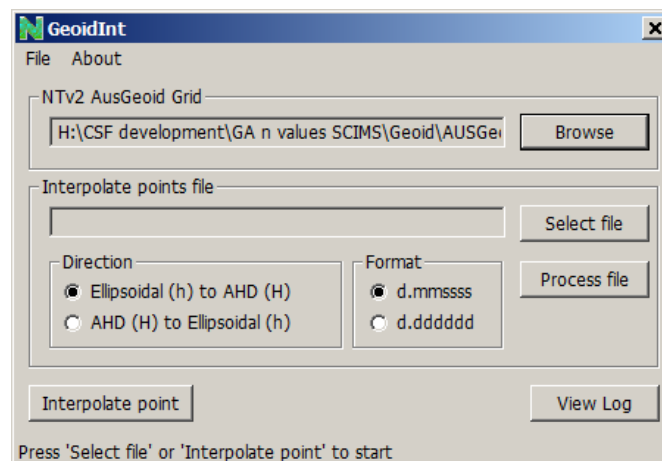


Figure 21: GeodInt user interface.

Download AUSGeoid files

The AUSGeoid files in text file format and binary format (NTv2) can be downloaded from [AWS S3](#). To download a file, cut and paste the bucket path (<https://s3-ap-southeast-2.amazonaws.com/geoid/>) into a browser and append the file name you would like to download (e.g. AUSGeoid2020_20170908.gsb) and tap Enter.

Figure 22: GSB file download (GA, 2018a).

Using the CSF (Point) to Calculate the CSF (Line)

For lines measured in surveys of limited extent, i.e. the majority of cadastral surveys, the CSF (point) can, depending on the length of the line and the terrain over which the line is measured, be used to calculate the CSF (line) with adequate results within the context of the Regulation.

Methods of calculating the CSF (line) using the CSF (point) in a cadastral survey vary. Some methods are summarised here:

- (a) Mean of the CSF (point) of each terminal. The mean of the point scale factors for the terminals of a line is accurate to 1 ppm in a line extending 16 km in Easting (NMC, 1986):

$$CSF_{line} = \frac{(CSF_{P1} + CSF_{P2})}{2} \quad (6)$$

- (b) The CSF (point) for the mean Easting of the line. The point scale factor for the mean Easting of a line is accurate to 1 ppm in a line extending 33 km in Easting (NMC, 1986):

$$CSF_{line} = CSF_{mean\ E} \quad (7)$$

- (c) Use of Simpson's Rule:

$$CSF_{line} = \frac{(CSF_{P1} + 4(CSF_{mean\ E}) + CSF_{P2})}{6} \quad (8)$$

where:

CSF_{line} = CSF for a line between point 1 (P1) and point 2 (P2)

CSF_{P1} = CSF for point 1 (P1)

CSF_{P2} = CSF for point 2 (P2)

$CSF_{mean\ E}$ = CSF for the mean easting between point 1 (P1) and point 2 (P2)

Method (c) (i.e. Equation 8) is considered to have greater accuracy than either of methods (a) or (b) (Stern, 1995).

Calculating the Combined Scale Factor (Line)

A surveyor can calculate a more rigorous CSF (line) than the procedures shown in Equations 6-8 by calculating the height factor for the line then substituting that height factor along with the line scale factor as calculated by GRIDCALC.XLS (see section 2.1.3) into Equation 1. The height factor for a line from point 1 to point 2 can be calculated using Equation 9 (section 2.3.5 of the Australian Geodetic Datum technical manual – NMC, 1986) and Equation 10:

$$Height\ factor\ (line) = \left(1 - \frac{h_m}{R_\alpha + h_m}\right) \quad (9)$$

Also:

$$h_m = \frac{h_1 + h_2}{2} \quad (10)$$

where:

h_m = mean ellipsoidal height

h_1 = ellipsoidal height of point 1

h_2 = ellipsoidal height of point 2

R_α = radius of curvature in the azimuth of the line

An ellipsoidal height for points 1 and 2 can be calculated using Equation 4. As above, an error in the ellipsoidal height of 6 m will result in an error of approximately 1 ppm in the CSF (line) (Deakin, 2006).

The radius of curvature in the azimuth, R_α , can be calculated using either the Australian Geodetic Datum technical manual (NMC, 1986), the GDA94 technical manual (ICSM, 2014) or the GDA2020 technical manual (ICSM, 2018a). For the majority of cadastral surveys, a value of 6,370,100 m can be substituted as an approximation for R_α in Equation 9 (NMC, 1986). Also, an approximate mid-latitude value of the geometric mean radius for NSW on the GRS80 ellipsoid of 6,369,800 m can be used. Deakin (2006) reports that an error in R_α of 20,000 m (20 km) will result in an error of approximately 0.2 mm in the plane distance for a line with a local plane (ground) distance of 1,000 m, mean ellipsoidal height of 500 m and value of R_α of 6,370,000 m. Therefore, use of either 6,370,100 m or 6,369,800 m for R_α for cadastral surveys in NSW is adequate within the context of the Regulation. For higher accuracy applications, R_α should be calculated for individual lines.

For surveyors requiring calculation of the CSF (line) without use of GRIDCALC.XLS, the expanded equation for a line from point 1 to point 2 is given in Equation 11, with the first term being the height factor as per Equations 9 & 10. The second term is the line scale factor as per section 5.6.2 of the Australian Geodetic Datum technical manual (NMC, 1986). Equations 12-18 will also be required.

Using Equation 1:

$$CSF_{line} = \left(1 - \frac{h_m}{R_\alpha + h_m}\right) \times k_0 \left\{1 + \left[\frac{(E_1'^2 + E_1'E_2' + E_2'^2)}{6r_m^2}\right] \left[1 + \frac{(E_1'^2 + E_1'E_2' + E_2'^2)}{36r_m^2}\right]\right\} \quad (11)$$

Also:

$$r_m^2 = \rho_m v_m k_0^2 \quad (12)$$

$$v_m = \frac{a}{\sqrt{(1 - e^2 \sin^2 \varphi_m)}} \quad (13)$$

$$\rho_m = \frac{a(1 - e^2)}{(1 - e^2 \sin^2 \varphi_m)^{\frac{3}{2}}} \quad (14)$$

$$e^2 = \frac{(a^2 - b^2)}{a^2} \quad (15)$$

$$\varphi_m = \frac{\varphi_1 + \varphi_2}{2} \quad (16)$$

$$E'_1 = E_1 - 500,000 \quad (17)$$

$$E'_2 = E_2 - 500,000 \quad (18)$$

where:

a = length of the reference ellipsoid semi-major axis

b = length of the reference ellipsoid semi-minor axis

CSF_{line} = CSF for a line between point 1 and point 2

e = eccentricity of the reference ellipsoid

E_1 = false Easting of point 1 (Easting as reported by SCIMS)

E_2 = false Easting of point 2 (Easting as reported by SCIMS)

E'_1 = Easting of point 1 measured from a central meridian, positive eastwards

E'_2 = Easting of point 2 measured from a central meridian, positive eastwards

h_m = mean ellipsoidal height

k_0 = central scale factor = 0.9996 for MGA

R_α = radius of curvature in the azimuth of the line

φ_1 = latitude of point 1

φ_2 = latitude of point 2

φ_m = mean latitude

ν_m = radius of curvature in the prime vertical at the mean latitude

ρ_m = radius of curvature in the meridian at the mean latitude

Term 2 of Equation 11, the line scale factor, is accurate to 0.1 ppm for lines of plane distance less than 100 km (Bomford, 1980). If further rigour is required for the CSF (line), the ellipsoidal chord-to-arc correction should be included (see section 2.2.1).

2.2.3 Use of the Combined Scale Factor

Clause 70(2)(h) of the Regulation requires the CSF for the survey to be shown. This is a single value that best represents the extent of the survey shown in the survey plan. It is not necessarily the single value used for all lines in the survey. The surveyor may choose to use separately calculated CSFs for each line requiring a CSF to be applied, or separate CSFs for various areas of the survey – anisotropic (non-uniform) scaling methods might even be considered. Surveyors are no longer required to show differing CSFs for individual permanent survey marks for cadastral surveys of large extent.

It is left to the professional judgement of the surveyor as to how best to apply one or several CSFs to a survey – each survey will be different in extent and shape, with differing terrain profiles. An approach that might be appropriate for one survey may not be appropriate for another – large changes in height within a survey will need careful scrutiny. Due to the large number of variations that might be encountered, a generic approach to application of CSF(s) for a survey cannot be specified here.

The basic formulae for applying the CSF are shown in Equations 19 & 20, again assuming a negligible difference between the plane distance and grid distance:

$$\text{Plane (Grid) distance} = \text{Ground distance} \times \text{Combined Scale Factor} \quad (19)$$

$$\text{Ground distance} = \frac{\text{Plane (Grid) distance}}{\text{Combined Scale Factor}} \quad (20)$$

3 APPROVED GNSS METHODS AND THE DATUM LINE

Clause 12 of the Regulation requires, in certain circumstances, the use of approved GNSS methods to determine the MGA position and MGA orientation of the datum line for a survey. The cases where such a requirement is applicable can be easily determined by reference to the datum line flowchart available as Diagram 3.18 in Surveyor-General's Direction No. 7 (DFSI Spatial Services, 2017).

Using an approved GNSS method to determine the MGA position and MGA orientation of the datum line for a survey requires compliance with three basic outcomes:

- An MGA coordinate *must* be determined for *each* terminal of the datum line.
- The MGA coordinate for each terminal *must* have been determined using an approved GNSS method.
- The MGA coordinate for each terminal of the datum line *must* have been determined to an accuracy of Class D or better.

In concept, using an approved GNSS method to determine the MGA position and MGA orientation of the datum line for a survey can be thought of as the surveyor bringing their own MGA coordinates to the datum line of their survey, i.e. the surveyor is operating outside the SCIMS 'ecosystem' and its inherent rigour. This means that some of the elements required by the Regulation, for example the CSF, have to be calculated by the surveyor instead of being readily provided by a SCIMS report. The means by which a surveyor can calculate these elements have been provided in section 2.

3.1 Datum Line Terminals

When determining Class D MGA coordinates for each terminal of the datum line using an approved GNSS method, there are two requirements that must be complied with:

1. Each terminal must be marked with either a permanent survey mark or a reference mark.
2. The Class D MGA coordinates of the terminal mark must be determined by direct occupation of the mark using an approved GNSS method. That is, a surveyor cannot determine Class D MGA coordinates of an eccentric station by an approved GNSS method and then determine the MGA coordinates of the datum line terminal by traverse.

The mark types comprising the terminals of the datum line do not have to be of the same form and style, i.e. a reference mark at one terminal and a permanent survey mark at the other terminal is acceptable. If a mark of the form and style of a reference mark is being used exclusively to define a terminal of the datum line, i.e. if the mark has not been referenced to a boundary corner, then that mark does not need to be within 30 metres of a boundary corner. In

such a case, the mark should be shown by the appropriate symbol (the 'double circle') as described in Schedule 5 of the Regulation and have a closed connection to the land surveyed (Figures 23-27). Note that in Figures 23-27, 'PSM' is an abbreviation for permanent survey mark and 'RM' is an abbreviation for reference mark.

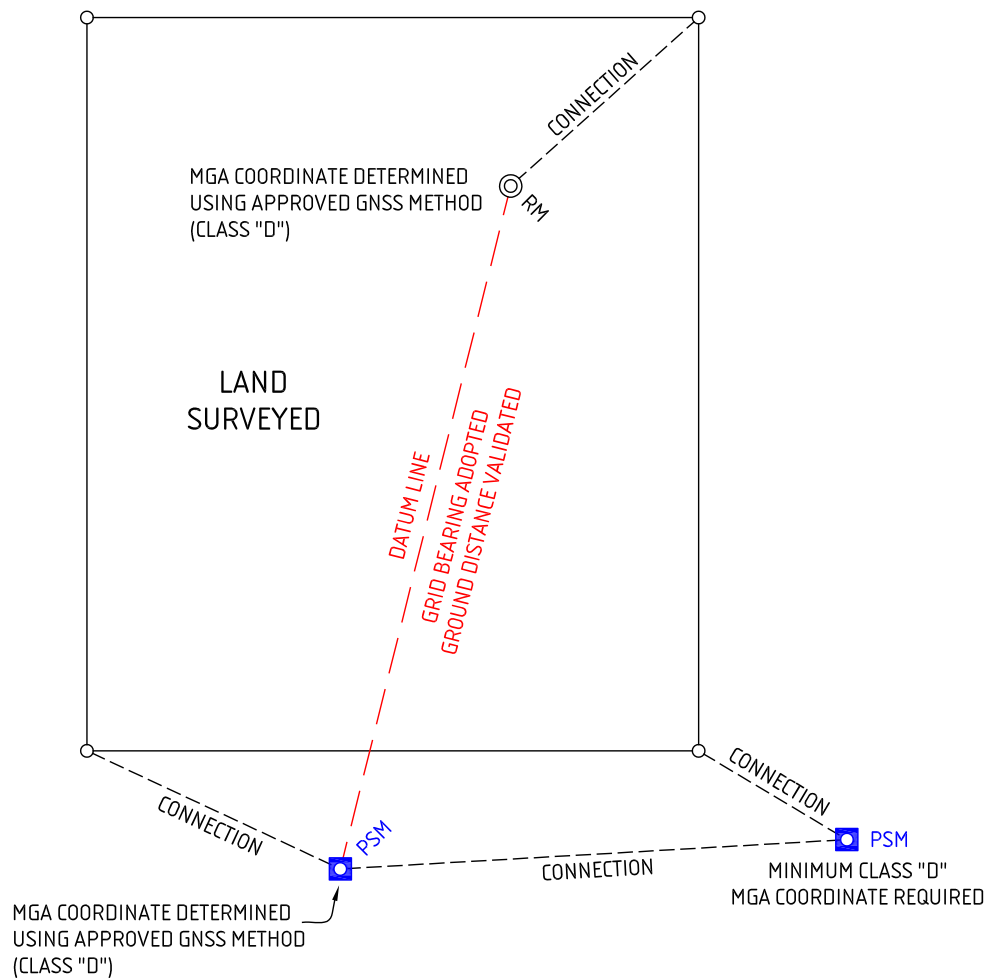


Figure 23: Datum line – permanent survey mark and connected reference mark.

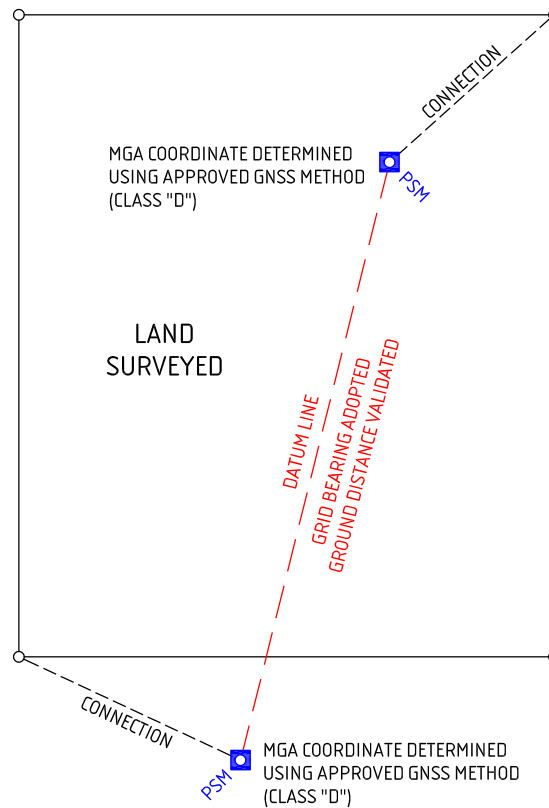


Figure 24: Datum line – permanent survey marks.

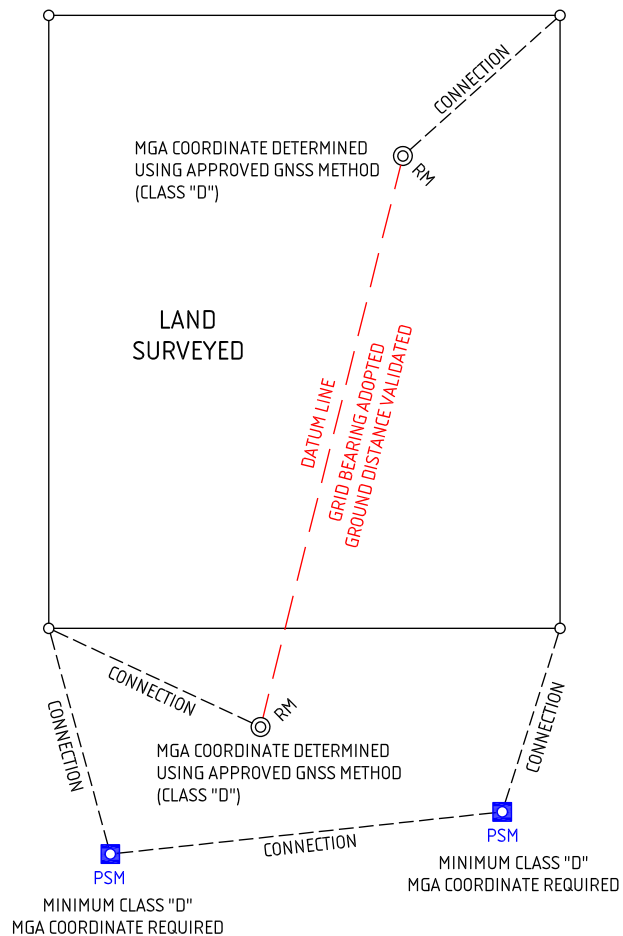


Figure 25: Datum line – connected reference marks.

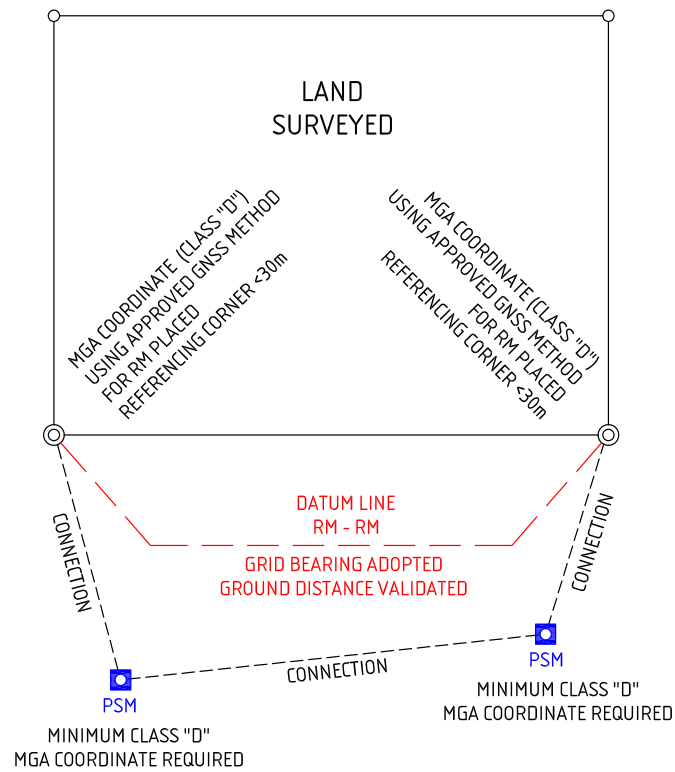


Figure 26: Datum line – reference marks referenced to a corner.

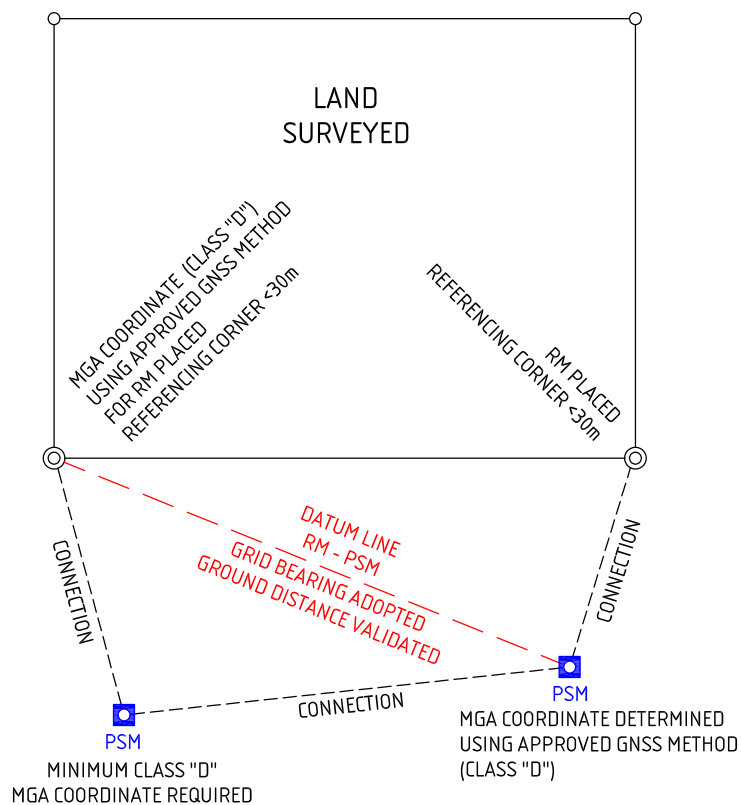


Figure 27: Datum line – reference mark referenced to a corner and a permanent survey mark.

It should be noted that when using a reference mark for a terminal or both terminals of the datum line, the surveyor must also connect the survey to the appropriate number of permanent survey marks as required by the Regulation. This means that, as an “accurate MGA

orientation” as per Clause 5 of the Regulation has been adopted, the surveyor is required, under Clause 70, to determine MGA coordinates of the unestablished permanent survey marks not used as datum line terminals to an accuracy equal to or better than Class D.

3.2 Approved GNSS Methods for Datum Line Position and Orientation

The approved GNSS methods that can be used to determine Class D MGA coordinates from which a grid bearing is derived and adopted for datum line orientation are:

- AUSPOS.
- CORS Network Real-Time Kinematic (NRTK).
- CORS single-base Real-Time Kinematic (RTK).
- CORS static.

The most commonly used methods are AUSPOS (GA, 2018b) and CORS NRTK. Each of the above methods is described in detail in both Surveyor-General’s Direction No. 7 (DFSI Spatial Services, 2017) and Surveyor-General’s Direction No. 9 (DFSI Spatial Services, 2014). For users of the AUSPOS GNSS method, the AUSPOS report is required to be lodged along with the survey plan when lodging the survey plan with the Registrar-General or a public authority.

There are also several commonly used GNSS methods which are *not* acceptable to determine the MGA coordinates adopted for datum line position and orientation. These include:

- Autonomous GNSS positions.
- Local single-base RTK based on a solitary mark with Class D (or better) MGA coordinates or a solitary mark with autonomous MGA coordinates.
- Static post-processed GNSS (without reference to CORS station/s) based on a solitary mark with Class D (or better) MGA coordinates or a solitary mark with autonomous MGA coordinates.

Users of geodetic GNSS equipment usually have the option to generate MGA coordinates using an ‘autonomous’ GNSS position. An autonomous GNSS position is considered to be a position determined by a single, standalone GNSS receiver relative to a datum as realised by the satellite control segment only, with no error modelling other than broadcast models. It is sometimes also called a ‘navigated’ position. Accuracy of an autonomous GNSS position is generally better than 10 m and can, in many instances, have an accuracy of better than 3 m. An example of a commonly used autonomous GNSS position is a GNSS position obtained using a mobile phone.

Use of autonomous GNSS positions to determine datum line position and orientation is not acceptable for the following reasons:

- MGA coordinates determined using an autonomous GNSS position do not achieve the required accuracy of Class D.
- MGA coordinates determined using an autonomous GNSS position have no traceability to a national standard.

Local single-base RTK and static post-processed GNSS (without reference to CORS station/s) are common methods used for carrying out a survey and are approved GNSS methods, which are acceptable to measure the relative position of marks and monuments within a survey. They are *not* acceptable methods to determine datum line position and orientation based on a

solitary mark with Class D (or better) MGA coordinates or a solitary mark with autonomous MGA coordinates.

For example, in the case of local single-base RTK, the local base station might occupy a datum line terminal having MGA coordinates of Class D or better, either a SCIMS established survey mark or a mark with the MGA coordinates determined by an approved GNSS method listed above. Coordination of the second datum line terminal solely by coordinate propagation using a measured baseline from the local base station's Class D MGA position is not acceptable. The second datum line terminal coordinates would then have no direct traceability to a national standard and would be solely reliant upon the projection parameters within the GNSS instrument or adjustment having been set correctly. That is, there would be no validation of the orientation against a national standard – it could be considered analogous to an unchecked radiation. The same principle applies to using a static post-processed GNSS baseline (without reference to CORS station/s) in the above situation as the sole measurement to coordinate the second datum line terminal.

In the case where a survey using either the local single-base RTK method or the static post-processed GNSS baseline method (without reference to CORS station/s) connects to two established survey marks within the distance restrictions specified by Clause 12 of the Regulation, then the survey is required to adopt a SCIMS MGA orientation and verify that orientation to a third established survey mark.

3.3 Selection of the Datum Line

When selecting the datum line for a survey where the datum line will adopt, as orientation, the grid bearing derived from Class D MGA coordinates as determined by the surveyor using an approved GNSS method, the surveyor should select the datum line with reference to the following matters:

- The site of either terminal of the datum line needs to be selected to minimise unwanted influences on the accuracy obtained by use of an approved GNSS method. Some of the elements that may influence the accuracy obtained using an approved GNSS method include the satellites in view, site stability, site obstructions and multipath sources.
- The length of the datum line must be commensurate with the size of the survey. As a general rule, the length of the datum line should not be less than 300 m. However, the surveyor must determine what length is appropriate for the survey. Generally, the longest length of the datum line practically feasible is desirable while having regard to the size of the survey. Note that Surveyor-General's Direction No. 9 (DFSI Spatial Services, 2014) specifies 100 m to be the minimum length of a line derived by GNSS methods.
- The position of the datum line with respect to the land surveyed has certain restrictions. The datum line must be within 300 m of the land surveyed for an urban survey and 1,000 m for a rural survey. The datum line should, if practically feasible, be integral or immediately adjacent to the land.

3.4 GNSS Validation

All GNSS constellations are operated by international parties. Most available GNSS networks are operated by Government (e.g. CORSnet-NSW, GPSnet) or commercial third parties and are not under the surveyor's direct control. As such, any GNSS equipment and methods used must be confirmed ("validated") against an independent external source of known accuracy for each survey where an approved GNSS technique is used. GNSS equipment is not a tool

which can be “calibrated” in the strict sense of the word and therefore the proper use of the equipment in accordance with Surveyor-General’s Direction No. 7 (DFSI Spatial Services, 2017) is important.

Clause 66 of the Regulation requires details of GNSS validation to be shown in an approved schedule. The approved schedule is shown in Diagram 3.32 of Surveyor-General’s Direction No. 7 (DFSI Spatial Services, 2017) (Figure 28).

GNSS VALIDATION SCHEDULE				
FROM	TO	GRID BEARING	DISTANCE	METHOD
SSM 66367	SSM 19764	289°09'34"	1092.340	EDM TRAVERSE
		289°09'34"	1092.332	CORS NRTK
SSM 172630	SSM 19087	12°44'44"	453.283	EDM TRAVERSE
		12°44'44"	453.290	AUSPOS
PM 169843	PM 169844	161°01'05"	1783.171	AUSPOS
		161°01'05"	1783.182	GNSS STATIC

Figure 28: Approved GNSS validation schedule (DFSI Spatial Services, 2017).

Where the datum line will adopt, as orientation, the grid bearing derived from Class D MGA coordinates as determined by the surveyor using an approved GNSS method, validation is required by Clause 66 of the Regulation to be performed and shown for the datum line of orientation. Validation can be thought of as being analogous to showing comparisons, for a line between two established survey marks, of the grid bearing and ground distance as measured against those derived from the SCIMS MGA coordinates. It is the same process, the only difference being that the MGA coordinates have been determined by the surveyor instead of being retrieved from SCIMS.

4 CASE STUDIES

To illustrate the application, within the context of the Regulation, of the geodetic concepts and available resources described above, two case studies where the datum line of the survey has adopted, as orientation, the grid bearing derived from Class D MGA coordinates as determined by the surveyor using an approved GNSS method. Each case study is based on a real-world survey, however the information has been modified for the purposes of illustration in this paper.

4.1 Case Study 1

The first case study is that of a survey that has determined the MGA position and orientation of the datum line via the use of the AUSPOS approved GNSS method (Figure 29). Both terminals of the datum line, i.e. PM#1 and PM#2, were directly occupied by GNSS receivers and static data logged for a minimum of 2 hours on each terminal. The static data was uploaded to Geoscience Australia’s AUSPOS processing facility, and AUSPOS reports were received. Extracts from the AUSPOS reports for PM#1 and PM#2 are shown in Figures 30 & 31 respectively. PM#3 was found and connected to the survey.

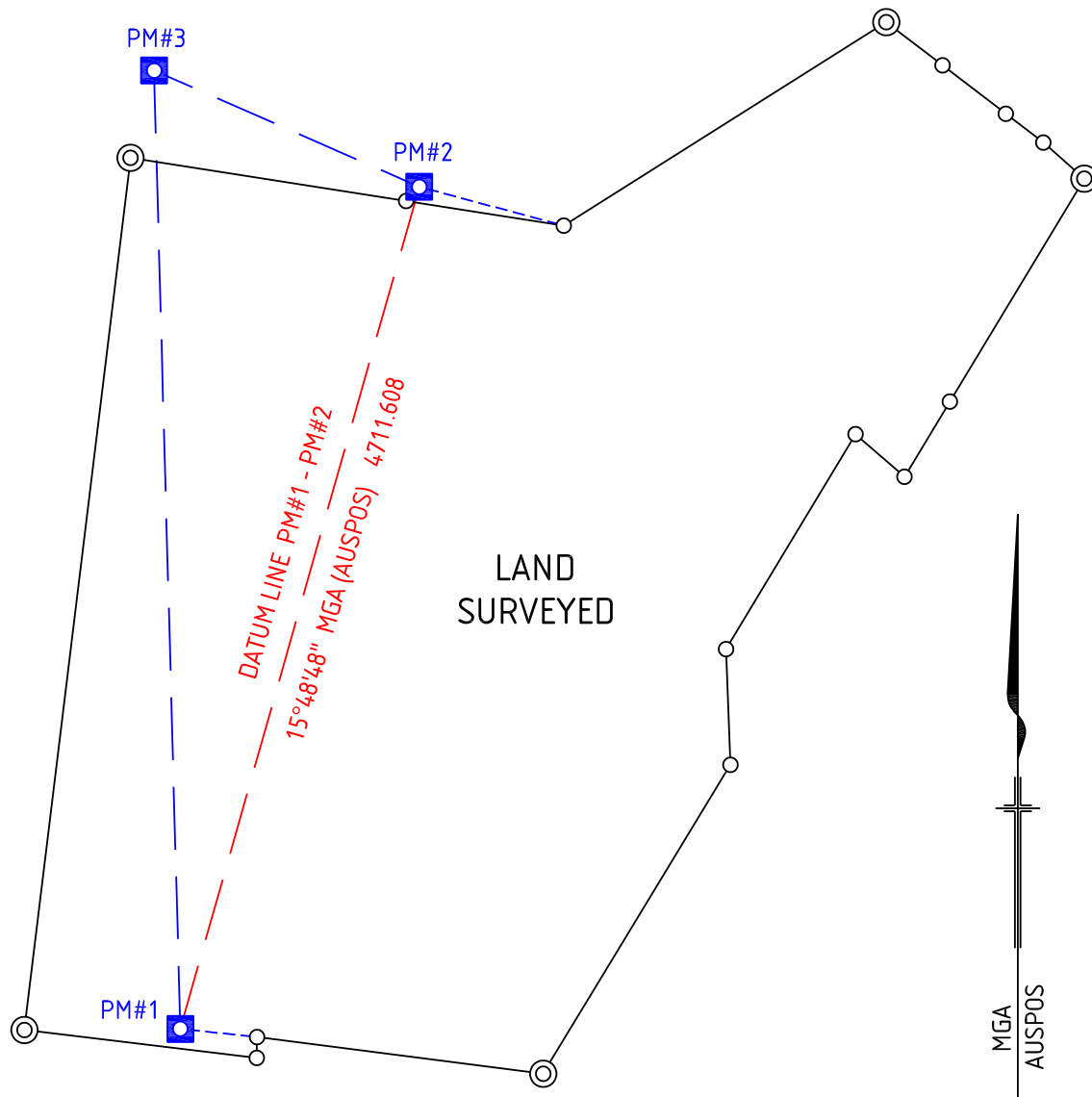


Figure 29: Case study 1.

3.3 MGA Grid, GRS80 Ellipsoid, GDA94

Station	East (m)	North (m)	Zone	Ellipsoidal Height (m)	Derived AHD (m)
0402	556935.957	6728431.135	55	156.924	128.106

Figure 30: Case study 1 – extract of AUSPOS report for PM#1.

3.3 MGA Grid, GRS80 Ellipsoid, GDA94

Station	East (m)	North (m)	Zone	Ellipsoidal Height (m)	Derived AHD (m)
5000	558219.393	6732962.691	55	157.495	128.581

Figure 31: Case study 1 – extract of AUSPOS report for PM#2.

To derive from the AUSPOS reports the grid bearing adopted and plane (grid) distance for the datum line, the coordinates from the AUSPOS reports (Figures 30 & 31) were entered into the spreadsheet GRIDCALC.XLS (see section 2.1.3) (Figure 32).

Grid Bearing and Ellipsoidal Distance from Grid Coordinates

MGA

	Name	East (E)	North (N)	Zone
From (1)	PM#1	556,935.957	6,728,431.135	55
To (2)	PM#2	558,219.393	6,732,962.691	55
Ellipsoidal Distance (s)	4711.491			
Plane Distance (L)	4709.799			
Grid Bearing (β_1)	15°	48'	48.49"	
Grid Bearing (β_2)	195°	48'	47.16"	
Arc to Chord correction (δ_1)	-0.66"			
Arc to Chord correction (δ_2)	0.67"			
Line scale factor (K)	0.999 640 91			

Figure 32: Case study 1 – GRIDCALC.XLS for the datum line.

The CSF for PM#1 and PM#2 were determined by entering the Easting, derived AHD value and the N-value calculated from the AUSPOS reports (Figures 30 & 31) into the spreadsheet CSF.XLS (see section 2.2.2) (Figures 33 & 34).

The N-value of PM#1 was calculated from the AUSPOS report for PM#1 (Figure 30) as:

$$156.924 - 128.106 = 28.818$$

The N-value of PM#2 was calculated from the AUSPOS report for PM#2 (Figure 31) as:

$$157.495 - 128.581 = 28.914$$

Easting (m)	Height(m)	N	CSF
556935.957	128.106	28.818	0.99961532

Figure 33: Case study 1 – CSF.XLS for PM#1.

Easting (m)	Height(m)	N	CSF
558219.393	128.581	28.914	0.99961705

Figure 34: Case study 1 – CSF.XLS for PM#2.

The CSF for the datum line between PM#1 and PM#2 was calculated using Equation 6, the mean of the CSFs of the datum line terminals:

$$\begin{aligned}
 CSF_{line} &= \frac{(CSF_{P1} + CSF_{P2})}{2} \\
 &= \frac{(0.99961532 + 0.99961705)}{2} \\
 &= 0.99961619
 \end{aligned}$$

For the datum line of this case, using Equation 7, the CSF of the mean Easting, and Equation 8, Simpson's rule, show differences to the above method of significantly less than 1 ppm. Other lines, especially those with a large difference in Easting and/or height, might require the more accurate methods of Equations 7, 8 or 11.

The ground distance between the datum line terminals from the AUSPOS coordinates was then calculated using Equation 20 with the plane (grid) distance taken from the GRIDCALC.XLS output shown in Figure 32:

$$\begin{aligned} \text{Ground distance} &= \frac{\text{Plane (Grid) distance}}{\text{Combined Scale Factor}} \\ &= \frac{4709.799}{0.99961619} \\ &= 4711.607 \end{aligned}$$

Having calculated, from the AUSPOS coordinates for each datum line terminal, the grid bearing to be adopted by the datum line and the ground distance between the AUSPOS coordinates, the datum line then had to be validated as per Clause 66 of the Regulation. The method used for validation was an Electronic Distance Measurement (EDM) traverse by total station. The results were then required by Clause 66 of the Regulation to be shown on the survey plan in an approved GNSS validation schedule (Figure 35).

GNSS VALIDATION SCHEDULE				
FROM	TO	GRID BEARING	DISTANCE	METHOD
PM#1	PM#2	15°48'48"	4711.608	EDM TRAVERSE
		15°48'48"	4711.607	AUSPOS

Figure 35: Case study 1 – GNSS validation schedule.

As per Clause 70 of the Regulation, an approved coordinate schedule was also required on the survey plan (Figure 36). Note that PM#3 (an unestablished survey mark) was found and connected to. Therefore, as the survey plan had adopted an “accurate MGA orientation” under the definition in Clause 5 of the Regulation, then, as per Clause 70, the MGA coordinates of PM#3 had to be determined to an accuracy of Class D or better. In this case study, the CSF shown in the coordinate schedule (Figure 36) is that of the datum line. The surveyor must place the single CSF that best represents the extent of the survey in the coordinate schedule (see section 2.2.3).

COORDINATE SCHEDULE						
MARK	MGA COORDINATES		CLASS	ORDER	METHOD	STATE
	EASTING	NORTHING				
PM#1	556 935.957	6 728 431.135	D	N/A	AUSPOS	PLACED
PM#2	558 219.393	6 732 962.691	D	N/A	AUSPOS	PLACED
PM#3	556 764.897	6 733 601.494	D	N/A	CADASTRAL TRAVERSE	FOUND
DATE OF GNSS COORDINATES: 17-10-2017			MGA ZONE: 55		MGA DATUM: GDA94	
COMBINED SCALE FACTOR: 0.999616						

Figure 36: Case study No. 1 – coordinate schedule

4.2 Case Study 2

The second case study is that of a survey that has determined the MGA position and orientation of the datum line via the use of the CORS NRTK approved GNSS method (Figure 37). Both terminals of the datum line, i.e. RMGIP "A" and RMGIP "B" were directly occupied by GNSS receivers and CORS NRTK MGA coordinates measured – each datum line terminal was occupied twice for 2 minutes per occupation (using the averaging technique) with a minimum of 30 minutes between each occupation. PM#1 and PM#2 were placed and connected to the survey as required by the Regulation.

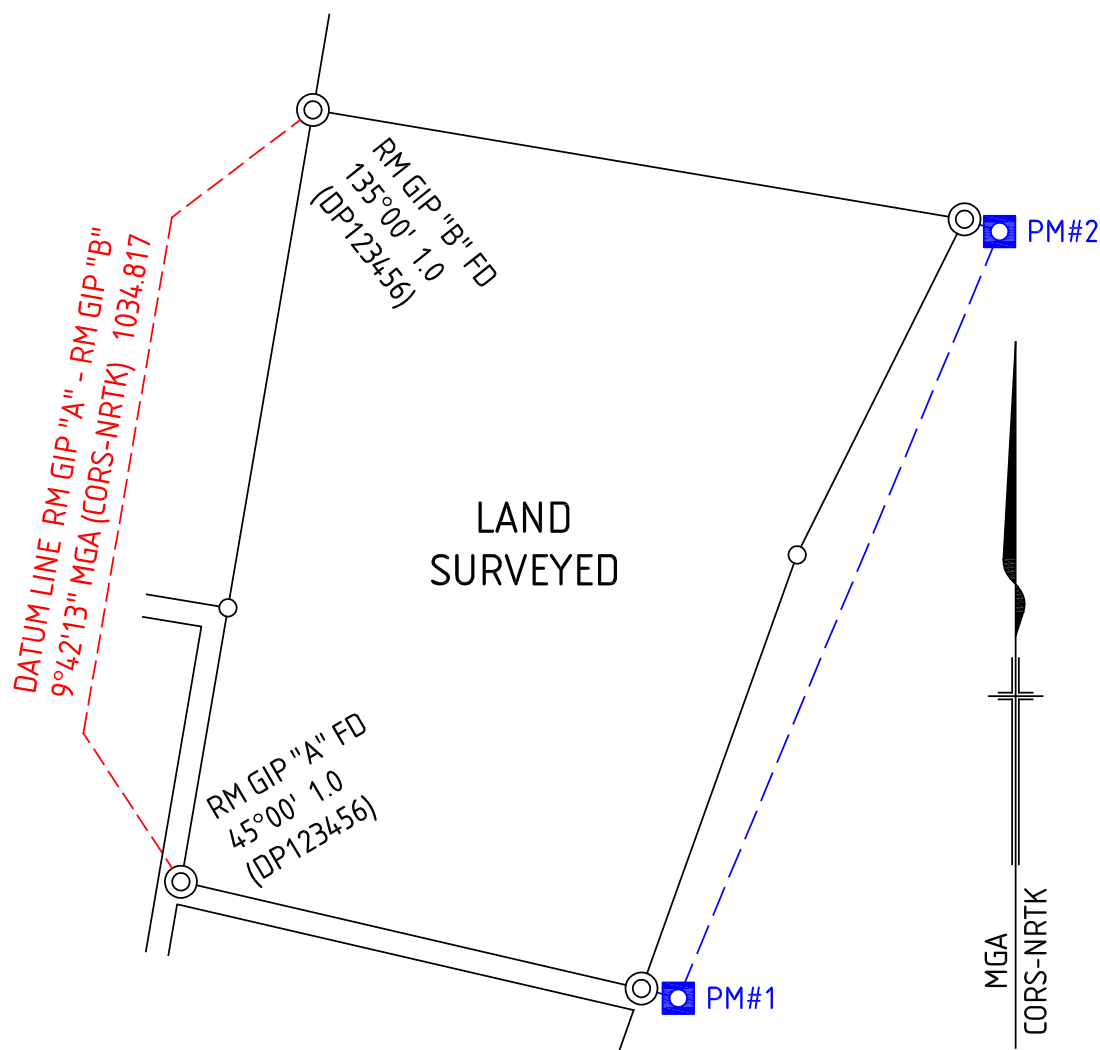


Figure 37: Case study 2.

Note that in this case, each datum line terminal is a reference mark that is within 30 m of a corner and has been referenced to that corner. Reference marks used for terminals of the datum line do not have to be *referenced* to a corner (within 30 metres) as per Clause 62 of the Regulation. However, if not referenced to a corner, then as per Clause 61(3) of the Regulation, they must be *connected* by closed connection to the survey (Figures 23 & 25).

To derive from the CORS NRTK coordinates the grid bearing adopted and plane (grid) distance for the datum line, the CORS NRTK coordinates were entered into the spreadsheet GRIDCALC.XLS (see section 2.1.3) (Figure 38).

Grid Bearing and Ellipsoidal Distance from Grid Coordinates

MGA

	Name	East (E)	North (N)	Zone
From (1)	RM GIP "A"	625,526.045	6,232,157.627	55
To (2)	RM GIP "B"	625,700.414	6,233,177.358	55
Ellipsoidal Distance (s)	1034.744			
Plane Distance (L)	1034.532			
Grid Bearing (β_1)	9° 42'	12.74"		
Grid Bearing (β_2)	189° 42'	12.09"		
Arc to Chord correction (δ_1)	-0.33"			
Arc to Chord correction (δ_2)	0.33"			
Line scale factor (K)	0.999 794 51			

Figure 38: Case study 2 –GRIDCALC.XLS for the datum line.

The CSF for RMGIP “A” and RMGIP “B” were determined by entering the Easting, derived AHD value and the N-value into the spreadsheet CSF.XLS (see section 2.2.2) (Figures 39 & 40). The derived AHD value is from the observed CORS NRTK data and the N-value was calculated using Geoscience Australia’s online N-value calculator (Figure 18). The latitude and longitude were taken from the CORS NRTK observed data.

Easting (m)	Height(m)	N	CSF
625526.045	401.970	20.239	0.99972790

Figure 39: Case study 2 –CSF.XLS for RMGIP “A”.

Easting (m)	Height(m)	N	CSF
625700.414	390.813	20.263	0.99973019

Figure 40: Case study 2 – CSF.XLS for RMGIP “B”.

The CSF for the datum line between RMGIP “A” and RMGIP “B” was calculated using Equation 6, the mean of the CSFs of the datum line terminals:

$$\begin{aligned}
 CSF_{line} &= \frac{(CSF_{P1} + CSF_{P2})}{2} \\
 &= \frac{(0.99972790 + 0.99973019)}{2} \\
 &= 0.99972905
 \end{aligned}$$

For the datum line of this case, using Equation 7, the CSF of the mean Easting, and Equation 8, Simpson’s rule, show differences to the above method of significantly less than 1 ppm. Other lines, especially those with a large difference in Easting and/or height, might require the more accurate methods of Equations 7, 8 or 11.

The ground distance between the datum line terminals from the CORS NRTK coordinates was then calculated using Equation 20 with the plane (grid) distance taken from the GRIDCALC.XLS output shown in Figure 38:

$$\begin{aligned} \text{Ground distance} &= \frac{\text{Plane (Grid) distance}}{\text{Combined Scale Factor}} \\ &= \frac{1034.532}{0.99972905} \\ &= 1034.812 \end{aligned}$$

Having calculated, from the CORS NRTK coordinates for each datum line terminal, the grid bearing to be adopted by the datum line and the ground distance between the CORS NRTK coordinates, the datum line then had to be validated as per Clause 66 of the Regulation. The method used for validation was an EDM traverse by total station. The results were then required by Clause 66 of the Regulation to be shown on the survey plan in an approved GNSS validation schedule (Figure 41).

GNSS VALIDATION SCHEDULE				
FROM	TO	GRID BEARING	DISTANCE	METHOD
RM GIP "A"	RM GIP "B"	9°42'13"	1034.817	EDM TRAVERSE
		9°42'13"	1034.812	CORS-NRTK

Figure 41: Case study 2 – GNSS validation schedule.

As per Clause 70 of the Regulation, an approved coordinate schedule was also required on the survey plan (Figure 42). Note that PM#1 and PM#2 were placed and connected to. Therefore, as the survey plan had adopted an “accurate MGA orientation” under the definition in Clause 5 of the Regulation, then, as per Clause 70, the MGA coordinates of PM#1 and PM#2 had to be determined to an accuracy of Class D or better. In this case study, the CSF shown in the coordinate schedule (Figure 42) is that of the datum line. The surveyor must place the single CSF that best represents the extent of the survey in the coordinate schedule (see section 2.2.3).

COORDINATE SCHEDULE						
MARK	MGA COORDINATES		CLASS	ORDER	METHOD	STATE
	EASTING	NORTHING				
RM GIP "A"	625 526.045	6 232 157.627	D	N/A	CORS-NRTK	FOUND
RM GIP "B"	625 700.414	6 233 177.358	D	N/A	CORS-NRTK	FOUND
PM#1	626 134.283	6 232 015.877	D	N/A	CORS-NRTK	PLACED
PM#2	626 558.713	6 233 027.473	D	N/A	CORS-NRTK	PLACED
DATE OF GNSS COORDINATES: 18-12-2017			MGA ZONE: 55		MGA DATUM: GDA94	
COMBINED SCALE FACTOR: 0.999729						

Figure 42: Case study 2 – coordinate schedule.

4 CONCLUDING REMARKS

GNSS equipment and devices are tools that have come from a geodetic origin and operate in geodetic reference frames and coordinate systems, yet are becoming integral parts of a widening, disparate set of applications where the operators of such equipment are not necessarily aware of the geodetic concepts involved. For many applications, geodetic knowledge is either necessary or advisable. Cadastral surveyors carrying out surveys under the Regulation using GNSS are an example where some geodetic knowledge is necessary for correct application of GNSS methods under the Regulation.

This paper has described certain geodetic concepts, tools available to cadastral surveyors for calculation of geodetic elements, the cases when approved GNSS methods for datum line purposes are to be used, use of approved GNSS methods for datum line purposes and their application to survey plan requirements under the Regulation with reference to case studies.

As GNSS equipment becomes more affordable and GNSS techniques become more widely used for cadastral surveying, more cadastral surveyors will be required to become familiar with the required geodetic concepts described in this paper and their application under the Regulation.

REFERENCES

- ANZLIC (2018a) ANZLIC council, <http://www.anzlic.gov.au/anzlic-council> (accessed Mar 2018).
- ANZLIC (2018b) Foundation Spatial Data Framework, <http://www.anzlic.gov.au/foundation-spatial-data-framework> (accessed Mar 2018).
- ANZLIC (2018c) ANZLIC, <http://www.anzlic.gov.au/> (accessed Mar 2018).
- Bomford G. (1980) *Geodesy* (4th edition), Clarendon Press, Oxford, United Kingdom, 855pp.
- Deakin R.E. (2006) Traverse computation on the UTM projection for surveys of limited extent, School of Mathematical and Geospatial Sciences, RMIT University, Melbourne, Australia, 20pp.
- Deakin R.E. (2010) Traverse computation on the ellipsoid and on the Universal Transverse Mercator projection, School of Mathematical and Geospatial Sciences, RMIT University, Melbourne, Australia, 55pp.
- DFSI Spatial Services (2014) Surveyor-General's Direction No. 9: GNSS for Cadastral Surveys, http://spatialservices.finance.nsw.gov.au/data/assets/pdf_file/0006/25944/sgddir9_Ver2.5_May_2014.pdf (accessed Mar 2018).
- DFSI Spatial Services (2017) Surveyor-General's Direction No. 7: Surveying and Spatial Information Regulation 2017 – Applications, http://spatialservices.finance.nsw.gov.au/data/assets/pdf_file/0019/217243/SG_Direction_No_7_v3_September_2017.pdf (accessed Mar 2018).
- DFSI Spatial Services (2018) Conversion software, http://spatialservices.finance.nsw.gov.au/surveying/geodesy/conversion_software (accessed Mar 2018).

- Featherstone W.E. and Rüeger J.M. (2000) The importance of using deviations of the vertical for the reduction of survey data to a geocentric datum, *The Australian Surveyor*, 45(2), 46-61.
- GA (2018a) AUSGeoid, <http://www.ga.gov.au/ausgeoid/> (accessed Mar 2018).
- GA (2018b) AUSPOS – Online GPS Processing Service, <http://www.ga.gov.au/scientific-topics/positioning-navigation/geodesy/auspos> (accessed Mar 2018).
- ICSM (2014) Geocentric Datum of Australia technical manual, version 2.4, http://www.icsm.gov.au/gda/gda-v_2.4.pdf (accessed Mar 2018).
- ICSM (2015) Cadastre 2034: Powering land & real property – A national strategy, <http://www.icsm.gov.au/cadastral/Cadastre2034.pdf> (accessed Mar 2018).
- ICSM (2018a) Geocentric Datum of Australia 2020 technical manual, version 1.1.1, <http://www.icsm.gov.au/gda/GDA2020TechnicalManualV1.1.1.pdf> (accessed Mar 2018).
- ICSM (2018b) Transformation products and tools, <http://www.icsm.gov.au/gda/soft.html> (accessed Mar 2018).
- Janssen V. (2009) Understanding coordinate reference systems, datums and transformations, *International Journal of Geoinformatics*, 5(4), 41-53.
- Janssen V. (2017) GDA2020, AUSGeoid2020 and ATRF: An introduction, *Proceedings of Association of Public Authority Surveyors Conference (APAS2017)*, Shoal Bay, Australia, 20-22 March, 3-20.
- Janssen V. and Watson T. (2011) Performance of AUSGeoid09 in NSW, *Proceedings of Association of Public Authority Surveyors Conference (APAS2011)*, Bathurst, Australia, 6-7 April, 27-36.
- Janssen V. and Watson T. (2018) Evaluating the performance of AUSGeoid2020 in NSW, *Proceedings of Association of Public Authority Surveyors Conference (APAS2018)*, Jindabyne, Australia, 9-11 April, 3-18.
- Mahdi H.A. (2006) A modified method for determination of scale factor of the projected geodesic, *Journal of Engineering*, 13(3), 882-894.
- Moritz H. (2000) Geodetic Reference System 1980, *Journal of Geodesy*, 74(1), 128-133.
- NMC (1986) The Australian Geodetic Datum technical manual, Special Publication 10, National Mapping Council of Australia, Canberra, Australia, 65pp.
- NSW Legislation (2017) Surveying and Spatial Information Regulation 2017, <https://www.legislation.nsw.gov.au/#/view/regulation/2017/486> (accessed Mar 2018).
- Perkins B (2010) Have you mapped your data today? *Computerworld*, <https://www.computerworld.com/article/2549741/it-management/have-you-mapped-your-data-today-.html> (accessed Mar 2018).
- Stern J.E. (1995) The State Plane Coordinate System of 1983, NOAA Manual NOS NGS 5, National Geodetic Survey, National Oceanic and Atmospheric Administration, Maryland, USA, 119pp.
- UN (2015) A global geodetic reference frame for sustainable development, General Assembly Resolution 69/266, UN GAOR, 69th Session, 80th Plenary meeting 26 February 2015, UN Document A/RES/69/266 (11 March 2015).