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WGS – AGD – GDA: Selecting the correct datum, coordinate system and projection for north Australian applications

JBC Lowry

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JBC Lowry

Hydrological and Ecological Processes Program
Environmental Research Institute of the Supervising Scientist
GPO Box 461, Darwin NT 0801

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Preface

The Supervising Scientist Division (SSD) undertakes a diverse range of activities for which the use, collection and maintenance of spatial data is an integral activity. These activities range from recording sample site locations with a global positioning system (GPS), through to the compilation and analysis of spatial datasets in a geographic information system (GIS), and the use of remotely sensed data, to simply reading a map. Associated with the increased use of spatial data is the requirement to understand the most appropriate manner in which it is collected, stored and managed. In particular, the recent investment of SSD in a new data management system, has reinforced the need for data to be managed properly and efficiently. This report aims to

- Identify the correct spatial coordinate reference system which should be used by staff at a local scale (in either Kakadu or Darwin), at a regional scale (northern Australia) and on a international and global scale;
- Describe the correct method for recording and referring to coordinates collected using the different coordinate reference systems and datums;
- Describe / define the terminology associated with the use of spatial data and coordinate systems; and
- Provide a background on the development and application of coordinate references systems, to assist with the implementation of the current systems in use.

Quick reference / Frequently Asked Questions

What is a datum

A datum provides a frame of reference for measuring locations on the surface of the earth.

What is a projection

Map projections are mathematical formulae which allow areas on the surface of the Earth (a spheroid) to be represented on a map (a flat surface).

What is a coordinate system

A reference system used to measure horizontal and vertical distances on a planimetric map. It is used to locate x,y positions of point, line, and area features.

What datum is used in Kakadu / Darwin / Northern Australia?

The Geocentric Datum of Australia (GDA) is the current datum for all of Australia. It was first implemented in 1994.

What is WGS84

WGS84 is the World Geodetic System 1984. It provides the current standard for locational measurement worldwide, particularly in conjunction with the Global Positioning System (GPS) satellite network. Data collected in WGS84 is directly compatible with that collected in GDA94.

What do AGD, AMG, GDA and MGA stand for?

AGD stands for the **A**ustralian **G**eodetic **D**atum. It was produced in two versions, 1966 and 1984 (hence reference to AGD66 and AGD84), and was the standard datum used by Australia up to 1994. There is no significant difference between AGD66 and AGD84.

AMG is the **A**ustralian **M**ap **G**rid, as applied to either AGD66 or AGD84, in a projected coordinate system (as opposed to a geographic coordinate system). AMG uses Cartesian coordinates (easting, northings) rather than latitude/ longitude.

GDA is the **G**eocentric **D**atum of **A**ustralia. It has been implemented as the standard datum since 1994, replacing AGD66/84. All data in Australia should be now be recorded using a GDA coordinate system (either projected, or geographic coordinates).

MGA is the **M**ap **G**rid of **A**ustralia as applied to GDA94, in a projected coordinate system (as opposed to a geographic coordinate system). MGA uses Cartesian coordinates (easting, northings) rather than latitude/ longitude. Kakadu National Park falls with MGA grid zone 53, whilst Darwin lies in MGA zone 52.

To find out about datums and projects in more detail – read on !

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Introduction

The need to be able to record the location of a position, and describe it to others has existed since humankind first felt the need (or inspiration) to travel from one tree or cave to another. Until surprisingly recently (within the last 300 years) a reliable and consistent means of recording position and navigating accurately did not exist. A significant break through in the 18th Century was the ability to measure longitude (along with latitude), which, from a navigational perspective, reduced the haphazard nature of many long journeys. Prior to this, sailors had no reliable means of knowing how far east or west they had come – and in consequence, many came to grief on reefs, or islands. The coast of Western Australia in particular, is the resting place of several Dutch East India Company ships which, sailing east from South Afrca, misjudged the point at which they should have turned north for the spice islands of the Dutch East Indies (present-day Indonesia), and continued sailing onto the reefs and islands lying off Western Australia.

These days, the use of global positioning systems (GPS) has significantly enhanced the ability of sailors, pilots, geologist, surveyors, and indeed the general public, to navigate between their desired locations.

This report is divided into two components. The first part describes the datum and associated coordinate systems and projections which represent the current standard in Australia. A brief description of the datums / coordinate systems which have been superceded, but which may still be encountered is also provided. Importantly, the first part of this report identifies the correct datum to use, and possible scenarios under which different coordinate systems and projections would be used in the Darwin and Alligator Rivers Regions. The second part of this report take thes form of two appendices, which introduce the science of geodesy, focussing on the concepts of projections, datums and coordinate systems, and provide additional background information on datums which may be encountered in Australia.

Projections , Datums and Coordinate Systems in Australia

The concepts of '**projections'**,'**datums'** and **'coordinate systems'** are fundamental to the creation, acquisition, storage and application of *spatial data*. For the purposes of this paper, '*spatial data***'** refers specifically to data created, collected, maintained, analysed and stored in either a GPS, geographic information system (GIS), relational database management system (such as SSD-Explorer), or remote sensing software package.

A '**datum'** provides a frame of reference for measuring locations on the earths surface. A '**projection'** is a mathematical formulae which enables areas on the surface of the earth (a spheroid) to be represented on a map (a flat surface). A '**coordinate system'** is a reference system used to measure horizontal and vertical distances on a planimetric map. A coordinate system is usually defined by a map projection (its units and characteristics), a spheroid of reference, a datum, one or more standard parallels, a central meridian, and possible shifts in the x and y directions. It is used to locate x,y positions of point, line, and area features. There are two broad types of coordinate systems in use: **Geographic Coordinate Systems** (GCS) and **Projected Coordinate Systems** (PCS). A GCS uses latitude and longitude (expressed either as decimal degrees or degrees-minutes-seconds) to represent the location, distribution and extent of a dataset. A PCS typically uses Cartesian coordinates, such as eastings and northings for the same purpose. It is important to note that a datum may employ **both** forms of coordinate system. The concepts of datums, coordinate systems and projections are described in more detail in Appendix 1 of this report. It is important to note that while datums, coordinate systems and projections are related concepts, they are not interchangeable.

The datum which is currently applied as the national standard throughout Australia is the **Geocentric Datum of Australia (GDA),** which was first implemented in 1994. When applied as a geographic coordinate system, GDA is known as GDA94. Conversely, when applied as a projected coordinate system GDA is referred to as the Map Grid of Australia 1994 (MGA94). More information on GDA may be found in Appendix 2. The application of the GDA across Australia is significant because

1 it provides direct compatibility with the **World Geodetic System 1984 (WGS84)** – and thus by default, with the information received from the network of global positioning system (GPS) satellites maintained by the United States;

2 removes the need for complex conversion procedures as the coordinates read from the GPS will be the same as those of the GDA94;

3 it provides a single standard datum across the states and territories of Australia – replacing a number of different datums which had been adopted to varying degrees by the different states and territories Australia;

4 positional accuracy is enhanced, as the datum is derived from a model of the earth with greater accuracy than earlier datums; and

5 data collected matches international standards

Since European settlement, Australia has adopted a variety of datums. For example, by 1966 some twenty different datums, using four different figures of the earth as their reference had been employed by the different national, state and territory governments at different times. This diversity was in part a legacy of the development of separate surveying and mapping agencies in the different states and territories; and in part a reflection of the evolving understanding of surveying and geodetical concepts. However, the traditional spheroid in general use until 1966 was the Clarke 1858. **Prior** to 1966, the rectangular grid coordinate system used in conjunction with this Clarke 1858 spheroid was called the Australian National Grid (ANG).

Between 1966 and 1994, data was gathered using the **Australian Geodetic Datum (AGD)**, calculated in 1966 and again in 1984, using the Australian National Spheriod (ANS). When applied through a geographic coordinate system in conjunction with the AGD datum, the projection was referred to as AGD66 or AGD84, depending on which datum year was used. The corresponding projected coordinate systems were known as the AMG66 (Australian Map Grid 1966) or AMG84. Additional information on the AGD can be found in Appendix 2. Most 'historic' data (pre-GDA) collected in the Northern Territory used AGD66 as their datum; however some states, such as Queensland, used AGD84 as their standard datum prior to the implementation of the GDA.

A variety of projected coordinate systems currently exist which may be applied to the Australian continent. These are described in more detail in Appendix 1 of this report. One of the more commonly used of these projections is the **Universal Transverse Mercator** (UTM) system, which divides the globe into 60 zones, each spanning six degrees of longitude. Each zone extends from 84° N to 80° S, with each zone being split into north and south components at the equator (in effect doubling the number of zones). UTM Zones 1N and 1S start at -180° W and extend east for 6 degrees; this process is repeated sequentially until the world is circled. Each zone uses its central meridian and the equator as its origin.

UTM projections have been applied to **both** the superceded Australian Geodetic Datum (where the zones comprise the Australian Map Grid) and the current Geocentric Datum of Australia (through the **Map Grid of Australia**).

Within continental Australia, there are 8 UTM Zones, numbered 49-56 going from west to east (see Figure 1). As shown in Figure 2, there are two zones in the Northern Territory zones 52 and 53, with Darwin falling in zone 52, and the Alligator Rivers Region primarily within zone 53. The correct way to refer to these zones is as the 'Map Grid of Australia (1994), zone 53 (or 52)'. This is ofen shortened to MGA zone 53.

UTM projections are particularly useful for measuring area and distance within a zone. However, a limitation of the UTM projection is that error and distortion increase for regions that span more than one UTM zone. For this reason, it is recommended that all **data collected in Kakadu/ the Alligator Rivers Region should be projected into the Map Grid of Australia, zone 53**, whilst those **datasets collected in the Darwin region should be projected into MGA zone 52**. Datasets which span across several zones are best represented through geographic coordinate systems.

It is **very important** to understand that while **GDA is the current datum**, there are many datasets around – both within the SSD, and in the broader spatial community in Australia, that were created using earlier datums. Further, datasets may use a common datum, but may be created in different coordinate systems or projections. *SSD users are most likely to encounter data which uses either the GDA or WGS84 datums, or in older datasets (those created prior to 1994), the AGD datum. Similarly, datasets are most likely to be created using either a geographic coordinate system, or a projected coordinate system.*

Key differences between AGD / GDA

The Australian Map Grid (AMG66/84), the projected coordinate system based on the superceded Australian Geodetic Datum, was based on the Australian National Spheroid (ANS) which was an ellipsoid designed to be the best estimate of the earth's shape around the Australian continent rather than the world. As a result, the origin of the ellipsoid used in its definition did not correspond with the centre of the earth - it was about 200m away from it. Consequently the shift to the new Geocentric Datum of Australia (GDA) will mean that all coordinates will shift by approximately 200m to the north east. The new projected coordinate system based on the GDA, the Map Grid of Australia (MGA94), uses the GRS80 ellipsoid. This ellipsoid was designed to be a best estimate of the earth's shape globally, and its centre corresponds with the centre of the earth.

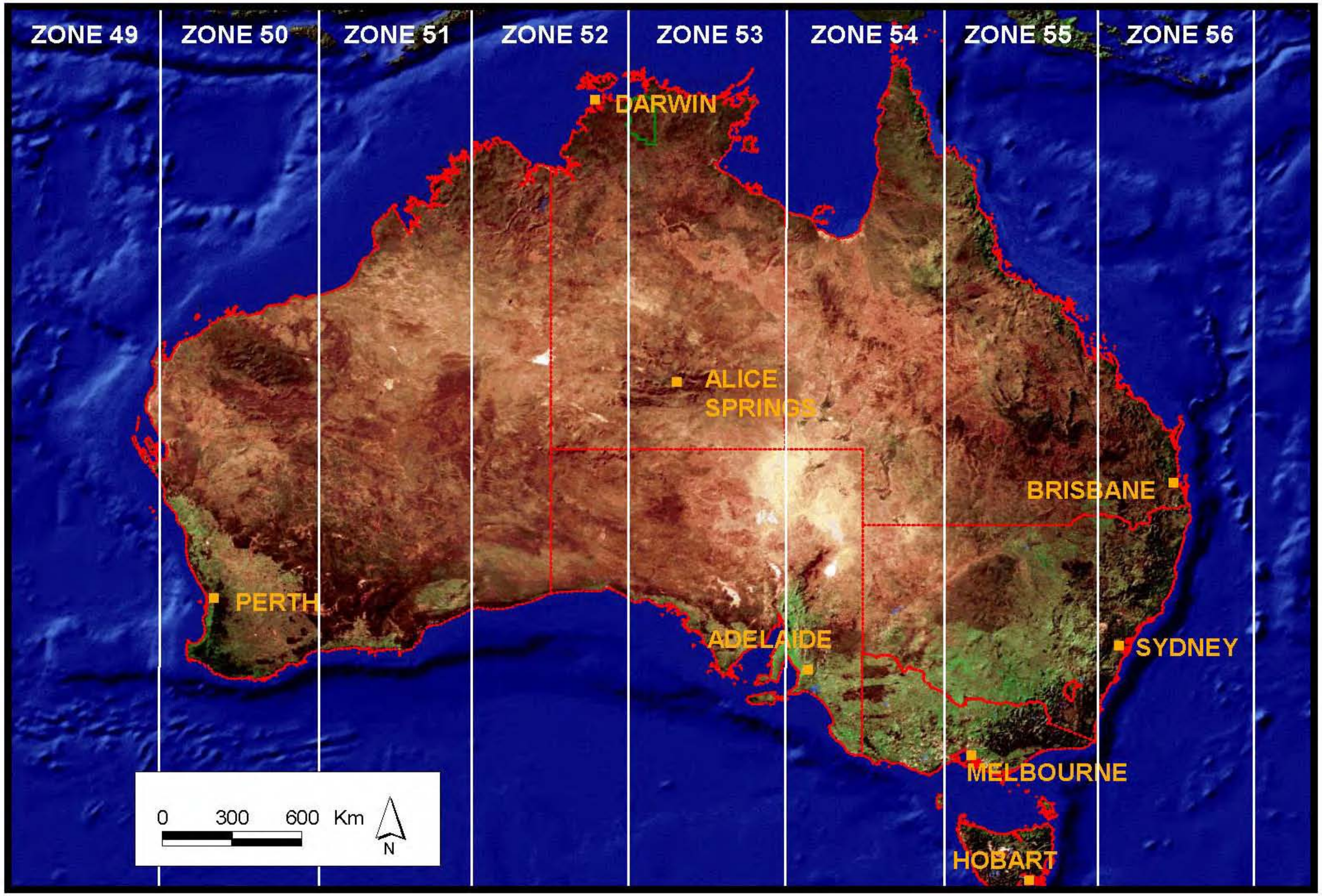

Figure 1 Grid Zones within Australia used by the projected coordinates systems of both the AGD and GDA datums

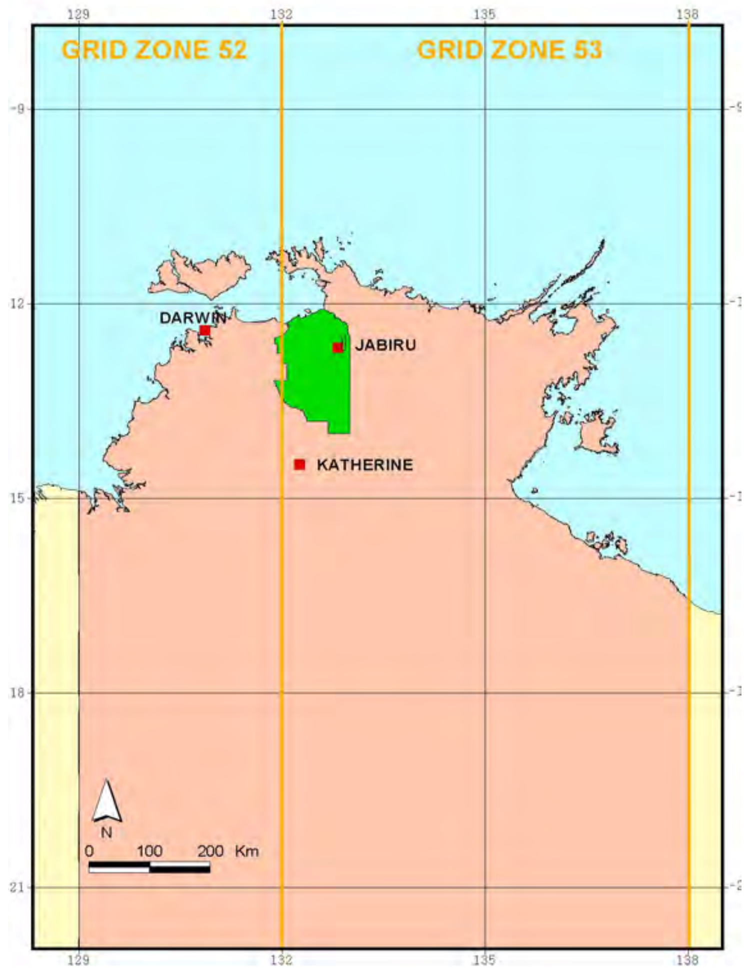

Figure 2 – Grid Zones in the Northern Territory used by both the AGD and GDA coordinate systems

Spatial data users, who are trying to integrate datasets in a GIS, should take particular note of the datum, coordinate system and projection associated with a dataset. Integrating datasets with different datums and coordinate systems will result in outputs (maps, images etc) that are inaccurate or incomplete. For example, using the coordinates shown in Table 1 below, it is not possible to immediately integrate a dataset of the Darwin region which used a series of projected coordinates with a second dataset utilising geographic coordinates, irrespective of the datum used, as the types of coordinates (eastings and northing, and latitude and longitude) and units of measurement (metres and degrees, respectively) are completely different. Similarly, it is not possible to automatically integrate datasets which use different datums, even if they use similar coordinate systems, as the resulting offset between the datums will cause inaccuracies and errors in the position of the features.

In order to be able to integrate a number of datasets, it is therefore necessary to ensure that all **datasets use the same datum and the same coordinate system**.

GIS and remote sensing software used by SSD have the ability to convert data from one datum, and one coordinate system to another. In the interests of adhering to the national standard, it is recommended that all spatial corporate datasets of the SSD be created, and stored using the GDA. Special care should be taken to document which datum was used in the creation of a particular dataset, for example through the creation of a metadata record. This will help both present and future users in managing and applying spatial data efficiently.

Table 1 Coordinates of Darwin and Jabiru represented through different datums, and coordinate systems

Town	Datum: AGD66		Datum: GDA94 / WGS84	
	Projected coordinates (zone: easting and northings)	Geographic coordinates (latitude and longitude expressed as degrees-minutes-seconds*)	Projected coordinates (zone: easting and northings)	Geographic coordinates (latitude and longitude – expressed as decimal degrees*)
Darwin	Zone 52:	-12°27'36'	Zone 52:	-12.46
	699986.79	130°50'24'	699986.07	130.84
	8621881.85		8621886.61	
Jabiru	Zone 53:	-12°40'12'	Zone 53:	-12.67
	264323.09	132°49'48'	264618.34 8598062.26	132.83
	8598373.21			
Jabiru Field Station	Zone 53:	-12°39'36'	Zone 53:	-12.66
	270833.28	132°53'24'	271262.61	132.89
	8599533.16		8599532.88	

* geographical coordinates may be recorded as either degrees-minutes-seconds(dms) or decimal degrees (dd) for both the AGD and GDA datums. However, in order to be able to integrate multiple datasets, they must all use the same type of geographic coordinates eg dms or dd.

MetaData

Metatdata is often defined as 'data about data' (ANZLIC 2001). While this is a valid and succinct description, it is important to understand what is meant by this definition and its significance.

Metadata has many elements that can include information that describes the age, accuracy, content, currency, scale, reliability, lineage, authorship and custodianship of an individual dataset. Metadata elements particularly relevant to the capture, storage and application of spatial datasets include its lineage – who, how and when a dataset was created, including what standards (if any) were used in the creation of the dataset.

Programs, such as ArcGIS, and SSD Explorer have built-in templates for creating and recording metadata. Information which should be recorded include :

- The datum used eg AGD or GDA.
- Whether the data utilise a geographic coordinate system (eg latitiude and longitude / Geocentric Datum of Australia) or a projected coordinate system (eg UTM / Map Grid of Australia).
- If a projected coordinate system is used, the name of the system *eg* Map Grid of Australia 1994, and the relevant zone *eg* 53 should be recorded.
- The coordinates for the site should be given in full. For example, the location of Darwin expressed as easting and northing is 699986.79, 8621881.85.
- A brief, but succinct, description of the area in which the site was recorded should be provided.

- What was used to record the site position eg a hand-held GPS receiver; a differential GPS receiver; or just a wild estimate as to the approximate position.
- The date on which the data were collected should be recorded.
- The purpose for which the data were collected.
- Who collected the data.
- Where the data are currently stored, and any access issues associated with their use.

If this information is not recorded using the templates available in SSD Explorer or ArcGIS, a simple file created in Microsoft NotePad or Word, describing the points above should be created and labelled to identify it as a metadata record for the relevant dataset.

Summary and Recommendations

The Geocentric Datum of Australia is the current standard for recording spatial data with in Australia. It is directly compatible with the World Geodetic System 1984, which is itself the international standard used in conjunction with the Global Positioning Systems. Important points to understand when creating, applying or managing spatial data are:

- AGD and GDA are **datums** – not **projections**.
- AGD84 is not the same as WGS84. As mentioned earlier, GDA94 may, for practical purposes, be regarded as the same as WGS84.
- AGD and GDA may be represented through both geographic coordinate systems, and projected coordinate systems – thus it is incomplete to simply say a dataset is 'in GDA' – you should also specify the type of coordinate system employed – for example.
- GDA is the current national standard, as applied through both geographic and projected coordinate systems. It replaces the AGD.
- In Australia, the standard projection used with projected coordinate systems is the Map Grid of Australia (MGA94) which utilises the Geocentric Datum of Australia (GDA).
- MGA94 is divided into 8 equal zones across Australia. Two of these zones – zone 52 and zone 53 – cover the NT

This paper recommends that all SSD staff who collect, create or maintain spatial data:

- Use the GDA in the first instance, except in exceptional circumstances (which should be documented); and
- Irrespective of the circumstances, a metadata record should be created for each dataset. At a minimum, this information should include:
    - The datum and type of coordinate system used
    - The full set of coordinates for the site location
    - Information on how the data was collected eg using a hand-held GPS
    - When and who collected the data
    - A succinct description of the location of the site.
- Data collected within the Allligator Rivers Region / Kakadu National Park should be recorded in the Map Grid of Australia 1994, projected into Zone 53. By recording coordinates in these units, the accuracy of attributes such as area is maximised –

which should be beneficial to the general largescale nature of the mapping activities being undertaken.

- Data collected around Darwin should use the Map Grid of Australia, projected into Zone 52.
- Projects which run across several grid zones, should record their coordinates in a geographic coordinate system, using the Geocentric Datum of Australia 1994.
- In exceptional circumstances, projects which run across 2-3 grid zones could project all data into one of the grid zones – normally the zone which is most within the study area. Note that in doing do, the accuracy of measurements such as area will degrade towards the edgest furthest from the centre of the zone into which the data is projected.

For users benefit, a summary checklist has been compiled of tasks and actions to consider in choosing a datum, coordinate system and projection in the NT in Table 2.

Table 2 Quick checklist for creating / using spatial datasets in the NT

Task	Action	Further action
Select the datum to use	GDA be should used except in exceptional circumstances. Note that if GDA does not appear as an option on the GIS or GPS, than select WGS84, as this is compatible with GDA.	1.If data are being integrated with other datasets, confirm that other datasets are using the same datum 2. If a non-GDA datum is in use, convert that data to the GDA datum
Identify which type of coordinate system to use	Choose geographic coordinate system (GDA94) if dataset extends across several UTM zones Use projected coordinate system (MGA94) if dataset lies within a single zone	
Identify the most appropriate projection to use	MGA94 is most appropriate projection to use for sites in single-zone projects	Select appropriate zone to project data into eg if in Darwin region, zone 52; if in ARR, zone 53.
Create metadata record for dataset	Metadata records can be created in GIS programs, or in SSD-Explorer	
Store data in SSD Explorer		

References (and suggested reading)

ANZLIC 2001. *ANZLIC Metadata Guidelines – Version 2, February 2001*. Available from http://www.anzlic.org.au/asdi/metaelem_ch2.htm#ch2guidelines

Defense Mapping Agency 1987. *World Geodetic System 1984, its definition and relationships with local geodetic systems*. DMA Technical report 8350.2, United States Department of Defence.

http://www.ga.gov.au/nmd/geodesy/datums/agd.jsp

Kennedy M & Kopp S 2000. *Understanding Map Projections*. Environment Systems Research Institute, Redlands, United States.

Appendix 1 – Background to projections, datums and coordinate systems

Geodesy

Geodesy is the study of:

- The size and shape of the earth ;
- The measurement of the position and motion of points on the earth's surface; and
- The configuration and area of large portions of the earth's surface.

Geodesy supports a range of activities, ranging from land titling and mineral exploration, to navigation, mapping and surveying, to the use of remote sensing data and resource management. It is through the measurement, and study of the size and shape of the earth that geodesy forms the basis for the development and application of coordinate systems.

From a geodetical perspective, the shape of the earth can be viewed in four different ways (figure 3):

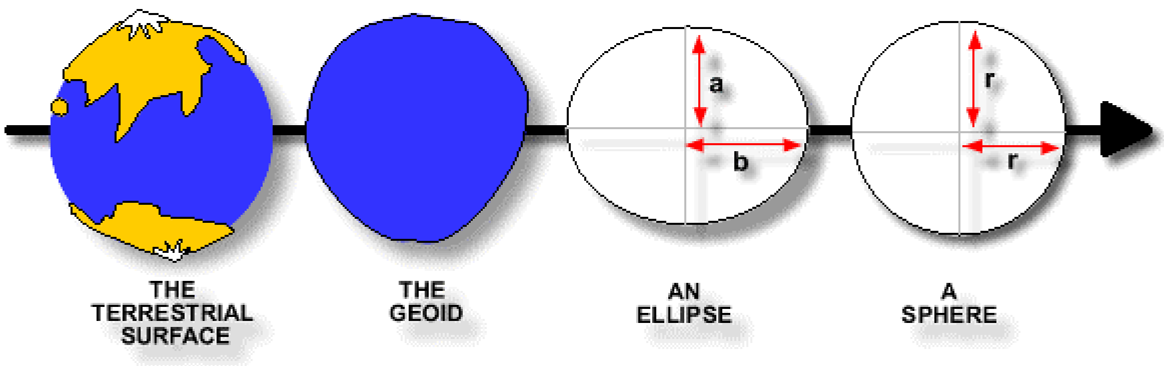

Figure 3 Ways in which the earths shape and size may be described (from http://www.ga.gov.au/nmd/geodesy/datums)

The *terrestrial surface* refers to the earth's topography. It is very complex with mountain ranges and oceans and it is the surface upon which we live and measure. Because the earth is not even (mountain ranges, valleys and oceans and the like get in the way !), it is not suitable for exact mathematical computations.

- The *geoid* estimates the earth's surface using the mean sea level of the ocean with all continents are removed. Due to variations in the earth's mass distribution (oceans and land), the Geoid has an irregular shape that may be best described as 'undulating'. Because the potential gravity is the same at every point on its surface, the geoid is known as an equipotentia surface.
- Measurements have shown that the earth is in fact slightly 'squashed' at the poles and bulges at the equator due to forces acting upon whilst it spins.
- In order to calculate precise measurements over long distances eg across continents or oceans, the earth is represented as an *ellipsoid*.
- The *ellipsoid* is an oval that revolves about its shortest dimension. It is a mathematical approximation of the *geoid*.

- The *ellipsoid* can be further simplified into a *sphere*. To define a sphere, only the radius is required. The radius often used when modeling the earth as a sphere is 6378137.00 metres.

Coordinate systems

There are two types of coordinate systems: ***geographic*** and ***projected***.

Geographic coordinate systems use latitude and longitude coordinates on a spherical model of the earth's surface. *Projected* coordinate systems use a mathematical conversion to transform latitude and longitude coordinates that fall on the earth's three-dimensional surface to a two-dimensional surface, on which the surface features can be represented – such as a map. Projected coordinates are typically expressed as Eastings and Northings, and are measured in metres.

Features on the surfaces of the earth may thus be represented using either a geographic coordinate system, or a projected coordinate system. As will be explained in the succeeding sections, different coordinate systems are appropriate for different applications – you should choose the system most appropriate to the task at hand.

Geographic Coordinate systems

A geographic coordinate system (GCS) uses a three-dimensional spherical surface to define locations on the earth. A GCS has three components: an angular unit of measure, a prime meridian, and a datum (based on a spheroid).

The shape and size of a geographic coordinate system's surface is defined by a sphere or spheroid. While the earth may be best represented by a spheroid, the earth is sometimes treated as a sphere to make mathematical calculations easier. The assumption that the earth is a sphere is possible for broad-scale maps (eg those at 1:5,000,000), where the difference between a sphere and a spheroid is not detectable on a map. However, to maintain accuracy for more detailed maps (scales of 1:1,000,000 or larger), a spheroid is necessary to represent the shape of the earth. Between those scales, choosing to use a sphere or spheroid will depend on the map's purpose and the accuracy of the data..

A point is referenced by its longitude and latitude values. Longitude and latitude are angles measured from the earth's center to a point on the earth's surface. The angles often are measured in degrees (or in grads). Figure 4 shows the world as a globe with longitude and latitude values.

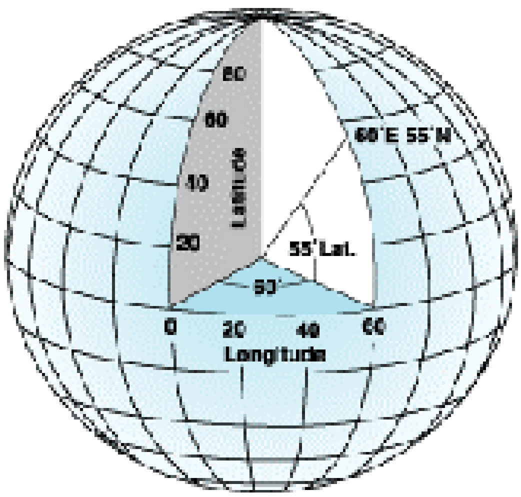

Figure 4 Latitude and longitude values on the globe (from Kennedy et al 2000)

In the spherical system, ‘horizontal lines’, or east–west lines, are lines of equal latitude, or parallels. ‘Vertical lines’, or north–south lines, are lines of equal longitude, or meridians. These lines encompass the globe and form a gridded network called a graticule.

The equator is the line of latitude midway between the poles, and has a value of zero degrees. The line of zero longitude is called the prime meridian. For most geographic coordinate systems, the prime meridian is the longitude that passes through Greenwich, in England.

The origin of the graticule (0,0) is defined by where the equator and prime meridian intersect. The globe is then divided into four geographical quadrants that are based on compass bearings from the origin. North and south are above and below the equator, and west and east are to the left and right of the prime meridian – thus Australia is in the southern hemisphere; the United States is in the western hemisphere. An illustration of the of the spherical system is shown in Figure 5.

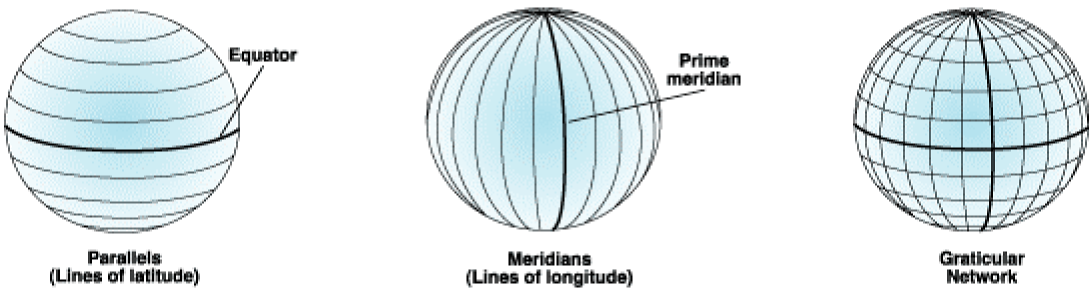

Figure 5 Spherical representations of the earth (from Kennedy et al 2000)

Latitude and longitude values are traditionally measured either in decimal degrees or in degrees, minutes, and seconds (DMS). Latitude values are measured relative to the equator and range from -90° at the South Pole to +90° at the North Pole. Longitude values are measured relative to the prime meridian. They range from -180° when traveling west to 180° when traveling east. If the prime meridian is at Greenwich, then Australia, which is south of the equator and east of Greenwich, has positive longitude values and negative latitude values.

Another means of representing geographic coordinates is as decimal degrees, in which latitude and longitude are expressed in decimal format rather than as degrees-minutes-seconds. Given that there are 60 seconds in a minute, and 60 minutes in a degree, the formula for converting degrees-minutes-seconds (DMS) to decimal degrees (DD) is as follows :

Decimal degrees = Degrees + Minutes/60 + Seconds/3600.

Thus, the coordinates for Darwin, in DMS would be expressed as

-12^{o} 27’ 55.26 South 130^{o} 50’ 40.16’ East,

wheras in decimal degrees, the same coordinate would be expressed as

-12.47^{o} South and 130.84^{o} East.

Although longitude and latitude can locate exact positions on the surface of the globe, they are not uniform units of measure. Above and below the equator, the circles defining the parallels of latitude get gradually smaller until they become a single point at the North and South Poles where the meridians converge. As the meridians converge toward the poles, the distance represented by one degree of longitude decreases to zero. On the Clarke 1866 spheroid, one degree of longitude at the equator equals 111.321 km, while at 60° latitude it is only 55.802 km. Since degrees of latitude and longitude don't have a standard length, you can't measure distances or areas accurately or display the data easily on a flat map or computer screen.

Spheroids and datums

While a spheroid approximates the shape of the earth, a datum defines the position of the spheroid relative to the center of the earth. The shape of the Earth may be represented through a number of spheroids, which in turn may be the base for many datums. A datum provides a frame of reference for measuring locations on the surface of the earth. It defines the origin and orientation of latitude and longitude lines.

Whenever you change the datum, or more correctly, the geographic coordinate system, the coordinate values of your data will change. Here are the coordinates in degrees-minutes-seconds of a control point in Darwin, using the Geocentric Datum of Australia 1994 (GDA94):

-12^{o} 27' 55.26' 130^{o} 50' 40.16'

Here's the same point on the Australian Geodetic Datum 1966 (AGD66):

-12^{o} 28' 0.12' 130^{o} 50' 35.81'

The AGD coordinate will appear to lie approximately 200 metres to the south-west of the GDA coordinate. While the difference may appear to be minor for some scenarios, in other circumstances, a 200-metre difference can be very significant!

Geocentric datums

Within the last 15 years, satellite data has provided geodesists with new methods to define the best earth-fitting spheroid, which relates coordinates to the earth's center of mass. An earth-centered, or geocentric, datum uses the earth's center of mass as the origin. The most recently developed and widely used datum is the World Geodetic System 1984 (WGS84). It serves as the framework for locational measurement worldwide, particularly in conjunction with the Global Positioning System (GPS) satellite network. WGS84 is itself based on the Geodetic Reference System 1980 (GRS80) , which was was developed by the United States Defense Mapping Agency. While there are some very minor differences in the ellipsoid parameters betweem GRS80 and WGS84, they may be regarded as essentially the same.

Local datums

A local datum aligns its spheroid to closely fit the earth's surface in a particular area. A point on the surface of the spheroid is matched to a particular position on the surface of the earth. This point is known as the origin point of the datum. The coordinates of the origin point are fixed, and all other points are calculated from it.

The coordinate system origin of a local datum is not at the center of the earth. The center of the spheroid of a local datum is offset from the earth's center. The Australian Geodetic Datum 1966 (AGD66) is a local datum developed for the Australia continent. Because a local datum aligns its spheroid – (in the case of AGD66, this is the Australian National Spheroid) so closely to a particular area on the earth's surface, it's not suitable for use outside the area for which it was designed. Thus, there would be little point using the Australian Geodetic Datum to collect points outside of Australia.

The Australian Geodetic Datum was proclaimed in the Australian Commonwealth Gazette of 6 October 1966. This proclamation included the parameters of the local ellipsoid, known as the Australian National Spheroid (ANS), and the position of the origin point - Johnston Geodetic Station (Geoscience Australia 2003). The Johnston Geoedetic Datum is located in the Northern Territory and has the following coordinates:

S 25° 56' 54.5515', E 133° 12' 30.0771'

The adoption of this origin and best fitting local ellipsoid means that the centre of the ANS does not coincide with the centre of mass of the earth but lies about 200 metres from it.

Projected Coordinate systems

Projection formulae take the geographic coordinates from the spherical earth (longitude and latitude) and convert them to cartesian coordinates (X & Y). These coordinates may expressed in a variety of ways, but the most common form is as 'eastings' and 'northings'. Similarly, while the units of measurement of a projected coordinate system may vary, the most common unit of measurement is metres. Projected coordinate systems use a variety of *map projections* to convert and display data from a geographical location (latitude and longitude) on a sphere or spheroid to a representative location on a flat surface, in Cartesian coordinates.

A projected coordinate system is defined on a flat, two-dimensional surface. Unlike a geographic coordinate system, a projected coordinate system has constant lengths, angles, and areas across the two dimensions. A projected coordinate system is always based on a geographic coordinate system that is in turn based on a sphere or spheroid.

In a projected coordinate system, locations are identified by x,y coordinates on a grid, with the origin at the center of the grid. Each position has two values that reference it to that central location. One specifies its horizontal position and the other its vertical position. The two values are called the x-coordinate and y-coordinate. Using this notation, the coordinates at the origin are x = 0 and y = 0.

On a gridded network of equally spaced horizontal and vertical lines, the horizontal line in the center is called the x-axis and the central vertical line is called the y-axis. Units are consistent and equally spaced across the full range of x and y. Horizontal lines above the origin and vertical lines to the right of the origin have positive values; those below or to the left have negative values. The four quadrants represent the four possible combinations of positive and negative x- and y-coordinates (figure 6).

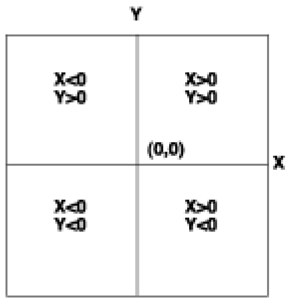

Figure 6 x and y axes of a grid system

What is a map projection?

A map projection is a mathematical formulae which may be applied to transform three-dimensional space onto a two-dimensional map. A variety of mathematical expressions and formulae may be used to convert data. The projection process inevitably distorts at least one of these properties - shape, area, distance, direction - and often more. Because measurements of one or more of these (distorted) properties are often used to make decisions, anyone who uses maps as analytical tools should know which projections distort which properties, and to what extent.

Since all map projections distort shape, area, distance or direction to some extent, the impact of this distortion on your work depends on what you will be using your map for, and its scale.

On large scale maps, such as those of the Ranger mine site, the distortion caused by the map projection being used may be negligible because your map will typically cover only a small part of the Earth's surface.

On smaller scale maps, such as regional and world maps, where a small distance on the map may represent a considerable distance on the Earth, this distortion may have a bigger impact, especially if your application involves comparison of the shape, area or distance of different features. In these cases, knowledge of the characteristics of the map projection you are using becomes more important.

Map projections are designed for specific purposes. One map projection might be used for large-scale data in a limited area, while another is used for a small-scale map of the world. Map projections designed for small-scale data are usually based on spherical rather than spheroidal geographic coordinate systems.

Projection types

Conformal projections preserve local shape. To preserve individual angles describing the spatial relationships, a conformal projection must show the perpendicular graticule lines intersecting at 90-degree angles on the map. A map projection accomplishes this by maintaining all angles. The drawback is that the area enclosed by a series of arcs may be greatly distorted in the process. No map projection can preserve shapes of larger regions.

Equal area projections preserve the area of displayed features. To do this, the other properties – shape, angle, and scale – are distorted. In equal area projections, the meridians and parallels may not intersect at right angles. In some instances, especially maps of smaller regions, shapes are not obviously distorted, and distinguishing an equal area projection from a conformal projection is difficult unless documented or measured.

Maps produced using **Equidistant projections** preserve the distances between certain points. Scale is not maintained correctly by any projection throughout an entire map; however, there are, in most cases, one or more lines on a map along which scale is maintained correctly. Most equidistant projections have one or more lines for which the length of the line on a map is the same length (at map scale) as the same line on the globe, regardless of whether it is a great or small circle or straight or curved. Such distances are said to be true. For example, in the Sinusoidal projection, the equator and all parallels are their true lengths. In other equidistant projections, the equator and all meridians are true.

Whether you treat the earth as a sphere or a spheroid, you must transform its three-dimensional surface to create a flat map sheet. This mathematical transformation used to do this is commonly referred to as a map projection. Map projections enable spheroidal coordinates to be transformed into planar coordinated which could be used with a flat map sheet.

As mentioned previously, different projections cause different types of distortions. Some projections are designed to minimize the distortion of one or two of the data's characteristics. A projection could maintain the area of a feature but alter its shape.

Figure 7 illustrates how three-dimensional features are compressed to fit onto a flat surface.

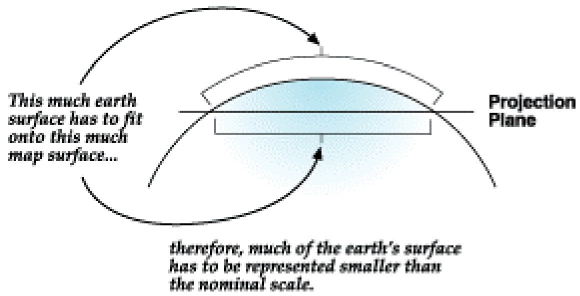

Figure 7 Applying 3d-features to a 2-d surface (from Kennedy et al 2000)

Projection surfaces

Because maps are flat, some of the simplest projections are made onto geometric shapes that can be flattened without stretching their surfaces. These are called developable surfaces. Some common examples are cones, cylinders, and planes. A map projection systematically projects locations from the surface of a spheroid to representative positions on a flat surface using mathematical algorithms.

The first step in projecting from one surface to another is creating one or more points of contact. Each contact is called a point (or line) of tangency. A planar projection is tangential to the globe at one point. Tangential cones and cylinders touch the globe along a line. If the projection surface intersects the globe instead of merely touching its surface, the resulting projection is a secant rather than a tangent case. Whether the contact is tangent or secant, the contact points or lines are significant because they define locations of zero distortion. Lines of true scale are often referred to as standard lines. In general, distortion increases with the distance from the point of contact (Kennedy et al 2000).

Many common map projections are classified according to the projection surface used: conic, cylindrical, or planar.

Conic projections

The most simple conic projection (figure 8) is tangent to the globe along a line of latitude. This line is called the standard parallel. The meridians are projected onto the conical surface, meeting at the apex, or point, of the cone. Parallel lines of latitude are projected onto the cone as rings. The cone is then 'cut' along any meridian to produce the final conic projection, which has straight converging lines for meridians and concentric circular arcs for parallels. The meridian opposite the cut line becomes the central meridian.

In general, the further you get from the standard parallel, the more distortion increases. Thus, cutting off the top of the cone produces a more accurate projection. You can accomplish this by not using the polar region of the projected data. Conic projections are used for midlatitude zones that have an east–west orientation.

Somewhat more complex conic projections contact the global surface at two locations. These projections are called secant projections and are defined by two standard parallels. It is also possible to define a secant projection by one standard parallel and a scale factor. The distortion pattern for secant projections is different between the standard parallels than beyond them. Generally, a secant projection has less overall distortion than a tangent projection. On still more complex conic projections, the axis of the cone does not line up with the polar axis of the globe. These types of projections are called oblique (Kennedy et al 2000).

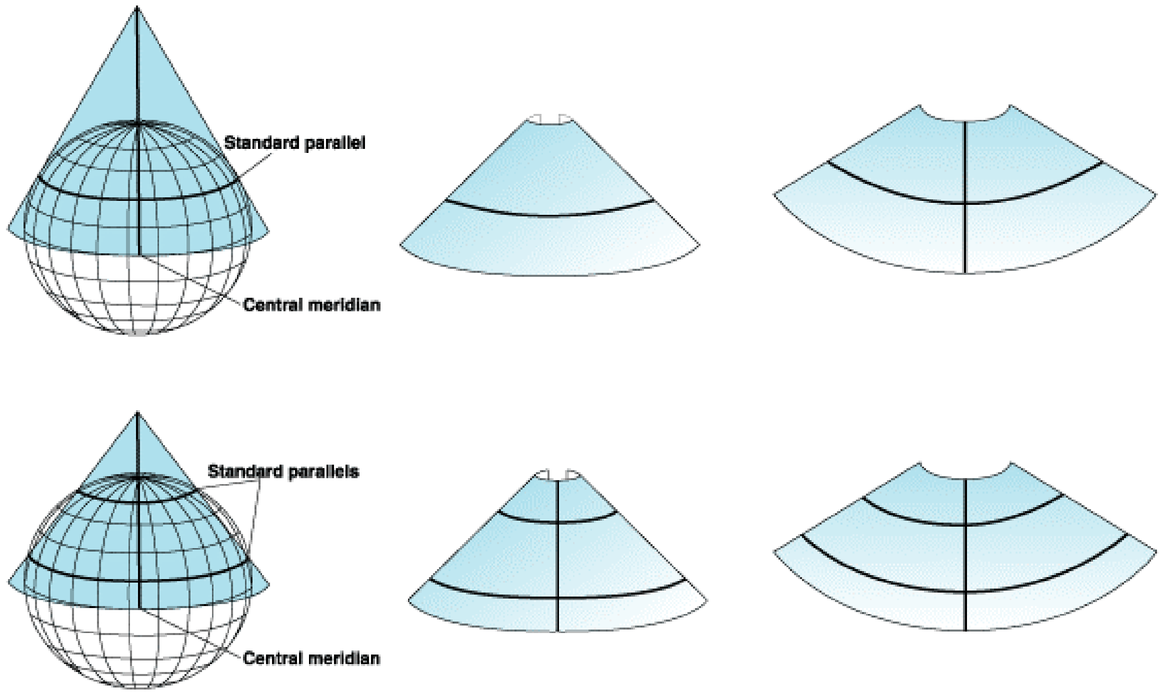

Figure 8 Simple (Top) and complex (lower) conic projections (from Kennedy et al 2000)

The representation of geographic features depends on the spacing of the parallels. When equally spaced, the projection is equidistant north–south but neither conformal nor equal area. An example of this type of projection is the Equidistant Conic projection. For small areas, the overall distortion is minimal. On the Lambert Conic Conformal projection, the central parallels are spaced more closely than the parallels near the border, and small geographic shapes are maintained for both small-scale and large-scale maps. On the Albers Equal Area Conic projection, the parallels near the northern and southern edges are closer together than the central parallels, and the projection displays equivalent areas.

Cylindrical projections

Like conic projections, cylindrical projections (figure 9) can also have tangent or secant cases. The Mercator projection is one of the most common cylindrical projections, and the equator is usually its line of tangency. Meridians are geometrically projected onto the cylindrical surface, and parallels are mathematically projected. This produces graticular angles of 90 degrees. The cylinder is 'cut' along any meridian to produce the final cylindrical projection. The meridians are equally spaced, while the spacing between parallel lines of latitude increases toward the poles. This projection is conformal and displays true direction along straight lines. On a Mercator projection, rhumb lines, lines of constant bearing, are straight lines, but most great circles are not.

For more complex cylindrical projections the cylinder is rotated, thus changing the tangent or secant lines. Transverse cylindrical projections such as the Transverse Mercator use a meridian as the tangential contact or lines parallel to meridians as lines of secancy. The standard lines then run north–south, along which the scale is true. Oblique cylinders are rotated around a great circle line located anywhere between the equator and the meridians. In these more complex projections, most meridians and lines of latitude are no longer straight (Kennedy et al 2000).

In all cylindrical projections, the line of tangency or lines of secancy have no distortion and thus are lines of equidistance. Other geographical properties vary according to the specific projection.

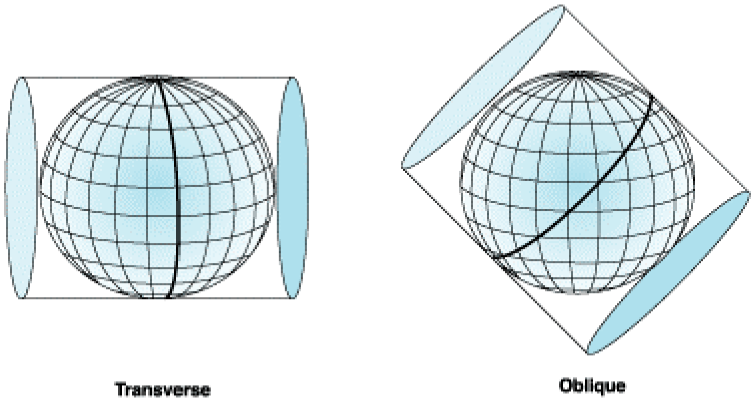

Figure 9 Cylindrical projections (from Kennedy et al 2000)

Planar projections

Planar projections (figure 10) project map data onto a flat surface touching the globe. A planar projection is also known as an *azimuthal* projection or a *zenithal* projection.

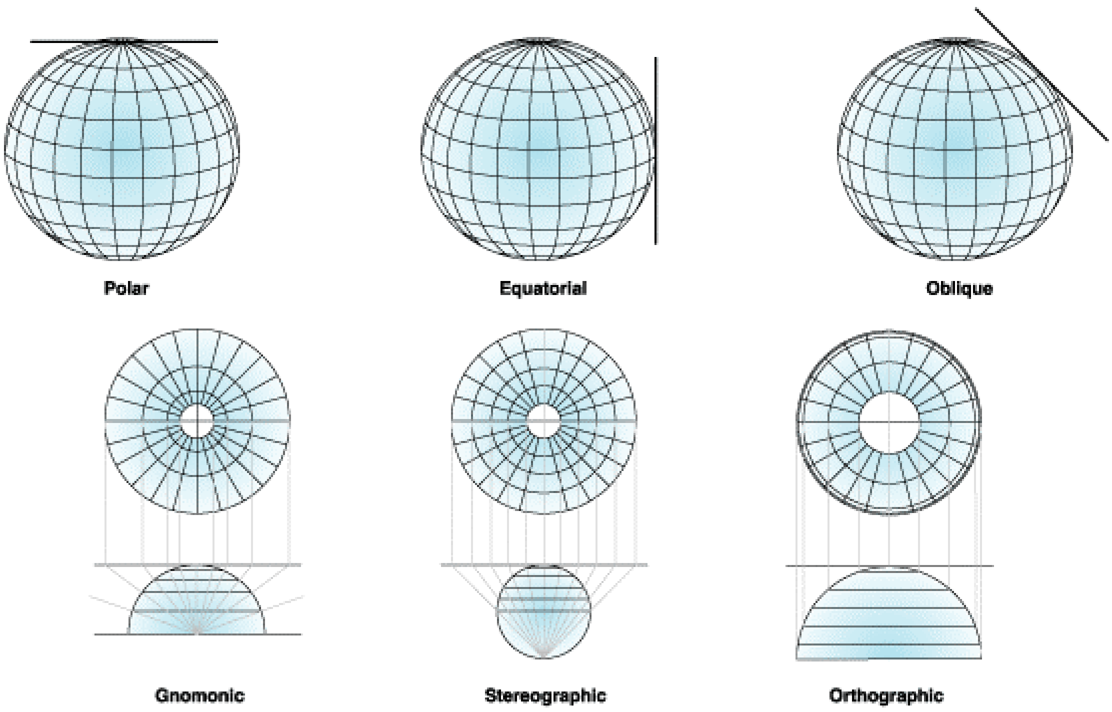

Figure 10 Planar projections (from Kennedy et al 2000)

This type of projection is usually tangent to the globe at one point but may be secant, also. The point of contact may be the North Pole, the South Pole, a point on the equator, or any point in between. This point specifies the aspect and is the focus of the projection. The focus is identified by a central longitude and a central latitude. Possible aspects are polar, equatorial, and oblique.

Polar aspects are the simplest form. Parallels of latitude are concentric circles centered on the pole, and meridians are straight lines that intersect with their true angles of orientation at the pole. In other aspects, planar projections will have graticular angles of 90 degrees at the focus. Directions from the focus are accurate.

Great circles passing through the focus are represented by straight lines; thus the shortest distance from the center to any other point on the map is a straight line. Patterns of area and shape distortion are circular about the focus. For this reason, azimuthal projections accommodate circular regions better than rectangular regions. Planar projections are used most often to map polar regions.

Some planar projections view surface data from a specific point in space. The point of view determines how the spherical data is projected onto the flat surface. The perspective from which all locations are viewed varies between the different azimuthal projections. The perspective point may be the center of the earth, a surface point directly opposite from the focus, or a point external to the globe, as if seen from a satellite or another planet (Kennedy et al 2000).

Azimuthal projections are classified in part by the focus and, if applicable, by the perspective point. The **Gnomonic** projection views the surface data from the center of the earth, whereas the Stereographic projection views it from pole to pole. The **Orthographic** projection views the earth from an infinite point, as if from deep space. Note how the differences in perspective determine the amount of distortion toward the equator.

Example of map projection – UTM

The Universal Transverse Mercator system is a specialized application of the Transverse Mercator projection. The globe is divided into 60 north and south zones, each spanning six degrees of longitude. Each zone has its own central meridian. Zones 1N and 1S start at -180° W. The limits of each zone are 84° N and 80° S, with the division between north and south zones occurring at the equator. A different coordinate system is applied to the polar regions.

The origin for each zone is its central meridian and the equator. To eliminate negative coordinates, the coordinate system alters the coordinate values at the origin. The value given to the central meridian is the false easting, and the value assigned to the equator is the false northing. A false easting of 500,000 meters is applied. A north zone has a false northing of zero, while southern zones – such as those in Australia - have a false northing of 10,000,000 meters.

Within continental Australia, there are 8 UTM Zones, numbered 49-56 going from west to east (see Figure 1). UTM projections have been applied to **both** the Australian Geodetic Datum (with the Cartesian coordinates expressed through the zones of the Australian Map Grid) and the Geocentric Datum of Australia (through the Map Grid of Australia). Note that irrespective of the datum employed, the number of the UTM zones remains the same.

UTM uses a Cylindrical projection method, and applies a conformal shape, which means data in this projection are able to provide an accurate representation of small shapes, and minimal distortion of larger shapes within the zone. A limitations of the UTM projection is that error and distortion increase for regions that span more than one UTM zone.

Data on a spheroid or an ellipsoid cannot be projected beyond 90 degrees from the central meridian. In fact, the extent on a spheroid or ellipsoid should be limited to 15–20 degrees on both sides of the central meridian. Beyond that range, data projected to the Transverse Mercator projection may not project back to the same position. Data on a sphere does not have these limitations (Kennedy et al 2000).

Appendix 2 : Background information on the Australia Geodetic Datum and the Geocentric Datum

AGD

Between 1966 and 1994, Australia used two datums – the Australian Geodetic Datum 1966 (AGD66) and the Australian Geodetic Datum 1984 (AGD84). Both AGD66 and AGD84 use the gazetted Australian Geodetic Datum, which is based on the Australian National Spheroid (ANS), and are for most practical purposes, similar. The coordinates differ only because of the readjustment using additional data and improved adjustment techniques. The difference between these two coordinate sets varies from about 2 metres in south east Australia to about 5 metres in the north west, but the variation is not uniform. Because of the inconsistent nature of AGD66 there are no national transformation parameters available to automatically transform between, AGD66 and AGD84.

As has been mentioned previously, the UTM projection has been applied to the AGD, with coordinates expressed as easting and northings in the Australian Map Grid. Figure 1 shows the range of Grid Zones across continental Australia. Note that in the Northern Territory, there are two grid zones – 52 and 53 (Figure 2). Kakadu and the Alligator Rivers Region fall almost entirely within Grid Zone 53 (the western boundary of the park is right on the boundary between zones 52 and 53), whilst Darwin falls within Zone 52. The recommended way to refer to these zones is as Australian Map Grid (AMG) zone 52 (or 53). Cartesian coordinates (eastings and northings) in the NT would be assigned to one or the other of these zones.

Datum	Australian Geodetic Datum 1966
Geographical coordinate set: (latitude and longitude)	Australian Geodetic Datum 1966 (AGD66)
Grid Coordinates	(Universal Transverse Mercator, using the ANS ellipsoid) Australian Map Grid 1966 (AMG66) /

GDA

The **Geocentric Datum of Australia** (**GDA**) is the current Australian coordinate system, replacing the Australian Geodetic Datum (AGD). GDA is part of a global coordinate reference frame and is directly compatible with the Global Positioning System (GPS) network established by the United States Defence Mapping Agency.

GDA may be seen as the Australian component of the World Geodetic System 1984 (WGS84), with which it is fully compatible. Thus, data received through a GPS receiver in WGS84 coordinates can be immediately integrated with other datasets which were generated using GDA. For the purposes of consistency, however, it is recommended that data recorded as WGS84 coordinates be saved and re-projected as GDA coordinates in the corporate database.

The UTM projection, as expressed through the GDA, provides Cartesian coordinates in the Map Grid of Australia. Note that as with the earlier projection in the AGD, there are two Map Grid zones in the Northern Territory (52 and 53).

Datum	Geocentric Datum of Australia (GDA)
Geographical coordinate set: (latitude and longitude)	Geocentric Datum of Australia 1994 (GDA94)
Grid Coordinates	(Universal Transverse Mercator, using the GRS80 ellipsoid) Map Grid of Australia 1994 (MGA94)