The Geodetic Infrastructure in Australia and New Zealand: Differences and Similarities

Graeme BLICK, New Zealand and Robert SARIB, Australia

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SUMMARY

Australia and New Zealand are both island nations in the southwest Asia Pacific. Geodetic activities across both nations are coordinated through the Australia / New Zealand Intergovernmental Committee on Surveying and Mapping, Geodesy Technical Sub-committee. This committee has representatives from the Australian Federal, State, and Territory governments and the government of New Zealand. Through this forum, cooperation among jurisdictions and national geodetic interests is coordinated. Both countries share a common interest in developing an accurate geospatial reference system and there are many similarities between both the land administration and cadastral systems of both countries.

There are however some significant differences between the geodetic infrastructures that have been driven by the different geographic and economic features of both countries. For example, Australia is the largest island nation in the world located solely within the Australian tectonic plate and New Zealand is a small island nation straddling the Pacific/Australian plate boundary. Australia's topography is relatively flat and the population is generally located on the coast with large areas of uninhabited land through the centre while New Zealand has a much more rugged and varied landscape with the population distributed over a greater percentage of the land area. Australia also has an extensive mining and large scale agriculture and farming industry while New Zealand is more focused on intensive farming. These differences have led to significant variations in the development of the current geodetic infrastructures of both countries. Australia has adopted a static geodetic datum and a national GNSS CORS network that to date has provided a sparse infrastructure across Australia. New Zealand uses a semi-dynamic datum and its CORS network has focused on monitoring crustal deformation across the plate boundary that New Zealand straddles.

While there are significant differences there is an increasing desire and reasons to adopt more common reference systems. Australia is considering the adoption of a dynamic datum and is now extending the GNSS CORS network to monitor continental movement and crustal deformation, and both countries are extending their GNSS CORS networks to meet the broader and specific requirements of geospatial and geoscience users respectively.

This paper will contrast the geodetic infrastructures in both countries and look towards the future where a more common geospatial reference system and infrastructure might exist between both countries.

The Geodetic Infrastructure in Australia and New Zealand: Differences and Similarities

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1. INTRODUCTION

The purpose of this paper is to highlight the differences and similarities of the Australian and New Zealand geodetic infrastructures or geospatial reference systems. It will also emphasize the fact that even though each country may have different reasons or drivers to implement an initiative to obtain their geospatial or geodetic objectives, there is a need for collaboration. Such co-operation can be facilitated through a joint geodetic strategy and the development of a regional reference system and frame which will be fundamental to the success of both countries' geodetic future.

2. GEOGRAPHICS

2.1 Australia "The Sunburnt Country" [1]

Australia is the world's biggest, oldest island continent and is the sixth largest country (Fig. 1). The total land area is 7,682,300 km^2. The land mass lies between the Indian and Pacific oceans and is approximately 4,000 km from east to west and 3,200 km from north to south, with a coastline 36,735 km long.

The Australian continent is part of the Indian-Australian tectonic plate and is currently moving north-east at a rate of 73 mm per year. Although the continent experiences some internal plate tectonic strain, it is generally geologically stable, with limited significant seismic activity.

The landscape of Australia is unique and varied. In the centre and west there are vast stony and sandy deserts; in the east, sweeping plateaus and plains flanking narrow coastal slopes; the coasts have sandy beaches with lush vegetation and in some locations backed by steep cliffs or eroded volcanic and flat plains. Despite being rich in biodiversity, the soils and seas are among the most nutrient poor and unproductive in the world. The average elevation is only 330 m and the highest point is 2228 m (Mt Kosciuszko).

Australia's climate is temperate and it is one of the driest inhabited continents on earth with only 6.5% of the landmass being arable. The national average rainfall is 465 mm but can vary greatly each year and be distributed unevenly around the continent. The Murray and Darling rivers are the two longest river systems and form a basin that covers 14% of the mainland. In the centre of Australia is a salt lake known as Lake Eyre which is 9000 km^2 in area.

[1] Information and facts in this section have been compiled from 'Department of Foreign Affairs and Trade', 'Australian Bureau of Statistics' and 'Our Country Australia' government websites.

The multi-cultural population in June 2009 was just over 22.1 million, with 80% Australians living within 100km of the coast, and the majority living in either Melbourne or Sydney.

Australia's parliamentary democracy follows a Westminster system of government and law. This constitutional monarchy model was inherited from the British who originally colonised the country, hence Australia's head of state is presently the Queen of the Commonwealth. Australia is administered by a Federal or Commonwealth government, as well as 6 State and 2 Territory parliaments.

Australia's trade accounts for 1% of world trade, and mainly deals with markets from countries in the Asia Pacific Region such as China, Japan, United States, Republic of Korea, and New Zealand. Primary merchandise and service exports are coal, iron ore, education services, personal travel (tourism), gold, crude petroleum, aluminium ore, aluminium, professional and technical services, natural gas, beef, and passenger transportation services. Australia's largest import items are crude petroleum and passenger motor vehicles.

Fig 1 - Map of Australia (source Geoscience Australia https://www.ga.gov.au/products/servlet/controller?event=GEOCAT_DETAILS&catno=47987)

2.2 New Zealand "The Land of the Long White Cloud" [2]

New Zealand lies across the obliquely convergent Australian and Pacific plate boundary. To the northeast of New Zealand the Pacific plate is subducted beneath the Australian plate and to the southwest of New Zealand the Australian plate is subducted beneath the Pacific plate. Through central New Zealand the oblique collision of the continental plates has resulted in a combination of strike slip and uplift motion with horizontal motions of 40-55mm/yr along the plate boundary (Walcott 1984). In addition to the plate motions, New Zealand experiences

[2] Compiled from Statistics New Zealand 2009

the effects of other deformation events such as large earthquakes, volcanic activity, and more localised effects such as landslides.

New Zealand comprises two main islands, the North and South Islands, and numerous smaller islands, notably Stewart Island/Rakiura and the Chatham Islands (Fig. 2). Its area of interest extends to the Ross Dependency in Antarctica. It is notable for its isolation, being situated 2,000km from Australia, and its closest neighbours to the north are New Caledonia, Fiji and Tonga with Antarctica to the south.

New Zealand's total land area of 268,021 km^2 makes it a little more than the United Kingdom; Australia is more than 28 times its size. The country extends more than 1600 km along it main north-south axis with approximately 15,134 km of coastline. Because of New Zealand's location across the Australian and Pacific plate boundary its landscape is youthful. The North Island is volcanically active and the South Island has the high snow-covered Southern Alps, a range running almost 500km along the island. New Zealand has an oceanic temperate climate given its small land mass relative to the expansive ocean surrounding it.

New Zealand's population is approximately 4.3 million people and it is a predominantly urban country with 72% of the population living in 16 main urban areas and 53% living in the four largest cities, Auckland, Christchurch, Wellington and Hamilton.

New Zealand is multi-party democracy and constitutional monarchy with one legislative house. Unlike Australia, New Zealand is managed as one entity with no State Governments. Its principal export industries are agriculture, horticulture, fishing and forestry. These make up about half of the country's exports.

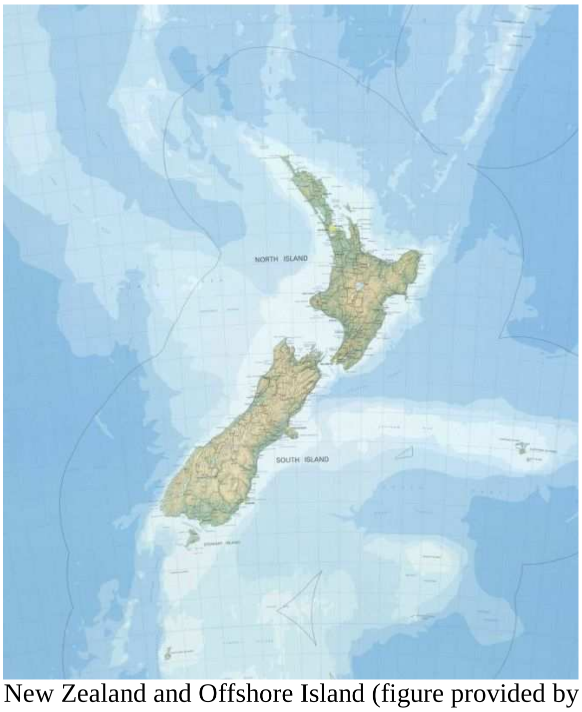

Fig 2 - New Zealand and Offshore Island (figure provided by LINZ)

3. GEODETIC INFRASTRUCTURE OVERVIEW

3.1 Australia

The following is a brief historical précis of the technical evolvement of Australia's national geodetic datums and framework or geospatial reference system (GRS), and has been compiled from publications NMC (1986) and ICSM (2009).

3.1.1 <u>Reference Ellipsoids and Datums</u>

Between 1858 and 1966, geodetic surveys in Australia were computed on either a State or regional basis using several different spheroids and as many as twenty co-ordinate origins. During this period some of the larger States employed two or more origins simultaneously and various values were adopted for the imperial system units of length then in use. Clarke 1858 was mostly used as the reference ellipsoid and the Australian National Grid (ANG) was the rectangular grid co-ordinate system.

In April 1965, the then National Mapping Council (NMC), adopted the spheroid recommended by the International Astronomical Union and called this spheroid the Australian National Spheroid (ANS). Following this decision, the Division of National Mapping (DNM) commenced the re-computation and adjustment of all geodetic surveys to the ANS in June 1965, and completed this task by March 1966. The NMC gazetted the newly defined Australian Geodetic Datum in April 1966 (AGD 66). The co-ordinates (latitude and longitude) produced by the 1966 adjustment were known as AGD 66 and the universal transverse mercator (UTM) grid co-ordinates were labeled as AMG66. The centre of the ANS was called the Johnston Geodetic Station. The co-ordinates for this origin were derived from astronomical observations at 275 stations distributed over Australia; and the spheroidal height adopted equaled the geoidal height that was determined from trigonometrical levelling. That is, the geodial separation (N) was assumed to be zero!

The implementation of AGD 66 allowed geodetic surveys to be on a 'unique system of co-ordinates' and removed the discontinuities caused by the various State co-ordinate origins. It also provided a 'point reference system' for lower order surveys and mapping.

In 1971, geodial profiles were observed using astro-geodetic techniques. Combining this data with gravimetrically computed data allowed the creation of N values and a subsequent contour map of the geoid.

A readjustment of the national geodetic survey occurred in 1982. This adjustment known as the Geodetic Model of Australia 1982 (GMA82) used spaced based measurements such as Doppler, satellite laser ranging (SLR) and very long baseline interferometry (VLBI) observations. It also included the 1971 geoid model and results of the national Australian Height Datum (AHD) levelling adjustment. By 1984 the NMC recognised the need to convert to a geocentric geodetic datum and resolved that adoption of the GMA 82 adjustment would be the first step in the conversion process. Consequently, the co-ordinates resulting from

GMA82 were adopted by the NMC in 1984 and were known as the Australian Geodetic Datum 1984 (AGD 84) and the equivalent UTM grid co-ordinates as AMG84.

In 1988, the Intergovernmental Committee on Surveying and Mapping (ICSM)[3] recommended that a geocentric datum be adopted by 1 January 2000. The primary drivers for the Australian geodetic framework and infrastructure to move to an earth centred or geocentric datum, which was linked mathematically to the ITRF, were –

- To ensure compatibility and consistency across various geographic information and data systems / themes at the local, regional and global level
- To ensure compatibility with global navigation satellite systems (GNSS) such as GPS
- To allow users to use GPS navigation devices more easily

As part of a global campaign through the (then) International GPS service, continuous GPS observations were performed at 8 locations across Australia in 1992. This network of permanent GPS reference stations formed the Australian Fiducial Network (AFN). In addition to these observations, numerous high accuracy GPS observing campaigns were performed during 1993-94 at 70 sites across Australia at a nominal spacing of 500km. This network was named the Australian National Network (ANN).

The AFN and ANN GPS observations were subsequently combined into a single regional GPS solution in terms of the International Terrestrial Reference Frame 1992 (ITRF92) and the resulting co-ordinates mapped to a common epoch of 1994.0. The AFN co-ordinates were then adopted to define the Geocentric Datum of Australia (GDA) and were gazetted on 6 September 1995.

Since 1995 States and Territories have progressively re-adjusted their local geodetic networks onto GDA and have performed various geodetic surveys to maintain the integrity of the datum. Both States and Territories have also assisted dataset custodians to transform their co-ordinate systems to the new datum. Consequently, numerous transformations parameters and utilities to assist users to convert to GDA have been developed and made available by ICSM and relevant jurisdictions.

3.1.2 Australian Height Datum (AHD)

Although Australia adopted GDA as its geodetic datum majority of the geodetic survey control still use the Australian Height Datum (AHD) as its official height reference. The origins of Australia's vertical reference frame began in 1945 when the DNM undertook a project to create a levelling network that spanned the Australia continent. This immense level survey consisted of 97,230 kms of two way third order levelling and was substantially completed in 1970.

[3] The formation of ICSM to cover both surveying and mapping issues occurred in 1988 after the cessation of the NMC. Refer to Section 5 - Joint Geodetic Strategy for a more detailed explanation of this government based organisation.

Prior to 1971, Australia had numerous levelling datums that were based on local tide gauges or arbitrary points. State and local government authorities such as water boards, road authorities, councils primarily used such datums for local or regional mapping or engineering works. Thus in order to reduce confusion and the complexity of integrating such information the NMC in 1971 agreed to unify the multitude of datums by determining a vertical datum surface from a national simultaneous level adjustment of the 1945-70 levelling, and 30 tide gauges on the coasts of Australia. Note in this adjustment the mean sea level (MSL) of 1966-68 was assigned a value of zero at the subject tide gauges. This derived vertical datum surface for survey control was adopted by the NMC in May 1971 and was referred to as the AHD71 "surface which passes thorough MSL at the tide gauges and through points with zero AHD height vertically below the other basic junction points in the levelling network"

AHD71 continued to serve the needs of users for several years until the evolution of GPS. With its popular uptake in remote / regional areas and rapid use this increased the need to provide better (and accurate) models for the vertical relationship between the adopted national geodetic datum and AHD. Consequently there have been several national geoid models derived to cater for this, such as AUSGeoid 1991, 93 and 98. During this era ICSM recognised this emerging need to improve these models in 1997/98 and endorsed a height modernization project which involved GPS surveys at tide gauges and most AHD71 junction points and /or bench marks. The result of this project is that a new national geoid model combining gravimetric and geometric data will be available in 2010. It is expected that this model will enable GPS users to derive AHD heights to decimeter accuracy. Please refer to the presentation by Brown et al (2010) 'Ausgoeid09: Improving the Access to Australia's Vertical Datum'.

3.1.3 Status and future of the Australian Geodetic Network or "GRS"

As previously described Australia is made up of federal, state and territory government agencies. The management of the national geodetic network or geospatial reference system (GRS) of Australia is facilitated by the federal agency Geoscience Australia (GA). States and Territories in Australia assist and support GA to manage and maintain this network but also administer their local geodetic and cadastral frameworks.

Prior to 2000 the GRS of Australia consisted primarily of thousand's of ground marks, 20 permanent GPS base stations (ARGN[4]), 15 tide gauge sites with semi–permanent GPS facilities, and a combination of VLBI / SLR facilities in Western Australia, South Australia, Canberra, New South Wales and Tasmania. This geodetic infrastructure at the time appeared to meet most user needs. However the increasing trend of ubiquitous positioning and demand for more accurate positioning (especially in real time) in both traditional and non-traditional spatial sectors caused the geodetic community to examine the integrity and reliability of the existing geospatial / geodetic infrastructure to meet future needs. As a consequence it was determined that for the next generation GRS (at the national level) to -

[4] ARGN is the Australian Regional GPS Network. It consists of a network of permanent geodetic quality GPS receivers, on geologically stable marks, in Australia and its Territories, with eight stations within Australia known as the Australian Fiducial Network (AFN).

- remain compatible;
- maintain integrity and reliability;
- satisfy modern and future requirements for applications;
- leverage and utilise advancements in GNSS; and
- allow the spatial accuracy of datasets (especially public ones) to be equivalent to the accuracy of available positioning services,

the present GRS needed to be upgraded to *sub-centimetre* accuracy or better by 2011.

To refine the GRS, measurement of precise baselines transecting the Australian continent would be required and would involve establishing a world class national infrastructure network of complementary space-based measuring systems such as VLBI, SLR and GNSS observatories. Refer to Fig 3 for a diagram of the GNSS network. By 2005 the GRS infrastructure plan consisted of -

- Upgrading existing VLBI facilities and establishing 3 new VLBI – to determine the earth's orientation parameters and scale for the terrestrial reference frame;
- Upgrading or purchasing a SLR – to refine the geo-centre of the earth for the terrestrial reference frame;
- Establishing approximately 100 GNSS Continuously Operating Reference Stations (CORS) – to develop more accurate models of the Earth's tectonics;
- Acquiring equipment for absolute and relative gravity measurements – as an independent validation for height variations detected by the space geodetic techniques;
- Developing a data management regime.

For a more detailed report of this national GRS initiative, please refer to the technical paper by Johnston & Morgan (2010) – "The Status of the National Geospatial Reference System and Its Contribution to Global Geodetic Initiatives".

Like the ARGN GNSS network, these new GNSS CORS sites will measure and monitor the scale, motion and deformation of the Australian continent and provide three-dimensional coordinates of a fundamental network of points as a function of time. The geodetic data will then be used to determine a sub-centimetre reference system for Australia. This GNSS network will also be used for other earth science or research applications, such as climate change, atmospheric modelling and sea level rise. Data from some base station sites within this new GNSS CORS network may also contribute to the International GNSS Service (IGS)[5] and thus aid the realisation of the next ITRF. In addition, such infrastructure will act as the backbone or framework for regional and local clusters of GNSS base stations operated primarily by State / Territory Governments or even commercial entities in major cities or regions demanding positioning services.

3.1.4 Other Aspects of Australian Geodetic Infrastructure

Both federal and jurisdictional (states and territories) governments manage their own geodetic data. Most agencies have web based 'on-line' systems as mechanisms to access geodetic data

[5] Refer to website http://igscb.jpl.nasa.gov/

and records. Storage, archiving and integration of geodetic data however are still primarily via ‘static’ digital file systems / formats / applications. ICSM initiatives such as *ePlan* however have instigated investigation into *eGeodesy*, and the development of a geodetic data transfer / exchange standard and subsequent archiving regime. For more information about these projects refer to technical papers Fraser and Donnelly (2010) “Progress Towards a Consistent Exchange Mechanism for Geodetic Data in Australia and New Zealand” and Cumerford (2010) “The ICSM ePlan Protocol, Its Development, Evolution and Implementation”

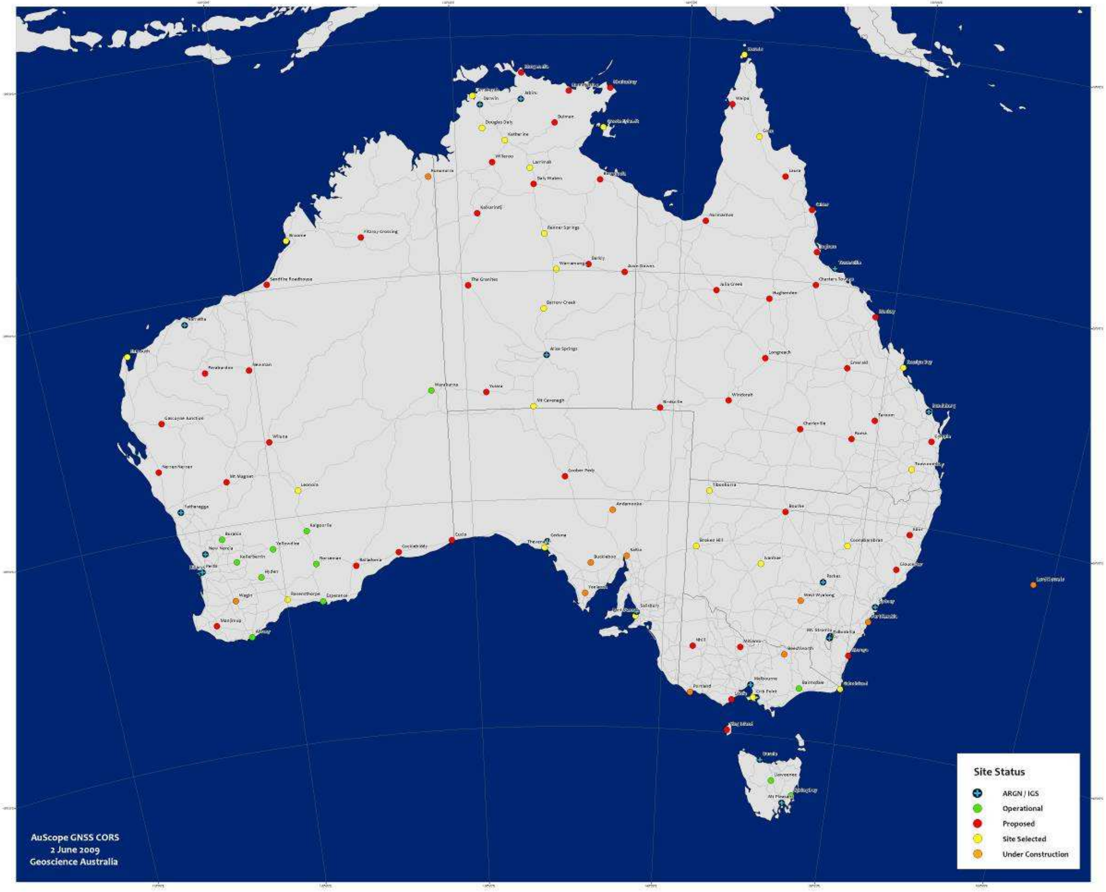

Fig 3 - National GNSS CORS Network (as at Nov 2009)

Most government agencies or jurisdictions in Australia have or are developing a GNSS ‘positioning’ infrastructure network (non geodetic quality) that allows a variety of traditional and non spatial users to access network services such as real time positioning or post processing products. GA currently provides an on line positioning service called ‘AusPos’ and post processing products from the existing Australian national network of GNSS permanent stations. As previously mentioned, it is envisaged that a combination or unification of national, state and regional networks would formulate the foundations for positional infrastructure for high accuracy positioning (centimetre) in real time across the continent. It is expected that this will be achieved by streaming data from these sites to third party ‘value add’ retailers. Various standards, policies and models for infrastructure, organisational, business, data, financial and product issues are being developed for this aspect of national GNSS CORS infrastructure and activity by the AuScope GNSS Sub Committee [6].

As previously mentioned, in Australia each State and Territory governs and manages their cadastral infrastructure and systems. The common link between them is that they all operate under the Torrens title system, however from geodetic perspective it appears unification of these fundamental datasets is attributed to the geodetic reference frame or more specifically GDA. In most States and Territories there is a trend to upgrade the spatial accuracy of their digital cadastral database (DCDB). To achieve this and obtain a seamless dataset across the continent most cadastral systems require connections to GDA co-ordinates (geo-referencing) on salient cadastral points as a means of adjusting and subsequently improving the integrity and accuracy of their cadastral data. Currently most jurisdictions in Australia have this objective on their agenda but have implemented such systems and processes (legal and administrative) to various degrees, levels, and timeframes.

3.2 New Zealand

An overview of the New Zealand geodetic system is provided by Blick (2009). The specific features that have driven the development of the geodetic system have been:

- Its geographic isolation and location astride the Australian New Zealand plate boundary;
- The high dependence and interrelationship between the geodetic and cadastral systems in New Zealand;
- The management of the geodetic and cadastral systems by one agency, i.e. no separate States as in Australia;
- No adjoining states/countries;
- Economic considerations with it being a small country.

3.2.1 <u>Horizontal and Vertical Datums</u>

The national geodetic triangulation of New Zealand is considered to have commenced with the measurement of the Wairarapa Baseline in 1909. However it was not until 1949, with the completion of the first order triangulation, that there was a national geodetic datum, New Zealand Geodetic Datum 1949 (NZGD1949) which used the Hayford (International) ellipsoid [Lee 1978]. By the mid 1990s a number of issues identified with NZGD1949 were becoming significant. Notably its accuracy was insufficient to support surveying technology such as high precision EDM and GPS, and because it did not account for the effects of crustal deformation it was no longer able to meet modern requirements for a national datum.
A decision was subsequently made to implement a new geodetic datum, New Zealand Geodetic Datum 2000 (NZGD2000). This new three-dimensional semi-dynamic datum had

[6] AuScope GNSS Sub Committee was formed by AuScope to manage the national GNSS CORS implementation. AuScope is a non-profit company formed to facilitate the implementation of a world-class infrastructure system for earth science through the delivery of a range of technologies and capabilities in data acquisition, management, modelling and simulation across the geospatial and geoscience spectrum. Refer to website - http://www.auscope.org.au/index.php

increased accuracy and used the GRS80 ellipsoid. Notably it included a deformation model (Fig. 3) to convert geodetic observations made at different times to a common reference epoch of 1 January 2000 and accommodate the effect of crustal dynamics [Blick 2003]. The technology used to carry out surveys for this datum moved from the more traditional triangulation techniques to the use of Global Navigation Satellite Systems (GNSS) such as GPS, although many older triangulation observations were readjusted and included.

NZGD1949 was a two dimensional datum. Normal-orthometric (approximate sea level) heights were referenced to 13 separate levelling datums that were located across parts of the country. Each of these levelling datums has its origin at a tide gauge at which mean sea level was determined. Precise levelling was used to extend each network from its origin, primarily following the major road networks. As with triangulation, extensions to the levelling networks increasing coverage across New Zealand were to continue until the 1990s. NZGD2000 is a three dimensional datum and uses ellipsoidal heights. New Zealand has now adopted a new national vertical datum (NZVD2009) that is based on ellipsoidal heights and uses a national geoid model (NZGeoid2009) (Amos and Featherstone 2009).
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3.2.2 Projections

In 1877 28 meridional circuits were established for cadastral surveying. Nine were located in the North Island and 19 in the South Island. Each had a physical initial station and they were assumed to be on a plane. In 1949 these circuits were upgraded to transverse Mercator projections.

Separate North and South Island transverse Mercator projections were implemented for national 1 inch to 1 mile topographic mapping from the 1940s. During the 1970s, and driven by decimalisation, a decision was made to metricate mapping in New Zealand. In 1973 a new national mapping projection unique to New Zealand was implemented and called the New Zealand Map Grid (NZMG) [Lands and Survey 1973]. This was a conformal projection with a single national metric grid across New Zealand which was adopted for the new national 1:50,000 topographic mapping series introduced at that time.

Following the move to NZGD2000 a decision was made to adopt a new single transverse Mercator projection for topographic mapping in New Zealand. Consequently, in 2001 the New Zealand Transverse Mercator 2000 projection (NZTM2000) [LINZ 2007b] was implemented for national mapping and is being used for the new 1:50,000 Topo50 map series [Blick 2009].

3.2.3 Survey Control Networks

In New Zealand the traditional network of control marks consists of a hierarchy of marks based on accuracy called orders. The most accurate control marks (order 0) are the CORS stations. The least accurate control marks (order 5) are placed primarily to enable cadastral surveys to connect to NZGD2000. There are currently more than 75,000 control marks and of these about 4000 have beacons. The survey control network is continually being upgraded and extended to meet the needs of a range of users. Much of the focus over recent years has been on extending the coverage and accuracy of the order 5 control marks, particularly to enable the original NZGD1949 triangulation networks and control traverses to be incorporated into NZGD2000.

3.2.4 <u>PositioNZ Network</u>

PositioNZ is a national network of 33 Continuously Operating GNSS Stations (CORS) stations located across mainland New Zealand (Fig. 3), two on the Chatham Islands, and three in the Ross Sea Region of Antarctica. The primary reason for this network is to monitor national-scale crustal deformation and to maintain the deformation model which is an integral component of NZGD2000.

Several of the PositioNZ stations are also International GNSS Service (IGS) sites and it is through these stations that New Zealand connects and contributes to global reference systems. These connections ensure that New Zealand's geodetic system is compatible with international systems. Providing data from these stations assists with the development of accurate global reference frames.

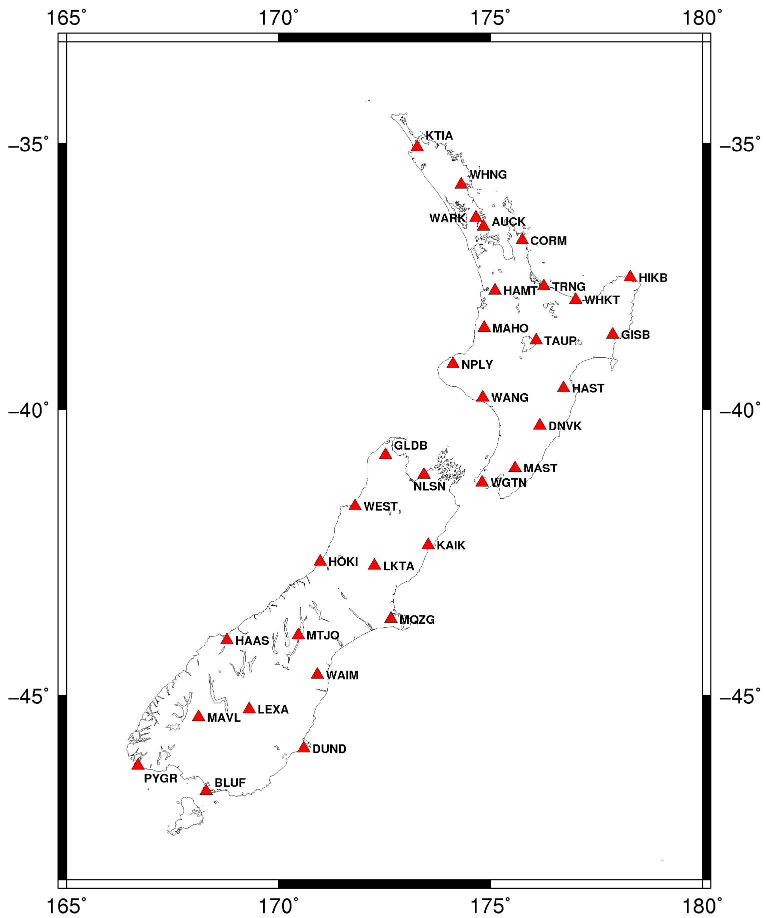

Fig 4 - PositioNZ stations on mainland New Zealand

3.2.5 Geodetic Data Management

During the late 1990s Land Information New Zealand implemented an automated survey and title system called Landonline. When Landonline was conceived it was designed to cater for the automation of not only the cadastral survey and title systems, but also the geodetic system. Since the initial implementation of Landonline all control surveys have been made by contractors and the electronic survey control datasets supplied are loaded into Landonline. Information on control marks, maintenance, coordinates, survey data, and accuracy are retained and managed in Landonline. However much of this information can be accessed from the geodetic database on the LINZ website. The geodetic database is updated daily from downloads of geodetic data held in Landonline. Searching the database for control mark information can be done textually or via a spatial search using Google Maps.

3.2.6 The Geodetic System and the Cadastre

When Landonline was implemented the division between control marks and cadastral marks, including boundary marks, became blurred because all marks are referenced to the same geodetic datum (NZGD2000). The cadastre in New Zealand can be considered a geodetic cadastre. While New Zealand does not have a legal coordinate cadastre, accurate coordinates for cadastral marks improve the efficiency of cadastral surveys and enable the data to be used for a wider range of purposes.

With the strong connection of the cadastre to survey control, issues for LINZ now include managing the spatial alignment between the survey control and cadastral systems. Readjustment of control marks following resurvey, a deformation event such as an earthquake, or addition of new or more accurate survey data now flows through to the cadastre requiring readjustment of the cadastre also. Readjusting a relatively small number of control marks can be a relatively trivial task, however subsequent readjustment of a large number of cadastral marks connected to that control is a much more complex and time-consuming task. There is also an increasing focus on connecting cadastral survey networks in non-survey-accurate areas to survey control networks to enable the spatial accuracy of the cadastre in these areas to be improved.

4. COMPARISONS

Australia and New Zealand have developed modern geodetic systems that are relatively new and support contemporary land information systems which underpin the Torrens system of land administration and titles. Both geodetic infrastructures also have a wide range of other uses and users that range from the traditional geoscience sectors to non-traditional sectors such as tourism. Although both systems incorporate modern horizontal and vertical datums and modern 'active and passive' infrastructures (that is GNSS CORS networks and ground marks and beacons respectively), there are also significant differences between the Australian and New Zealand systems. The previous précis of the separate geodetic systems demonstrated this and is characterised by the following:

- **Focus of the geodetic systems**: The geodetic systems in both Australia and New Zealand play an important role in the maintenance of their datum however there are subsidiary focuses that often create conflict or competition amongst stakeholders. In Australia there is a parallel focus for geodetic infrastructures to not only support the scientific arena but to be an "enabling infrastructure" that can assist the development of the Australian economy in key sectors. For example recent studies indicate the effect that high precision positioning services can have on the GDP. Figures from Allen (2008) state –

  > *"The gross benefit flowing from existing uptake in the agricultural, mining and construction sectors is estimated to range between $829 million and $1486 million per annum, depending on the size of productivity gains assumed. This represents a contribution to national GDP of between 0.08 per cent and 0.14 per cent.*
  >
  > *Application of precision GNSS to asset mapping by utilities and local government Australia-wide is estimated to result in operating cost savings of $435 million to $870 million per annum and capital cost savings of up to $2.3 billion per annum."*

  Such potential benefits have been used to justify the roll out of geodetic infrastructure. In New Zealand the rugged landscape and its tectonic setting have had an influence on the design and implementation of the geodetic infrastructure, which has a focus on the monitoring of regional deformation. The geodetic infrastructure has also been influenced by its strong aim to support the cadastre in New Zealand.
- **Management of the geodetic network**: The geodetic infrastructure across Australia is managed both at the national and State / Territory level. Co-operative workings to date amongst jurisdictions in ICSM has resulted in the adoption of GDA and other geodetic strategic achievements, however in the future a more collaborative attitude will be required to ensure a unified approach to management of GNSS CORS, data and downstream positioning infrastructure in Australia. In New Zealand the geodetic and cadastral infrastructure is managed by one organisation, Land Information New Zealand, at the national level. The management of the infrastructure is thus simplified and well coordinated across the country.
- **Management of geodetic data:** In New Zealand the management of geodetic data is managed centrally by Land Information New Zealand in its Landonline application. This electronic system includes survey, title, and geodetic electronic data held in one electronic database. Geodetic data is available through the web on the LINZ geodetic database (www.linz.govt.nz). In Australia most jurisdictions manage geodetic data via modern databases however to have a unified approach to managing GNSS CORS data from different tiers will need standard protocols for management of geodetic GNSS CORS data from an accessing, transferring and archiving perspective.
- **Horizontal datum:** Australia uses a static geocentric national 2 dimensional datum while New Zealand has adopted a semi-dynamic geocentric national 3 dimensional datum. The inclusion of a deformation model in NZGD2000 has meant that the accuracy of the datum can be maintained over a longer time period and the effects of crustal deformation managed.
- **Vertical datum:** Australia uses a national sea level datum (AHD) which ties to a number of sea level gauges while New Zealand uses 13 main sea level vertical datums

across various areas, each connected to a separate sea level gauge as its origin. New Zealand has adopted for its national vertical datum the NZGeoid2009 as the datums reference surface. This enables heights in terms of the national vertical datum (NZVD2009) to be calculated and offsets between it and the separate sea level datums have been calculated to allow transformations. Unlike the AHD, the definition of NZVD2009 does not involve setting heights of any tide gauges to zero.

- **Physical infrastructure - ground marks and beacons:** Both countries maintain a network of physical marks and beacons. The fact that New Zealand is a dynamic country experiencing the effects of crustal deformation means that there has been a strong focus on maintaining a large network of ground marks to enable surveys to be connected of geodetic control over short distances where the effects of deformation can be minimized. In Australia with its vast area, geodetic control is very sparse across a large portion of the country and thus there is a need for densification of both passive and active physical infrastructure.
- **Physical infrastructure - GNSS CORS:** The New Zealand national CORS network (PositioNZ) has a station spacing across the country of about 100km and was initially set up to monitor the dynamics of New Zealand. It is subsequently being upgraded to support other applications including real time applications. This network is closely aligned with a denser network of CORS stations established along the shear belt and volcanic areas of the North Island for geologic hazard monitoring. In Australia CORS networks (of varying "Tiers" [7], types and uses) are owned / managed at the national, state and in some cases regional level. The national network, which primarily is used for reference frame and datum maintenance, is managed by GA. Similarly, the new GRS CORS network spanning across Australia will be used predominantly for the same purpose. This network is nominally spaced at 200km apart; at secure and stable sites where there is supporting infrastructure such as power and communications; along transit or infrastructure corridors, and at significant geoscience locations. Conversely, GNSS CORS which are established mainly for positioning service purposes, are to be managed by States / Territories, commercial entities or other, and will be placed at locations (i.e. on top of buildings) and near markets with the greatest demand. For more information about GNSS CORS specifications in Australia refer to Burns and Sarib (2010) "Standards and Practices for GNSS CORS Infrastructure, Networks, Techniques and Applications".
- **Geodetic data and the cadastre:** In New Zealand the cadastral and geodetic systems are connected. The cadastre in urban areas is survey accurate and tightly connected to the geodetic control network. A programme is underway to increase the spatial accuracy of the cadastre in non-survey accurate areas. In Australia, the relationship between geodetic and cadastral systems is narrowing as there is a strong desire for jurisdictions to spatially upgrade the accuracy of their DCDB's. To achieve this in a cost effective way most States and Territories have turned to coordinating and adjusting their cadastres using either an adhoc approach, incrementally or by programmed campaign and legislation. The method used has largely depended on

[7] 'Tiers' is the term espoused by Rizos (2008) to categorize the hierarchy of GNSS CORS infrastructure or networks.

inter-related factors such as resources, the number of parcels to co-ordinate, and the cost per parcel.

5. JOINT GEODETIC STRATEGY

Australia and New Zealand maintain an Intergovernmental Committee on Surveying and Mapping (ICSM). Its role is to provide leadership, coordination and standards for surveying, mapping/charting and national datasets in Australia and New Zealand. ICSM is made up of senior representatives from New Zealand and Australian (Commonwealth, States & Territories) government surveying and mapping / charting agencies. Within ICSM a sub-committee of technical specialists from each of its jurisdictions, the ICSM Geodesy Technical Sub-committee, coordinates geodetic projects across Australasia and assists ICSM to meet its objectives.

A recent project of the GTSC has been to develop a joint geodetic strategy between Australia and New Zealand. While acknowledging the differences between the geodetic systems in both countries, it also acknowledges there are common interest aims to strengthen the ties between both countries and foster joint working groups on projects of mutual interest. A schematic diagram of the geodetic reference system and its components is shown in Fig 5. *Note - a draft copy of this strategic planning document, which has yet to be endorsed by the ICSM, can be provided upon written request to the authors of this paper.*

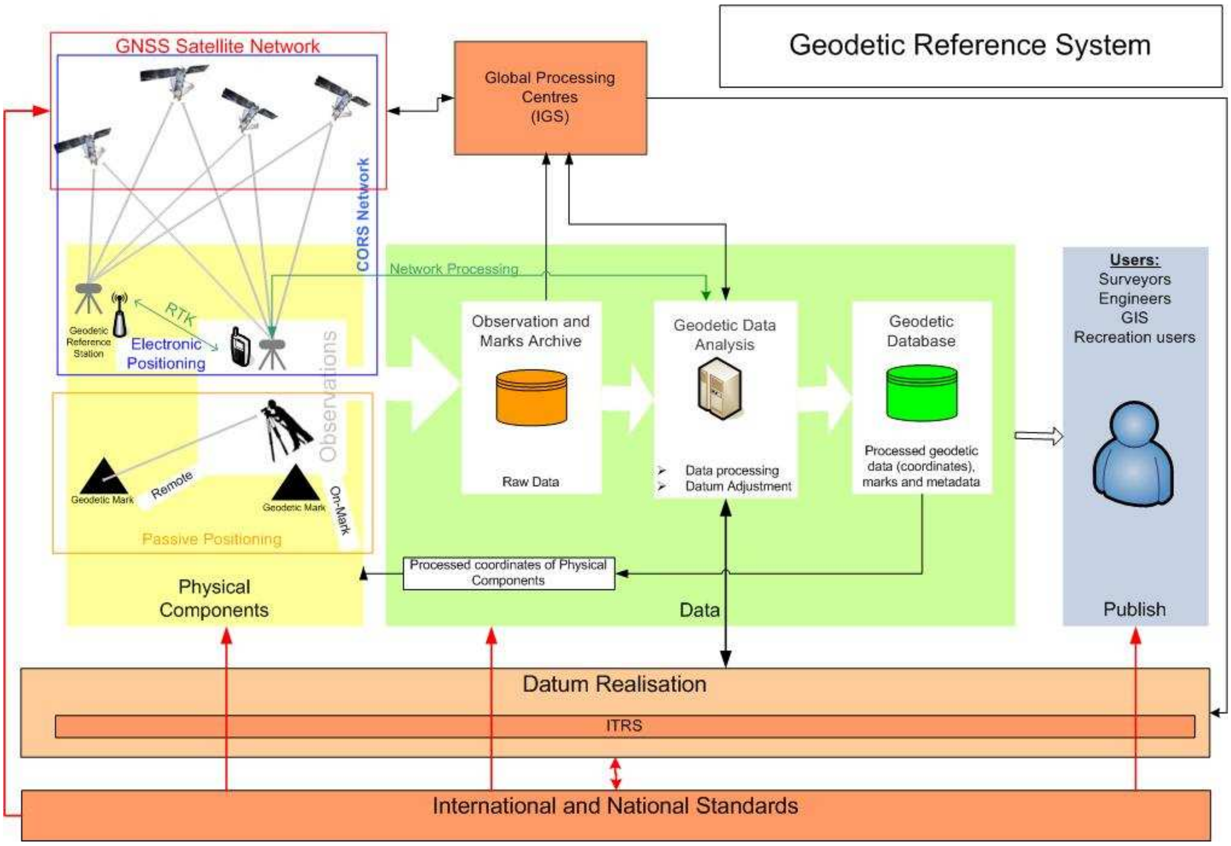

Fig 5 – Geodetic Reference System

5.1 Strategy Vision and Mission

The Vision and Mission of the joint strategy are:

Vision: *An accurate geospatial reference system (GRS) that is accessible, and enables the efficient use of geospatial information to support economic growth, environmental sustainability and social prosperity across Australia and New Zealand.*

Mission: *The provision of an accurate geospatial reference system or GRS that:*

- *is mathematically connected to and contributes to the global reference system such as the International Terrestrial Reference Frame (ITRF) ;*
- *enables spatial consistency between diverse geospatial datasets; and*
- *enables spatial consistency over time for datasets relating to physical environment*

5.2 Proposed 5 Year Work Objectives

The proposed joint strategy identifies the following high level work objectives for the next 5 years:

- Provision of a semi –dynamic National 3 Dimensional datum
- Provision of a Unified Geodetic Data Model and XML schema
- Development of a National Geodetic Data Archive
- Ability to integrate all geodetic data sets within *eGeodesy*
- A Unified CORS network across Australasia
- AuScope is the primary scientific network underpinning geospatial activity
- Implementation of a modern automated web-based GNSS post processing system (AUSPOS, PositioNZ PP)
- Development of a Geodetic GNSS Data Analysis or Central Bureau for the Asia Pacific Region
- Implementation of systems that allow calibration and standardization of GNSS measuring devices
- Development of National Geodetic Adjustment software package(s) (DynaNet, SNAP)
- Development of internationally accepted geodetic standards across Australasia
- Establishment of a modernized Vertical Reference Frame for Australasia
- Development of a strategy to assist with monitoring and measurement of climate change through activities such as for the geodetic component of sea level monitoring
- Monitor the impact of Positioning Technology and Infrastructure

5.3 APREF

During the development of the joint strategy it was realised there were benefits and a tactical need for both countries to operate on a single reference frame for the region. Upon investigation it was found that the objectives and drivers of a regional project known as the Asia Pacific Reference Frame (APREF) were aligned with ours and would thus significantly assist both countries to achieve the joint vision. Subsequently it was agreed that the ICSM – GTSC should take an active role in collaborating and supporting the APREF project.

The following information about APREF has been taken from several presentations by Dr. John Dawson and Dr Hu Guorong (PCGIAP Representatives Regional Geodesy Working Group [8]) at the recent FIG Regional Conference in Hanoi. According to Dawson and Guorong (2009) APREF is a regional project that will address issues associated with the definition, realisation and maintenance of the Asia and the Pacific Reference Frame, focusing on both the horizontal and the vertical components.

The broad objective of the Asia-Pacific Reference Frame (APREF) Project will be to create and maintain an accurate and densely realised geodetic framework, based on continuous observation and analysis of GNSS data that will support many geospatial applications across the region. APREF will be a voluntary, collegial, non-commercial endeavour, and will require wide participation from government agencies, research institutes and the private sector, although there will be no central funding source and each participating organisation will contribute their own resources.

In the short-term, the APREF will:

- Encourage the sharing of GNSS data from Continuously Operated Reference Stations (CORS) in the region; and
- Develop an authoritative source of coordinates and their respective velocities for geodetic stations in the Asia-Pacific region.

In the longer term, the APREF will:

- Develop the APREF Permanent Network, in close cooperation with IGS for the maintenance of the Asia-Pacific Reference Frame, as a contribution to the ITRF and as infrastructure to support other relevant projects;
- Establish a dense velocity field model in Asia and the Pacific for scientific applications and the long-term maintenance of the Asia-Pacific reference frame; and
- Organise regular symposia addressing activities carried out at national and regional level related with the global work and objectives of APREF.

6. SUMMARY

Both Australia and New Zealand provide geodetic infrastructures that support a wide range of uses and users. While there are many similarities between both systems, there are some significant differences in the way that they have been developed and implemented. Despite this, through the ICSM GTSC a joint geodetic strategy has been developed to enable both countries to co-ordinate resources and to maximize the outcomes. A strong focus of the two countries is to work together and foster the development of APREF as this has been identified as an integral component of the Australian and New Zealand vision for geodesy in this region.

[8] Permanent Committee for GIS Infrastructure Asia-Pacific Refer to website http://219.238.166.217/pcgiap/98wg/98wg1.htm

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8. BIOGRAPHICAL NOTES

Graeme Blick, National Geodesist, Manager Geodesy in the Customer Services Group of Land Information New Zealand, member of the New Zealand Institute of Surveyors.

Graeme Blick obtained his Bachelor of Surveying from Otago University in 1980. He worked for the then New Zealand Geological Survey (now GNS Science) in their Earth Deformation Section using geodetic techniques to measure, monitor and study crustal deformation across New Zealand. In 1992-1993 he received a visiting Scientist Award to work at the University NAVSTAR Consortium in Boulder Colorado using GPS to measure plate tectonics in Turkey, the South Pacific, and in USA. In 1995 he moved to Land Information New Zealand where he worked for the Office of Surveyor-General before moving to his current position 3 years ago where he continues to work on the development and implementation of the geodetic system in New Zealand.

Graeme is currently the New Zealand representative for the FIG Commission 5 – Position and Measurement and the New Zealand delegate on the Inter-governmental Committee on Survey and Mapping - Geodesy Technical Sub Committee. He is also the Geodesy examiner for the New Zealand Institute of Surveyors Admissions Panel.

Robert Sarib, Manager, Survey Services in the Land Information Division of the Northern Territory Government's Department Lands and Planning, Licensed Surveyor, member of the newly formed Surveying and Spatial Sciences Institute, and Vice Chair of Administration for FIG Commission 5 – Position and Measurement.

Robert Sarib obtained his degree in Bachelor Applied Science – Survey and Mapping from Curtin University of Technology Western Australia in 1989. He was registered to practice as a Licensed Surveyor in the Northern Territory, Australia in 1991 and achieved this during his employment with the Northern Territory Government. Since then he has work in the private sector as a cadastral surveyor, and was more recently re-employed by the Northern Territory Government to manage the Northern Territory Geospatial Reference System and administer the Survey Services work unit of the Office of the Surveyor General. He also holds a Graduate Certificate in Public Sector Management received from the Flinders University of South Australia.

Mr Sarib is currently a member of the FIG Commission 5.2 Working Group – Reference Frame in Practice, and the Northern Territory delegate on the Inter-governmental Committee on Survey and Mapping - Geodesy Technical Sub Committee. He is the Northern Territory representative on Land Survey Commission of the Surveying and Spatial Sciences Institute. He is also a board member of the Surveyors Board of Northern Territory for Licensed or Registered surveyors.

9. CONTACTS

Mr Graeme BLICK
Land Information New Zealand
PO Box 5501
Wellington 6145
New Zealand
Tel. +64 4 498 3833
Fax. +64 4 498 3837
Email: gblick@linz.govt.nz
Web site: www.linz.govt.nz

Mr Robert SARIB
Department of Lands and Planning
GPO Box 1680
Darwin NT
AUSTRALIA
Tel. +61 8 8995 5360
Fax. +61 8 8995 5365
Email: robert.sarib@nt.gov.au
Web site: www.dpi.nt.gov.au