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Implementation and Development of NZGD2000

INTRODUCTION

A national geodetic system, and its associated national survey control system, are fundamental components of a nation's infrastructure. The unique property of the geodetic system is its ability to integrate multiple geographically-dependant data sources into a single geographic reference frame.

In 1998 Land Information New Zealand implemented a new geocentric datum, the New Zealand Geodetic Datum 2000 (NZGD2000) to replace the existing New Zealand Geodetic Datum 1949 (NZGD49) [Lee 1952]. The reasons for the adoption of a new datum have been well documented [eg Grant and Blick 1998].

New Zealand Geodetic Datum 2000 is a significant step forward in meeting New Zealand's future spatial positioning needs. This paper discusses the current status of implementation and development of NZGD2000 and possible future developments.

NEW ZEALAND GEODETIC DATUM 2000

The primary requirement for the design of a new datum was that it should be compatible with international standards and systems, notably with international positioning systems such as the Global Positioning System (GPS). The new datum is based on the International Terrestrial Reference System (ITRS) and uses the Geodetic Reference System 1980 (GRS80) [Moritz 1980] ellipsoid. The initial realisation uses the International Terrestrial Reference Frame 1996 (ITRF96) at epoch 1 January 2000 (2000.0) which has a geocentric origin (an origin at the centre of mass of the earth).

A major conceptual departure from the definition of NZGD49 and other international datums was that coordinates of points in terms of NZGD2000 would be modelled to account for the effects of crustal deformation. To account for these effects a velocity model is incorporated in the datum and used to propagate coordinates and observations between the reference epoch (2000.0) and the observation epoch. It was further decided that coordinates of geodetic marks in terms of NZGD2000 would not be fixed and that they could be updated as required to account for new observations, earthquakes, or localised mark movement. LINZ has referred to this new datum as a semi-dynamic datum but stopped short of implementing a fully dynamic (four dimensional) datum where coordinates of marks could change continuously to account for the effects of crustal deformation.

The major impact of moving to the new datum is that NZGD2000 coordinates (latitude and longitude) of a point will be different to its NZGD49 coordinates. This difference, approximately 190m north and 10m east, is mainly because NZGD2000 is a geocentric datum whereas NZGD49 is not.

The rational behind the design of the new datum is provided by LINZ [1998a].

REALISATION OF NZGD2000

NZGD2000 is realised through ITRF96 and uses the GRS80 ellipsoid [Grant et al 1999, and Pearse 2000]. Coordinates for 29 primary 1st Order 2000 network stations were generated at an epoch of 1996 using data from 5 repeat GPS surveys made between 1992 and 1998. These stations were all existing NZGD49 stations to enable a

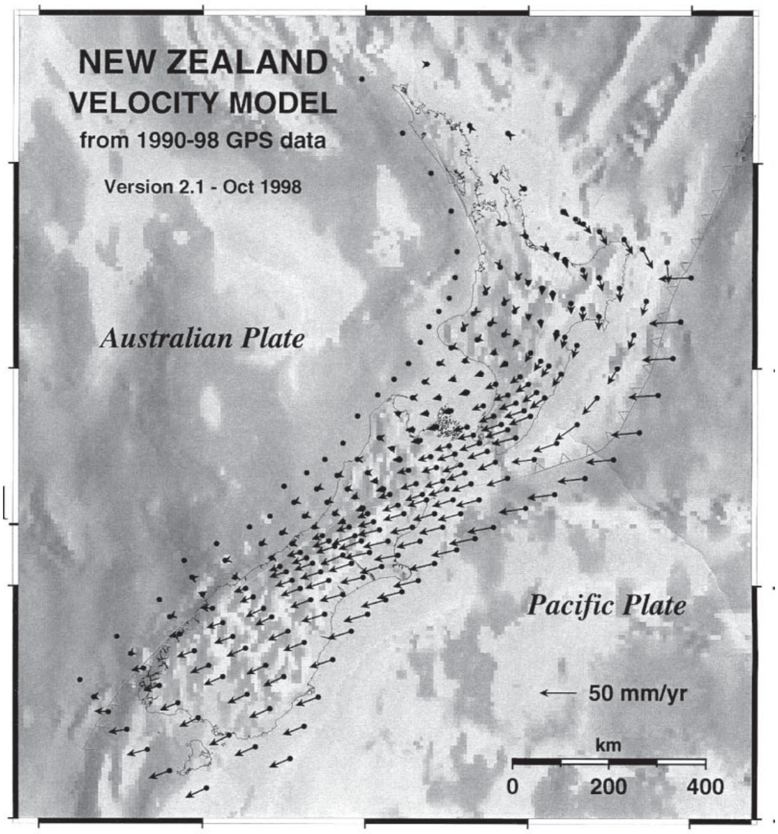

Figure 1. Diagrammatic representation of velocities relative to the Australian plate (developed by the Institute of Geological and Nuclear Sciences)

strong connection to be made between the then existing and proposed new datums.

Data from these repeated 1st order surveys and other repeat surveys were used to generate a velocity model by the Institute of Geological and Nuclear Sciences (GNS) [Beavan and Haines 2001]. The velocity model (Figure 1) is used to account for broad scale crustal deformation across New Zealand, primarily due to the effects of plate tectonics.

The derived velocity model was then used to propagate the observations and generate coordinates at epoch 2000.0 (the reference date for the new datum of 1 January 2000) for the 1996 dataset. The velocity model is incorporated into the datum to generate epoch 2000 coordinates from observations made at other times. A future enhancement to the access of geodetic data, will be to allow specialised users to generate up-to-date coordinates for times other than the reference epoch.

THE IMPACT OF NZGD2000

Cadastral Surveys

Prior to the adoption of NZGD2000, cadastral surveys were generally in terms of 28 meridional circuits. These used transverse Mercator projections based on NZGD49. These are incompatible with NZGD2000 so the implementation of the new datum necessitated the development of a new projection(s) in terms of NZGD2000 for cadastral surveys to replace the existing circuit projections. Various options were considered for replacing the 28 circuit projections, including the use of one national projection for cadastral surveys (LINZ 2000).

After consideration of the options it was decided to replace the existing circuits with 28 new circuits based on NZGD2000 and using transverse Mercator projections. As there is little change in orientation between NZGD49 and NZGD2000, a significant reason for retaining the meridional circuit transverse Mercator projections was that this would avoid introducing a significant difference in projection bearings used in cadastral surveys.

The origins of latitude and longitude of the new projections are almost the same as their

Order	Description	Relative Accuracy	Horizontal Coordinate Accuracy (95%)	Vertical Coordinate Accuracy (95%)
0	International Control Network	0.003m + 0.01ppm	50 mm	150 mm
1	National Control Network	0.003m + 0.1ppm	71 mm	212 mm
2	Regional Control Network	0.003m + 1ppm	87 mm	260 mm
3	Local Control Network	0.01m + 3ppm	100 mm	300 mm
4	Urban Control Network	0.01m + 10ppm	112 mm	336 mm
5	Cadastral control (includes new control, and resurveyed and/or adopted and adjusted existing NZGD49 or Old Cadastral urban and rural control)	0.01m + 30ppm	123 mm	369 mm

Table 1. Orders of geodetic control and accuracy.

NZGD49 equivalents being rounded to the nearest second, and the central meridian scale factors from the old circuits were retained. To easily distinguish between coordinates in the two sets of projections the false origin coordinates of the new projections are 100,000m greater than their NZGD49 equivalents (i.e. 800,000mN and 400,000mE).

The new circuits were introduced in 2000 and are the official projections used for cadastral surveying in terms of NZGD2000.

Mapping

Since 1972 the New Zealand Map Grid (NZMG) was used for national mapping purposes. This is a projection defined in terms of NZGD49 by a unique formula [Reilly 1973] – it is not a conventionally used projection such as transverse Mercator. As with the meridional circuits this projection is not compatible with NZGD2000 because it uses a different reference ellipsoid.

In 2001 after wide consultation LINZ adopted a new national mapping projection, New Zealand Transverse Mercator (NZTM) [Robertson 2000]. The new Transverse Mercator projection has its origin of latitude and longitude at 0° South and 173° East. The false origin coordinates of the new projection are 10 000 000m N and 1 600 000m E.

The new projection is used for LINZ's 1:50,000 and 1:250,000 national mapping, and use of the projection by other spatial data users is encouraged. Both the current Topomap 260 and Topomap 262 series, using NZGD49 and the NZMG, will be retained until such time as the replacement series are fully implemented.

BREAKDOWN TO LOWER ORDERS

The design of NZGD2000 provides for six orders of geodetic control (Table 1).

The principle for defining the accuracy of each order is [LINZ 1998b]: *'the accuracy of a mark's coordinates relative to adjacent marks of the next highest order shall be dependent on the distance between them and shall not exceed 0.05m horizontally and 0.15m vertically.'*

The order of a mark indicates the quality of its coordinates, and the role of the survey mark in the development of the geodetic control and cadastral survey framework. For marks coordinated in both NZGD49 and NZGD2000, the order of the NZGD2000 coordinate generally bears no relationship to the order for the NZGD49 coordinate.

Since April 2000 the geodetic control data, including mark orders, have been maintained in the Land*online* system in conjunction with cadastral data.

Along with the resurvey of the old 1st order NZGD49 network and realisation of NZGD2000, development of the new datum initially focused on the breakdown to the 2nd and 3rd order network across urban and rural areas and higher density 4th order control in urban areas. During this period over 300 2nd order marks, 2000 3rd order marks, and 2500 4th order marks were surveyed in terms of NZGD2000. The majority of these marks were existing NZGD49 or cadastral marks. In areas where no suitable marks were available new marks were installed and surveyed.

Because of the number of existing NZGD49 marks newly resurveyed by GPS, a decision was also made to use this data to compute coordinates in terms of NZGD49 and referred to as the 'd' series of coordinates. The 'd' series were surveyed in terms of a prototype NZGD2000 and transformed to NZGD49 using a prototype NZGD49 – NZGD2000 transformation model. This resulted in marks with two sets of NZGD49 coordinates since the networks contain different stations, observations, and use different processing methodology. Users should take care with NZGD49 coordinates not to mix 'd' and non 'd' coordinates, as they may not be compatible.

FIFTH ORDER NETWORK

In 2000 work commenced on the provision of 5th order (cadastral control) in support of Land*online* and the development of Survey Conversion Areas (SCAs). These are the areas where the DCDB has been enhanced with the capture of survey dimensions to create a Survey-accurate Digital Cadastre (SDC). The aim of this work was to provide reliable NZGD2000 control at an adequate density to support Land*online* projects and cadastral surveyors. The density of NZGD2000 control in SCA areas is:

- Urban areas – 95% of boundary marks shall be no more than 200m from a geodetic control mark;
- Peri-urban areas – 95% of boundary marks shall be no more than 600m from a geodetic control mark;
- Rural areas – 95% of boundary marks shall be no more than 2000m from a geodetic control mark.

This provides control at a spacing of approximately 300m, 800m and 3km respectively, although in many areas the control will be at a greater density.

The 5th order control was established using two very different methods. LINZ contracted out the capture of both existing and new control. Where reliable urban or rural control traverses (or Standard Traverses) existed, sufficient observations and marks were captured from those plans to meet the above density requirements. These traverses were connected to the NZGD2000 network and readjusted in terms of the new datum. Where there were gaps in the coverage or where existing data was insufficient to meet accuracy requirements, existing cadastral marks were re-surveyed in terms of the geodetic network or new marks were installed and surveyed.

During this phase of the programme over 60 000 5th order marks have been added to the geodetic database. The majority, over 50 000 marks, are readjusted former control traverse marks, however some 10 000 cadastral or new marks have been surveyed in terms of NZGD2000 and added to the database.

An issue to be aware of when using the 5th order control captured from old traverse work is that there is no guarantee that the control is present in the ground or that it is stable. This is because some of the data captured is old and it has not been possible to verify the existence or stability of all of these marks. The easiest way to identify these marks in the geodetic database is that they will not have an ellipsoidal height, unlike newly survey 5th order control that will have an ellipsoidal height associated with them. When using these marks they should be proved reliable as with the use of any cadastral mark.

The major thrust of this work to support Land*online* development was completed in 2002. In future years LINZ will continue to provide additional 5th order control at the above densities to extend the SCA's areas and support future development.

UPGRADING OF EXISTING NZGD49 CONTROL

Since 2002 the control programme has focused on upgrading existing NZGD49 trig stations to NZGD2000 status, particularly where they are beaconed and are currently being used for bearing origins in cadastral surveys. The first process has been to select those important marks that should be upgraded. The method of upgrade has been to use existing survey data where it is available and readjust in terms of NZGD2000, or where this data is not available or of insufficient quality, to resurvey the marks concerned.

During 2002/03 this phase of work focused on the South Island with over 1000 marks being upgraded and during 2003/04 work will commence in the North Island. This project will continue as further NZGD49 control is identified as needing upgrade. LINZ will continue to seek user feedback on control that needs upgrading.

DEVELOPMENT OF AN ACTIVE CONTROL NETWORK

In 2001 LINZ commenced development of an active control network (PositioNZ) in partnership with the Institute of Geological and Nuclear Sciences (GNS). PositioNZ stations are the highest accuracy points in the New Zealand Geodetic Datum 2000. A continuous tracking GPS receiver located at each station receives data from the constellation of GPS satellites.

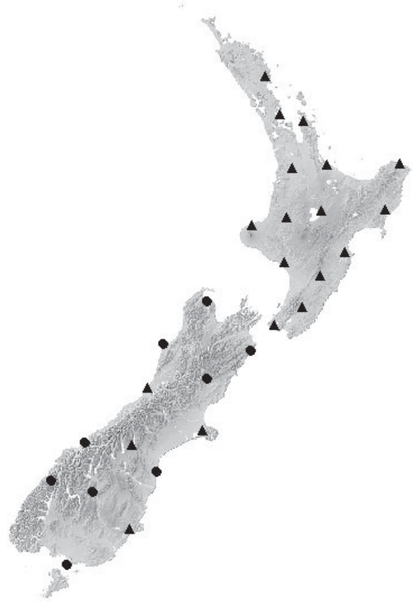

Figure 2. Active control network (Chatham Island excluded). Triangles represent operating stations as at July 2003 and circles planned stations.

The completed network will consist of approximately 30 continuously tracking GPS stations across New Zealand and the Chatham Islands. By July 2003 15 stations will be operational in the North Island, 4 in the South Island and a station on the Chatham Islands (Figure 2). The Active Control Network is expected to be fully operational by 2005/06.

The primary objectives of this network are to:

- facilitate improved efficiency in the survey and maintenance of geodetic control;
- ensure NZGD2000 is rigorously linked to the global geodetic system;
- enable cadastral and other surveys to be more easily tied to geodetic control;
- monitor the dynamics of NZGD2000 and contribute to the refinement of a national velocity model;
- coordinate the investment by several government and private sector agencies in GPS networks; and
- locally monitor the integrity of the GPS system.

Currently thirty second RINEX data for the operational sites is freely available from the LINZ web site at www.linz.govt.nz/positionz. This data can be used with data collected from roving GPS receivers for post-processing of the data to derive positions in terms of NZGD2000.

Further enhancements being considered for this project include the ability to submit GPS data through the Internet for automated post-processing of the data and the ability to use one-second data for real time positioning applications.

VERTICAL DATUM

Unlike NZGD49, which is a two dimensional (horizontal) datum, NZGD2000 is a three dimensional (horizontal and vertical) datum. In terms of the NZGD49 datum, heights of marks were determined in terms of a separate vertical datum based on a number of tide gauges at Standard Ports around New Zealand. All newly surveyed NZGD2000 geodetic marks have ellipsoidal heights generated in terms of the GRS80 ellipsoid.

LINZ is currently implementing a project to better define a national vertical datum in New Zealand [cf *Amos and Featherstone 2003*]. This project aims to define an accurate New Zealand geoid model to enable orthometric heights to be generated from NZGD2000 ellipsoidal heights. A secondary aim is to determine the relationship between the 13 separate existing vertical datums. Amos provides details of the development of a national vertical datum in this issue of New Zealand Surveyor.

MANAGEMENT OF THE VELOCITY MODEL

As detailed above, NZGD2000 has been defined in a form known as "semi-dynamic", in order to account for the significant ongoing earth deformation in New Zealand. This means that published coordinates are defined in terms of their values at reference epoch 2000.0, but deformation is provided for in that 1) no coordinates are treated as permanently fixed, and 2) a velocity model is used to propagate coordinates and observations between the reference epoch and the observation epoch. The initial velocity model used was generated from GPS surveys between 1990 and 1997 and assumes a constant velocity through time. As we move further away from the reference epoch, errors in the velocity model or the effects on spatially localised and temporally non-linear deformation, e.g. earthquakes, will downgrade the accuracy of the datum. The following issues now need to be considered:

- How much error can be accommodated in the current velocity model before a new model is required.
- When there is local and spatially complex deformation, how much should be accommodated by the velocity model, and how much should be accommodated by changing the reference epoch coordinates.
- What temporal model should be used to accommodate non-linear changes in deformation.
- How should vertical deformation be modelled, given that the determination of it is more difficult than for horizontal deformation.

Not to consider and account for these issues will lead to a gradual degradation in NZGD2000. Ways of accommodating these effects will need to be considered given that now the cadastre SCA areas are directly connected to NZGD2000, and any changes made to coordinates in the geodetic system will have a flow-on effect to the cadastre.

At some point LINZ may need to consider changing the reference date of NZGD2000 in order that the official coordinates of survey marks are not inconveniently different from their current actual positions. Another option is to move to a four dimensional, or fully dynamic, datum. Under such a system geodetic coordinates would change continuously to account for the effects of crustal deformation. This was initially considered during development of NZGD2000 however it was discounted because the continual change of coordinates was felt to be too disruptive.

DISCUSSION

New Zealand Geodetic Datum 2000 is a significant step forward in meeting New Zealand's future spatial positioning needs. The alignment with the ITRS ensures compliance with international standards and consistency with satellite positioning methods.

In making decisions on a new datum, the need to develop a system that was robust and would stand the test of time was of prime importance. The adoption of any new datum and the associated changes to map projections is disruptive. However, to have adopted a new fixed datum would inevitably lead to the requirement for a new datum in the not too distance future as New Zealand is effected by crustal deformation causing coordinates in the physical world to drift away from their representation in databases. The adoption of a semi-dynamic datum model including a national velocity model provides for a level of future proofing of the national datum, at least in the short term, while minimising the adverse impact on users.

As users increasingly move to digital technology for management of spatial data, the transition to a fully dynamic datum may become possible and more practicable. If international systems such as the ITRS are able in the future to incorporate deformation models at a level more detailed than current plate models, it may be that the concept of national geodetic datums will become redundant. At that stage, the accessibility of international systems and their accuracy and stability at a detailed level, may be such that they can fully meet all national spatial referencing requirements.

NZGD2000 will continue to be maintained and undergo development and enhancements to ensure that spatial user requirements in New Zealand continue to be met in the future. As part of this LINZ will continue to seek user input to ensure that user requirements are met.

ACKNOWLEDGMENTS

The development of NZGD2000 over the past 6 years has been due to the efforts of many people. The author would like to thank the staff of LINZ and the former Department of Survey and Land Information as well as geodetic survey contractors who have supported and worked on this project. All have helped contribute to the development of a world class geodetic system in New Zealand.

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