PROGRESS TOWARDS A NEW GEODETIC DATUM FOR NEW ZEALAND

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ABSTRACT

The geodetic datum of New Zealand was developed in 1949 (NZGD 49). This has served the cadastral system of New Zealand well but it cannot now meet the rigorous requirements demanded by users of new technologies such as GPS, the requirements for unified GIS systems over large areas, and higher accuracy requirements which will require the need to account for earth movements. Distortions in the current datum of over 5m have been recognised. In 1995 a programme was commenced by the Department of Survey and Land Information to re-observe the 1st Order triangulation network (293 stations) which define NZGD 49. In addition, a new network was established and surveyed to form the basis of a new datum, tentatively referred to as New Zealand Geodetic Datum 2000 (NZGD 2000). These stations replace old 1st Order stations and are located for ease of access. The new network consists of a hierarchy of stations, as at the time of writing consisting of 4 continuous tracking stations, 26 1st ‘Order 2000’ and 220 2nd ‘Order 2000’ stations. Observation of the 2nd ‘Order 2000’ network, using GPS, was completed in March 1996 and processing of this data is progressing. Coordinates of the new stations will be derived in terms of NZGD49 and the International Terrestrial Reference System (ITRS). A precision of better than 1 ppm has been obtained for the 2nd ‘Order 2000’ GPS observations, but once constrained by the NZGD49 1st Order stations the coordinate accuracy in some cases exceeds 25ppm. Investigations are underway to decide on the form of the new datum for New Zealand which is expected to be implemented before the turn of the century. One option being considered is a ‘Dynamic Datum’ which would maintain a relationship to the ITRS and accommodate crustal deformation within New Zealand. Regular surveys of the ‘Datum 2000’ network will enable a velocity model to be derived which will track ground movements and update the new datum.

INTRODUCTION

The New Zealand geodetic control network is the culmination of developments over the past century (*Lee* 1978). Geodetic triangulation was commenced in 1909 and completed in 1949, forming the 1st Order triangulation of New Zealand. The coordinates of the 1st Order trig stations were held fixed and used to define the New Zealand Geodetic Datum 1949 (NZGD49). This horizontal datum (a vertical datum was not included) is based on the International Spheroid and is a best fit between the local geoid and the International Spheroid. Subsequently, lower order 2nd and 3rd order networks have been surveyed in many parts of the country to densify the network. Bevin and Hall [1995] provide a review of the current datum and distortions within it.

The current geodetic control network has served the cadastral system of New Zealand well but it cannot now meet the requirements of new survey technologies such as GPS or unified high accuracy GIS applications over large areas and higher accuracy requirements which will require the need to account for earth movements. This, and the movement towards a proposed accurate integrated digital survey system, means there is a requirement for a new homogeneous geodetic control network across New Zealand.

In 1995 a programme commenced by the Department of Survey and Land Information (DOSLI)[1] to re-observe the 1st order triangulation network (293 stations) which define NZGD49. In addition, a new network was established and surveyed to form the basis for a new datum, tentatively referred to as New Zealand Geodetic Datum 2000 (NZGD 2000), and geodetic control framework.

This paper presents the authors views on options for a new datum and geodetic control network, and reviews current progress towards a new network and datum.

LIMITATIONS OF NZGD49

NZGS49 suffers from a number of problems and limitations.

- **A vertical datum is not included**. NZGD49 only defines a horizontal datum and is separate from the numerous vertical datums through the country[2].

- **The density of stations is technology dependent.** The density of stations defining NZGD49 (Fig. 1) are dependent on the technology that was used to define them. For example, where baselines were established stations are close together (< 5km) and in areas of difficult topography, such as Fiordland and along the Southern Alps, stations are completely absent. Because of the survey technology used (triangulation), the location of stations are also topography dependent; intervisibility is required between stations.

- **For modern use it is of low accuracy**. When NZGD49 was established it was of high quality and accuracy for the standards of the day. However, this accuracy is now

[1] On 1 July 1996 DOSLI split into two new organisations; Land Information New Zealand (LINZ), a Government Department, and Terralink NZ Ltd., a State Owned Enterprise.

[2] With the adoption of new technologies such as GPS there is a requirement for a unified three dimensional datum.

insufficient to meet modern requirements and new technologies. Cumulative errors in the datum across the country of up to 5m have been recorded (*Bevin and Hall* 1995). These errors are due to survey error (mainly scale errors in baseline measurements), the restrictions due to network design, and the effects of ground deformation.

- **It is not flexible**. Perhaps the greatest limitation with the current datum is its lack of flexibility. The datum has been defined by fixing the coordinates of the 1st order stations and lower order stations do not contribute to the definition of the datum nor do new high precision surveys. In practice, newer higher precision surveys are distorted and errors introduced to make the data fit the existing datum. As described above, the density and location of stations has been technology and topography dependent and accordingly they have not been placed to meet user needs in many instances.

- **Ground deformation is degrading the accuracy of the datum.** New Zealand, lying across the Australian/Pacific plate boundary, is subject to ground movements across the country of c. 5cm/year, disregarding the effects of large earthquakes (*Walcott* 1984). This amounts to c. 2.5m in the last 50 years since NZGD49 was established. In this time there has also been the effect of large earthquakes, such as the 1987 Edgecumbe Earthquake, where approximately 2m of vertical and horizontal movement occurred at the time of the earthquake (*Beanland et al* 1989). Added to this are the more localized effects of landslides, ground creep, and subsidence due to geothermal extraction. These movements have lead to distortions in and a deterioration in the accuracy of the current datum which continue to increase with time.

REQUIREMENTS OF A NEW DATUM

When considering the requirements of a new datum 4 issues were addressed.

- **It must satisfy user requirements.** The new datum and geodetic control network must meet the requirements of the users of the system and the proposed new 1996 survey regulations. In particular there is a requirement from the cadastral and LIS/GIS systems for a national spatial infrastructure to provide a consistent coordinate accuracy over large areas. Other requirements include the need for national mapping and science applications.

- **It must be of a suitable accuracy.** With modern survey technology it is possible to have a very accurate datum but this would come at great cost. The datum must be of a suitable accuracy to meet user requirements. For most cadastral applications the accuracy should be sufficient to locate a parcel boundary within the area of the boundary peg (+/- several centimetres). When considering accuracy requirements the definition of the datum should be such that it is technology independent. This will allow for increases in accuracy as requirements change. In a country such as New Zealand the need to account for ground deformation needs to be considered; a fixed datum will degrade with time.

- **The density and location of stations must suit user needs.** In the past control stations have been located for ease of surveying. With new technology it is possible to locate stations with regard to user needs, ie with ease of accessibility and with a greater density of stations in areas of land settlement or new development.

- **It should be flexible**. New surveys and resurveys should contribute to the datum not be distorted to fit it. The datum should allow for additional stations to be added and the accuracy upgraded as used requirements change. It should also accommodate the effects of ground deformation.

OPTIONS FOR A NEW DATUM

Two options for a new datum exist, a 'fixed' or a 'dynamic' datum [*Grant* 1995]. The current NZGD49 is a fixed datum, however through the course of time it has degraded and now fails to meet many user requirements. A new fixed datum will also degrade through time due to the effects of ground deformation and changing user requirements. With a dynamic datum the coordinates of geodetic stations can be allowed to change to reflect ground movements (the coordinates will track the ground movements). This will enable the datum to be kept up to date as the ground deforms and user requirements change.

LINZ is currently addressing the issue of whether the new datum will be 'fixed' or 'dynamic'. It is clear that the coordinates of the control stations that will be initially used to define the new datum will be fixed at some epoch, say 1 January 2000.

Given that data for the new datum has been collected over a number of years prior to this date, and that ground deformation is occurring, the effects of ground deformation will be factored into and modeled to derive the new coordinates at the given datum epoch date. In order to model the effects of ground deformation a joint project has been established with the Institute of Geological and Nuclear Sciences (IGNS) to develop a velocity model of New Zealand using the data from repeated surveys and geological information. An initial velocity model is expected to be available by 30 June 1997. This will enable the velocity of control stations to be determined thus enabling the coordinates of control stations to be projected forward to the new datum epoch date; ie the year 2000. Periodic reobservation of parts of the control network will enable the velocity model to be checked and refined through time.

Using the velocity model and the coordinates of control points defined at the datum epoch, forward or backward estimation of the coordinates at any control station at another date will be possible. At any given date the accuracy of the coordinates thus derived will be a function of the time interval from the reference epoch, the accuracy of the velocity model, and the extent to which deformation may have deviated from that model, ie whether any large earthquakes have occurred in the intervening period.

The implementation of a truly 'dynamic' datum [*Grant* 1995] where the coordinates of the datum will continually change is being considered. However its implementation will be some time away.

PROPOSED NEW NETWORK CONFIGURATION

There is merit in continuing with a hierarchy of orders of stations in the new geodetic network. This can be justified on economic grounds as high accuracy long range observations cost more to observe and process than lower order accurate short range observations. The new geodetic control network may allow for five orders of survey station, Zero, 1st, 2nd, 3rd, and 4th order stations. To distinguish from earlier orders of stations are referred to as ‘Order 2000’ stations.

- **Zero Order 2000 (Fiducial Network).** A national and worldwide fiducial network of continuous tracking stations used to define stations in a nation wide and global framework. Inter-station spacing in the global network are 1000 - 5000 km and in the nation wide network 200 - 1000 km. These stations will be located on secure stable rock sites and will be used to monitor deformation of, and control, the survey datum on a national scale. Station positions will be calculated and updated on a regular basis and data will be made available to the international community for use in determining GPS satellite orbits. The primary function of these stations will be to connect the New Zealand survey system to global geodetic networks which will increasingly be used by modern survey technology.

- **1st Order 2000 (National Network)**. A national network of stations used to monitor dynamics of the datum. Station spacing is typically up to 200 km. Stations will be surveyed on a regular basis to monitor distortions of the datum. Some stations may be continuous tracking stations, referred to as Active Control Stations. These will be used as base stations for surveying applications as well as monitoring the survey infra-structure. 1st Order 2000 continuous tracking stations will physically differ from Zero Order 2000 stations in that they may be located on buildings (e.g. a stainless steel pin grouted into the building structure) whereas the Zero Order 2000 stations must be located on solid rock.

- **2nd Order 2000 (Regional Network).** Primary regional survey network of stations across New Zealand with station spacing up to 70 km. In wilderness, national park, and back country areas this network will form the basis for cadastral surveys. Where distortions are found in the 1st Order 2000 network from repeated surveys, the 2nd Order 2000 network in the affected area may need to be re-surveyed.

- **3rd Order 2000 (Local Network).** Lower precision regional survey network with station spacing up to 20 km. These stations are required about urban areas to link the breakdown from the 2nd Order 2000 to the 4th Order 2000 cadastral control network. They may also form the basis for cadastral survey in rural areas.

- **4th Order 2000 (Cadastral Control Network).** The 4th Order 2000 network forms the densification of the 3rd Order 2000 (Local Network) which will provide control for cadastral surveys in urban and some rural areas. In urban and intensively developed rural areas the future station spacing may be 1.5-2 km and in rural areas up to 7 km. For the next 10 years the density of stations in urban areas may need to be increased to approximately 700m spacing to satisfy the requirements of surveys which continue to be carried out with theodolite and EDM instrumentation.

WORK IN PROGRESS

Zero Order 2000 Network

Dual frequency permanent tracking GPS receivers are operating at four sites. Two of these, Whangaparoa near Auckland and Chathams on the Chathams Islands, are Zero Order 2000 stations operated jointly by LINZ, IGNS, and the Jet Propulsion Laboratory. The other two sites in Wellington and Dunedin, are located on buildings and are therefore only given 1st Order 2000 status. The Wellington station is operated jointly by LINZ and Australian Survey and Land Information Group (AUSLIG) and is due to be moved to a rock site shortly when it will be upgraded to Zero Order 2000 status. The Dunedin site is operated by Otago University.

1st Order 2000 Network

Twenty six stations comprise the 1st Order 2000 network. These are located for ease of access and where possible they are existing NZGD49 1st Order trig stations upgraded to new 1st Order 2000 station status. Complete surveys (three 24 hour occupations using dual frequency GPS receivers) have been made of this network in 1995 and 1996 and partial surveys in 1993 and 1994. Another survey of this network is planned for early 1997. Data from the 1993 survey has been processed using Gamit [*Pearse and Morgan* 1995]. The repeated occupations will be utilised in determining the New Zealand velocity model.

2nd Order 2000 Network

Two hundred and fifteen stations comprise the current 2nd Order 2000 network. These stations were located for drive on access and all except fifty were existing survey marks; many of the existing marks are bench marks. The new stations straddle the whole of New Zealand whereas the old NZGD49 1st order network was absent in some areas of New Zealand, notably in the South Island along the Southern Alps and in Fiordland. It is expected that some additional 2nd Order 2000 stations will be required. To enable a detailed transformation model to be determined between the existing NZGD49 datum and the proposed new datum, all 293 existing NZGD49 1st order trigs and some 2nd order trigs, notable on the West Coast of the South Island, were surveyed and tied into the new 2nd Order 2000 network. Field work for this commenced in January 1995 and was completed in March 1996.

Processing of the GPS data is underway using the Trimble GPSurvey software package. Coordinates of the new stations will be derived in terms of NZGD49 and the International Terrestrial Reference System (ITRS). Processing of the GPS data for the North Island has been completed and, based on a least squares free network adjustment, shows the precision of the data to be better than a ppm. Comparison of the new data with the existing 1st Order data shows distortions in the NZGD49 1st Order network averaging in excess of 15ppm across the North Island and in some areas it is greater than 25 ppm. Once the 1st Order 2000 data has been processed the 2nd Order 2000 results will be constrained by the 1st Order 2000 stations.

3rd and 4th Order 2000 Network

Little progress has been made towards the establishment of the 3rd and 4th Order 2000 networks other than for a test area around Rotorua and some stations in Dunedin.

FUTURE WORK

Extension of the Order 2000 network

It is expected that the Zero Order 2000 network will be extended as resources permit. Further surveys at 2 yearly intervals of the 1st Order 2000 network are planned to enable the velocity model to be refined and updated. Some infilling of the 2nd Order 2000 network is required and when processing of the data is completed, it is expected that some repeat observations will be required. Should a large earthquake occur, it is envisaged that the 1st and 2nd Order 2000 network in the affected area will be reobserved.

Greatest expansion of the new network over the next few years is expected to come from extension of the 3rd and 4th Order 2000 network. Specifications for the density of these networks, and methodology to tie this network to the cadastre are being established. In the future it is planned that these lower order networks will also contribute to the datum.

New datum.

It is planned to implement a new datum by mid 1998, to be known as Datum 2000. Initially this will consist of adjusting all Zero, 1st, and 2nd Order 2000 stations in terms of a global reference frame such as ITRF. By utilising the velocity model, coordinates of these stations can be projected forward to the year 2000.

Future development of the datum may see the velocity model being used to continually update the datum on a regular basis, and the move toward a 'dynamic' datum in which the coordinates will be continually change. As new control data becomes available this will be used to updated the datum and refine the velocity model on a continuous basis.

CONCLUSIONS

LINZ is progressing towards the implementation of a new datum before the year 2000. This datum will provide an accurate spatial survey infrastructure across New Zealand that will meet user needs, be of a suitable accuracy, and will be flexible.

Processing of the 1st and 2nd Order 2000 data is almost complete and standards and specifications are being established for the next stage of the project, the densification and establishment of the 3rd and 4th Order 2000 networks.

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Figure 1. New Zealand Datum Investigation Control Stations 1994-1996