

# Should Active Control Networks Replace Passive Control Networks?

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## SUMMARY

A geodetic infrastructure has traditionally consisted of physical (passive) geodetic marks in the ground and associated data, including coordinates and datum. Over the past two decades, there has been a move away from providing passive geodetic marks to providing active control networks via Continuously Operating GNSS Reference Station (CORS) networks. Many countries are discouraging the ongoing maintenance and development of passive control networks in favor of developing CORS. In actively deforming countries such as New Zealand there is a strong driver to maintain a passive control network to supplement a national CORS network such as PositionNZ. This paper considers whether active control networks (CORS) can completely replace passive control networks (traditional marks in the ground). The paper considers use of active and passive networks following several recent large earthquakes in New Zealand.

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## 1. INTRODUCTION

The backbone of any modern geodetic reference frame defined by a national geodetic agency is a network of Continuously Operating Reference Stations (CORS). These stations are permanently occupied by Global Navigation Satellite System (GNSS) equipment and the data is processed so that the national geodetic agency can monitor the datum for deformation. Coordinates can be calculated at almost any desired frequency and regular coordinate updates may be published to reflect changes due to deformation.

Users of the geodetic system are usually able to access the data to generate centimetre-level positions wherever and whenever they are needed. This may be via post-processing, or in real-time where there is appropriate communications equipment at the CORS. This is referred to as active control, since the GNSS equipment is continuously collecting observations at the mark and making it available to users.

Prior to the widespread installation of CORS in the late 1990s, a nation's geodetic reference frame was based on hierarchical networks of marks in the ground. These marks are occupied on a temporary basis, either with GNSS or theodolite/EDM equipment. Measurements are made over timespans ranging from minutes to days and used to calculate a coordinate at the time of occupation.

Users normally access the geodetic system through this network of marks by setting up their equipment on or over the mark and making measurements to marks they have installed, on which they wish to calculate coordinates. This is referred to as passive control, since most of the time no observations are being collected at the mark.

Like many other countries, New Zealand's official datum, New Zealand Geodetic Datum 2000 (NZGD2000) (Blick et al. 2003) contains both active and passive control. When the datum was realized in the late 1990s, CORS networks were still in their infancy. While there were several CORS in New Zealand at the time, the inter-station spacing was of the order of 1000km, so densification with passive control was essential.

Each year Land Information New Zealand (LINZ), the government agency responsible for managing New Zealand's geodetic system, continues to expend significant resources surveying and re-surveying passive control marks, despite the presence today of a reasonably dense CORS network.

This paper explains the roles that active and passive control play in New Zealand's geodetic system, focusing on why LINZ continues to see passive control as vital to meeting its obligations to users of the geodetic system. A detailed case study using the 2010 and 2011

Canterbury earthquakes is presented, highlighting the role of passive control. Finally some considerations for the future are discussed, to help answer the question: Should active control networks replace passive control networks?

## **2. ACTIVE CONTROL IN NEW ZEALAND**

New Zealand's official datum, NZGD2000, was developed in the late 1990s, just prior to the widespread uptake of CORS technology. Nevertheless, the country has a dense network of publically-owned CORS with freely accessible data (both in real-time and as RINEX files). There are also numerous privately-run CORS, some of which provide data for a fee.

### **2.1 Advantages of Active Control**

CORS as active control have a number of advantages over traditional passive control, which has seen them widely adopted as countries modernise their geodetic infrastructure. Some of the advantages that have been realised in New Zealand are:

- Continuous monitoring of deformation (important in a tectonically active region such as New Zealand)
- Ability to separate modes of deformation, such as distinguishing long-term deformation from seasonal effects
- Ability to calculate updated coordinates almost immediately in the event of an earthquake or other deformation event
- Contribution in near real-time to hazard monitoring, such as in New Zealand's tectonic shear belt and Taupo Volcanic Zone
- Contribution to international reference frame realisation, which increases the accuracy of positioning in New Zealand
- Unlikely to be accidentally destroyed
- GNSS users need only one receiver to obtain a centimetre-accurate position, anywhere in the country (although long occupations and the deformation model will be required in many places)
- Relatively easy to connect to for non-surveyors (particularly for real-time positioning), as there is no need to locate the mark and prove it reliable

### **2.2 Active Marks in Survey Control Networks**

Different survey control networks have been defined in New Zealand to cover the range of uses of the geodetic system. There are eight networks, three of which are comprised substantially of active control. Any mark purporting to be a survey control mark must be contained in at least one of these networks. A fuller description of these networks, including details of their implementation is contained in Donnelly and Amos (2010) and the relevant geodetic standards (LINZ 2009a, 2009b, 2009c).

Network	Purpose	Local Accuracy (m + m/m)	Use of Active Control	Reason for Active Control
National Reference Frame (NRF)	Connect official three-dimensional and vertical datums to international reference frames	Hz: $0.003 + 3 \times 10^{-8}$ Vt: $0.003 + 3 \times 10^{-8}$	Mandatory for three-dimensional marks	Provides continuous, long-term data required for incorporation into realisations of international reference frames
National Deformation Monitoring Network (NDMN)	Enable deep-seated, ongoing tectonic deformation at a national level to be measured and incorporated into deformation models <sup>1</sup>	Hz: $0.003 + 1 \times 10^{-7}$ Vt: $0.003 + 3 \times 10^{-7}$	Mandatory	Continuously monitors deformation, so that seasonal movements can be separated from long-term deformation
Regional Deformation Monitoring Network (RDMN)	Provide a denser picture of deformation across the country, including monitoring of large discrete events such as earthquakes	Hz: $0.003 + 1 \times 10^{-6}$ Vt: $0.010 + 3 \times 10^{-6}$	Preferred. Will eventually be mostly active control through the shear belt of New Zealand <sup>2</sup>	Accurate deformation modelling. Almost immediate indication of coseismic displacements. Also provides quick access to the geodetic system after an earthquake

Table 1: Survey Control Networks utilising active control marks

## 2.3 CORS Networks

There are two active control CORS networks from which data is freely available to the spatial community; PositionNZ and GeoNet. There are also a number of smaller networks, set up for private use mostly by commercial companies.

### 2.3.1 PositionNZ

<sup>1</sup> A deformation models is part of the definition of NZGD2000, and is used to generate coordinates at a reference epoch from observations made at different times

<sup>2</sup> As the GNS Science GeoNet CORS network is extended through New Zealand's South Island

Operated by GNS Science on behalf of LINZ, this network contains 35 stations on the North and South Islands, 2 on the Chatham Islands and 3 in Antarctica. It forms the basis of the geodetic datum with station spacing in New Zealand of about 100km and enables deformation modelling at the national level. The network is considered complete in terms of the number of stations. Data is freely available both in real-time and for post-processing.

### 2.3.2 GeoNet

Run by GNS Science, as at March 2012 GeoNet contains 122 stations, mostly in the central and eastern parts of the North Island with a station spacing of about 40km. The network is currently expanding into the South Island. Its main purpose is to support earthquake hazard monitoring, but it is also used to densify New Zealand's deformation model. Data is freely available for post-processing.

GNS Science also makes data available from 14 other CORS, often operated in conjunction with the University of Otago in support of specific applications, such as tide gauge monitoring.

### 2.3.3 Private Use

There are a number of privately-owned CORS, mainly near urban areas. Many of these are operated by commercial companies who sell the data.

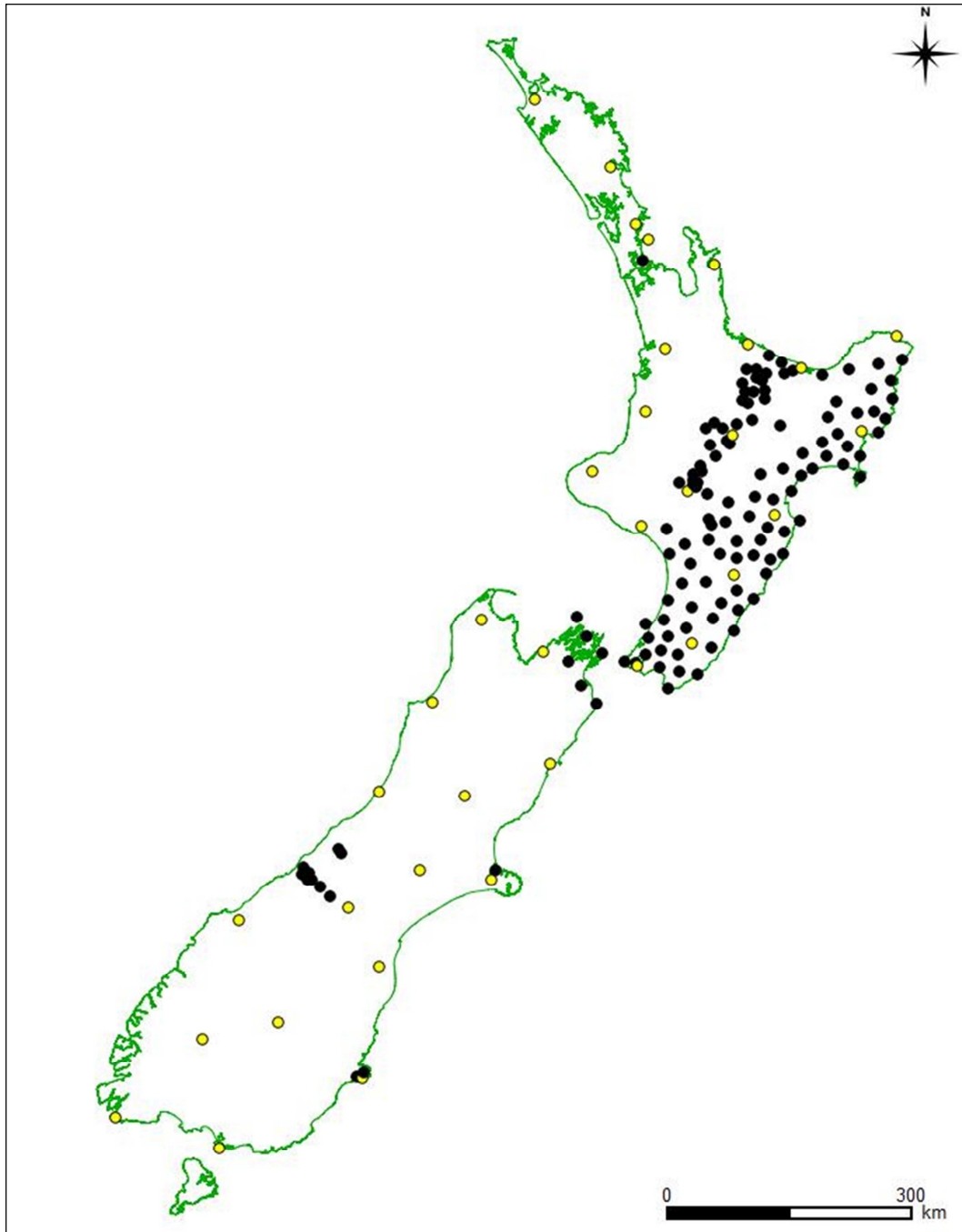


Figure 1: PositionNZ (yellow) and GeoNet (black) CORS in New Zealand

### 3. PASSIVE CONTROL IN NEW ZEALAND

Passive control comprises over 99% of the marks in New Zealand's geodetic survey control system, and numbers are increasing by approximately 2000 marks per year.

### 3.1 Advantages of Passive Control

Some advantages of passive control marks for New Zealand are:

- Numerous marks already exist, some with a long history of geodetic data collection
- Often directly connected to important national datasets, such as the cadastre
- Cheap to install
- Few or no ongoing costs
- Can have structures placed over them for imagery and other control purposes
- Suitable for occupation by non-GNSS techniques

### 3.2 Passive Marks in Survey Control Networks

Five of the eight survey control networks are comprised primarily of passive marks.

Network	Purpose	Local Accuracy (m + m/m)	Use of Passive Control	Reason for Passive Control
Local Deformation Monitoring Network (LDMN)	Monitor deformation in urban areas, where positioning accuracy demands are greatest and where significant deformation is expected	Hz: $0.010 + 1 \times 10^{-5}$  Vt: $0.010 + 5 \times 10^{-5}$	Some CORS, but mostly passive control to obtain the required density	Active control would be ideal, but cost is the driving factor
Cadastral Horizontal Network (CHN)	Ensures that cadastral surveys are connected to the official geodetic datum, which supports centimetre-level cadastral mapping	Hz: $0.010 + 5 \times 10^{-5}$  Vt: NA	Completely passive	Connections to the cadastre
Cadastral Vertical Network (CVN)	Ensures that cadastral surveys with a vertical component are connected to the official vertical datum	Hz: NA  Vt: $0.020 + 1 \times 10^{-4}$	Completely passive	Connections to the cadastre

Basic Geospatial Network (BGN)	Provides positioning infrastructure in regions not served by other networks and for remote sensing applications (primarily satellite and aerial imagery)	Hz: $0.010 + 5 \times 10^{-5}$ Vt: $0.020 + 1 \times 10^{-4}$	Completely passive	Large structures, visible from above, can be placed over the marks to provide control for imagery
National Height Network (NHN)	Provides precise normal-orthometric heights	Hz: NA Vt: $0.010 + 3 \times 10^{-6}$	Completely passive	GNSS cannot provide the normal orthometric heights with the required accuracy

Table 2: Survey Control Networks utilising passive control marks

### 3.3 Terrestrial Geodetic Networks

Terrestrial Geodetic Networks (TGNs) are not formally part of the geodetic survey control system, but are a common means for surveyors to connect to the datum. A TGN is a network comprised of observations made by precise control traversing. They are connected to NZGD2000 through the Cadastral Horizontal Network, giving them accurate coordinates in terms of the official datum. Adjacent TGN marks are usually intervisible, so they provide an efficient means of connecting and orienting a survey in terms of NZGD2000 when using terrestrial equipment, for example cadastral surveys.

## 4. THE IMPORTANCE OF PASSIVE CONTROL

At a time when many countries are stopping or significantly reducing their passive survey control programmes, New Zealand has increased the numbers of marks surveyed in recent years. This is primarily to support the accurate positioning of the digital representation of the cadastre, but also reflects the desire of the survey community for passive control marks near to any survey job they might undertake.

### 4.1 Datum Access

Currently we remain in a transition period with regard to user uptake of GNSS for positioning. Many surveyors, particularly those working for small firms, do not have ready access to GNSS. In other cases, environmental factors make GNSS inefficient or impossible to use. This is particularly common in urban environments where there are substantial sky obstructions and high-multipath environments. Passive control provides efficient access to the datum in these circumstances.



A government agency should promote the benefits of updated technology, such as active control. However it needs to have very sound reasons before mandating the purchase of expensive technology, which would effectively be the case if only active control were provided. Within 5-10 years the vast majority of users will have easy access to GNSS equipment. At this time, for efficiency reasons, it may be desirable to stop actively extending and replacing passive control networks.

#### **4.2 Detailed Deformation Modelling**

In areas of significant deformation, typical CORS density is insufficient to monitor the finer details of this deformation. It is not economically viable to install large numbers of CORS over a small area, so GNSS campaigns using passive marks provide the level of infill required.

#### **4.3 Localised Transformations in Deforming Regions**

Most surveys, eg cadastral surveys, take place over a small area, where relative deformation is negligible, even in a geophysically-active country such as New Zealand. However, the use of active control often means connecting to CORS that are many tens of kilometres distant. Over these distances, relative deformation is often significant. While the deformation model can be used for post-processed data, it requires the use of specialist software. It is currently not possible to use the deformation model in real-time.

The solution to this problem is for the user to survey three or more passive control marks and compute a local transformation in the GNSS software to bring their survey in terms of the passive control. The transformation removes any effects from relative deformation between the CORS and survey area.

In this case, the passive control is enabling the use of active control to carry out an efficient survey.

#### **4.4 Realising the Survey-Accurate Digital Cadastre**

For around 70% of the land parcels in New Zealand, bearings and distances have been captured from survey plans and tied to survey control marks. The coordinates generated have local accuracy of a few centimetres and network accuracy of better than 0.2m in urban areas. This is referred to as the Survey-Accurate Digital Cadastre (SDC).

LINZ is gradually extending the SDC, as new surveys get lodged and through direct capture of data from hard-copy plans. The SDC requires a dense network of survey control marks, with connections to the cadastre. To ensure the desired accuracy is achieved, in urban areas almost every point should be within 200m of a survey control mark. In rural areas, this can be relaxed up to 2000m, depending on factors such as parcel size.

## **4.5 Control for Imagery**

Control for aerial and satellite imagery requires the use of structures or markings that will be clearly visible in the image. It would be possible to build structures around a CORS station to suit this purpose, but this is an expensive option. In New Zealand, there are large numbers of four-metre beacons over geodetic marks. These are used by surveyors for orientation purposes, but are also visible in most imagery. In this way, existing passive control marks and associated structures supports the rectification of modern imagery at negligible cost to the user.

## **5. A CASE STUDY: PASSIVE CONTROL FOR EARTHQUAKE RECOVERY**

Passive control is playing an important role in the recovery of the geodetic system in the Canterbury region of New Zealand.

### **5.1 The Canterbury Earthquakes**

In 2010 and 2011, the Canterbury region of New Zealand's South Island experienced a prolonged earthquake sequence including four earthquakes of magnitude 6.0 or greater (Beavan et al. 2010). Three of these were centered in close proximity to Christchurch, the South Island's main city. Each caused significant disruption to the geodetic control system, necessitating surveys to re-establish an accurate spatial infrastructure.

### **5.2 Control for Infrastructure Repair Surveys**

One of the most immediate concerns after each earthquake was the need to repair damaged infrastructure, such as sewer systems. Initial surveys were carried out by local councils, with a focus on providing updated heights on key marks around the city of Christchurch (Donnelly et al. 2011). These surveys used GNSS and a geoid model to derive normal-orthometric heights. A mix of new and existing marks was surveyed. While passive marks were surveyed, active control was provided by CORS in the city.

### **5.3 Deformation Mapping**

Control surveys carried out by LINZ and the Christchurch City Council enabled maps of the deformation to be produced. These maps and the accompanying coordinate changes were used by surveyors and engineers to carry out more detailed analysis of movements in local areas. These maps also provided the most detailed city-wide indications of block shifts.

It was the presence of a dense network of passive control marks, with accurate pre-earthquake coordinates, that enabled these maps to be produced.

## 5.4 Support for Cadastral Boundary Re-establishment

The Surveyor-General has published rules and guidelines to assist cadastral surveyors re-establishing cadastral boundaries affected by the earthquakes. The surveyor is required to assess the nature of the deformation affecting the property subject to survey and the immediate surrounds, as this will impact on where the boundaries are located. For example, they need to determine how much movement is deep-seated block-shift, in which case boundaries move with the block-shift, and how much is due to shallow surface effects such as liquefaction, in which case the boundaries remain in their “original” position (as if there had been no shallow surface deformation).

To help ensure that there is sufficient evidence to enable these decisions to be made correctly and efficiently, LINZ is in the process of surveying marks to re-establish the Cadastral Horizontal and Vertical Networks. Along with the updated coordinates, LINZ will use the deformation model to provide details of how much of the movement at the mark is due to block-shift and how much is due to localized surface effects.

While it would be possible for a surveyor to utilise active control and the deformation model directly to determine this information, the use of deformation models is not incorporated into standard cadastral software. It is much easier for LINZ to provide the required information on passive control marks that the surveyor can then tie into their survey.

## 5.5 Precise Heighting

The Canterbury region, including Christchurch, has very flat topography. The feedback from local councils was that the combination of GNSS and a geoid model was not going to provide sufficient accuracy for the long-term precise heighting needs in the region. Therefore, LINZ commenced a programme of precise levelling along existing benchmark runs, installing new marks as required to ensure an even distribution of marks.

Active control networks and geoid models in New Zealand are not yet able to provide the level of normal-orthometric heighting required.

## 6. THE FUTURE OF PASSIVE CONTROL

Despite its current value, the role of passive control in the geodetic system may decrease substantially in the future.

### 6.1 New Technologies

New technology will impact on the feasibility of moving to a system based solely on active control. For example, InSAR can currently only be used to estimate deformation in the direction of line-of-sight of the satellite. If future constellations of InSAR satellites were to enable three-dimensional estimates of deformation, then this could remove the need to survey dense networks of passive marks for deformation monitoring. Using photogrammetric

methods or LiDAR may also enable the detailed mapping of displacements due to deformation events.

Of more immediate potential benefit is the projected increase in the number of positioning satellites over the next decade. As systems such as Galileo and Compass become operational, GNSS positioning in areas of high multipath and low sky visibility will become more feasible, reducing the need for passive marks to support terrestrial survey techniques.

## 6.2 New Zealand's Changing Focus

The LINZ program of actively extending passive control into rural areas, and limited renewal in urban areas, will be completed in the next few years. By then, almost every point in an urban area will be within 200m of a passive control mark. In rural areas (excluding very remote, wilderness areas), almost every point will be within 2000m of a passive control mark.

The steady increase in the use of GNSS for cadastral (see Figure 2) and other surveys is leading to reduced demand for intervisible and beacons marks.

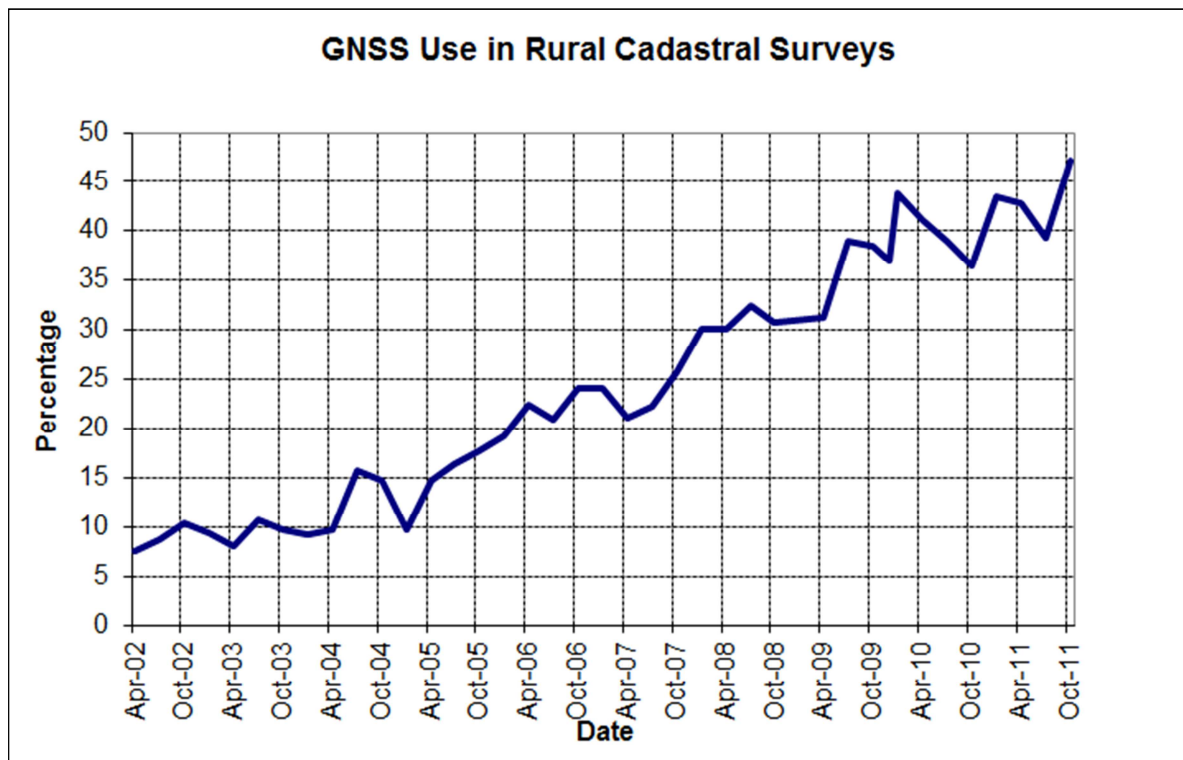


Figure 2: Percentage of rural cadastral surveys carried out using GNSS in New Zealand

A much-reduced passive control programme will focus on regular GNSS campaigns to monitor key passive control marks for deformation, to supplement the data from an increasing number of CORS. While other passive marks will remain available for use, very few of these will be actively maintained, except as required to ensure the mark and associated structures remain safe.

This changing focus will enable greater resources to be invested in making active control more usable for the spatial community. For example, accurate and extensive gravity data is required to develop a geoid model to enable accurate normal-orthometric heighting using active control.

## 7. CONCLUSION

For a geodetic datum to be useful, it needs to be easily accessible to its users. Active control provides an efficient means of connecting to the fundamental reference stations in the datum, and its use will continue to increase substantially. As more datum users become GNSS-enabled, datum managers such as LINZ will divert more resources to support these customers using active control.

Active control alone will only provide accurate positioning over long distances where:

- 1) Relative deformation between the CORS and user's GNSS equipment is negligible;  
or
- 2) A deformation model is used when calculating the position

Neither of these situations is generally applicable in New Zealand, so augmentation with passive control is currently the most practical means of obtaining accurate coordinates.

Given New Zealand's active tectonic setting, computing deformation models of sufficient accuracy to support active control will require a denser network of marks than is feasible using CORS. Repeat GNSS campaigns on a relatively dense network of marks will provide the necessary detail.

So to answer the question posited in this paper: No, active control networks should not replace passive control networks at the moment. Eventually this may be feasible, but in a country like New Zealand, this is likely to be decades, rather than years, in the future.

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## **BIOGRAPHICAL NOTES**

**Graeme Blick** After graduating from Otago University in 1980, Graeme worked as a scientist for the Institute of Geological and Nuclear Sciences using geodetic techniques to study plate tectonics and crustal deformation. After joining Land Information New Zealand in 1995 he worked for the Office of the Surveyor-General as Geodetic Survey Advisor and worked on projects such as the development of a new geodetic datum and map projection for New Zealand. He is currently the Chief Geodesist for the National Geodetic Office, as well as Manager of the National Topographic Office.

**Nic Donnelly** Nic is a Geodetic Surveyor within the National Geodetic Office at LINZ. His interests and responsibilities include geodetic adjustments, maintenance and enhancement of the geodetic cadastre and geodetic data transfer standards. He is currently involved in the recovery of the geodetic system from the Canterbury earthquakes of 2010 and 2011.

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