Implementation of a New Survey Control Standard for New Zealand

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SUMMARY

In September 2009 Land Information New Zealand promulgated a new standard for the survey control system in New Zealand. This standard is the result of a rigorous process of risk analysis, technical investigations and consultation with interested parties. It is an outcome-based standard consistent with the principles of optimal regulation.

The standard takes an unconventional approach to defining control system requirements. Rather than specifying geodetic networks at various levels of accuracy, the standard specifies six geodetic networks which are required to meet the diverse purposes of a national survey control system.

Each network has a different purpose. The National Reference Frame enables connections to be made to international reference systems. The Deformation Monitoring Network allows determinations of local and national deformation to be made. Cadastral Horizontal and Vertical Networks enable connection of cadastral surveys to official datums. A National Height Network supports certain non-cadastral heighting requirements and the Basic Geospatial Network provides control for mapping and other government-directed activities in locations where the other networks may not exist.

This paper outlines the characteristics of these networks, as well as other key requirements of the survey control system standard. There is a particular focus on the continuing work to fully implement this standard, some of the challenges that have arisen and how these have been overcome.

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1. INTRODUCTION

In New Zealand, the legislative framework for the regulation of the geodetic system is provided in the *Cadastral Survey Act 2002*. Land Information New Zealand (LINZ) is the government department charged with implementing this legislation. Section 7 of the Act specifies functions and duties of the Surveyor-General. These include the requirement to:

- Maintain a national geodetic system
- Maintain a national survey control system

The *national geodetic system* is a collective term that includes the geodetic and vertical datums, projections and transformations that enable spatial information to be consistently described in terms of a common reference frame. The national survey control system is part of the geodetic system.

The *national survey control system* comprises the control marks, information about them, such as coordinates, and other physical and electronic infrastructure. This infrastructure includes marks in the ground and the supply of data from a Continuously Operating Reference Station (CORS) network. The national survey control system is the means by which users access the geodetic system and in particular its geodetic and vertical datums.

The Surveyor-General is responsible for the geodetic system and its composite survey control system. The maintenance of the survey control system has been delegated to the Customer Services group within LINZ – the Surveyor-General retained the function to maintain the geodetic system. Standards are therefore required to ensure that the control system is maintained to the satisfaction of the Surveyor-General.

This paper details the use of a regulatory framework to determine appropriate levels of intervention to support the high level legislative requirement for a national survey control system. It then discusses the planned implementation of the control system, with a particular focus on the six new geodetic networks specified by the new survey control standard.

1.1 New Zealand Geodetic Datum 2000 (NZGD2000)

New Zealand's official geodetic datum, New Zealand Geodetic Datum 2000 (NZGD2000), is a geocentric, semi-dynamic datum. Its geocentric characteristic ensures close compatibility with international positioning and navigation systems, such as the Global Positioning System (GPS). The semi-dynamic nature means that New Zealand's ongoing secular deformation can be accounted for within the datum. There is also the facility for the impact of localised deformation events such as earthquakes to be incorporated into the datum. NZGD2000 is defined in LINZ (2007).

NZGD2000 is intended primarily for use by spatial professionals, including surveyors and managers of geographic information systems. It needs to be capable of supporting spatial consistency within datasets. For example, a primary purpose of NZGD2000 is to support the New Zealand cadastral system, which facilitates increased certainty and accessibility of the spatial extents of property rights. It also needs to enable the integration of diverse datasets. For example, local government agencies often overlay the cadastre with accurate aerial photography to enable efficient management of public resources.

To meet and support these requirements, the survey control system needs to provide access to the official geodetic datum at a level that enables relative positioning to an accuracy of about 1cm and absolute positioning to an accuracy of about 10cm.

1.2 Optimal Regulation

A standard regulatory analysis framework is used by LINZ to ensure that government intervention is at an optimal level. The concept of optimal regulation can be summarised by the phrase "as little as possible, as much as necessary". The aim is to have a regulatory system which encourages efficiency and innovation, but still ensures that public interests are protected. In practice, this means that the Surveyor-General specifies *what* is required of the survey control system, but leaves it to others (including the private sector) to determine *how* these requirements are best achieved.

The regulatory analysis framework is described in Grant and Haanen (2006). The four steps in this framework are summarised in Figure 1.

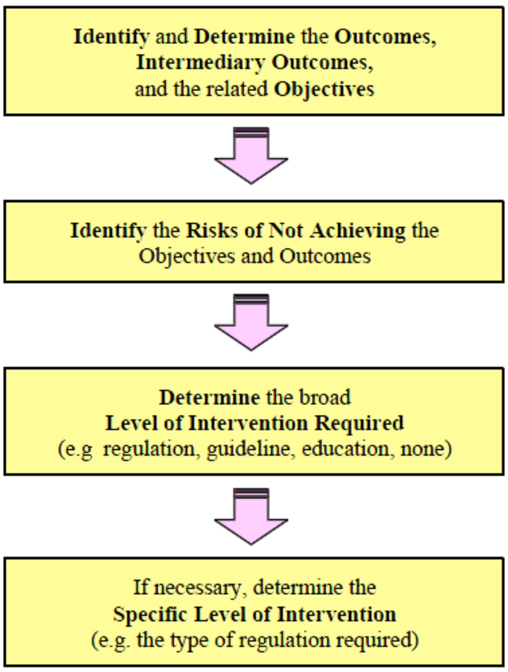

Figure 1: Regulatory Analysis Framework (Grant and Haanen, 2006)

Following this framework, the following end outcome was set for the geodetic system:

"A single common reference system that underpins the efficient operation of the cadastral, hydrography and topography systems and meets directed government needs"

A difficulty with the above end outcome is that it is difficult to quantify whether or not it has actually been achieved. As such, it was progressively expanded into the intermediate outcomes, objectives, and sub-objectives as detailed in Table 1. The sub-objectives relate to discrete areas of the geodetic system and are written in a way that enables compliance with them to be measured.

A risk analysis was carried out for each of these sub-objectives. From this risk analysis, it was determined that the optimal level of regulation for the survey control system would be achieved using a standard, with an associated guideline.

Two additional standards were written that cover accuracy requirements. These were separate from the survey control standard since accuracy is something which pertains to all spatial data, not just survey control data. This enables the accuracy of coordinates to be consistently specified between different data sets.

1.3 Survey Control System Standards

The New Zealand survey control system is regulated by three standards and a guideline. The primary standard is the *Standard for the New Zealand survey control system* (LINZ 2009a). This refers to two standards which define accuracy: *Standard for the geospatial accuracy framework* (LINZ 2009b) and *Standard for tiers, classes, and orders of LINZ data* (LINZ 2009c). Expanding on the material in the survey control system standard is a guideline, *Guideline for the provision and maintenance of the New Zealand survey control system* (LINZ 2009d).

1.3.1 Standard for the New Zealand survey control system

This standard prescribes the Surveyor-General's requirements for:

- the location, accuracy, construction, and access to control marks within survey control networks
- the provision of information about control networks and control marks
- monitoring official datums for the effects of surface deformation

1.3.2 Standard for the geospatial accuracy framework

This standard provides the framework for specifying accuracy for other LINZ standards and datasets. It describes and specifies formulas for calculating network (absolute) accuracy and local (relative) accuracy.

Intermediate Outcome	Objective	Sub-Objectives
A1 Coordinates that accurately represent positions (e.g. longitude, latitude & height) on Earth and the orientation (e.g. north) of lines	A1(a) Common preferred geodetic datums and projections are used by Managers of geospatial data	A1(a)(i) Unique and reproducible three dimensional positions in space can be determined throughout New Zealand and its continental shelf in terms of a (geometric) geodetic datum
		A1(a)(ii) Unique and reproducible heights above a level surface can be determined throughout New Zealand in terms of a vertical (gravimetric) datum
		A1(a)(iii) Unique and reproducible three-dimensional positions in space can be determined throughout the Ross Dependency in terms of a (geometric) geodetic datum
		A1(a)(iv) Unique and reproducible heights above a level surface can be determined throughout the Ross Dependency in terms of a vertical (gravimetric) datum
		A1(a)(v) Cadastral data can be oriented in terms of a mapping projection based on the national geodetic datum
		A1(a)(vi) Cadastral data can be scaled in terms of a mapping projection based on the national geodetic datum
		A1(a)(vii) Geospatial data (cadastral, topographic, hydrographic, etc) within New Zealand's continental shelf can be readily located and displayed in terms of a mapping projection based on the national geodetic datum
		A1(a)(viii) Geospatial data (topographic, hydrographic, etc.) outside of New Zealand's continental shelf but within New Zealand's jurisdictional responsibility can be readily located and displayed in terms of a mapping projection
	A1(b) National datasets and positioning systems accurately relate to global datasets	A1(b)(i) The relationship between New Zealand datums and international geodetic reference frames is defined
		A1(b)(ii) Geodetic datasets from New Zealand locations are available which have a known relationship with global datasets
		A1(b)(iii) Contribute to International geodetic standards for reference frames to ensure they can be used in the New Zealand setting
		A1(b)(iv) The global reference frames, on which New Zealand relies, include New Zealand data which meets international standards
	A1(c) Data in terms of historical datums are able to be converted into the preferred datums	A1(c)(i) Geospatial data can be transformed between historic and official New Zealand datums and projections without significant loss of accuracy
		A1(c)(ii) Geospatial data can be transformed between official New Zealand datums and international reference frames without significant loss of accuracy
	A1(d) Accurate data for geodetic marks are available to users	A1(d)(i) The accuracy of survey observations is identified in a quantitative and qualitative manner
		A1(d)(ii) The accuracy of coordinates is identified in a quantitative and qualitative manner
		A1(d)(iii) Current and historic coordinates are provided in a timely manner and are published in a way that is discoverable, accessible, in a useable format, easily interpreted and able to be readily assessed
	A1(e) Coordinates are maintained up to date to reflect movements of the Earth	A1(e)(i) Temporal variations in the positions of geodetic marks are monitored and measured
		A1(e)(ii) Observations and coordinates acquired or generated at different times can be transformed to a common epoch

Intermediate Outcome	Objective	Sub-Objectives
		A1(e)(iii) Mark density is sufficient to allow local variations in deformation to be monitored and quantified with an accuracy sufficient for Cadastral, Hydrographic and Topographic systems
A2 A network of reference points across New Zealand that can be easily connected to	A2(a) The marks are spaced and located to allow easy access and visibility	A2(a)(i) Mark density enables geodetic marks to contribute to and maintain the accuracy of surveys and efficiently connect them to the geodetic system
		A2(a)(ii) Marks are in usable locations
		A2(a)(iii) Marks and any associated structures can be easily identified
	A2(b) Geodetic marks are protected and maintained to prevent physical deterioration and minimise loss or safety hazards	A2(b)(i) Marks are sufficiently stable and maintained while being used as a geodetic mark for their published coordinates to accurately reflect their current positions
		A2(b)(ii) Mark and their associated structures are stable for their effective life
		A2(b)(iii) Marks and their associated structures are safe and do not pose a hazard to people and property
	A2(c) Information about geodetic marks accurately records its physical condition	A2(c)(i) Information about marks and their associated structures is reliable, correct and up to date
		A2(c)(ii) Information about marks and their associated structures are provided in a timely manner and are published in a way that is discoverable, accessible, in a useable format, easily interpreted and able to be readily assessed

Table 1: Geodetic end outcomes, intermediate outcomes, objectives and sub-objectives

1.3.3 Standard for tiers, classes, and orders of LINZ data

This standard assigns numerical values to the framework specified in LINZ 2009b. Network accuracy is described by classifications called *tiers*. There are three tiers which apply to the horizontal position of control marks, with accuracies of 0.05m, 0.10m and 0.15m.

Local accuracy is described by classifications called *classes*. Each class contains a constant and distance-dependent component. For the horizontal position of control marks, the distance-dependent component ranges from 0.01mm per km for the highest accuracy marks to 50mm per km for lower accuracy marks. Class is assessed against all other control marks within a specified distance that have the same or better class.

Finally, coordinates can be described by an *order* if it achieves both the applicable tier and class requirements. Table 2 summarises the survey control network orders and the composite tier and class accuracy requirements from LINZ (2009c).

1.3.4 Guideline for the provision and maintenance of the New Zealand survey control system

This guideline provides greater detail which expands on the content of (2009a). It details the Surveyor-General's expectations of how the standard can be complied with. However, its status as a guideline means that there is the potential to use methodologies not described in the guideline, so long as compliance with the standard can still be demonstrated.

Order	Horizontal tier accuracy (m)	Horizontal class accuracy (m, ppm)	Vertical tier accuracy (m)	Vertical class accuracy (m, ppm)	Order purpose
0	0.05	0.003 + 0.03	0.05	0.003 + 0.03	national reference frame
1	0.05	0.003 + 0.1	0.10	0.003 + 0.3	national deformation monitoring
2	0.10	0.003 + 1	0.25	0.003 + 3	regional deformation monitoring
3	0.10	0.01 + 3	0.35	0.01 + 10	-
4	0.15	0.01 + 10	0.35	0.01 + 50	local deformation monitoring
5	0.15	0.01 + 50	0.35	0.02 + 100	• cadastral horizontal control • basic geospatial network
1V	-	-	0.25	0.003 + 3	national height network
2V	-	-	0.35	0.01 + 10	-
3V	-	-	0.35	0.02 + 100	cadastral vertical control

Table 2: Orders, tiers and classes for survey control networks

2. NEW ZEALAND SURVEY CONTROL SYSTEM

The most fundamental change to the control system standards resulting from the optimal regulation framework was that the control networks should be *use-focused* rather than *accuracy-focused*. The standard is high level in nature. It specifies what is required of the control system, but deliberately does not state how the standard should be achieved.

Until now, New Zealand's control networks, like most other countries, have been hierarchical in nature. A mark's position in the hierarchy has been determined primarily by the quality of its monumentation and coordinate accuracy. This has resulted in control marks being placed with an accuracy or density that does not meet, or significantly exceeds, the requirements of users. The new standard (LINZ, 2009a) specifies six control networks, each of which serves a specific use of the control system, rather than being simply another level in an accuracy hierarchy.

2.1 National Reference Frame

The National Reference Frame (NRF) control marks provide the connection between NZGD2000, New Zealand Vertical Datum 2009 (LINZ 2009e) and international reference systems. There are two types of NRF marks: Geodetic Datum Reference Marks (GDRM), which provide the three-dimensional connection, and Vertical Datum Reference Marks (VDRM), which provide the height connection. These must be co-located at each NRF site.

2.2 Deformation Monitoring Network

The purpose of the Deformation Monitoring Network (DMN) is to enable surface deformation to be determined at national, regional and local scales. The national DMN monitors tectonic plate movements, while the regional and local DMN monitors finer deformation, including that caused by discrete events such as earthquakes. The density of the DMN is dependent on the rate of deformation. Fewer marks are required where deformation is uniform and significant localised events are not expected.

2.3 Cadastral Horizontal Control Network

The Cadastral Horizontal Control Network (CHN) provides the high-density control which is required to ensure that cadastral surveys can be efficiently connected to the official geodetic datum. The standard requires that this network contains sufficient marks to ensure that 98% of all new surveys are capable of generating coordinates of better than order 6.

2.4 Cadastral Vertical Control Network

The Cadastral Vertical Control Network (CVN) ensures that cadastral surveys with a heighted boundary point can be efficiently and accurately referenced to the official vertical datum.

2.5 Basic Geospatial Network

The Basic Geospatial Network (BGN) ensures that there are sufficient control marks available in areas where they might not otherwise be required by the DMN, CHN or CVN (such as on small, offshore islands). This network supports government-directed geospatial activities such as topographic mapping and hydrographic surveying.

2.6 National Height Network

The National Height Network (NHN) provides for the protection and maintenance of existing control marks with precisely levelled normal-orthometric heights. Although LINZ no longer undertakes large-scale precise levelling surveys, the existing height infrastructure remains a valuable part of the survey control system.

3. IMPLEMENTING THE STANDARD

Initial planning has indicated that many of the requirements of the new standard for the six control networks can be satisfied using existing control marks, some of which may be in more than one network. However, most of the networks will require some degree of survey fieldwork to be carried out to obtain full coverage across the country. This fieldwork has already commenced and will continue over the next five to ten years.

3.1 National Reference Frame

Final sites for the NRF have yet to be determined. There will be at least three: one on the Australian plate, one on the Pacific plate and one in Antarctica. The relationship between the co-located GDRM and VDRM at each site will be monitored regularly. GDRMs will be occupied by continuous GNSS. VDRMs will periodically have gravity measurements made at them.

3.2 Deformation Monitoring Network

The national DMN will consist of stations in the existing national CORS network, PositioNZ (Figure 2). These stations have been in existence for a number of years, so their inclusion in the national DMN means that the longitudinal record of deformation at these sites is maintained.

The regional DMN will be developed in partnership with GNS Science, New Zealand's government-owned Earth science research institute. GNS Science already has a dense network of CORS throughout much of the central and eastern North Island. Supplementing this is a network of campaign GPS sites throughout the country. The combination of CORS and campaign sites provides the required density in most of the country. In areas of lesser scientific interest, such as the north of the North Island, LINZ will work with GNS Science to install and survey an appropriate number of new marks.

Local DMN networks are only required in areas of significant deformation. To date, analysis has not been carried out to identify these areas, but given New Zealand's active geology, it is anticipated that a number of local DMNs will be required.

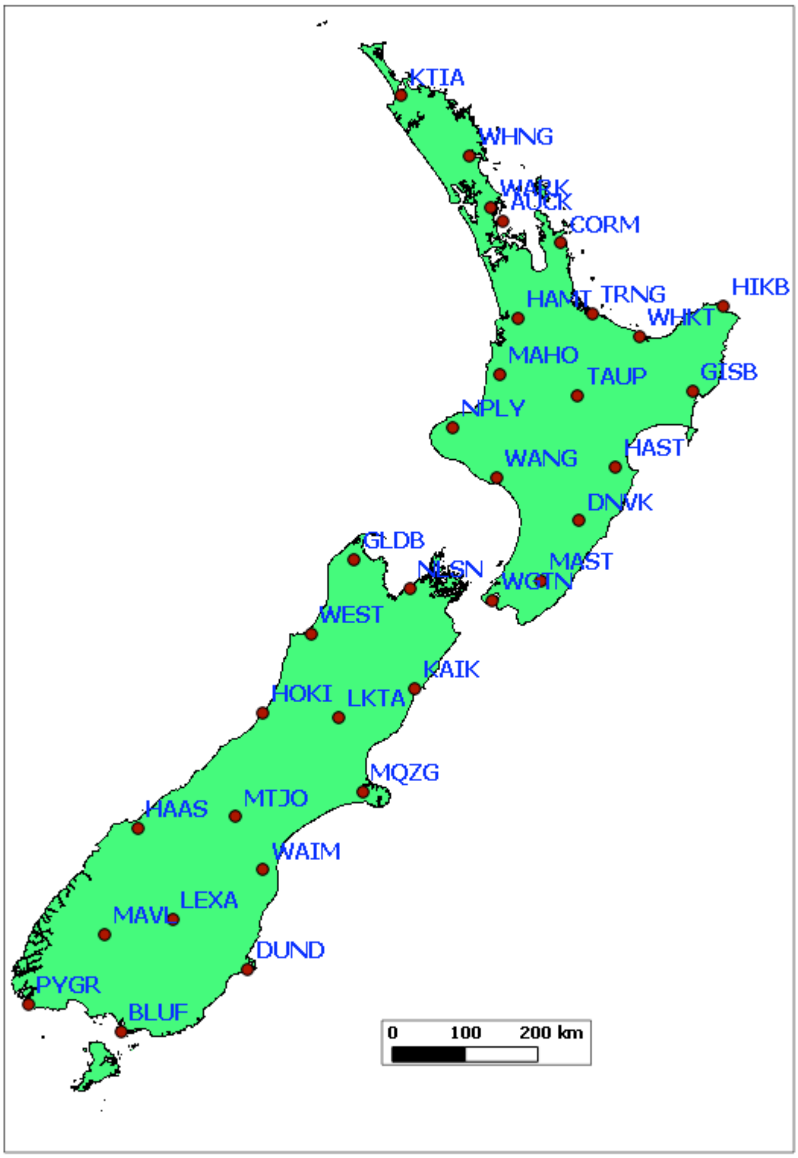

Figure 2: The National Deformation Monitoring Network

3.3 Cadastral Horizontal Control Network

The biggest challenge in establishing the CHN is that a number of the marks which are currently used to provide control to cadastral surveys are not sufficiently accurate to form part of this network. These are marks have horizontal coordinates which were computed from the least-squares adjustment of historic control traverse information (often referred to as 5th order adopted or '5a' marks in New Zealand). Although these traverses were sufficiently accurate for their original purpose, the coordinates are generally not accurate enough to meet current survey control requirements, particularly with regard to local accuracy where two nearby marks do not have a measured vector between them. This means that the marks are not sufficiently accurate to fully control the cadastre. However, in most cases they are adequate for use by cadastral surveyors, who typically re-observe the inter-visible vectors originally surveyed in the control survey.

This problem is not related to the introduction of the new standard. In fact, the new standard has slightly relaxed the accuracy requirement for the CHN. However, the introduction of the new standard provides an opportunity to resolve this long-standing issue. It is proposed that all existing "5a" control marks will be re-assigned to order 6. At this level, their accuracy is still suitable for use as an origin for cadastral surveys. Ongoing fieldwork will ensure that key marks are upgraded through re-survey to eventually provide a CHN of appropriate density throughout the country.

Initially, the CHN will be populated with existing order 5 survey control marks which are of sufficient accuracy to retain their order 5 classification. These are marks which have been surveyed with GPS over the past decade.

Meeting the 98% target in the standard will be assisted by the fact that the *Rules for Cadastral Survey 2010* (LINZ, 2009f) for the first time require bearings to be oriented in terms of an official NZGD2000 projection. For most surveys, this will involve a connection to survey control marks, which in rural areas may require the use of GPS to do this efficiently. The density of the CHN can be significantly reduced in rural areas, where good sky visibility means that GPS is practical for use in cadastral surveys. Over the past eight years, the use of GPS in rural cadastral surveys has been steadily increasing (Figure 3), to the point where 40% of such surveys are now carried out using the technology.

3.4 Cadastral Vertical Control Network

The CVN will initially be populated using marks which have ellipsoidal heights associated with them. The ellipsoidal heights will be converted to the official normal-orthometric vertical datum, New Zealand Vertical Datum 2009 (NZVD2009), which is based on the NZGeoid2009. This provides reasonable coverage at a national level, but within many urban areas, coverage is not sufficiently dense (see Figure 4). Due to the relative difficulty and expense of transferring accurate heights over long distances, cadastral surveys in urban areas will only be required to connect to an official vertical datum if a heighted control mark is within 200m of their survey.

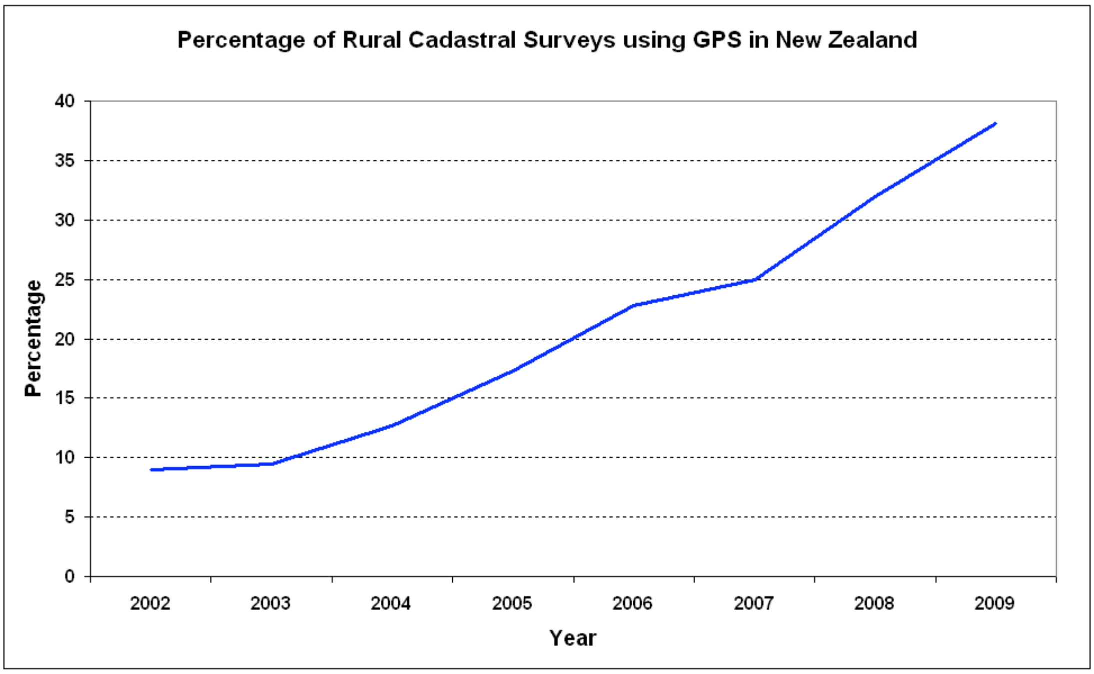

Figure 3: Percentage of rural cadastral surveys carried out using GPS

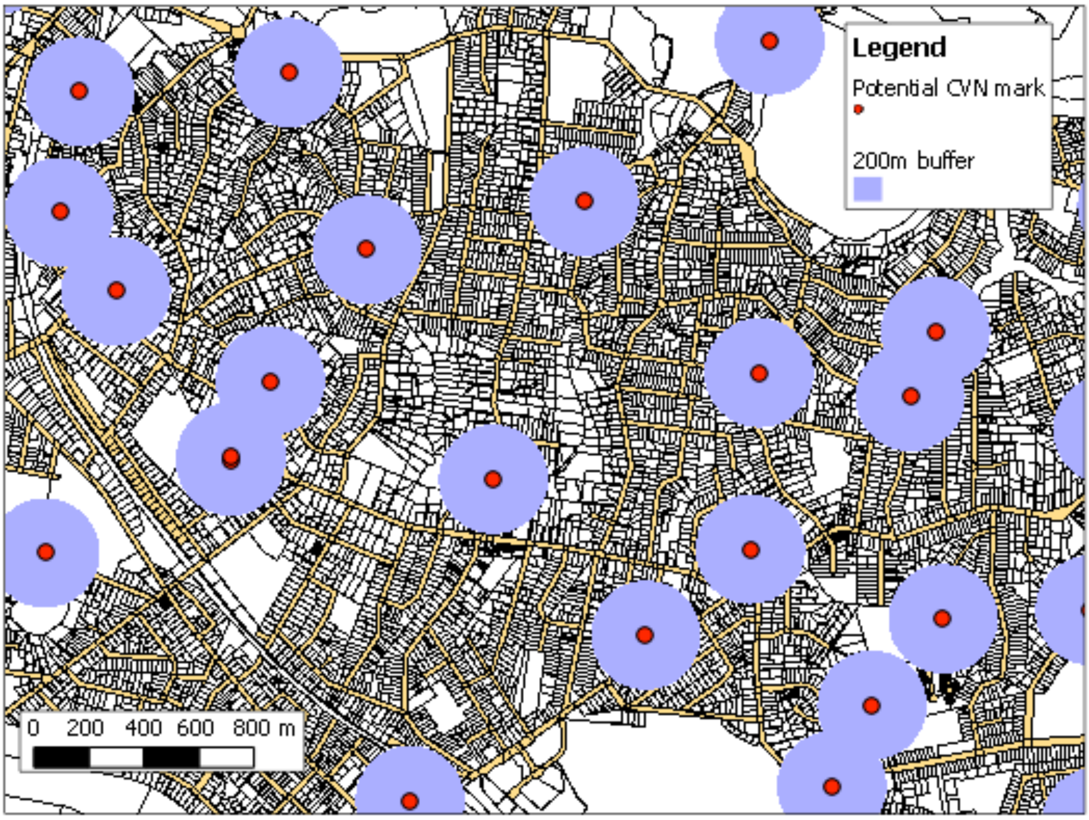

Figure 4: The CVN in a major urban area. Coverage is currently insufficient to ensure that cadastral surveys with heighted boundaries can connect to an official vertical datum.

3.5 Basic Geospatial Network

On mainland New Zealand, a distinctive requirement for BGN marks is that they be visible in overhead aerial or satellite imagery. Experience has shown that the only marks which currently meet this requirement are those with large, four-metre wooden or metal beacons over them. Any point in New Zealand must be no more than 50km from a BGN mark.

As Figure 5 shows, a BGN can be formed using existing beaconed marks, which covers all of the North Island and most of the South Island. Those areas which are not covered are typically isolated, rural areas.

New Zealand's offshore islands will have a BGN installed as opportunities arise. The expense and logistical difficulty of accessing these islands means that control will be surveyed in conjunction with other activities. For example, control marks suitable for the BGN were installed on Raoul Island during work to install tide gauges on the island.

3.6 National Height Network

The NHN will consist of existing control marks that have previously been surveyed to first– or second–order precise levelling standards. Because precise-levelling is expensive and slow, there are no plans to extend the NHN beyond the extents of the existing marks. The focus instead will be on maintaining the existing marks so that they remain accessible and usable.

4. CONCLUSIONS

New Zealand's new survey control standard has been developed through a formal, rigorous process. As part of this process, clear outcomes for the geodetic system have been defined and the risks associated with not achieving these outcomes have been analysed.

The new standard specifies what is required of the survey control system, rather than how the requirements should be achieved. This will increase the longevity of the standard, providing certainty to users of the control system, while facilitating innovation as new technologies and methodologies become available.

In a change of focus from previous control system standards, the New Zealand survey control system standard has been developed giving strong consideration to how the control system is used. This has led to the specification of six survey control networks, each with characteristics and requirements which directly pertain to their intended use. Many of the marks required for these six new networks will come from the existing control system. Gaps in the networks will be filled over the next few years through new survey work.

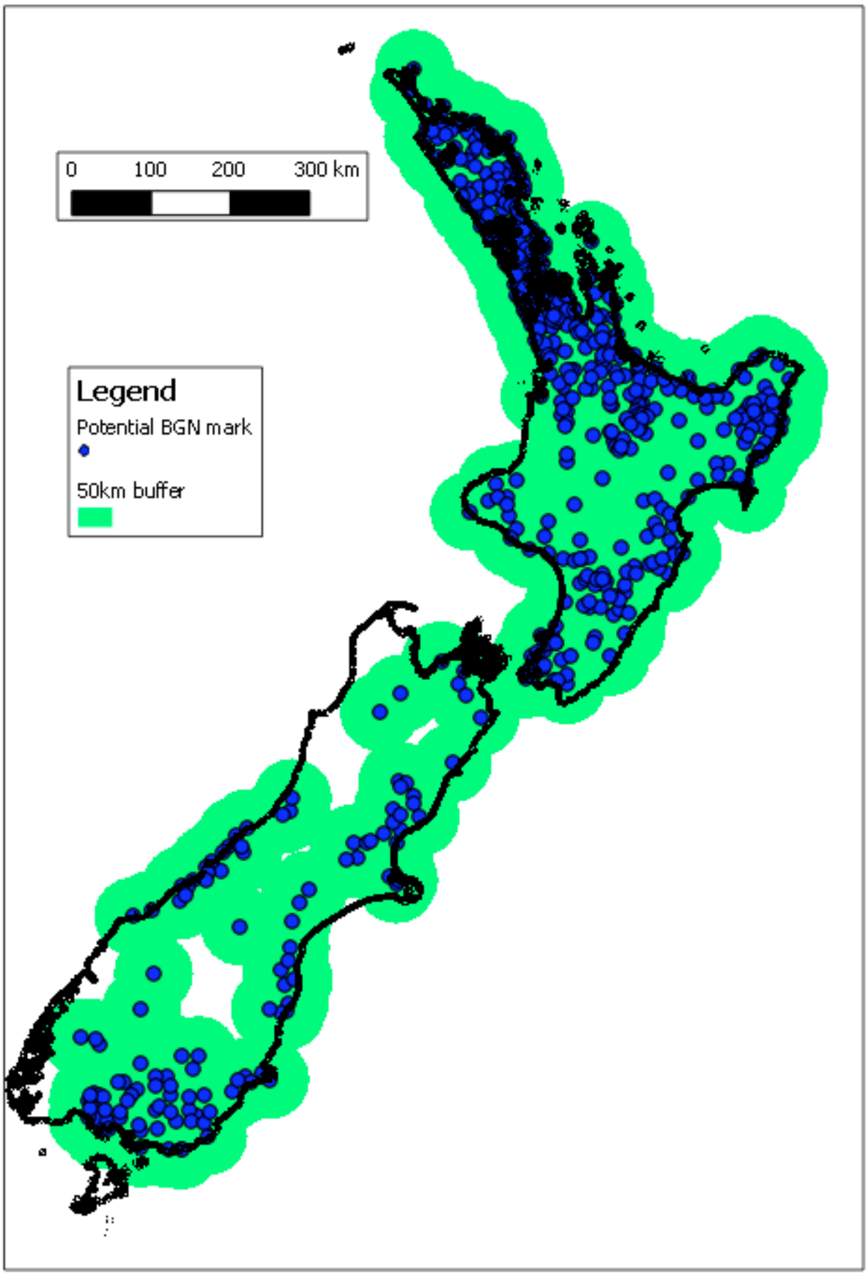

Figure 5: The proposed BGN, consisting of existing order 5 and better control marks with four-metre beacons.

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BIOGRAPHICAL NOTES

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