Toitu te
Land whenua
Information
New Zealand

Proposal for Continuous Access to the NZ Spatial Infrastructure

OSG Technical Report 6

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Office of the Surveyor-General

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Foreword

Land Information New Zealand (LINZ) (Toitu te Whenua) was established in July 1996. It is a government department with roles and responsibilities in the following key areas:

Regulatory Responsibilities	**LINZ Regulatory Groups**
National spatial reference system and cadastral survey infrastructure and information	Office of the Surveyor-General
Topographic and hydrographic information	National Topographic/Hydrographic Authority
Land Titles	Office of the Registrar-General of Land
Setting rules for rating valuations	Office of the Valuer-General
Crown Property	Office of the Chief Crown Property Officer (Crown Property)
Assisting the government address land related aspects of Treaty of Waitangi issues	Office of the Chief Crown Property Officer (Crown Property)

The main role of the department is a regulatory one, to set guidelines and standards and manage contracts with the private sector for carrying out the day to day business associated with each of the key areas.

LINZ also offers a range of services to customers related to land titles, survey plans and Crown property. These services are carried out by the Operations Group based in LINZ regional offices throughout New Zealand.

LINZ overarching objective is to be recognised as a world leader in providing land and seabed information services. For further information see our Internet site on http://www.linz.govt.nz

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PROPOSAL FOR CONTINUOUS ACCESS TO THE NZ SPATIAL INFRASTRUCTURE

1 Executive Summary

Land Information New Zealand has the mandate to define, develop, and maintain the spatial infrastructure in New Zealand. A number of requirements have been identified for the provision of continuous access to the spatial infrastructure. This access is currently provided through a network of high quality "passive" geodetic marks and, in particular, remote access is provided through observable trig beacons. The benefits that these beacons once provided for geodetic survey have been eliminated by GPS technology. They are now only used for cadastral survey.

To update the existing requirements for efficient continuous and remote access to the spatial infrastructure, the development of a permanent GPS tracking network is proposed. Experience in many other countries is that it is efficient for national geodetic survey agencies to coordinate, through partnerships with a wide range of public and private agencies, development of continuously tracking GPS stations. These are known as "active control networks". The alternative is a number of disparate networks which are cumulatively more expensive and which provide much more limited benefits to their providers.

Recommendations for the development of a New Zealand GPS permanent tracking network over the next five years to satisfy LINZ and other user requirements are:

- development of a permanent GPS tracking network through partnership with other organisations;
- the partnerships to be formalised through memoranda of understanding or contracts;
- the density of LINZ partnership stations to be similar to the current 1st Order 2000 network i.e. approximately 20-30 stations nationally;
- the highest priority for installation of LINZ partnership stations to be for sites near populated areas; and
- LINZ to provide standards and a process to enable additional permanent tracking stations, which exceed LINZ's direct requirements, to be certified as meeting the Surveyor-General's standards for cadastral or geodetic survey.

2 Introduction

2.1 Scope of this Report

This report discusses LINZ plans to update its requirements for providing access to the New Zealand spatial infrastructure. The update is in response to emerging needs of new technology. It provides a set of recommendations for development of a system to provide this access over the next 5 years. These recommendations are in general accord with recent developments by national geodetic agencies in many other countries.

2.2 New Zealand Geodetic Strategic Business Plan

In 1998 a New Zealand Geodetic Strategic Business Plan [*Office of Surveyor General* 1998a] was developed. The business plan included the provision and development of the geodetic system in New Zealand, including the Ross Dependency.

The purpose of the Strategic Business Plan was to articulate a vision and plan for the development of the geodetic system which supports the spatial infrastructure. Business drivers and issues were detailed and a number of short-term (three-year) and long term (10-year) goals identified to enable the business drivers to be satisfied. The following are the goals from this business plan:

Short Term

1 *To provide a cost-effective system that can generate current geometric (three-dimensional) coordinates of points in terms of a globally accepted system to an acceptable and defined accuracy.*

2 *To provide a cost-effective system that can generate orthometric heights of points in terms of a nationally accepted system to an acceptable and defined accuracy.*

3 *To support multiple projections, and authoritative transformations of coordinates between those projects and the official geometric (three-dimensional) datum, to an acceptable and defined accuracy.*

4 *To support (in the short term) multiple vertical datums and authoritative transformations of heights to an acceptable and defined accuracy.*

Long Term

5 *To enhance the automated cadastral system and extension to include the seabed.*

6 *To consider the implementation of a four-dimensional datum.*

7 *To develop a height system to a defined accuracy that enables the generation of orthometric heights from spheroidal heights.*

8 *Where appropriate, to contribute to and become an integral part of, the global geodetic system.*

9 *To adapt the design and management of the physical network to take greater advantage of the potential efficiencies offered by new technology.*

10 *A user community that understands, accepts, obtains benefit from and uses the New Zealand Geodetic System.*

11 *To reduce geodetic mark installation and maintenance costs.*

The development of a system to provide continuous access to the spatial infrastructure will contribute to goal 9 in particular. It will also contribute indirectly to goals 1 and 2 through more efficient and flexible observation of the geodetic network. It will assist LINZ to meet goal 8 and ultimately, it will enable goal 11 to be achieved.

3 Access to the New Zealand Spatial Infrastructure

The New Zealand Spatial Infrastructure is the authoritative infrastructure for New Zealand underpinned by the New Zealand Geodetic System. Spatial referencing of legal and administrative features is provided by the land (and future seabed) cadastre and physical spatial referencing by topographic and hydrographic databases.

LINZ and its predecessors have long had a responsibility to ensure that users of the spatial infrastructure have reasonable and efficient access to the geodetic network. This access takes two forms – physical access to the marks (provided for in the Survey Act 1986) and remote access provided by observable trig beacons.

LINZ maintains trig beacons through geodetic maintenance contracts. In the past, trig beacons reduced the cost of both geodetic survey and cadastral survey by reducing the need to visit and occupy distant trig stations. However, the beacons are now only useable with conventional survey methods. These methods are still used for cadastral survey but have been completely supplanted by GPS for geodetic survey. Therefore, while the beacons are still maintained through LINZ contracts in support of cadastral survey, they provide no benefits for LINZ geodetic survey contracts and are actually a nuisance in some cases due to being difficult to setup GPS receivers on or under. Beacons have a secondary, but useful role, in providing protection to the ground mark by virtue of being a visible marker.

It is appropriate to consider whether this service of providing a mechanism for remote access to the geodetic network should be updated to provide the same efficiencies for GPS survey as they currently do for cadastral survey. Geodetic agencies in several other countries have adopted the concept of an "active" control network. The word "active" distinguishes such a network from the passive role played by trig beacons.

An active geodetic control station consists of a geodetic station occupied by a continuously operating GPS receiver with the data from this receiver being made widely available through some mechanism. Other GPS users, even if they only have a single receiver, can calculate their position relative to one or more active stations by processing the data together with the data from their own receivers. This is equivalent to the conventional technique of determining position (resection) or orientation by observing distant trig beacons.

For a moderate number of GPS stations, continuous tracking is economically efficient because of the deployment costs avoided. An example of this is the two GPS receivers provided by the Jet Propulsion Laboratory for permanent tracking stations at Whangaparoa and Chatham Islands. These were provided to New Zealand at no cost to avoid the high cost of deployment of receivers for individual GPS survey campaigns. This is the same reason why, especially in the past, establishment of a permanent trig beacon was considered more efficient than deployment of temporary beacons on a survey-by-survey basis.

However, the cost of establishing and maintaining a continuously operating GPS receiver is significantly greater than the cost of erecting and maintaining a single trig beacon. LINZ certainly cannot afford to establish an active control station on every trig where there is now a beacon. Nevertheless, there are two factors that make the active control network financially efficient.

1. Because line of sight is not required between the active control stations and the users, the number of stations required to cover a given area is much less than for conventional trig beacons.

2. The number of agencies that can benefit from a permanently tracking GPS station is much wider than the geodetic or cadastral survey user base. This can be seen from the number of GPS stations currently operating in New Zealand (see Annex A). These stations serve a range of scientific, environmental or local survey requirements. While LINZ had a role in establishing some of these stations, none of them are the sole or even primary responsibility of LINZ.

The trend in other countries (e.g., USA, Japan, UK, Germany, Sweden, etc) is for a number of public and private agencies, including the national geodetic survey agency, to co-operate in the establishment of GPS tracking networks to mutual benefit [eg *Davis* 1999, *Spofford and Weston* 1998, *Ottoson and Jonsson* 1998].

The aim of this report is to establish LINZ's requirements and expectations of such a GPS network. It is important to identify these before getting into detailed discussions with other agencies that are, or might be, interested in establishing GPS tracking stations.

4 Benefits of Access to GPS Tracking Data

A number of desirable outcomes or benefits can be identified that result from the provision of continuous access to GPS tracking station data through an active control network.

4.1 Opportunities

Access to the spatial infrastructure can be provided, as at present, through a large number of geodetic marks. This requires reasonably high maintenance and ongoing survey costs. There is an increasing use of space positioning systems such as GPS and these can offer significant cost savings in geodetic and other surveys. There is a trend both overseas [eg *Davis* 1999 and *Spofford and Weston* 1998] and in New Zealand for the development of GPS permanent tracking stations. Some of the specific benefits to LINZ and LINZ clients are identified in sections 4.2 and 4.3 below.

GPS permanent tracking stations are used internationally, and to an increasing extent in New Zealand, to support the geodetic infrastructure in the following ways:

- They provide greater confidence in the geometry and performance of the datum through continuously collecting and analysing data;
- They enable significant gains in the way that the datum (through geodetic control) can be developed and maintained through new survey control being surveyed directly into the high integrity spatial infrastructure (eg Zero Order network);
- They allow connection of local surveys, eg. cadastral surveys, into the high integrity spatial infrastructure (e.g. Zero Order network) to enable seamless and spatially consistent data sets to be developed and contribute to the local geodetic framework;
- Future improvements in the processing of longer GPS baselines will allow greater efficiencies in the design of the geodetic network and the way that surveys can be carried out;
- They will lead to an enhancement of the spatial infrastructure that benefits all users through simplifying the integration of spatial data sets within New Zealand and internationally.

Other positioning applications supported by these stations can include:

- Continuous monitoring of the movement of large engineering structures such as bridges;
- Acting as the basis for air and sea transport safety including precision airport approach;

- Supporting law enforcement by providing proof of the integrity of evidence based on GPS positions.

In addition, such networks are used for scientific and environmental studies including the following:

- Continuous monitoring of crustal deformation;
- Continuous monitoring of the atmosphere for weather forecasting and climate research;
- In association with other sensors, they contribute to studies of ocean circulation patterns, which, in turn contributes to vertical reference systems, climate research and marine resource management.

Annex B provides more detail on the uses and benefits of a GPS permanent tracking network.

4.2 Direct Benefits to LINZ

Two Zero Order marks, Whangaparoa and Chatham, are permanent GPS tracking stations and are also global fiducial sites contributing data used to determine GPS orbits and maintain the ITRF. Thus New Zealand already contributes to, and is a beneficiary of, the global "active control network", part of which is managed by the International GPS Service (IGS) and which includes these 2 stations. LINZ has also benefited from other (non-IGS) tracking stations in New Zealand (see Annex A) and Australia in geodetic work to date.

LINZ will receive the following direct and indirect benefits from an active control network of GPS tracking stations:

- High quality data available for periodic monitoring and maintenance of the relationship between NZGD2000 and the international reference systems on which it is based.
- Data available of deformation in New Zealand to allow periodic update of the velocity model on which NZGD2000 is based.
- Data available for periodic monitoring and maintenance of the high order (Zero and 1st Order 2000) networks without the cost of field survey. Note that episodic campaigns currently require field survey.
- Data available to LINZ geodetic contractors to improve the efficiency of field survey for lower order (2nd, 3rd, 4th, & 5th Order 2000) surveys.
- Data available to LINZ topographic and hydrographic contractors improve the efficiency of connecting topographic and hydrographic data to the spatial infrastructure.

- Data available to cadastral surveyors to increase compatibility of their surveys with Land*online* survey-accurate boundary coordinates.

- Contributions to the geodetic infrastructure from other non-geodetic agencies interested in GPS tracking.

- Coordination of the network design and deployment of GPS stations by a range of government, scientific and commercial agencies.

- Development of a system that will allow future reduction in the cost of maintaining conventional geodetic stations and beacons as GPS becomes increasingly used for cadastral and other surveys.

- Capability to implement a system for continuously determining and recording the integrity of the GPS system in general and specific satellite signals and data in particular.

4.3 Benefits to Other Spatial Users

Other spatial users have requirements for access to the New Zealand spatial infrastructure. As noted in section 3, LINZ and its predecessors have long had a role in providing an appropriate level of access to the geodetic network for these users – the right to physical access being provided for in the Survey Act 1986 and remote observational access provided through maintained trig beacons. Section 4.1 lists some of the applications that can benefit from GPS tracking stations. With the role of GPS steadily increasing, other government and private agencies will develop their own GPS tracking systems. These will have the potential to also contribute to the wider accessibility of the spatial infrastructure. LINZ can offer the providers of these stations the legal status and authority to be part of the geodetic control system by certifying that their stations meet certain Surveyor-General standards in respect of coordinate accuracy, observation quality, permanency, stability, and data access.

5 Desired Characteristics of GPS Tracking Stations

From Land Information NZ's perspective, permanent GPS tracking stations will fall into two broad groups:

1. "LINZ partnership" stations which provide direct benefit in LINZ's role of managing and maintaining the geodetic system. LINZ may make a contribution to the establishment or running costs of these stations in return for specified access to data for LINZ geodetic surveys and long term protection of, and access to, the ground mark.

2. "LINZ certified" stations which exceed LINZ's direct requirements but which generally contribute to the utility of the geodetic network for other users. On request and on provision of supporting data, LINZ may agree to certify that these stations comply with an appropriate geodetic standard and are useable for geodetic or cadastral surveys.

For a GPS permanent tracking network to meet LINZ's requirements for providing efficient access to the spatial infrastructure the following characteristics will need to be satisfied. Where the requirements differ for "LINZ partnership" or "LINZ certified" stations, this will be identified. Note also Annex C which describes in detail the site characteristics required by UNAVCO of a GPS permanent tracking station.

5.1 Site Characteristics

Any site forming part of such a system should be stable and secure. Any LINZ partnership station should have legal protection under the Survey Act 1986 in order to secure the long-term availability of the ground mark. This can be achieved by the Surveyor-General identifying the station as part of the "National Survey Control System". This will also ensure that a registered surveyor may, with the written permission of the Chief Surveyor, gain physical access to the station. This will seldom be required because the observed GPS data effectively provides access to the station. However, it is possible that occasional access may be required for audit purposes to confirm the stability or correct setup of the equipment, eccentricity measurements, etc. It also ensures the continued availability of the mark should the principal agency establishing the GPS receiver, decide to withdraw from the network.

LINZ may need to consider whether continued sky visibility and freedom from electrical interference needs to be protected by some form of easement or other agreement over land in the vicinity of the GPS receiver.

Ideally, key stations will have the ability to house multiple geodetic sensors (eg DORIS, other positioning techniques).

5.2 Density of Active Control Network

To satisfy LINZ requirements and monitor the dynamics of the NZGD2000 geodetic network a network of GPS permanent tracking stations spaced at a similar density to the current 1st Order 2000 network is proposed (20 – 30 stations) for the LINZ partnership stations. This density of approximately 80km spacing between stations means that most parts of New Zealand will be no more than approximately 60km from a permanent tracking station. Over this distance most commercially available software will be able to compute results within the LINZ accuracy specifications for geodetic control surveys. To allow efficient upgrading and densifying of the geodetic and cadastral network it is intended that stations near population centres be implemented first to gain the maximum benefits from this network at an early stage of the project.

The density of LINZ certified GPS permanent tracking stations will be determined by the providers or owners of these stations. It is anticipated that many of these will also be located in major population centres. Others will be in areas of high scientific interest which may be in areas of lower economic activity.

5.3 Hardware

Hardware used for an active control network needs to be of a design and type that is capable of measuring inter-station vectors to LINZ geodetic standards. For LINZ partnership stations deployed at the density of the 1st Order 2000 network, the appropriate standard will be B100H/B300V (*Office of Surveyor-General* 1998b) which is the Class 2000 associated with the 1st Order Network. Accordingly, GPS receivers at these stations will need to be of a dual frequency type and will require an antenna that minimises the effects of multipath.

For LINZ certified stations, which may be higher density and intended for use over shorter distances, it is possible that single frequency stations may be used. The order of the station coordinate can be specified and the class of observations that this station is capable of supporting will be dependant on the type of hardware installed (ie the station can be certified to a given order of accuracy).

5.4 Access to Data

The following is required for access to data by LINZ or LINZ geodetic contractors for LINZ Partnership stations:

- Data must be available at 30 second intervals. Higher data logging rates may be required for other applications and users. This will be acceptable provided that the data-logging interval is an exact divisor of 30 seconds.

- Data shall be provided in at least RINEX format. Other proprietary formats may also be provided.

- A clear process will be required for providing assurance of data quality.
- Data shall be recorded and made available for at least 95% of any week. A mechanism will be required to allow potential users to identify whether a station is operating at a given time or not.
- Data shall be available for downloading and use within 24 hours from the time of observing.
- Provision must be made for data storage and archive. The exact LINZ requirements for how long data is archived and the time taken for retrieval are yet to be specified.

LINZ certified stations will need to have a mechanism to provide data to the general survey community (either free-to-air or, more commonly, on a commercial basis) in order to be considered for LINZ certification. The following are the expectations for access to data by general users for LINZ Certified stations. Note that these expectations are available for discussion with GPS tracking station providers.

- Data logging intervals should be an exact divisor of 30 seconds so that data from these stations and the LINZ partnership stations can be processed together.
- Data should be provided in commonly used formats. These may be proprietary formats such as those of the major GPS receiver manufacturers. Ideally, data for post-processing should also be available in RINEX format or should be readily translatable to RINEX.
- A clear process should be in place for providing assurance of data quality.
- Data should be recorded and made continuously available for at least 95% of any week.
- Data should be available either immediately for real time survey, or within 24 hours for post-processing.

6 Recommendations for Improving Access to the New Zealand Spatial Infrastructure

The development of a planned GPS Permanent Tracking Network will enhance the geodetic network and provide continuous access to it. It will also lead to efficiency gains in the way the geodetic network is densified and maintained and will bring efficiencies and advantages to spatial data users.

Recommendations for the development of a GPS permanent tracking network over the next five years to satisfy LINZ requirements are:

- development of a permanent GPS tracking network through partnership with other organisations;
- the partnerships to be formalised through memoranda of understanding or contracts;
- the density of LINZ partnership stations to be similar to the current 1st Order 2000 network i.e. approximately 20-30 stations;
- the highest priority for installation of LINZ partnership stations to be for sites near populated areas; and
- LINZ to provide standards and a process to enable additional permanent tracking stations, which exceed LINZ's direct requirements, to be certified as meeting the Surveyor-General's standards for cadastral or geodetic survey.

7 References

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Ottoson C. and B Jonsson 1998: GPS positioning cm-level accuracy in real time. *Paper presented at the XXI Congress of the International Federation of Surveyors (FIG) Brighton United Kingdom Commission 5 Technical Session 10.*

Pearse M. and G Rowe 1997: New Zealand’s primary GPS sites. *LINZ Geodetic System Technical Report GS1997/3.*

Spofford P.R. and N.D. Weston 1998: CORS The National Geodetic Survey’s continuously operating reference station project status and plans. *American Congress on Surveying and Mapping Bulletin, March/April 1998.*

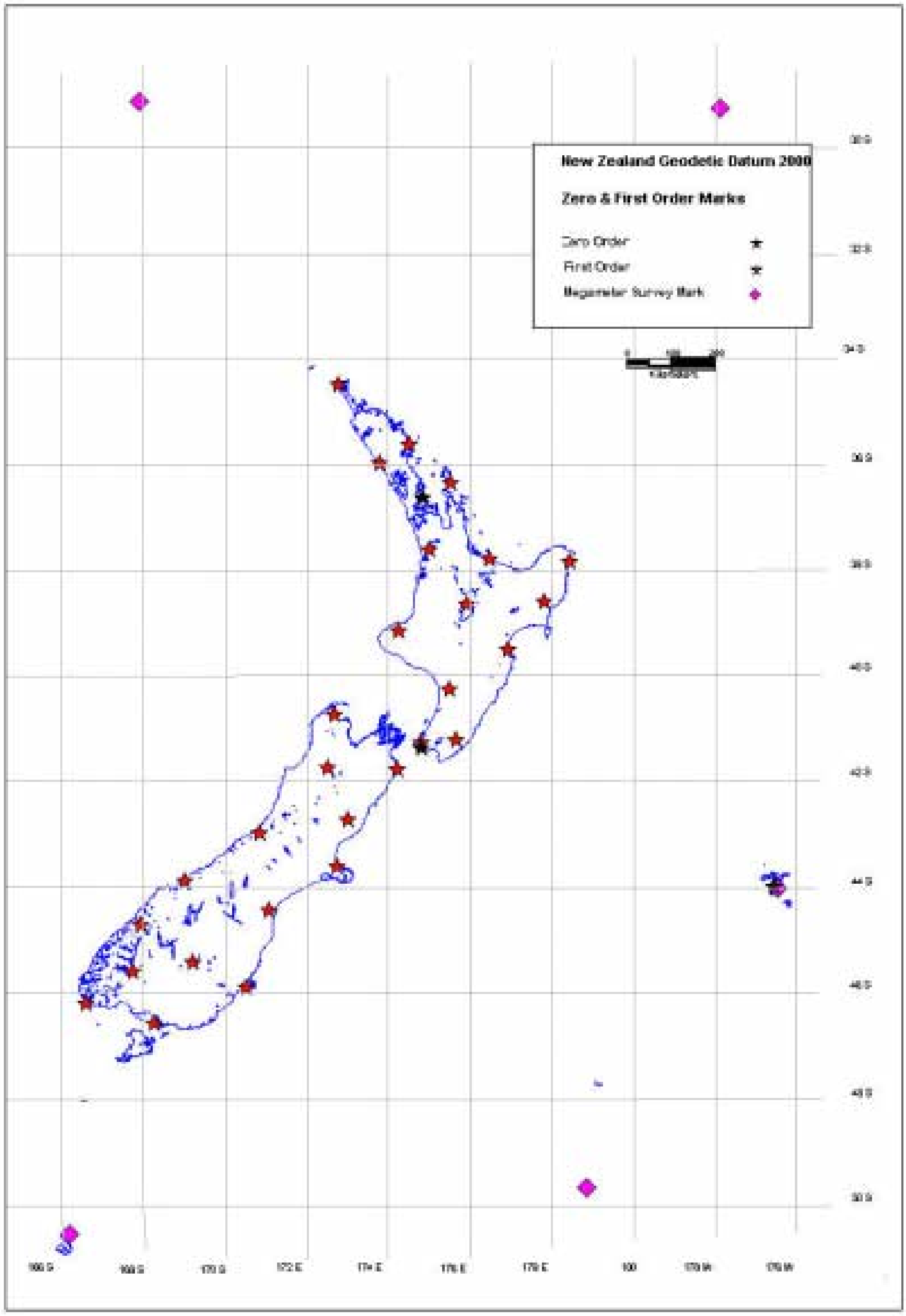

Figure 1. Datum 2000 1st Order Stations.

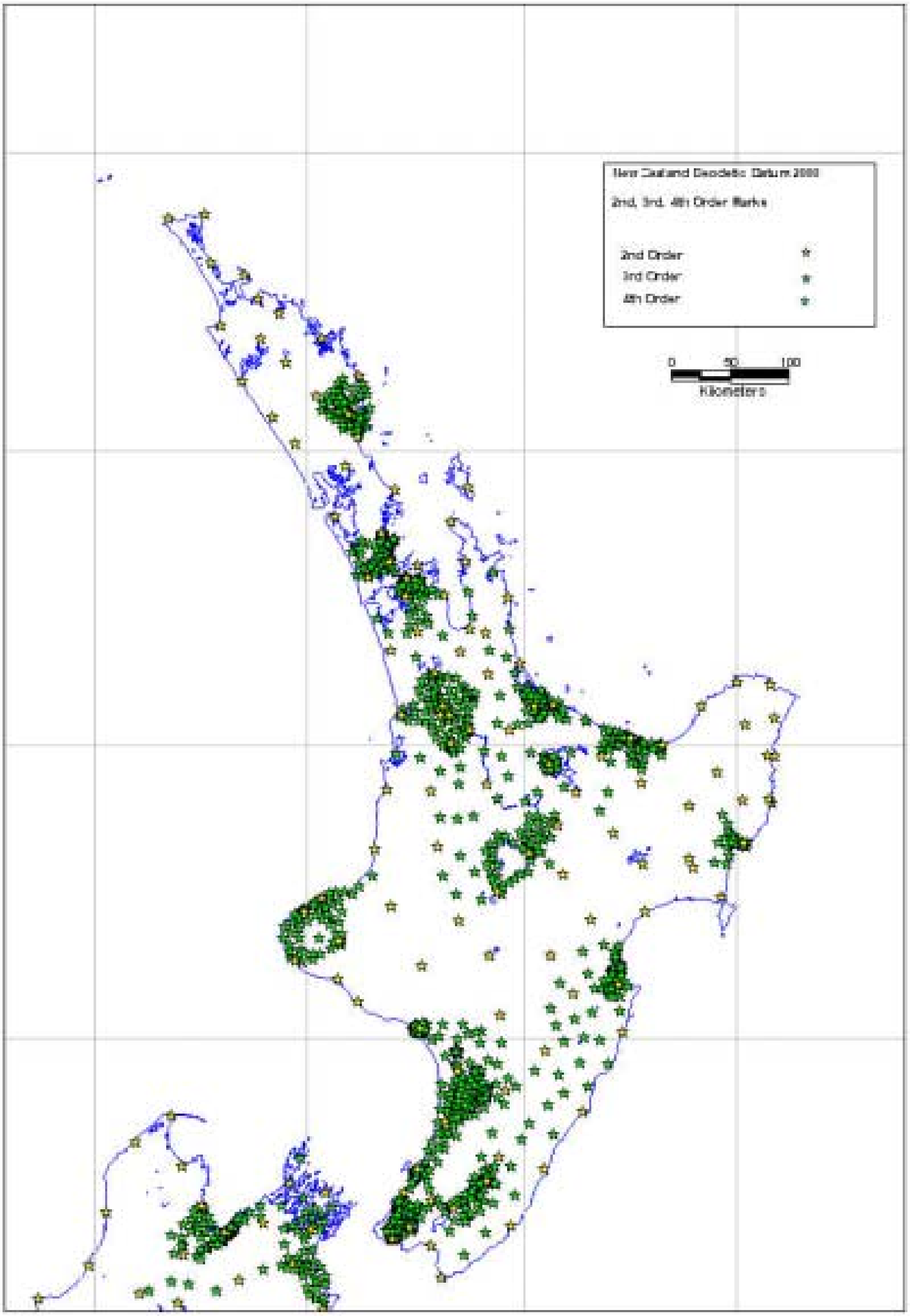

Figure 2. North Island Datum 2000 Marks

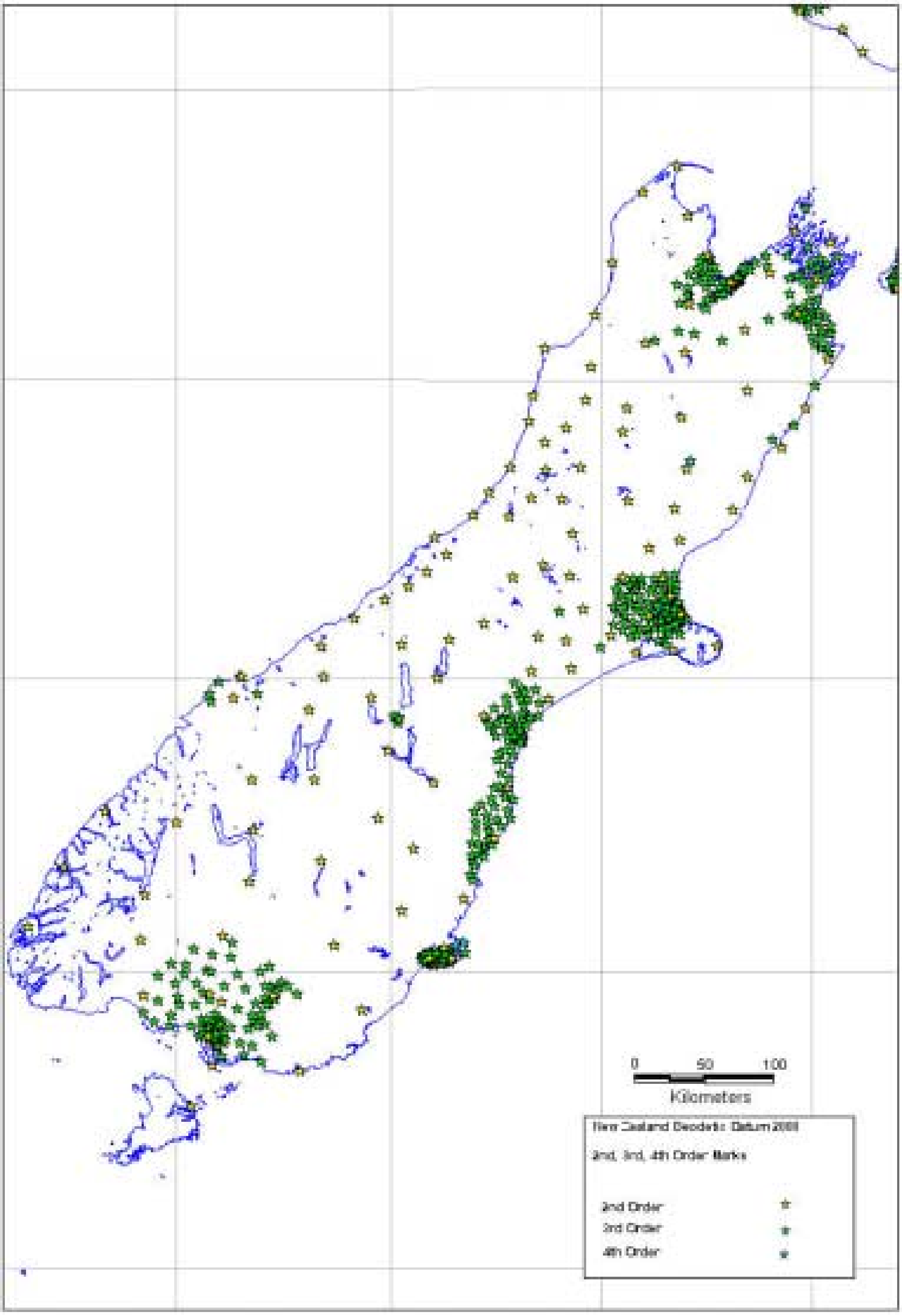

Figure 3. South Island Datum 2000 Marks

Annex A

1 Proposed GPS Permanent Tracking Stations

1.1 IGNS Hazard Monitoring Network

A Hazard Monitoring Network is being established by IGNS to obtain near real-time information about geological hazards, eg volcanic activity, earthquakes, landslides and tsunamis. Some sites will include permanently operating dual frequency GPS receivers. The GPS receivers at the hazard monitoring sites are to be located with other instruments such as seismographs and weather stations. The proposal is to install 10 sites over the next 3 years and at least another 10 sites in the following 3 years with a relatively even distribution along the plate boundary and around major population centres.

1.2 Otago University Tide Gauge Monitoring Network

The Surveying School at Otago University and IGNS have received funding to investigate the changes in sea level around the New Zealand coastline. The project plans to co-locate permanently operating dual frequency GPS receivers at the Dunedin, Christchurch, Wellington and Auckland tide gauges. This co-location of GPS receivers at tide gauges will help monitor the stability of the tide gauge installations.

1.3 Other

A number of other single frequency GPS permanent tracking stations are operated throughout New Zealand including the Terralink TERRANAV GPS network and various receivers operated by private survey companies.

2 Currently Operating GPS Permanent Tracking Stations

The information is an update of that contained in LINZ Geodetic System Technical Report 1997/3.

Auckland (Whangaparaoa No 3)

Responsible Organisation/s :	Jet Propulsion Laboratory (JPL), University Navstar Consortium (UNAVCO), Institute of Geological and Nuclear Science Ltd (IGNS).
Contact :	John Beavan, IGNS, (04) 5704641, j.beavan@gns.cri.nz
Receiver Type :	Rogue SNR 8000; with Dorne Margolin T antenna
Data Storage Site :	International GPS Service for Geodynamics (IGS)
Data Access :	Free from IGS FTP site (igscb.jpl.nasa.gov)
Data Commenced :	18 September 1995
Geodetic Code :	AUCK

Station Description :	Situated in a Met Service station located in the Army/Navy camp on the Whangaparaoa Peninsula.
LINZ involvement :	no longer any formal input
Station History :	The station was established as a more secure site than either 1334 or 5515.
Primary Data Use :	Geodynamic Studies

Auckland (NZOT)

Responsible Organisation/s :	New Zealand Ocean Technology Ltd (NZOT) and Fugro (Perth)
Contact :	Ron Tyson, NZOT, (09) 486 6806
Receiver Type :	Trimble 4000 SSI; with Dorne Margolin T antenna
Data Storage Site :	Fugro STARFIX Pty, West Perth, Western Australia.
Data Access :	RTCM data through Fugro’s Starfix DGPS service, data charges apply.
Data Commenced :	early 1995
Geodetic Code :	none
Station Description :	Situated on the roof of the Canon Building, Fred Thomas Drive, Takapuna.
LINZ involvement :	none
Station History :	unknown
Primary Data Use :	Real Time Differential GPS for primarily navigation

Chatham Island

Responsible Organisation/s :	Jet Propulsion Laboratory (JPL), University Navstar Consortium (UNAVCO), Institute of Geological and Nuclear Science Ltd (IGNS)
Contacts :	John Beavan, IGNS, (04) 5704641, j.beavan@gns.cri.nz
Receiver Type :	Rogue SNR 8000; with Dorne Margolin T antenna
Data Storage Site :	International GPS Service for Geodynamics (IGS)
Data Access :	Free from IGS FTP site (igscb.jpl.nasa.gov)
Data Commenced :	4 October 1995
Geodetic Code :	CHAT
Station Description :	Situated next to the Met Service station on Waitangi - Tuku Road, 0.5 km SW of Waitangi.
LINZ involvement :	no longer any formal input
Station History :	This station was chosen in preference to either 5503, 5504 or 5505 due to site security and communication facilities.
Primary Data Use :	Geodynamic Studies
Notes :	The Chatham Island station (CHAT) is currently not situated on rock. It is possible that this receiver will be relocated to a more suitable site in the future.

Christchurch (Terralink)

Responsible Organisation/s :	Terralink NZ Ltd
Contact :	Glen Rowe, Terralink, (04) 4706084
Receiver Type :	Trimble 4000 SSI; with an L1/L2 permanent antenna
Data Storage Site :	Terralink
Data Access :	Request from Terralink, data archived for only the last 70 days and data charges apply.
Data Commenced :	December 1995
Geodetic Code :	none

Station Description :	Situated on roof of Transport House, 151 Kilmore Street, Christchurch.
LINZ involvement :	none
Station History :	unknown
Primary Data Use :	Real Time Differential GPS

Hokitika

Responsible Organisation/s :	Institute of Geological and Nuclear Science Ltd (IGNS)
Contacts :	John Beavan, IGNS, (04) 5704641, j.beavan@gns.cri.nz
Receiver Type :	Ashtech Z-XII3; with Ashtech Choke Ring antenna
Data Storage Site :	IGNS
Data Access :	Request from IGNS
Data Commenced :	7 July 1998
Geodetic Code :	HOKI
Station Description :	Situated at the NZ Met Service station on within the grounds of Hokitika Airport.
LINZ involvement :	Funded installation of pillar.
Station History :	This station was chosen to reduce the need to occupy the Mt Greenland station (1420) which has difficult access and J Blue Spur (1421).
Primary Data Use :	Geodynamic Studies

Otago University

Responsible Organisation/s :	Otago University, Department of Surveying
Contacts :	Joseph Mulder, Otago University, (03) 479 7585, mulder@albers.otago.ac.nz
Receiver Type :	Trimble 4000 SSE and compact antenna with ground plane
Data Storage Site :	Otago University, Department of Surveying
Data Access :	Request from Otago University, Department of Surveying.
Data Commenced :	January 1995
Geodetic Code :	OUSD (initially OTA1)
Station Description :	Situated on the roof of the New Sciences Building, 304 Castle Street, Dunedin.
LINZ involvement :	None.
Station History :	The station was established in 1993 as a replacement for OTAG (also known as A21R), due to the relocation of the Department of Surveying.
Primary Data Use :	Real Time Differential GPS and forms part of the Fugro STARFIX network.

Wellington Airport

Responsible Organisation/s :	Institute of Geological and Nuclear Science Ltd (IGNS), and LINZ
Contacts :	John Beavan, IGNS, (04) 5704641, j.beavan@gns.cri.nz
Receiver Type :	Ashtech Z12 receiver and Dorne Margolin T antenna
Data Storage Site :	IGNS
Data Access :	Request from IGNS
Data Commenced :	August 1996
Geodetic Code :	WGTN
Station Description :	Situated midway along the western side of the Wellington Airport runaway.

LINZ involvement :	Funding datalink costs for line rentals from Telecom (Ed Wilson 382 3203) and Airways Corporation (John Meyer 387 8129) used to remotely monitor and download data from the receiver.
Station History :	The station was established as a replacement for WELL, due to the concerns about site stability of the Heaphy House building.
Primary Data Use :	Geodynamic Studies, though originally Australian GPS Integrity Monitoring Service.

Annex B

Improving Access to the New Zealand Spatial Infrastructure

1 Background

The existing NZGD49 network of 1st order marks consists of approximately 290 marks. These marks are the primary realisation of the NZGD49 datum. Since the new datum (NZGD2000) acknowledges that the network is deforming, the primary network needs to be monitored to detect significant variations in the spatial relationship of the ground marks.

The primary realisation of the NZGD2000 network is via the current 3 Zero and 28 1st Order 2000 marks. This network has approximately 10% of the defining marks that NZGD49 had and therefore the costs of re-surveying the network are significantly lower.

It has been shown that mounting large campaign style geodetic surveys are less efficient than using a smaller number of roving receivers in conjunction with data from GPS permanent tracking stations [*Bevis et al* 1997]. GPS Permanent Tracking networks are now forming an integral part of geodetic networks worldwide [eg *Spoff and Weston* 1998, and *Davis* 1999].

GPS Permanent Tracking Stations are used to support the geodetic infrastructure in the following ways:

- They enable the continuous monitoring of crustal deformation. This data is used to develop and maintain the velocity model required for the implementation and maintenance of NZGD2000. The current velocity model has been developed using repeated annual GPS surveys, which includes the 28 First Order marks. The development and installation of a significant number of permanent tracking stations would eliminate the need for re-surveys of the 1st Order network to monitor crustal deformation;

- They provide greater confidence in the geometry and performance of the datum through continuously collecting and analysing data. An improved confidence in the network is required as distortions in the Zero and 1st Order network will highlight discrepancies when fixing a point from two or more of these distant marks;

- They enable significant gains in the way that the datum (through geodetic control) can be developed and maintained through the control being surveyed directly into the high integrity spatial infrastructure. Because the permanent tracking stations are operating continuously, contractors can use this information along with their data to complete geodetic contracts more efficiently, and with less field personnel and equipment. Examples in the US

[*Spofford and Weston*] and Europe [*Ottoson and Jonsson* 1998] show the trend towards permanent stations replacing more dense conventional geodetic networks;

- Connecting local surveys, eg. cadastral surveys, into the high integrity spatial infrastructure (Zero Order network) will ensure seamless and spatially consistent data sets and will contribute to the local geodetic framework;

- With future improvements in the processing of longer GPS baselines, the design of the geodetic network will change. With a small number of high integrity stations (eg permanent tracking stations) it will be possible to replace the current six tiered (eg Zero-5th Order) system with a two or three tiered system (eg Zero, 3rd and 5th Order) due to the ability to survey directly off the Zero Order network when fixing control marks. This will result in considerable maintenance cost savings due to the smaller reliance on many intermediary marks and the ability to easily and efficiently replace 5th Order marks. The 2nd and 3rd Order infrastructure was installed to provide a method of efficiently densifying NZGD2000 so that the users of the system had accessible marks. With GPS base stations and improving methodologies the user may one day be able to skip straight to the 5th order from the zero order;

- As other permanent tracking stations of suitable specification are implemented by spatial positioning users, eg cadastral surveyors, utility companies and local authorities, they should be incorporated into the Zero Order network. This will lead to an enhancement of the spatial reference system that benefits all users through simplifying the integration of spatial data sets within New Zealand and internationally. This will enable the seamless conversion between global and regional networks;

The following issues must also be considered:

- GPS permanent tracking stations need to have a higher level of security, permanence and stability of operations than conventional marks, over a relatively long (10-20 years) term;

- GPS will not satisfy all applications and provision will need to be made for the use of conventional survey methods in some areas;

In the future satellite positioning methods (eg GPS) based on post-processing of data will only be an interim step towards the time when real-time precise positioning will be possible from a network of permanent tracking stations across the country. This is likely to be possible within 5 years given a network of permanent tracking stations. At this time the importance of maintaining all geodetic marks will diminish as it will be a simple and relatively inexpensive task to re-establish new marks and also coordinate existing marks from the zero order network with the exception of areas where GPS is not effective.

2 Future Development of the Zero Order 2000 Network

2.1 Zero Order 2000 Network

Collaboration with other organisations to ensure the long term existence of the ground marks and operation of GPS stations is a prime goal for LINZ where these stations satisfy its needs to monitor the integrity of the spatial infrastructure and provide access to the geodetic network. It is envisaged that a network of approximately 20-30 stations (at the approximate density of the current 1st Order 2000 network - see Figure 1) will satisfy the need to monitor the datum.

Efficiency gains will be attained through the ability to coordinate geodetic and other surveys directly from this permanent tracking network.

2.2 Secondary GPS Permanent Tracking Stations

In addition to the network of Zero Order 2000 marks, LINZ should provide the standards and operational guidelines to enable secondary GPS permanent tracking stations to be incorporated into the Datum 2000 network. The advantage of a secondary network is that it increases the number of stations and provides a uniform system of reference stations for users that also contribute to the spatial infrastructure.

An example of guidelines for the establishment of GPS permanent tracking stations from the University NAVSTAR Consortium (UNAVCO) is included as Annex C. Where stations meet the standards required by LINZ they will be incorporated into the Datum 2000 network and LINZ will provide authoritative recognition of these stations and coordinates in terms of the datum.

Adoption of this option would see a continual enhancement and development of the spatial infrastructure.

3 Issues

In considering the development of a network of GPS permanent tracking stations there are a number of issues which need further consideration:

- Does LINZ, as the authoritative agency for the maintenance of the NZ spatial infrastructure, need to maintain a data archive of all data from the Zero Order and/or secondary network?

- How can LINZ maintain the long term availability and operation of the Zero Order network, particularly where some potential partners may have shorter term objectives?

- Are LINZ needs better accommodated through a partnership, or through a contractual arrangement with potential suppliers?

- What is the long term viability of a GPS based Zero Order network to satisfy spatial referencing needs in NZ using the current or future technology?
- How can LINZ maintain the long term protection of GPS tracking sites through legislation, eg. trig reserves? Protection would need to cover sky visibility and electrical interference.
- What specifications are required for monument stability, data stream reliability, data availability, and other characteristics of GPS tracking sites that need to be stipulated?
- To what extent do existing technologies need to be provided for?

Annex C

Site Planning and Reconnaissance Guidelines

These guidelines for the establishment of a GPS permanent tracking stations are taken from the University NAVSTAR Consortium (UNAVCO), Boulder, Colorado.

1 Site Selection

An important consideration in selecting a site is a clear view of the sky with no obstructions above an inclination angle of 10-15 degrees. Keep in mind that tall, dense trees near the site can contribute to intermittent loss of lock of the signal, just as buildings do. Be aware of the impact of foliage when reconnaissance is conducted during the cold season. If small trees are present but do not block the sky appreciably, assess their rate of growth if the station is to be occupied for several years. Flat surfaces (vertical or horizontal) near the antenna can cause serious problems with multipath interference. As a rule of thumb, a one-story building should be at least 50 feet away while taller buildings need to be farther away.

Other potential fixed reflectors include chain-link fences, metal objects located in the vicinity, and time-varying reflectors such as parked cars, moving vehicles, scaffolding, etc. A station obstruction diagram should be sketched to identify the approximate distance and bearing to the nearest obstacles. Include potential sources of radio interference such as high-power television or microwave transmission towers. Ideally, the site should be kept at least 1 km away from such structures.

During the initial visit to the proposed site, try to collect data for at least 24 hours (preferably 48 hours) to assess the quality of the site. Consider also ease of access and proper authorisation from private property owners. For example, permission to build a station may be granted by the owner, but access may have to be negotiated with landowners whose properties are adjacent to the site in question. Names and numbers of site contacts should be well documented.

Weather conditions are not normally a factor for permanent site selection since automation is a primary goal and maintenance visits can be arranged during period of good weather. The local climate will mainly dictate the choice of equipment and standards that must be met. For instance, in a cold climate, snow accumulation on the antenna may become a factor.

2 Monumentation

A permanent, stable, high-quality monument is a must for a continuous site installation. A typical monument has a ground-level base that is anchored at depth and decoupled from the surface as much as possible, and an antenna mount that can be precisely positioned on this base. The actual specifications for the monument will depend on the application and local site characteristics. Stability, cost, and access are the driving considerations.

Geodetic quality monuments must meet the most stringent quality standards. Weather-related changes that affect soil stability can mask important geodetic signals. Soil expansion and compaction in response to varying amounts of moisture, or thermal expansion are examples of such problems. So, the lack of significant outcropping in the area of interest may require the construction of a deeply anchored, isolated, braced monument to minimise environmentally caused displacements. If bedrock is available, assess its quality and look for unfractured, unweathered, highly indurated rock that is free of clay minerals. You may consider clean carbonates too, but watch for fractures which fill with soil, as well as water. These fractures will be subjected to expansion and contraction with varying temperature and water saturation. In any case, avoid placing a monument in an area likely to be affected by runoff or natural drainage during precipitation events or snow melt. The depth of the water table and its fluctuations due to natural or human causes are also important considerations in the long-term stability of a monument. Finally, make sure that the "outcrop" or boulder you are looking at is not just embedded in surrounding soil. Such a marker will move around with the soil as it creeps, expands, contracts, etc. Based on the above considerations, it is quite obvious that ultimate stability is dictated by the ground material. The accuracy of the geodetic signal is only as good as the weakest link in the measurement process and the burden is typically placed on the monument.

Other long-term GPS monitoring applications such as subsidence studies for sites built on unconsolidated materials may dictate the use of shallow monuments allowing the recording of the stabilisation process (i.e. deltaic sinking vs sea level rise). An extreme situation involves the monitoring of ecosystems, soil dynamics where the signal of interest is not geodetic in nature, but based on biological processes. In such cases, care should be taken to isolate the marker from extraneous motion which is not part of the process being studied.

As outlined above, reconnaissance requires evaluation of the rock quality or, if no outcroppings are present nearby, the determination of the expansive characteristics of the soil. Also include an estimate of the time and expense needed for building the monument. For instance, the hardness of the rock will determine the type of drill bit for the marker. Simple design can often be achieved for monuments being placed on very high quality bedrock, while a more elaborate design will be required for a monument anchored in highly expansive soils. Remember that the quality and stability of the permanent marker must reflect its intended use to keep construction costs reasonable. The need for specialised equipment, and the presence of water for construction are also important considerations.

3 Power

All permanent GPS sites require a reliable power supply for continuous data logging and periodic downloads. The simplest alternative is to install the receiver and ancillary equipment near a local AC power outlet, or to string a power cable out to the instrument box. Therefore, it is necessary to consult local utility companies or local owners of nearby power hook-ups. If a cable must be used, decide whether it will run above ground or will be buried for security or safety reasons. The cost for trenching may become significant, both in terms of labour and the contracting of earth-moving equipment. The reliability of the power supply should be assessed. Brown-out conditions are especially worrisome in developing countries and the autonomy provided by the battery backup should cover the longest expected power failure. Inquire with nearby power customers on the frequency of occurrence of power failures.

If a GPS site is located in a remote area, an independent source of power may be required. A photovoltaic (solar-powered) system with a battery backup is normally used to ensure a stable power supply. Design considerations are particularly important and the size of the system must be balanced against the cost of using more panels for increased autonomy. Solar panel efficiency is dependent on the season, latitude, and local climate (cloud cover and temperature). Solar radiation statistics should be obtained from the weather facility nearest the proposed GPS site along with worst-case scenarios based on a return rate corresponding to the estimated length of occupation for the station. It is important to remember that power requirements increase for additional equipment and, therefore, use foresight in designing the system. As an example, it may be that, initially, downloads will be done to a local disk (on site) with semi-annual or annual visits to recover the data. At the outset the site is a stand-alone station with no need for communication hardware. However, it may be that some time later, you want to include a modem to transfer data daily for near real-time use. The use of a modem and possibly a cellular phone will place a significant additional load on the system which may then become too lean without an upgrade.

The battery bank size will determine the autonomy or reserve time for the system in case of prolonged overcast conditions. Keep in mind that a total overcast is not necessary to deplete battery charge over time. If, for instance, the system was designed for an average of 3.5 hours of bright sunshine daily, and, that for an unusually cloudy month, sunshine averages only 2 hours per day, the deficit in power output by the solar panels will have to be supplemented by the batteries which will then register a voltage drop over time. Therefore, proper design must include battery discharge and charge rates for various scenarios.

The decision of using solar power vs local AC power to supply the site may not be an easy one if local AC power is available but some distance away, and must be brought in. There are no hard-and-fast rules on the maximum distance for which a cable can be run to the nearest power source. A higher-gauge power cable will be required for lengths exceeding a few meters to prevent significant voltage drop over distance. The final decision is usually one of cost: at which point does a self-powered continuous station becomes cheaper than one relying on AC power? The question may not even arise if the reliability of local power cannot be demonstrated.

4 Communications

Besides being self-sufficient with power, the significant advantage of unmanned, maintenance-free GPS sites lies in the capability to download data on a regular basis which provides a way to monitor ground motion rates and station performance on a near "real-time" basis. Remote communications equipment comes in a wide variety of hardware configurations depending on the application.

First, determine the desired location of the data relay site. Can the download computer be co-located with the receiver, or is it required to place it some distance away from the equipment box (i.e. in a nearby building)? If co-location is not feasible, a communication link between the receiver and computer will be needed. If local phone service is available nearby, will the line be shared by other users, so that a dedicated line may become necessary? As in the case of AC power, the cost of running a cable to the site must be looked into.

If phone service is not available, one should turn to short-haul modems or radio modems. A short-haul modem is required if the base computer is located at a distance greater than the practical limit of 50 feet for standard serial RS-232 cables. However, the requirement for a physical wire connecting the computer and receiver limits the usefulness of a short-haul modem to distances usually shorter than their intended limit of approximately 4 miles. One reason is that the transmission rate is a function of distance with maximum data rates of 19200 bps being achieved over distances of 1 mile or less.

New wireless technology offered by radio modems provides an effective data throughput (2.4-19.2kbps) using a carrier-independent mode of transmission over distances of up to 100 km so long as line-of-sight is maintained. For remote sites, this may be the only alternative to ensure regular data downloads. Radio modems require an external antenna for transmission and, therefore, inter visibility between the receiver and download sites is required. For truly remote sites, consideration should be placed on high power antennas, radio repeater sites, or the use of in-line amplifiers to boost the range and data throughput. Inquire with local communication licensing authorities regarding the use of high-powered radio communications. Another option for enhanced communications is the choice of a directional (Yagi) antenna over an omnidirectional one, particularly if only one leg is required between the master and slave. The initial investment for a radio modem is relatively high (2 to 3 times the cost of a phone modem), but the cost is somewhat offset by the fact that, once installed, the user does not incur additional toll charges for each connection. A mixed communication mode may also be a viable alternative where a remote radio link is connected to a remotely located phone line (especially if it means removing the need for radio repeaters).

Finally, it is common to use cellular phone communications for sites located within cellular coverage. The main disadvantage of such communication modality is the cost and relatively low throughput rate due to its analog design. It is not usually possible to achieve data rates beyond 4800 kbs because of unpredictable maintenance and testing activities performed by the local cellular provider (which may be undetectable for voice communications). Since cellular coverage may overlap between providers, it is worthwhile to look at different providers for the best and most reliable cellular connection.

Once a location has been selected for the base computer implement a data retrieval mechanism for distribution, post-processing, and archiving. The availability of an internet connection facilitates the process by allowing regular data transfers to regional processing centres. However, if internet access is not possible, you should consider backing up the data to a local removable medium. Arrangements must then be made to have a local contact person replace the disk on a regular basis (depending on the sampling rate, this operation may only be required once or twice a year for large capacity disks).

For all telecommunication modalities, it is important to test communication links. In the case of phone communications, intermittent noise on the line could prevent successful data downloads. For radio and cellular phone communications, physical obstructions or electromagnetic interference can seriously affect communications. In the case of cellular phones make sure that the site is well within range of cellular access (which can be different than the figures given by the provider).

5 Security

Site safety is especially important if the electronic equipment cannot be placed in a secure building adjacent to the site. There are two levels of protection one must consider for a permanent station: protection against the elements and security from manmade and/or animal interference. It is imperative that all external surface cables be protected against hoofed animals (deer, sheep, goats, cows, etc), rodents of any kind (squirrels, raccoons, etc), as well as pets. A good level of protection is achieved by using flexible tubing to house cables, or better yet, burying them.

The station should be as unobtrusive as possible to avoid drawing the attention of passers-by. However, ease of access must be balanced against the need to prevent potential acts of vandalism and/or theft. Inquire with locals and police about vandalism incidents. There may be additional cost involved if a fence or other perimeter enclosure has to be built to protect the site, or if special precautions must be taken to camouflage it.

Protection against environmental factors can follow somewhat better established guidelines by consulting the regional weather bureau on the local climate and extreme conditions likely to be experienced. Industry standards use rating systems to identify a lock box's ability to perform well under certain types of conditions. The lowest level of protection should prevent rain and/or snow from affecting everyday operations. Higher ratings may provide additional protection against factors such as windblown rain (in areas prone to tropical storm events), windblown dust (arid areas), icing conditions (mountain tops, cold climates), etc. The highest level of protection against environmental conditions is provided by a NEMA-4 box. All outdoor enclosures should be rated NEMA-3 or higher. For outdoor enclosures, temperature extremes should also be factored in, as well as their impact on each piece of equipment. Heat generated by electronic devices may sometimes compound high outside temperatures, and a fan or other cooling device may be needed.