Active GPS and Survey Marks

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Executive Summary

The ICSM Geodesy Technical Sub-Committee (GTSC) has identified two fundamental drivers for the uptake of digital Global Navigation Satellite Systems (GNSS) networks into the geodetic infrastructure. They are:

1. Improved positioning efficiency from new GNSS technology, including the ease with which the geodetic infrastructure can be upgraded or densified, and
2. The need to facilitate and manage the increasing uptake of GNSS technology by a wide group of users, ranging from cadastral surveyors to non-specialist indirect users, ensuring it is compatible with the existing infrastructure and works effectively with it.

The GTSC also identified a list of issues that need to be considered. Clearly the context of particular issues may vary with local conditions and requirements, but all must be considered when integrating new technology with the old. The following list introduces these issues:

- *Keeping the geodetic infrastructure relevant to the user base*
- *Cost effective use of existing GNSS equipment*
- *Improved efficiency for mark maintenance*
- *Global geodesy supporting national geodetic infrastructure*
- *Broader (non-survey) spatial community*
- *Increasing non-positioning uses for GNSS inetworks*
- *The need to maintain homogeneous geodetic infrastructure*
- *GNSS is not suitable in all circumstances*
- *GNSS is not well suited to the propagation of the vertical datum*
- *GNSS is useful for AHD benchmark maintenance*
- *Monuments provide positional integrity*
- *Monuments enable integrity of the datum to be monitored*
- *Risk management in a project may restrict GNSS use*
- *GNSS is global & dynamic*

When considering these issues several additional factors also need to be considered. Firstly, integration of GNSS in the geodetic infrastructure serves a far broader “positioning and navigation” community then ever before. One can also identify a non-positioning user community, that nevertheless would benefit from the ground GNSS infrastructure. As such the fiscal implications should be seen as an extension to business and an opportunity, rather than a refocus.

Secondly, the introduction of GNSS has allowed a more targeted approach to the maintenance of the existing physical geodetic infrastructure. The network of survey marks is rapidly changing shape to target areas of high activity and significance.

Finally, jurisdictions have different requirements & policies. For instance, an infrastructure that suits remote Western Australia is quite clearly going to have different requirements to that of central Victoria. The choice of the style and extent of integration of GNSS networks into the existing infrastructure is dependent on the jurisdiction.

Introduction

In May 2000, the GTSC prepared a report on "*The Australian Geodetic Infrastructure– 10 Years & Beyond*" (GTSC, 2000) which predicted that there would be an explosion in the use of positioning and GNSS in general, with a rapidly expanding user base and a broad range of applications. It stressed that all users need convenient access to the physical realisation of the geodetic framework and that although in the long run the need for ground marks will decline as the trend to real time positioning and navigation continues, initially there would be an increase in the number of ground marks as new useable 3-dimensional marks are established. In summary it stated that "*at the very least a relatively smaller number of marks will always be required to define the datum*".

In a subsequent report the GTSC noted that in Australia by 2008 the ITRF-GDA94 difference will exceed a metre and that high accuracy users were already able to see the difference (GTSC, 2002). However, this report also noted that transformation parameters were available to remedy this situation and a further report confirmed this option (GTSC, 2003). ICSM subsequently agreed to retain GDA94 and reassess the situation in 2008. Similarly it was agreed to retain AHD71, but proceed to develop a system to accurately convert ellipsoidal heights to AHD. In 2000, NZGD2000 was introduced in New Zealand incorporating a deformation model to account for the effects of crustal deformation to enable the currency of the datum to be maintained over a period of time. New Zealand chose to retain its 13 separate orthometric vertical datums and develop a new national ellipsoidal-based vertical datum and geoid model to accurately convert between the two systems.

The predictions of the GTSC reports are rapidly becoming evident and the use of GNSS is becoming far more prevalent in the maintenance and densification of the geodetic infrastructure both in Australia and New Zealand. It is also playing an increasing role in the wider spatial industry and other industries that are dependent on accurate positioning and navigation, such as asset management, precision farming and machine guidance in construction and mining, as well as bon-positioning applications such as timing, integrity monitoring and atmospheric sounding. It can be expected that GNSS/CORS will also become important for intelligent transport, emergency services and other previously unanticipated applications such as numerical weather modelling and prediction. For these reasons, ICSM has asked the GTSC to examine and monitor these issues and the following request was proposed.

"*To prepare an issues paper on the technical and fiscal implications of incorporating digital GPS networks into traditional geodetic infrastructures*"

A modern integrated geodetic infrastructure is the fundamental reference frame for all spatial datasets and is the means for all users to gain access to the datum. It consists of a number of elements including:

- Terrestrial networks of physical marks and beacons with horizontal coordinates and/or heights.
- Passive GNSS sites where suitably accurate GNSS observations have been used to establish datum connection on physical marks
- Continuously operating reference stations (CORS) (e.g. Australian Regional GPS Network (ARGN), GPSnet in Victoria, SYDNet, PositioNZ)
- Active or Real Time (RT) GPS systems (e.g. VRS, Omnistar, etc)
- Data, observations and intellectual property (e.g. datums, transformation parameters, standards, etc)

For the purposes of this paper the GTSC interprets the phrase "Digital GPS network" to mean CORS and Active or Real Time networks. These inherently include both post-processed data and real time coordinate solutions.

Drivers

There are two generic drivers for the uptake of digital GNSS networks into the geodetic infrastructure. They are:

1. Improved positioning efficiency from new GNSS technology, including the ease with which the geodetic infrastructure can be upgraded or densified, and
2. The need to facilitate and manage the increasing uptake of GNSS technology by a wide group of users, ranging from cadastral surveyors to non-specialist indirect users, ensuring it is compatible with the existing infrastructure and works effectively with it.

Issues / implications

The inclusion of digital GNSS networks into the geodetic infrastructure and the growing use of such positioning systems in a wide range of non-specialist areas presents a number of issues for the custodians of the geodetic infrastructure. The particular issues may vary with local conditions and requirements, but all must be considered when integrating new technology with the old.

Keeping the geodetic infrastructure relevant to the user base
Development and maintenance of the geodetic infrastructure is a fundamental component of the spatial data infrastructure. While the overriding influence has always been to continually maintain and improve the accuracy and density of the geodetic infrastructure so that it serves a broader section of the spatial industry, the recent development of GNSS positioning technologies has resulted in a change of emphasis. Now we are tasked with keeping the geodetic infrastructure relevant to the user base, which may involve much more than improved accuracy and geometric density of marks.

The number, quality and location of marks can now be more easily targeted directly to user "hot spots" or for specific applications. Depending on the application, users of digital GPS systems could also have specific requirements. The method of access to the real time signal (e.g. mobile phone, radio modem, etc); the format of the data (RTCM, etc); and the required level of accuracy, integrity and security may vary for different user applications.

Cost effective use of existing GNSS equipment
The trend with GNSS applications is to utilize costly GNSS units more effectively by establishing shared Continuously Operating Reference Stations (CORS) in secure locations. For example in New Zealand Land Information New Zealand has established a partnership with Geological and Nuclear Sciences (GNS) to develop their PositioNZ network which controls and monitors the geodetic infrastructure as well as providing information for geophysical studies and hazard mitigation. The next logical step is the augmentation of the system resulting in significant cost and time efficiency improvements for the user. Working cooperatively with government (national, state and local), commercial and academic organizations to reduce overlap and share costs can produce combined solutions that provides benefits to more than the originally intended market.

CORS have setup & maintenance costs, and various models are available for their installation and maintenance. These could range from purely commercial services; through commercial systems owned and operated by government, where real time corrections are sold to industry, as in the Queensland VRS network; wholly government owned systems that provide access to data for post-processing and enable commercial enterprises to value add for real time capability; and consortium infrastructures based on cooperation with industry, academic institutions, all levels of government and community groups where costs, maintenance and benefits are shared with hosts, contributors and partners and value adding and data distribution opportunities are made available to private industry as in Victoria's GPSnet.

Improved efficiency for mark maintenance

GNSS techniques allow datum transfer with high accuracy and reduced logistics & planning. Survey control can be directly established exactly where it is required and marks can be placed and maintained very effectively and efficiently. Intervisibility between the placed marks may need to be considered so they can then be used for exclusively terrestrial applications such as for cadastral surveying.

Global geodesy supporting national geodetic infrastructure

The data from the Continuously Operating Reference Stations, providing they are suitably monumented, can be used for a variety of globally based geodetic applications such as tectonics and geophysics as well as broader scientific studies (e.g. climate and global change). At the highest level they contribute directly to datum definition through the International Terrestrial Reference Frame (ITRF) and datum infill elsewhere. The benefits of a consistent global reference frame then flow back to Australia's and New Zealand's national framework and onto the jurisdiction infrastructure. However, there are a number of other geodetic "products" in addition to reference frame maintenance and point kinematics. These are described in the new document produced by the International Association of Geodesy (IAG) "The Global Geodetic Observing System: Meeting the Requirements of a Global Society on a Changing Planet in 2020". Improved CORS networks in Australiasia could increase this contribution for infrastructure & science

Broader (non-survey) positioning community

Australia and New Zealand have a history of rapidly adopting new technology and GNSS is no exception. In-car navigation systems, geo-referenced communication systems, precision agriculture, machine guidance, Location Based Services (LBS) and many more, are resulting in the range of users of positioning technology growing significantly. Positioning technology through GNSS is penetrating the broader community far deeper than any previous positioning system and terminology such as 'ubiquitous positioning' is becoming the norm. The vast majority of new users are non-survey based and have little understanding of issues like accuracy and datums. Yet the accuracy requirement for these users frequently exceeds that achievable without taking proper account of datum issues. It is therefore sensible that GNSS infrastructure should be setup for the benefit of all possible users

Increasing non-positioning uses for GNSS inetworks

GNSS CORS networks also provide infrastructure to a variety of important non-positioning applications such as time transfer, system integrity monitoring (e.g. for aviation and other mission critical applications), and GPS "meteorology" The latter includes both tropospheric sounding (temperature and water vapour profiles of the lower atmosphere – important for assimilation into weather prediction models) and ionospheric monitoring (Total Electron Content). GNSS meteorology requires RT GNSS data, as well as suitable density and location of the CORS. In fact, as such applications become more important, the density of CORS stations must also take into account the special requirements of such atmospheric monitoring stations.

Need to maintain homogeneous geodetic infrastructure

The proliferation of accurate, active GNSS services in the spatial industry is largely satisfying the requirements of users, with appropriately accurate services (e.g. SunPos, GPSnet, SYDNet, PositioNZ) available over zones of high development, and wide area services (e.g. Omnistar) with generally lower accuracy available elsewhere in Australiasia and worldwide. It does however place the onus on ICSM to ensure that the positioning information obtainable from these systems is compatible with the nationally adopted datums (i.e. GDA94, NZGD2000 and AHD71). The risk of datum fragmentation is serious and potentially economically damaging if a homogeneous geodetic infrastructure is not maintained. In all the examples of overseas active GNSS systems examined, an accurate and accessible method of providing the local coordinates and height is a prerequisite to success (see attached information). In addition, consistent standards for GNSS infrastructure are increasingly required to maximize their application.

GNSS is not suitable in all circumstances

While GNSS applications are expanding rapidly, a number of circumstances and applications still exist where the physical environment is not suitable or friendly to GNSS observations (or the project specifications do not warrant the use of GNSS or it is financially more viable to do it via other survey means). GNSS positioning when used in isolation requires good satellite geometry and sky visibility. The integration of GNSS capability into survey total station equipment extends the flexibility of using GNSS in difficult survey and mapping environments for spatial professionals. The use of GNSS in heavily vegetated areas and urban canyons, which are usually Central Business Districts where the accuracy requirements are generally paramount due to high land values, can be more difficult. In these cases the addition of extra satellites (such as Glonass, Galileo, Compass and Japan's QZSS[1]) will not necessarily improve accuracy significantly because of the inherent bad geometry caused by the restricted sky view and potential for increased multipath.

However combinations of other positioning technologies such as GNSS/CORS with pseudolite networks (e.g. Locata technology) and/or high bandwidth communications, can be expected in the not too distant future to overcome some or most of these limitations. In any case the small land areas covered by Australia's CBDs can, and largely are already, well serviced by a relatively small number of ground marks specifically suited for that particular purpose.

Some applications, such as cadastral definition, currently require connection to survey monuments in the vicinity of the survey and 'metes and bounds' survey rather than coordinated positions to fix land parcels. The integration of digital GNSS networks thus may require legislative changes for cadastral (and potentially other) applications. Legislative change to better support GNSS/CORS can also be expected to be triggered by international developments such as moves to implement the FIG Cadastre 2014 vision.

GNSS is not well suited to the propagation of the vertical datum

For a number of reasons GNSS techniques are inherently weak when realizing the vertical component. The first is the geometric uncertainty caused to GNSS heights by satellite constellation and antenna factors. The second is that orthometric based vertical datums such as AHD71 cannot be replicated geometrically by GNSS because of the geoid-ellipsoid separation and the variation between the geoid and mean sea level as evident in Australia in the case of AHD.

In Australia, despite significant improvements in geoid determination, and the current Height Modernisation project, the fact remains that the predominant rigorous method of propagation of the AHD at accuracies of 3rd order or better is by conventional levelling techniques from existing bench marks. A large proportion of users of survey marks are those primarily concerned with orthometric heights. This limitation will remain while an orthometric height datum is adopted, but in Australia & New Zealand it will be mitigated by accurate geoid models including the modeling of the AHD71 – geoid offset.

Although in Australia the Height Modernisation project is expected to produce a first version of the combined gravimetric and geometric geoid to reduce GNSS derived heights directly to AHD, it will take revisions over many years before this system alone, together with GNSS positioning, will replace some

[1] **QZSS is designed to combat urban canyon effects over Japan and will have a similar but reduced effect over Australia's CBDs and urban areas.**

benchmarks. It can be reasonably expected that a sparse network of physical benchmarks would still be required for some applications.

In contrast to Australia, New Zealand is adopting a new national vertical datum that will be based on GNSS derived ellipsoidal heights.

GNSS is useful for AHD benchmark maintenance

GNSS does however provide another tool for AHD71 benchmark maintenance. Once an accurate GNSS ellipsoidal height has been observed for an AHD benchmark, then that benchmark becomes recoverable by GNSS techniques. This can assist in safeguarding the significant investment made in its original establishment.

Monuments provide positional integrity

Generally, where integrity or confidence in position is needed, survey monumentation is still very important. This includes marks by which digital GNSS network positions can be checked, or when redundant methods are required for verification of data or to minimize risk and prove quality. Marks provide access to the datum in the local area for both GNSS and non-GNSS users. Significant numbers of survey projects (e.g. cadastral surveys and engineering projects where relative accuracy is paramount) are still completed using terrestrial techniques, and maintenance of survey marks allows a continuity of this service, which in the absence of GNSS CORS may still be the most economic technique. The integrity of the monuments themselves is of course also important, but this is usually provided by their relativity with adjacent marks.

Monuments enable integrity of the Datum to be monitored

In a country like New Zealand, subject to non-uniform deformation, the density at which active control stations can be economically placed is insufficient to monitor accurately the effects of non-uniform crustal deformation. Additional high quality marks are required at a density sufficient to monitor crustal deformation over more localized areas and at times following a deformation event such as an earthquake, so as to enable the datum to be monitored and upgraded following that event. Such networks have also been installed in WA and SA over seismic zones.

Risk management in a project may prohibit GNSS use

Applications may exist where risk management dictates that the positioning methodology should avoid or limit the use of systems outside the control of the project. Sovereignty can become an issue when exclusive reliance is placed upon a system owned by a foreign nation, to complete activities related to national security or high economic activity.

A hypothetical example would be maintenance of the cadastre if survey marks were not maintained and then GNSS accuracies were degraded or positioning services denied by system owners. However the prospect of total loss of publicly accessible GNSS services is considered a lower risk as there will be an increase in the number of interoperable GNSS constellations complementing GPS and Glonass with the upcoming Galileo and proposed Compass.

However a prudent and practical approach to risk management dictates that a suitable density of horizontal and vertically coordinated ground marks would limit the minimal risks involved with being reliant on GNSS CORS networks and infrastructure

GNSS is global & dynamic

GDA94 & AHD71 are static – they do not change with time – and this is not only satisfactory, but essential for most users. GNSS augmentation which provides GDA94 & AHD position is an effective addition to the geodetic infrastructure. However, augmented GNSS systems which provide global positions (in the ITRF) will differ from GDA94 and this difference will continue to change with time due to plate tectonics. Ideally these systems must provide GDA94 positions automatically and seamlessly for the users as many of them will not have an understanding of the problems involved.

NZGD2000 is a semi-dynamic datum that includes a deformation model that attempts to model the effects of ongoing crustal deformation across New Zealand. However it will also need to consider moves to newer realisations of the ITRF in the future to maintain accuracy and currency.

Conclusion

Integration of digital GNSS networks into the traditional geodetic infrastructure serves a far broader positioning (and non-positioning) community than was previously thought possible. While the "marks based" geodetic infrastructure is primarily used by professionals with survey skills, a GNSS enhanced geodetic infrastructure also serves many segments of the spatial community who have little or no survey training. This places the onus back onto ICSM to ensure that the geodetic infrastructure is homogenous, sufficiently accurate and accessible to suit the requirements of the broader community.

It should be noted that concurrent with the introduction of GNSS techniques to the geodetic infrastructure has come the changing shape of the traditional mark based networks. Visibility for triangulation or trilateration is no longer a prerequisite for mark placement (though it may still be an important consideration for some users of the geodetic network). This has resulted in "hill top" marks being no longer maintained while denser, more accurate networks of marks are being established in "hotspots" or areas of high demand. Generally GNSS techniques play a strong role in placing these new marks. This relationship and interdependence between traditional physical networks and GNSS will continue with both requiring maintenance and resources.

Apart from the requirements of specific "hotspots", the location and density of both digital GNSS base stations and physical marks will vary with the particular geography, demography and user applications in each jurisdiction. Network extension and maintenance strategies are assessed individually, taking into account specific needs including availability, location and quality of existing geodetic infrastructure, future development prospects/requirements and regulatory requirements relating to cadastral datasets and land registration processes.

Generally there is a need for improved relative accuracies in urban areas. This may dictate denser networks of survey control. However, there are some rural areas that may have the same requirement For example, mapping projects, environmental impact studies, precision agriculture, mining and engineering works and seismic activities will have particular requirements. If in the near future there is a full uptake of GNSS techniques by industry, the trend for physical marks is likely to be for a broad spacing of perhaps 100s of km in very remote areas; 20-100km in rural/pastoral areas; 5-20 km in peri-urban areas and street corner level to 5km in urban areas.

Currently, the distribution and density of GNSS base stations also depends on their application. AUSPos users are satisfied by the broad distribution of the ARGN (typically a thousand km or more); GNSS base stations for post-processed survey data may have spacing of the order of 100km; VRS networks need to have a 50-70km density; and RTK base stations have a useful range of about 20km. This is likely to change with future technological developments.

The fiscal implications of incorporating digital GNSS networks into traditional geodetic infrastructures are complex. However, while there are costs associated with the introduction of digital networks, there are also enormous benefits from a much wider user base than was previously served. The allocation of resources needs to be viewed in the context of an additional service provided to the spatial and other industries, rather than a reallocation away from the existing infrastructure. The benefits to the users and the community in general needs to be examined as well as the cost burden to the government.

Ultimately jurisdictions need to consider all of these issues to decide which mix best satisfies the user requirements in their area. Some jurisdictions may have their own additional drivers and issues to those discussed here.

AUSTRALASIAN CASE STUDIES

Victoria

The Department of Sustainability and Environment maintains both a network of permanent GNSS base-stations and a network of ground marks throughout the State. As at March 2008, the GNSS network consists of thirty two active GPS/GNSS reference stations called GPSnet (www.land.vic.gov.au/GPSnet). Six GPSnet sites are GNSS capable (receiving both GPS and Glonass signals) and all new or upgraded CORS sites will be GNSS capable. A dense 70 km network is currently in the process of being expanded to cover the state to support high accuracy NRTK positioning.

GPSnet allows registered users to download survey quality GPS data for their projects in real time or for post processing, providing an efficient means of establishing positions or to support a variety of navigation applications. GPSnet densification is now particularly targeting precision agriculture and machine guidance in Regional Victoria.

Martin Hale (2004) states that many GPSnet users are not surveyors, but spatial data professionals or para-professionals, while the primary users of the ground marked networks are surveyors. He also maintains that "*for the foreseeable future GPS/GNSS will not and cannot entirely replace ground mark networks for all forms of geodetic and other spatial positioning requirements*".

Since GPSnet NRTK services have become available from November 2004, rapid uptake of GPSnet services has been experienced, and often used in built up locations in and around Melbourne city and suburbs. This indicates that many GPSnet users are able to work effectively in what might previously have been considered 'GPS unfriendly' environments primarily due to the increase in GNSS satellites and improving receiver equipment and associated technologies such as combined GNSS/Survey total stations. This type of evidence supports the notion that reliance on ground marks is likely to decrease further as CORS networks are established and or technology develops.

All GPSnet sites have antenna coordinates computed by Geoscience Australia in terms of the ARGN and also processed or in the process for Regulation 13 certification under the National Measurement Act in support of legal traceability of position. State Government funding is currently being sought to complete GPSnet statewide densification to support NRTK. A final network configuration of an estimated 102 CORS stations across Victoria is anticipated (including 8 AuScope CORS sites).

A new primary GPSnet 'commercial grade' processing centre is currently being developed and installed by June 30 2008, to back up the existing processing centre (7 server cluster) located at Geelong and hosted by foundation GPSnet participant, Barwon Water. The two processing centres are being designed to work as an integrated system to increase service reliability to better than 99.98% target uptime.

The network of ground marks, the Survey Control Network (SCN) consists principally of physical ground marks having horizontal and/or vertical positioning values. The coordinate values of these ground marks (and other reference stations) are held in an on-line data base which allows industry and the general public free access to this information. The marks of greatest significance are protected and maintained to provide a physical means of traceability to the national horizontal datum (currently GDA94) and to the national height datum (currently AHD71).

The SCN currently comprises approximately 165,000 survey marks whose location and/or height are known to varying degrees of accuracy. The marks vary from standard brass plaque-inconcrete permanent marks (PM); deep driven steel rod PMs; to Primary Cadastral Marks (PCM) and the more recently developed network of *GPSnet* base stations. Of the 165,000 marks registered in SMES, it is estimated only half that number are currently useful for the majority of users (surveyors). Realistically, approximately 100,000 marks are estimated to be of sufficient class and order for surveying purposes, with approximately 30% of these estimated to have been destroyed or unable to be found.

The SCN was readjusted in 2006-07 to accommodate recent observations including the 50km passive GPS network, selected GPS reference stations and selected satellite point position determinations (AusPos). Work is continuing on satellite observations at national levelling section junction points to contribute to a national correction surface between the ellipsoid and the AHD surface in order to facilitate the use of GNSS to obtain reliable AHD heights.

Northern Territory

The NT Government have established two GNSS clusters in Darwin and Alice Springs. They are currently exploring a variety of positioning services and are undertaking such activities with local authorities and private sector survey related companies. The primary objectives of the NT GNSS CORS network will be to enhance the existing geodetic and cadastral infrastructure, to facilitate the evolvement of a co-ordinated cadastre, assist with the maintenance of key NT spatial datasets, and support the National Geospatial Reference System. It is expected this infrastructure will also facilitate the development of downstream applications by providing surveyors and other spatial users with the opportunity to utilise modern positioning technology efficiently and effectively to meet their business needs.

Queensland

The Queensland Department of Natural Resources and Mines operates a Real Time Kinematic Virtual Reference System (VRS) over a large part of Brisbane (Higgins, 2002). This system allows suitably equipped and registered users to obtain centimetre accurate GDA94 positions in real time. However Queensland also maintains a dense network of marks that have been accurately tied to the national geodetic network. With its widely varying population density and varying growth patterns the preference is for VRS style solutions in larger urban areas, while AusPOS will be more influential in the most remote areas, and in between there will be continued reliance on ground marks on a case by case basis.

New South Wales

As well as the extensive conventional survey network, New South Wales has developed an active GPS system network (SydNet) consisting of seven base stations covering the Sydney metropolitan area. This has been extended with additional sites outside the Sydney metropolitan area. Plans are for a statewide network, but with uneven CORS density. The system currently provides RTK positioning capability, but will support NRTK in the near future.

New Zealand

Five years ago Land Information New Zealand (LINZ) embarked on a programme to implement an active control station network, known as PositioNZ. The network consists of 30 GNSS permanent tracking stations across New Zealand with an additional station on the Chatham Islands and two in Antarctica. Data from the network and information on each site is available through the LINZ web site www.linz.govt.nz/positionz.

Work is currently underway to develop an online post-processing service in conjunction with the AUSPos system and investigations are underway to develop a real time network using 1-second data.

The business case developed to obtain support and funding for this project was on the premise that the active control network would enable geodetic control surveys to be undertaken more efficiently, and that the dynamics of New Zealand could be monitored and the results used to update the NZGD2000 deformation model which forms an integral part of NZGD2000. The business case was NOT built on the premise that such a network would reduce the need for conventional geodetic survey and control marks.

When NZGD2000 was developed, predominantly using GNSS technology in the late 1990s, it was proposed that the geodetic infrastructure consist of 6 orders of marks Zero – 5. Zero order marks were high accuracy GPS permanent tracking stations and 5th order geodetic marks used to support cadastral surveys and other users. The density of the 5th order marks was approximately 300m in urban areas, 1km in peri-urban areas, and 3km in rural areas. The intervening orders provided a breakdown from the high (Zero) to the low (5th) order network, much in the same way as had been developed under the old NZGD49 when conventional survey technology was used.

The development of Landonline and Survey Accurate Digital Control (SDC) areas led to the development of a dense 5th order network in urban and peri-urban areas. It also led to the concept of a geodetic cadastre with cadastral survey and boundary marks having geodetic coordinates. In SDC areas cadastral surveyors are required to tie their surveys to NZGD2000 control marks, and outside SDC areas, where NZGD2000 marks are close to the survey, surveyors are also required to tie to the NZGD2000 control network. The number of NZGD2000 geodetic marks rapidly increased during this period of development when over 50,000 marks were added to the geodetic database.

As the PositioNZ network has been rolled out across the country geodetic contractors have been required to tie to the PositioNZ network. In the future this will enable geodetic control to be placed much more efficiently as it can be surveyed directly from the PositioNZ stations (zero order stations). This has meant that for most requirements there is no longer the need for the breakdown in control from the zero to the 5th order network. This has resulted in a re-evaluation of the role of the geodetic network and the various orders of marks and the 1st, 2nd, 3rd, and 4th order networks are largely becoming redundant.

Often these (1st – 4th) order marks are in areas where they are little used and hence in the future they need not be maintained, at least to their high order of accuracy, nor these networks extended. Where they are being used they are being resurveyed to 5th order standards instead of 3rd or 4th, etc.

The development of the PositioNZ network has seen a simplification of the geodetic infrastructure to two orders of marks, zero order (PositioNZ stations) and 5th order. The small numbers of zero order marks (about. 30) are costly and expensive to maintain and run, and the large numbers of 5th order marks are cheap and easy to place and survey. This has meant that many more geodetic marks are being placed to satisfy user needs in locations where they are required, particularly to satisfy cadastral surveyors' needs. The development of the PositioNZ network has therefore seen a rapid increase in the number of 5th order marks and reduction to two main orders of mark, zero and 5th order.

In New Zealand like other countries, the use of GNSS is causing a re-evaluation of the basic geodetic infrastructure, its design, and usage.

INTERNATIONAL CASE STUDIES

Great Britain

Great Britain is an example of where traditional survey marks infrastructure has been modified by evolving GPS technology. The original network of survey marks coordinated by the Ordnance Survey of Great Britain in 1936 (OSGB36) has gradually become less usable, and few of the OSGB36 marks "*have been checked more recently than the 1960s*" (Ordnance Survey, 2004). This traditional network has largely been replaced by a network of thirty Active GPS stations and about nine hundred Passive GPS marks.

The network of Active GPS stations allows users to download data for post-processing with their own GPS data. The density means that most locations are within about 100km of an active GPS station. "*Typically, the Ordnance Survey active network would be used to position a small number of primary survey stations with a dual-frequency survey-grade GPS receiver and processing software, and surveying would then proceed from those primary stations using short-distance relative GPS methods (for example, Real-Time Kinematic, or a DGPS base station) or an optical survey instrument (for example, total station*)" (ibid).

A Passive GPS network consisting of about 900 marks whose 3-dimensional ETRS89 positions have been accurately determined by GPS survey (ETRS89 is a 1989 precursor to ITRF). Many of these are new, purpose-built marks, while others are upgraded existing survey or benchmarks that are physically annotated to indicate this. The precise ITRF positions of this passive network are monitored by the Ordnance Survey on a five year cycle and they recommend that "*all GPS surveys should be based on control stations with accurate and recent ETRS89 coordinates*" (ibid).

The Active and Passive networks are only able to replace the original OSGB36 network because Ordnance Survey have in place unique and accurate processes to transform between ETRS89 and OSGB36 positions and orthometric heights. With regard to height determination, Ordnance Survey recognises that "*GPS observation times must be longer to obtain precise heights*" and advises the use of several GPS coordinated marks on a project and levelling between them to check the consistency of the orthometric heights.

Although Great Britain has taken steps to modernise their geodetic infrastructure by introducing Active GPS systems, they have not dispensed with survey marks, but have rationalised them and made them more accessible. The maintenance of the nine hundred Passive GPS marks, in an area similar to Victoria (approximately 230,000 km^2), remains a significant task.

The Ordnance Survey works with partner organisations to utilise the Active GPS network to provide GPS data for real-time and post-processing applications. OS Net™ commercial partners include Leica Geosystems, (SmartNet service) and Trimble (VRS Now service). The Ordnance Survey maintains the accuracy and quality of geodetic calculation within the network while the commercial partners model GPS errors and provide end user correction services.

Canada

Canada has transferred responsibility for the maintenance of the classical networks of survey marks to the provinces. At the national level, a network of forty three active GPS stations, which make up the Canadian Active Control System (ACS), is operated along with a passive network of about two hundred stations known as the Canadian Base Network (CBN). The CBN is re-surveyed on a 5 year cycle. These provide the fundamental framework upon which provincial and other federal agencies densify and establish their own control networks. Most provinces are moving toward high precision networks with a combination of Active and Passive control points at various densities down to 30km (Legree, 2004).

Canada continues to use the Canadian Geodetic Vertical Datum 1928 (CGVD28) and between 1972 and 2000 nearly the entire network of 124,000km of levelling was re-surveyed. Canada is working towards a new geoid-based vertical datum compatible with GPS, but doesn't expect a suitable geoid model to be available until at least 2006. It also recognises that the "*transition from CGVD28 to a new datum will span several years or even decades*". Although the introduction of a new, GPS-compatible height datum would decrease reliance on the dense monumented ground network, it would require a set of transformation "shifts" to support the conversion of CGVD28 data. The existing benchmark networks would continue to remain during the transition period, which could last for decades (CGRSC, 2004).

Germany

The German National Survey Satellite Service Positioning (SAPOS) provides centimetre accurate positioning services for a range of users and connection to the ETRS89 datum. However, it still requires the Berlin State software products for transformation to the still-valid Soldner-Berlin plane coordinate system and into the uniform nationwide DHHN 92 height reference system. "*SAPOS will not be able to replace entirely the terrestrial measurement procedures for detail surveys. However the economic and technical advantages will lead to ever wider use of this modern technique*" (Senate Dept of Urban Environment, 2004).

United States

The United States National Geodetic Survey (NGS) has around 16,000 geodetic control stations in three categories, with shared establishment and maintenance (NGS, 2004a):

i. The high accuracy network known as the Federal Base Network (FBN) that consists of about 1400 passive GPS stations at about 100 km spacing. The FBN is managed by NGS.
ii. The Cooperative Base Network (CBN) of some 14,600 stations at about 25 to 30 kilometre spacing, which is maintained through cooperative agreements with other federal agencies, state and local governments.
iii. The User Densification Network (UDN) of additional monumented stations connected to FBN or CBN and surveyed by the private sector with no cooperative agreement.

In addition, NGS coordinates two networks of continuously operating reference stations (CORS): the National CORS network and the Cooperative CORS network. Around 300 CORS sites provide GPS carrier phase and code range measurements in support of 3-dimensional positioning activities throughout the United States and its territories (NGS, 2004). The Cooperative CORS network provides access to GPS data that are disseminated by organizations other than NGS.

NGS's OPUS on-line GPS processing system is similar to Australia's AUSPos system in that it provides both ITRF and locally adopted NAD83 positions (NGS, 2004c).

NGS is coordinating Height Modernisation activities to facilitate an upgrade to the National Vertical Datum and geoid determination and the use of GPS in the accurate determination of height. The current vertical datum for United States is the North American Vertical Datum 1988 (NAVD88) which was adopted in 1993, but the existing network of marks is inadequate to meet the needs modern users as a result of many marks being disturbed or destroyed. Business cases for this funding have been based on the need for accurate and consistent height information to serve as the foundation for improved transportation systems, subsidence monitoring, sea level rise estimation, floodplain mapping, urban planning, storm surge modeling, habitat restoration, emergency preparedness, resource management, site-specific farming, construction, mineral extraction, and seismic and infrastructure monitoring.

Two examples demonstrate the breadth of initiatives being undertaken to augment the National Geodetic Network.

In Washington State (75% the size of Victoria) it is proposed to integrate 80 GPS base stations and remeasure around 5,000km of levelling traverses using federal funding and a consortium of government and private industry representatives (NGS, 2004).

In Wisconsin (60% the size of Victoria), a Height Modernisation and Network Densification Project has been underway for 3 years and is due for completion in 2006. The key outcomes from this project are the densification of the existing GPS network at three different levels (primary base stations at 25km spacing; secondary base stations at 12-14km spacing; and local network stations at 6-8km spacing); locating new bench marks at 2km spacing along level lines; performing conventional levelling on benchmarks, HARNs, and primary base stations; and performing GPS on all levels of GPS stations to transfer elevations (NGS, 2004e).

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