University of Southern Queensland

Faculty of Engineering and Surveying

An investigation into the establishment of a Continuously Operating GPS Reference Station at Dubbo City Council, Central West NSW.

A dissertation submitted by

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ABSTRACT

Global Navigation Satellite Systems (GNSS), real time differential correction techniques, Continuously Operating Reference Station (CORS) networks, mobile internet and GNSS user equipment are now mature technologies. The challenge is to manage the combination of these technologies to fully benefit users and society.

The aim of this project was the investigation into the feasibility of establishment of a CORS site, servicing the requirements of Dubbo City Council, and surrounding geographical area, where this functionality does not currently exist.

For a State (and National) CORS network coverage that will provide at least Real Time positional applications, then these sites must be located relative to regional population centers, and that an optimal location, particularly for NSW, is the Local Government Organisation in that regional centre.

This project will focus on the validation of establishing such a model, particularly for current users of spatial technology, and as such the Council of the City of Dubbo will be both a case study for a similar exercise into other regions of the State of NSW, and perhaps nationally.

Dubbo City Council will also be the sponsor of the project, and as such, a questionnaire will be used to validate the process. Typical users and generators of spatial technology in the area, and including representatives of other Local Government organisations, State based Road and Traffic authorities, Agriculture and Precision farming, and consulting surveyors, shall be invited to participate in a questionnaire to gauge the level of interest and potential commitment to the establishment of enhanced GNSS functionality for this particular location.

The questionnaire of local spatial industry representatives was compared to other industry professional literature and similar academic exercises. Pertinent aspects of the questionnaire were highlighted and the salient points contributed to the preparation of a validating business case for the proposed model.

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CERTIFICATION

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NOMENCLATURE AND ACRONYMS

The following abbreviations have been used throughout the text and bibliography:-

AFN Australian Fiducial Network
AHD Australian Height Datum
AMSA Australian Maritime Safety Authority
ARGN Australian Regional GPS Network
AUSPOS GA automated web-based positioning service
CORS Continuously Operating Reference Stations
DGPS Differential GPS
DOL Department of Lands NSW
DLI Department of Land Information, Western Australia
ESA European Space Agency
EST Eastern Standard Time
GA Geoscience Australia
GDA Geocentric Datum of Australia
GGA Global positioning fixed data
GNSS Global Navigation Satellite Systems
GPS Global Positioning System
GPRS General Packet Radio System
GRAS Ground-based Regional Augmentation System
GSM Global System for Mobile communication
IGS International GNSS Service
ITRF International Terrestrial Reference Frame
LBS Location Based Service
MGA Map Grid Australia
NRTK Network Real Time Kinematic GPS
NRW Natural Resources and Water (QLD)
PSM Permanent Survey Mark
RINEX Receiver Independent Exchange format – for exchange of GNSS data
RTCM Radio Technical Commission for Maritime Services
RTK Real Time Kinematic
UNSW University of New South Wales
USQ University of Southern Queensland.
VRS Virtual Reference Station

CHAPTER 1 INTRODUCTION

1.1 Research statement

"……. permanent base stations should be located in a manner that builds a sound network of stations throughout the state as opposed to creating dense but isolated networks" (Takac,1997)

In NSW, Local Government Organisations have been the most active Government sector in establishing GPS Base Stations, mainly to meet their own position requirements for surveying, engineering, geographical information systems and asset management (NSW Dept. of Lands 2007).

Nationally and internationally, networks of Continuously Operating Reference Stations (CORS) are being developed to support a number of diverse applications such as precision agriculture, deformation monitoring, machinery control and location based services (LBS). These services are demanding solutions delivered through the computation and transmission of data in real time (Gordini et al. 2006).

The vast size of the Australian continent creates a huge economic and technical challenge for national real-time centimetre positioning services based on CORS networks. These challenges need to be addressed as there is increasing demand from many user groups to provide national real-time coverage from CORS infrastructure (Zhang et al 2006).

The challenge to providing CORS network coverage over a large and sparsely populated landmass and then distributing Network Real Time Kinematic (NRTK) corrections to GNSS users efficiently and effectively, often where little or no land based communication infrastructure exists, is a major impediment to the rollout of national CORS coverage by the various Australian States and Territory Governments (Zhang et al 2006).

CORS networks have a variety of benefits which have pushed the GPS community towards using Network Real Time Kinematic GPS (NRTK). They encourage the uptake of GPS as a positioning technique for a wide variety of users due to their accessibility. NRTK with CORS networks is simple to use as all that is required is the knowledge of the process of using the roving receiver. The cost to the user of utilising NRTK is relatively small (when compared to the costing and implementation of a modern GNSS setup), as the only requirement is one GPS receiver.

Despite these advantages, NRTK is still limited to some tens of kilometres from the reference stations (Rizos et al, 2003). Outside this range it is often not possible to obtain a NRTK position, thus presenting a problem for stations beyond this range.

In the Australian case, there is a vast area to cover. However, only a sparse CORS network across the continent is currently in place to service the population. It would be possible to place additional reference stations at intervals that would enable NRTK across entire states. However, this can be cost prohibitive (NSW Dept. of Lands 2007).

1.2 Research Aim and Objectives

The broad aim of this study is to determine the level of justification of creating a CORS site in a NSW Regional Population centre. This feasibility study is premised on the case that for a State based CORS Network coverage to become a reality in NSW, that these sites must be located relative to centres of larger regional populations, and that an optimal location is the Local Government Organisation in that regional centre.

In broad terms this research project will investigate the feasibility of establishing a CORS site in a location where similar infrastructure does not exist, whilst acknowledging that the main focus of recent studies into the extension of the existing (state of NSW) networked CORS System is the minimisation of CORS infrastructure duplication, maximising the coverage and supporting a broad user base.

The aim of this research is to determine what validation exists for the establishment of a CORS Site in a geographically 'remote' location, and to prepare a business case for the enhancement of GPS usage in the central west of NSW by validating the establishment of a permanent, geodetic quality, dual frequency, CORS site.

The project objectives are:

1: complete a Literature Review assessing the information available that addresses CORS justification, implementation, establishment and operation in Australia.

2: Research the experience of CORS service providers in Australia, as it applies to this problem, where they have engaged in the establishment of a CORS network or individual site and providing spatial data services.

3: Assess the suitability of the establishment of a CORS Network station in the Central West of NSW, based at Dubbo.

4: Determine the feasibility of incorporating this proposed dual frequency base station, or an existing Permanent Base Station, into the (proposed) DOL CORS network - NSWnet.

5: Determine the feasibility of alternative Spatial Data service provision, such as a dual frequency, geodetic quality, stand-alone base station 'cluster', servicing the needs of the spatial industry in, and around, the City of Dubbo, Central West NSW.

1.3 Research Method

As defined by the project aim, this project is an investigation of the feasibility of establishing a networked CORS site to cater to GPS users within industry, mining and agricultural infrastructure in the Central West of NSW, based at Dubbo.

The method for the project involved the following phases:

Background > Research Design > Data Collection > Analysis > Results > Business Plan Preparation

1. Background – the key outcome of this phase was the literature review, being a research activity to draw upon current knowledge within the industry and connect the problem to related work previously undertaken by others. The literature review offers a more detailed understanding of the problem.

2. Research Design – building on the background research, the problem was reviewed and the approach to solving the problem developed. The initial approach was to understand the various spatial data issues affecting existing and potential stakeholders for the proposed CORS site, through various communication strategies such as conducting of a questionnaire, direct conversation and literature research.

3. Data Collection – in this phase, data was collected based on the research design, using a questionnaire and completed as a telephone interview or as a written survey. The survey will be targeted to collect information in the following groupings:
    a. an assessment of the validity and adequacy of a CORS site establishment by Dubbo City Council in the central west of NSW,
    b. type of work undertaken by various recipients, that may benefit from the establishment of a local CORS site,
    c. the expectations and requirements of potential CORS stakeholders with respect to such issues as standards of service, data availability, continuity, access, equipment compatibility, pricing, infrastructure sustainability, privacy, and legally defensible measurements will be assessed using the questionnaires,
    d. the degree of support that could be extended by various stakeholders to the promotion and ongoing development of local CORS infrastructure.

4. Analysis – responses from various questionnaire participants to be formalised by the drafting of a summary of results. Comparisons and contrasts where possible will be made. Discussion of the results of this research will be brought together in a critical analysis that will merge the issues identified in the literature review with the data collected. This will lead to the formulation of an appropriate business model. This information will also be used to identify the typical accuracy requirements of a CORS Network and the use of the system for non-surveying purposes.

5. Business model or report - the preparation of a business model case that will hopefully justify the inclusion of the central west region of NSW into the proposed NSWnet system of CORS or the justification for a standalone single base permanently operating GPS base station or a cluster group comprising locally networked private/public co-operative base station of CORS.

6. Results – reporting of the results from the project to be in two stages:

- By presentation at the USQ ENG 4903 project conference in September 2007.
- Formally through this Project Dissertation.

1.4 Benefits

A very important advantage of using a CORS network is the savings made by not having to purchase a reference station receiver and antenna. The additional time and costs associated with installing, operating and maintaining this equipment are significant tasks for an organisation or business. Current quotations from some commercial equipment suppliers would indicate that establishment costs equate to approximately one hundred thousand dollars.

Rizos et al (2006a) asserts that the justification for the establishment of CORS networks was initially in support of geodesy and other geoscientific applications, at the global and regional level, however, increasingly GPS CORS network operators have sought ways of making their network infrastructure the basis of a profitable business. This has arisen with the introduction of real-time centimetre-level accuracy services, carrier phase-based modes of operation generally referred to as GPS-RTK (Real-Time Kinematic).

CORS Networks and Precision Agriculture (PA) - The need for improved arable land management practices and associated improved productivity can often be achieved by applying spatial technologies. Contemporary PA can support advanced arable land management practices using spatial technology including satellite navigation techniques, improving productivity and the lives of farm workers whilst simultaneously aiding sustainable environmental outcomes.

A coordinated approach to reference station infrastructure establishment and operation, will optimise capital investment and high accuracy navigation outcomes over cropping districts and other agricultural applications in Australia (Denham et al 2006)

One approach is to try to recruit a core group of users who are prepared to pay for the GPS-RTK services. But this is only feasible if the number of users, and the fees that are charged, are sufficient to generate a reasonable return-on-investment (ROI). This ROI (or at the very least "cost-recovery") is important for many network operators in order that they may provide for the maintenance and upgrade of the CORS infrastructure. On the other hand, there are those who advocate that there is no need to recoup CORS investment, and that the installed GPS receivers should be seen as public infrastructure, in a similar manner to roads, bridges, etc (Rizos et al 2006a).

This dissertation will provide the case for research into business models and operational models for GPS-RTK services ie the establishment and operation of a CORS infrastructure site based at Dubbo, in the central west of NSW, focussing on service provision, business cases, and options for value-added services beyond the standard GPS-RTK.

1.5 Conclusion

This dissertation aims to provide a quantifiable business case for the enhancement of GNSS functionality in regional NSW.
The research is expected to provide a justification for enhanced GNSS functionality at NSW Regional location – Central West City of Dubbo.
Having defined an approach for researching the problem to meet the stated aim and objectives, the next chapter, the Literature Review, connects the project problem to the external environment and places it into context through a review of academic and professional literature.

The case study project should serve as an approach that may be replicated by other NSW regional Local Government Organisations considering the placement or enhancing of GPS Base Station functionality.

CHAPTER 2 LITERATURE REVIEW

2.1 Introduction

In order for this research to be of value, the analysis and conclusions obtained should be useful to those organizations or individuals who wish to prepare a similar business case for the establishment of a CORS site in a regional area of NSW. Preparing a business case for the establishment of a dual frequency, geodetic grade, CORS in a NSW regional location such as Dubbo requires knowledge of both the existing and proposed infrastructure systems. This literature review will provide a thorough understanding of most issues that will influence the decision making process of the preparation of such a business model.

The aim of this chapter is to review background information on CORS networks and characteristics of the systems, as well as assessing the usage and validation of CORS infrastructure in other states of Australia, particularly Victoria. This will be carried out

2.2 Real-Time Kinematic (RTK) Positioning

At best, a stand-alone GPS receiver can generate repeatable positions accurate to 5m or so. This is inadequate for most surveying purposes, so people have been using differential correction for at least two decades (Rizos 2001).

RTK positioning with GPS is a common survey technique used today. RTK GPS allows the use of a static 'reference station' with known coordinates, while the second 'user' receiver simultaneously tracks the same satellite signals. When the carrier phase measurements from the two receivers are combined and processed, the mobile user's receiver coordinates are determined relative to the reference receiver.

This can be done in real-time, if the reference receiver data is transmitted to the user's receiver, even while the receiver is moving. With modern equipment only a few tens of seconds of data are typically required to fix the ambiguities associated with the GPS phase data observable and compute a baseline; the difference in latitude, longitude and height between the reference and rover positions (Higgins 2002). The ultimate implementation of such a technique is known as 'real-time kinematic' (RTK), and is capable of cm-level accuracy under certain constrained operational conditions (Rizos, 2002).

2.2.1 Limitations of Real-Time Kinematics (RTK)

One critical limitation of this conventional RTK approach is that the distance between the reference and rover receivers must be less than about 20km in order to be able to resolve the integer ambiguities reliably 'on-the-fly' (ie in kinematic mode) this limitation is due to distant-dependent biases such as the GPS satellite orbit error, and the ionospheric and tropospheric signal refraction (Zhang et al 2006). The so-called 'Network-RTK' technique is a logical extension of the conventional RTK to take advantage of the geometric strength of the network of CORS networks to spatially model these biases. The transition of one reference to a multiple

reference station technique improves the on-the-fly GNSS positioning capability over a larger area (Zhang et al 2006)

Wubbena et al (1996) maintains that RTK can provide centimetre position accuracy, though the accuracy and reliability of the standard RTK solution decreases with increasing distance from the reference station.

Classical RTK GPS requires that distances between the roving GPS unit and reference station should not exceed 10km to achieve a horizontal accuracy better than 10mm +/- 1ppm (HNTB 2004). This limitation on distance between the base station and mobile rover is due to systematic effects of ephemeris, troposphere and ionospheric errors. These errors result in an increased initialisation time and reduced accuracy (Wubbena et al. 1996). For most surveying work the 10km range would be sufficient but when completing a survey that covers a large area and requires measurement of longer baselines then these distance dependent errors become significant.
Network RTK minimises the distance errors leading to potentially faster work and more homogenous accuracy. RTK surveying is subject to numerous sources of error, many that have been eliminated through the development of CORS VRS.

The limitations of RTK surveying that can be highlighted and have led to the need to progress to a system of networked reference stations include:

- Productivity, security and accuracy issues caused by establishing and running a GPS receiver and radio from their own reference station on all survey projects,
- Increase in distance dependent errors caused when the roving receiver is working farther than 10km from the reference station,
- Limitations caused from the range of telemetry communications.

2.3 Continuously Operating Reference Stations (CORS)

CORS Defined
CORS are defined as GPS (GNSS) receivers located permanently at sites having very accurately pre-determined coordinates. A CORS tracks GPS (GNSS) satellites continuously 24 hours a day and may be an individual receiver or may form part of a group of receivers strategically located across a region. Groups of CORS are referred to as CORS networks. Such networks may span areas of several tens of kilometres in dimension (for example the Singapore CORS network), or be regional, continental or even global in scale.

CORS Network Establishment
High quality GPS reference stations have been established, in a sparse global network, since the late 1980's to support scientific applications such as tectonic/seismic research, geodetic reference frame definition and maintenance, and for atmospheric studies (Zhang et al 2006). These stations are located hundreds, or even thousands of kilometres apart. However, by improving the availability of reference station data for users that demand high positioning accuracy, reliability and integrity in real-time, the variety of applications can grow rapidly. CORS networks are therefore critical ground-based infrastructure enabling the basic utility of high accuracy positioning to become available to a diverse range of users (eg surveying, precision farming, structural monitoring, etc).

As Zhang et al (2006) maintains, regional CORS networks are currently being established in many countries as part of the foundation for the spatial data infrastructure.

The distribution and density of a CORS network is constrained by the establishment costs per reference station, the area to be serviced and positioning accuracy requirements (Zhang et al 2006).

Existing CORS networks in countries such as Germany, UK, Denmark, Austria and Japan are sufficiently dense to restrict the maximum baseline length between a user and a nearby reference station to be well under 40km (Zhang et al 2006), which is generally sufficient for cm-level accuracy techniques based on a single reference station, using high quality, dual frequency receivers that permit rapid "ambiguity resolution" (AR). However, as the inter receiver distance increases, the residual atmospheric biases (due to differential ionospheric and tropospheric delay of the GPS satellite signals) in the double differenced GPS observable increases, making AR more difficult (and even impossible using current rapid positioning techniques). Hence this distance constraint for rapid AR makes accurate positioning with respect to sparse CORS networks problematic, and this has profound ramifications in Australia due to its large area and relatively sparse population (Zhang et al 2006).

2.4 CORS Virtual Reference Station (VRS)

The VRS concept from Trimble is an extension of the RTK technique developed for GPS surveying and other forms of high precision positioning (Cislowski and Higgins 2006). The technique operates through CORS networks.

The VRS concept involves permanently operating Global Navigational Satellite System (GNSS) reference stations that are connected via data links such as modems to a control centre (see Figure 1 below). The control centre continuously gathers the GPS data from the reference stations and a central processing computer models the spatial errors and produces a 'living' database of regional area corrections (Landau et al. 2002). At the rover end, the GPS receiver makes a phone call giving its approximate location to the control centre. The central computer then generates the corrections as if there was a reference station at the rover's approximate position (see Figure 2 below). Algorithms are completed within the rover and it is positioned relative to this virtual reference station (Higgins 2001).

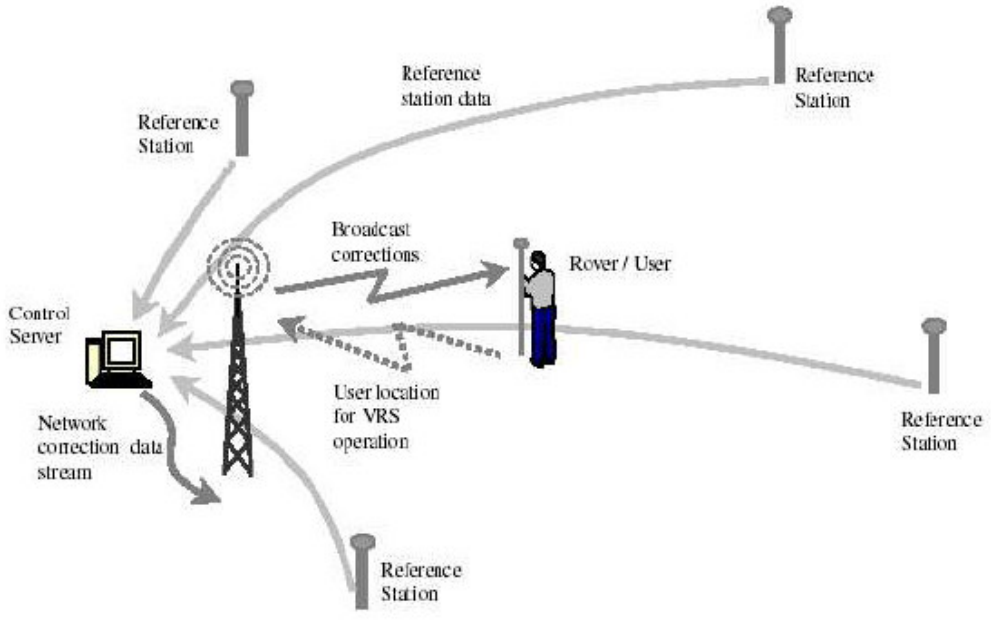

Figure 1 Network RTK system and data flow (Source: Talbot et al 2002)

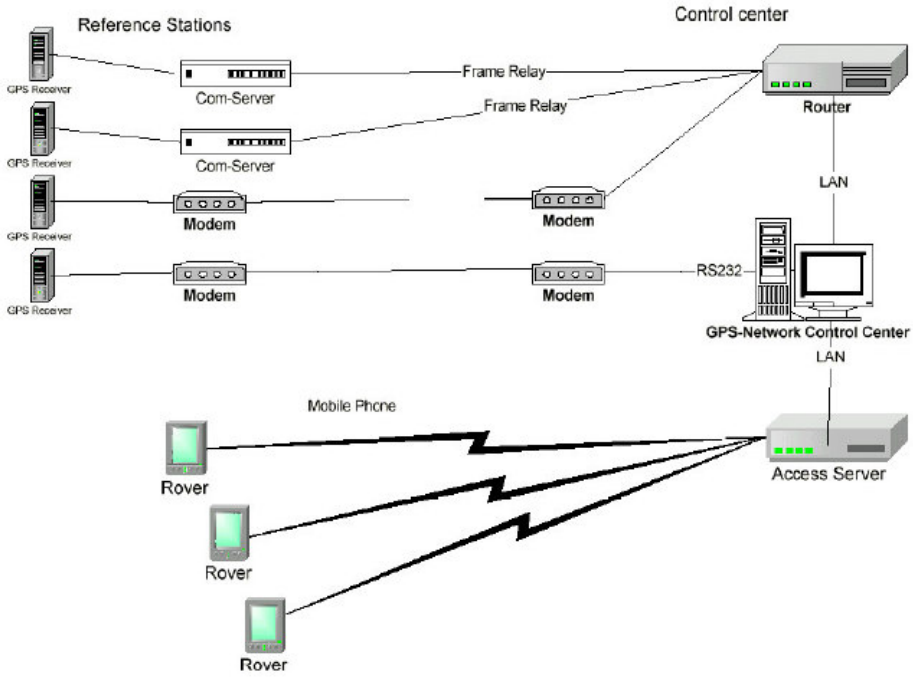

Figure 2 System Architecture of the VRS concept (Trimble 2003)

The improved performance of the VRS concept is due to the relatively short baselines between the virtual reference station and the rover receiver, as opposed to the physical reference stations. As such the positional accuracy is not degraded by being too far from the physical reference stations. The fact that the corrections from the virtual reference stations contributes to the improved accuracy. Cislowski and Higgins (2006) state that even when the rover is 30 to 40 km from the nearest physical reference station it retains a positional accuracy of +/- 20mm (horizontal)

VRS uses multiple reference stations whereas classic-RTK typically uses a single reference (or base) station research has found that multiple reference station networks enjoy advantages over classic-RTK including a larger service area coverage, increased robustness, and higher positioning accuracy (Hu et al., 2003 & Ong et al. 2005).

VRS overcomes three main limitations of the current RTK technique, namely ;

- Operators no longer need to establish and run their own GPS receiver and base radio every time they want to work,
- The use of mobile phone technology overcomes the limitation of the range of radio communications,
- Multiple base stations increase the redundancy and thus the confidence in the resulting rover positions.

Ong and Gibbings (2005) have demonstrated in their testing that the VRS system would at least be comparable, and in some instances may be superior to, the classic-RTK technique, and in many cases was able to produce results where conventional RTK failed. VRS also demonstrated great potential for post processing functionalities. They also point out that if the VRS system is

to be used for post-processing, it is critical to build sufficient redundancy into the network since the VRS post processing from three control stations is essentially reduced to one single short baseline from the virtual reference station.
They also were able to demonstrate that by using the GSM mobile network for data transmission with VRS-RTK, the constraints of being within 10km of a base station, and within stable radio communications, are negated. It is only necessary for the VRS to be within a GSM mobile coverage area.

2.5 CORS networks in Australia

The first GPS CORS network in Australia was the AFN established by Geoscience Australia (then Auslig). This has since been expanded with some extra sites in Australia and surrounding islands to form the Australian Regional GPS Network (ARGN) (Roberts 2006).
ARGN sites also contribute to the International GNSS Service (IGS) network.
As GNSS techniques became more robust, private surveyors have begun to use satellite techniques for a wider range of surveying tasks. Data from these ARGN sites is freely available to users but is of little value with baselines as long as 1000kms requiring scientific software – out of reach for commercial survey operators. In response, Geoscience Australia developed their AUSPOS service in the late 1990's, users simply observe 6 hours of dual frequency data and send their RINEX files to the AUSPOS server which computes a coordinate of the base station and emails this information back to the user within 15 minutes. This service uses scientific processing software connected to the IGS network (Roberts 2006).

In the early 1990's, the Australian regional GPS network was established to support geodetic applications, and now consists of 17 reference stations on mainland Australia (with an average spacing of one thousand kilometres) (Roberts et al., 2004).
A CORS network to support geodesy, surveying, mapping and high end navigation users was commenced in 1994 when stations of Victoria's GPSnet were first deployed (Hale, 2000). It has since grown to 24 reference stations providing online GPS data access. Users can combine these files with GPS data collected across Victoria, for both post-processing and real-time positioning (at selected sites) to obtain cm-level accuracy position results – (see figure 1). GPSnet has taken over ten years to fully implement, engage private sector reference station hosts, and is now virtually complete – although some additional stations will be added over the next few years to 'densify' the network in special areas (Asmussen, 2006, GPSnet, 2006). To date, this is the only state-wide CORS network in Australia.

2.7 CORS in NSW

CORS Implementation in NSW - SydNET
The CORS infrastructure in NSW commenced development as the SydNET project in 2003. SydNET is deployed in the Sydney basin area and is currently being extended to form Metronet which will consist of 10-15 reference stations and will service the eastern seaboard from Nowra to Newcastle and west to Bathurst (the location of the NSW Dept of Lands)
The reference stations around Sydney, in the SydNET system, are located at the State governments Rail Corporation owned train stations and linked to the network control centre (NCC) via the existing optical fibre network owned and operated by Railcorp. The Newcastle and Bathurst sites use the Lands WAN to stream data to the NCC. In the first instance, users will access the correction messages from the internet via a GPRS CDMA 1x or 3G connection. Other methods of broadcasting correction messages to users will be investigated as SydNET evolves (Kinlyside et al 2005).

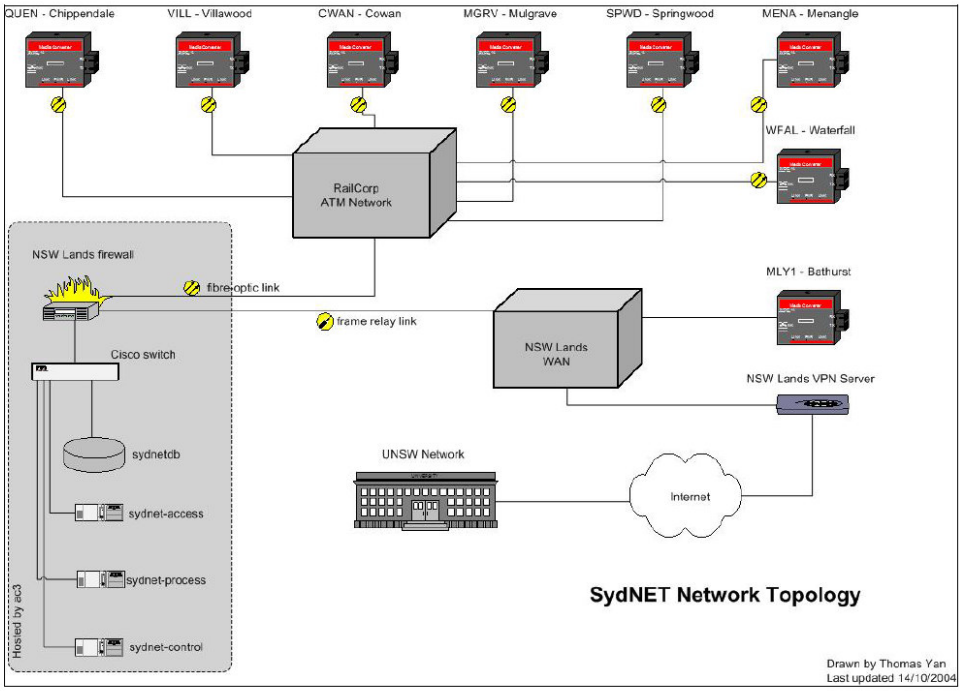

Figure 3 Diagram of SydNET Network connection

The SydNET real-time CORS network in NSW is being established with network-based positioning capability from the very start, including Network-RTK. The project is funded by the NSW Department of Lands (DOL) as an initiative of State Government infrastructure. DOL has been active in using GPS for a variety of surveying and mapping applications for over a decade (Kinlyside et al 2005).The development of a Network-RTK system for the state's largest capital city is a natural and logical extension of the organisation's previous and current involvement in GPS applications for surveying and geodesy.

SydNET is a project to establish a permanent real-time GPS network in the Sydney metropolitan area to provide GPS data for post processing and a network-rtk service for users in the region. SydNET has been developed by the DOL in partnership with the school of surveying and spatial information systems at the University of NSW (UNSW).

SydNET Reference station location

Sites were chosen to accommodate the best possible sky view, least radio interference, safety and suitable infrastructure for installing permanent GPS antenna and receivers. Nine stations have been installed. The sites were also determined as having provision for the best coverage of Sydney, with spacings of between 15-20 km for the stations (see Figure 4 below).

Figure 4 SydNET Configuration (Rizos et al 2004)

SydNET Business Case

Since the advent of differential GPS techniques, the NSW DOL has actively participated in forums focused on the need for establishing networks of permanent, public accessible GPS reference stations around NSW ((Kinlyside et al 2005, ICSM, 1991 and SMMF, 1994). The result from a NSW task force established in 1994 to investigate and plan a State DGPS service was that it was not justified as the cost was high compared with the benefits to government and users.

In view of all the factors above, along with the demands on government organizations to be more efficient and with the departments stated objectives of improving the spatial accuracy of the digital cadastral database, the SydNET project proposal has gained support internally within the DOL as well as NSW government agencies and local councils. The first phase of SydNET is only to service the Sydney basin region, but it is planned for expansion over time to cover other areas of NSW (Kinlyside et al 2005).

Hence, although SydNET is an ideal test network for proposed research, it is not a blueprint for a state-wide CORS network. The extension of the GPS network across the state of NSW would likely be based on a CORS density ranging from 50 to 200km (Zhang et al 2006)

2.8 CORS in Victoria

The Victorian Department of Sustainability and Environment (DSE) has coordinated and facilitated the development of GPSnet (a network of CORS infrastructure).

In 2004 the DSE implemented a State wide network known as VICpos. The service is based on a network of base stations that stream real time correction data to the GPSnet Server Cluster. State wide network corrections are generated by the Server Cluster and then distributed to users

via the internet. The VICpos reference stations spacings are up to 200km. A second service known as MELBpos has been established using reference stations located around Melbourne. The network is similar in architecture to VICpos with 8 reference stations spaced typically around 70km. MELBpos has been created to provide higher accuracy then VICpos (VIC Lands Home 2006 and GPSnet 2006).

CORS Model Implementation in Victoria

The existence of GPSnet is driving (and supporting) change including the demand for higher spatial accuracies and reducing reliance on traditional ground marked geodetic networks enabling more consistent realisation of the state's reference frame (Hale et al 2005, Ramm *et al*., 2004). The drivers for the initial GPSnet development phase came out of the mid 1990s and were based on the:

- improved ability to meet the needs of a wider range of users through easier access, faster results and more accurate positions;
- benefits of coordinating the rapidly expanding number of "private" base stations;
- difficulty of funding the relatively expensive maintenance of ground mark networks; and
- benefits for spatial data integration with the ability for users to readily and consistently generate accurate corrected GPS positions in terms of the Geocentric Datum of Australia (GDA).

GPSnet CORS sites were established by collaboration between industry, academia and various elements of the three levels of government with overall coordination and centralised operation by state government through the DSE. Such a model of infrastructure deployment and management is arguably more sustainable for providing spatial control than ground mark installation and management. This improved sustainability comes from efficient investment use, resource sharing across a wide range of users and the ability to continuously and remotely monitor and control CORS networks (Hale et al 2005, Ramm *et al*., 2004).

Justification for CORS in Victoria

Victoria has an extensive network of nineteen active GPS base stations covering most of the state – see figure 1 below, (GPSnet, 2004). The network allows registered users working within range to download survey quality GPS data for their projects, providing an efficient means of establishing positions. Seven other base stations are subject to negotiation to provide services to users such as precision agriculture and machine guidance. Martin Hale (2004) states that most users of GPSnet 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."

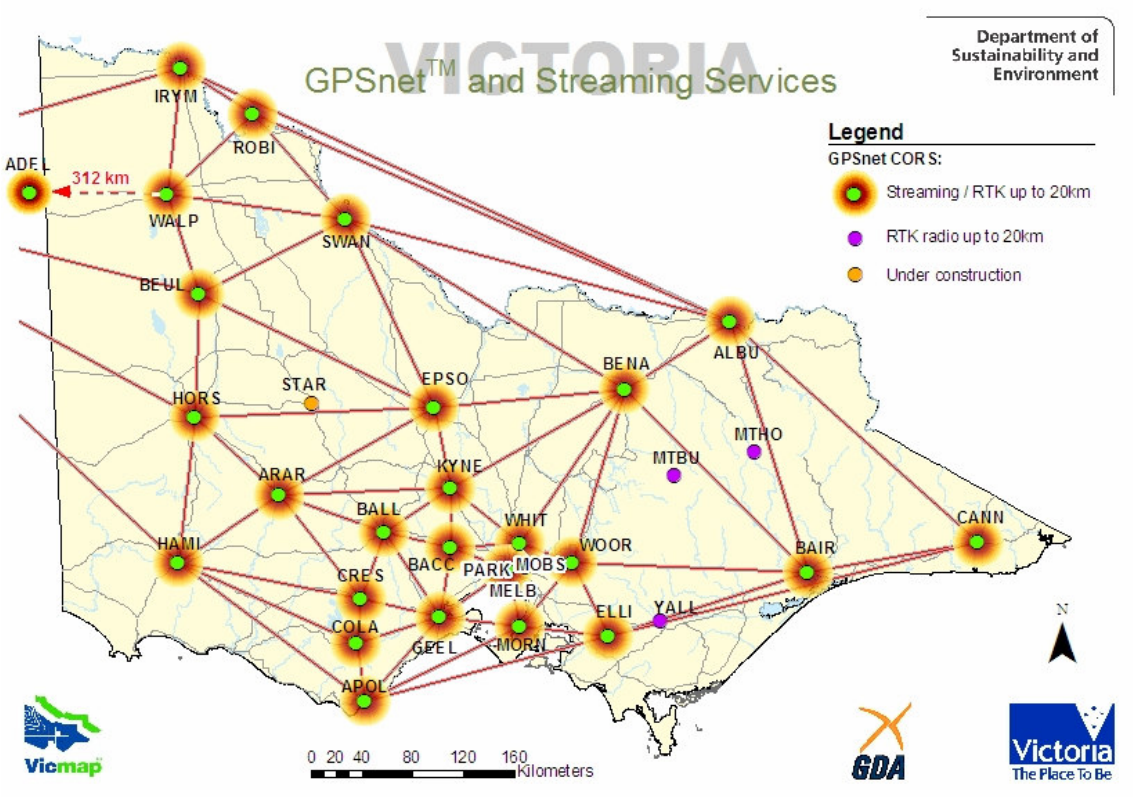

Figure 5 Victorian GPSnet Base Station Layout (Lands Vic.)

The Impetus For Implementation Of CORS Infrastructure in Victoria

The Victorian AGCC State Reference Group highlighted the need for access by many potential users to real time correction, particularly for sub-metre applications. At a Victorian AGCC State Reference Group forum in 2004 it was also made clear, during a presentation on precision agriculture, that support for local and network real time kinematic (RTK) solutions at the few centimetre level was also needed in the future by significant sectors in the agricultural community (Hale et al 2005).

Advances in machine guidance and CORS infrastructure allow support for auto-steering of machinery at high accuracy. This provides benefits to the farmer in the form of input savings, improved occupational health and safety and protecting the environment through the minimisation of chemical inputs and reducing soil compaction through controlled traffic farming techniques.

This type of feedback provided evidence of the demand for high accuracy, realtime 'virtual' spatial control using satellite-positioning technologies by non-traditional spatial infrastructure users.

Increased use of machine guidance more generally, particularly with road construction, and also mining has built pressure for real time centimetric accurate solutions.

Within the mapping community, easy access to GPS both highlights any problems concerning inaccuracy in maps and provides a potential solution. Many maps were originally created by digitisation at scales of 1:25,000 which could result in errors of up to 25m (Hale et al 2005). Autonomous GPS can now easily measure these differences. An accurate real time differential GPS (DGPS) service would also provide the ability to correct the map.

The Users of CORS in Victoria

Traditional and non-traditional spatial control users have been actively participating in the establishment, testing and use of real time network position correction services leveraged off the GPSnetTM infrastructure since 1996 (see Fig. 2). Initially a number of users made use of local RTK propagated by fixed base station radios connected directly to CORS nodes.

The VICpos service delivers real time network DGPS state-wide and local RTK at data streaming nodes, wirelessly via the Internet using GPRS mobile telephony. These more recent real time GPS users are representative of a diverse range of organisations and companies that are expected to become involved in a wide variety of similar positioning activities in the near future (Hale et al 2005, Ramm *et al*., 2004).

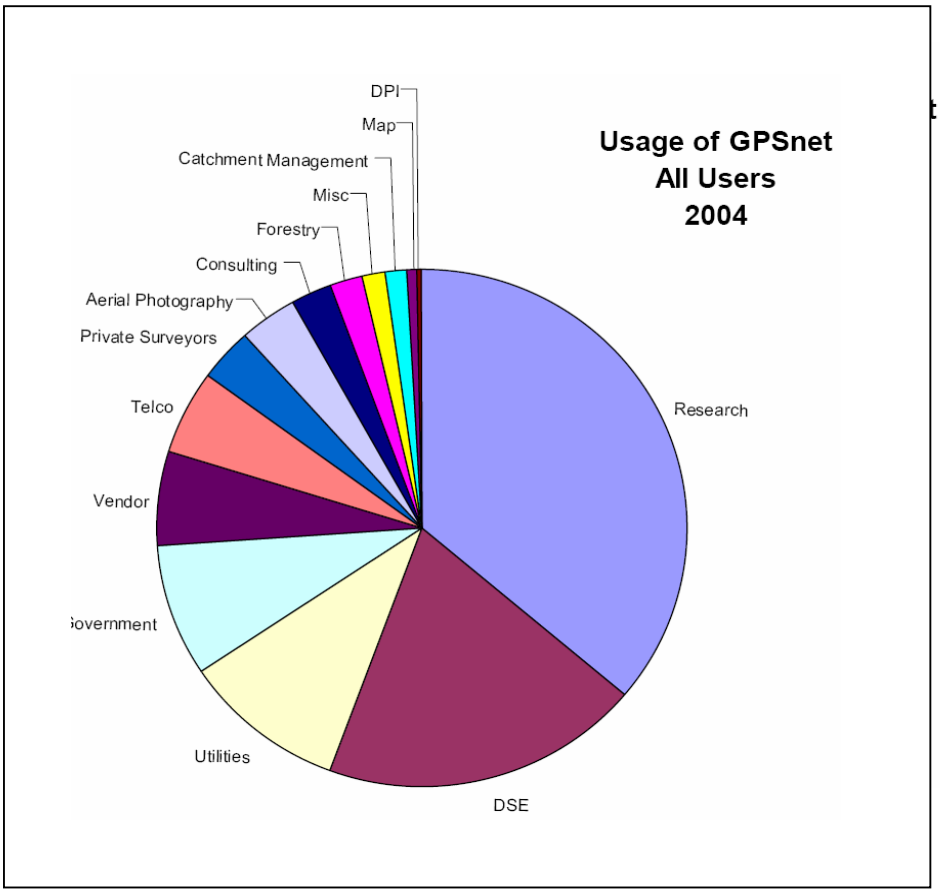

Figure 6 Victorian GPSnet usage by industry (NGRS Workshop, Vic. Dept of Sustainability and Environment. Author P.Ramm, Feb. 2006)

2.9 CORS in QLD

The Queensland Department of Natural resources and Mines operates a RTK 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.

The Department of Natural Resources and Water (NRW) of the Queensland Government is responsible for the surveying and geodetic infrastructure in the Australian state of Queensland (Higgins 2001). The NRW controls a CORS network situated in the South-East region which has been operating for several years. The network known as SunPOZ uses a mixture of receivers (See Figure xxx below).

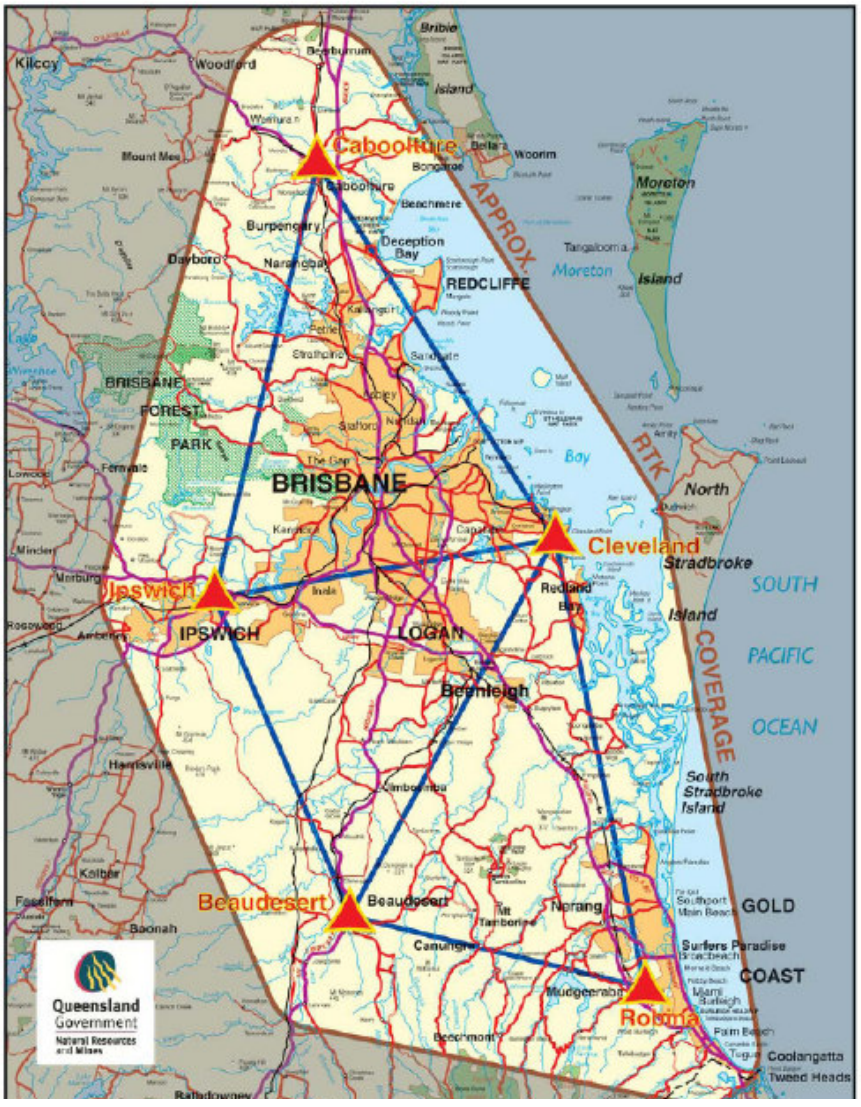

Figure 7 SunPOZ CORS Network in S.E. Queensland (NRW 2006)

2.10 CORS in Western Australia (WA)

A number of CORS networks are currently operating in WA, providing different levels of service to different and often very specific markets and users. The number of CORS networks and individual CORS is set to steadily increase over the next two to five years (Houghton 2005).

Although few of the existing CORS could be classed as being of geodetic quality, many could easily be upgraded to a geodetic level if necessary. Many agencies would consider such upgrades if they were to provide a concrete legal link to GDA.

WA is covered by commercial real-time positioning service down to 10-20cm level. Below the 10cm level, the positioning market is relatively small, being restricted mainly to surveyors, mining companies and scientific applications. Although major interest in high precision positioning is emerging from the agricultural sector, it may be some time before cm level positioning can be proven to be cost-beneficial to farming operations. Even then, the agricultural market for, say, NRTK, is relatively small (Houghton 2005).

No NRTK coverage is currently available anywhere in Western Australia. Although, the most likely short-term market for RTK users in the Perth Metropolitan region is finite, with most potential users coming from the survey sector, it is likely that at least one, and possibly more, NRTK systems will be operating in the region by early 2007 (Houghton 2005).

Perth VRS Network
The Perth VRS Network is operated by GPS network Perth and is the first privately owned VRS network in Australia. Covering the entire Metro-Perth area the network is built solely with Trimble NetR5 reference stations and is the first VRS network with GNSS capabilities. The GNSS network supports both the next-generation GPS L2C and L5 signals and GLONASS signals adding greater flexibility, fast initialisation times and more robust signal tracking for positioning applications (Trimble 2006).

Impetus for CORS Establishment in Western Australia
A bigger driver for NRTK is coming from the agricultural sector. For example, one resolution from the 3rd National Controlled Traffic Farming Conference in Gatton, Queensland, July 2005 was "that networks of 2cm GPS base stations be established in all cropping districts" (Houghton 2005).

A number of agricultural applications are beginning to require RTK/NRTK accuracies. These applications include guidance and automatic steering, precise fertiliser and seed placement, controlled traffic, bore coordination, clearing assessment etc. There is also a developing requirement in the agricultural sector for support from CORS networks for applications involving reliable and consistent positioning to national standards such as Genetically Modified plot trial management, fire ant management and canker virus. These applications require positioning that can support legal processes and actions.

Commercially, the main issue with providing NRTK services for the agriculture sector is the low density of users per region (Houghton 2005). The maximum NRTK CORS spacing of current off the shelf systems is the order of 70-100km, which would require many tens of stations to cover the entire Western Australian agricultural region. Whilst it is likely to be more

economical for farmers in local area to combine resources to install NRTK on a limited scale, rather than purchase individual RTK systems, before any such systems are installed a solid economic benefit will have to be clearly demonstrable to the farming community. In Western Australia at least, the adoption of NRTK for agriculture, should, in the short-medium term be market term, be market be market driven (Houghton 2005).

2.11 Impediments to CORS establishment

A challenge to CORS network establishment procedures is to make the spacing of reference receivers as great as possible, without sacrificing user accuracy and solution reliability. Most CORS networks currently offering NRTK services have reference station spacings of a few tens of kilometres at most. Internationally, research is being undertaken to extend the station spacing, primarily through improved atmospheric (Ionospheric and Tropospheric) bias modelling (Roberts et al., 2004).

Achieving cm-level positioning accuracy over distances of 70km or more has not been verified on an operational basis (though Zhang et al (2004) maintains that university studies have demonstrated promising results for short trials with optimised research software using the commercially available Trimble VRS system. Higgins (2002) has reported horizontal positioning accuracy of the order of +/- 50mm, for baselines up to 35km in length.

2.12 Stand-alone GPS Reference Stations and Networks

Background

Reference stations and networks require significant investments. A commercial supplier of one type of geodetic quality, dual frequency system has quoted that infrastructure supply only could amount to eighty to one hundred thousand dollars, and this does not include the setup of infrastructure, ongoing maintenance and network progression costs.

Therefore, organizations have established standalone reference stations or networks purely for their own usage. In NSW these organizations have included larger local government organizations and consulting surveying businesses. In the Dubbo area alone there are two semi-permanently operating geodetic quality GPS Base Stations.

Examples of stand-alone reference stations and networks

1) **stand-alone reference station for a small area such as an opencut mine, construction site, or local community**:
   a. mining work - this work is usually carried out by RTK, thus a single stand-alone reference station transmitting RTK data by radio directly from the receiver may be all that is required. In most cases it will be preferable to have reference station software running on a PC to control the receiver, and to download and archive logged data.
   b. Small community work – a single stand-alone reference station may be sufficient for this type of work ie local government surveying, utilities and asset collection. Radio and/or phone could be used to transmit RTK/DGPS data. A router or bank of phone modems would be needed in order that several users could phone in at the same time. Reference station software running on the PC will control the receiver, download and archive data. With a PC connected it is also possible to distribute RTK/DGPS data to a number of users at the same time via the Internet.

c. Civil engineering and construction sites ie for where high accuracy is required, may be optimal to setup a second independent reference station in order that the RTK rovers can obtain two independent positional 'fixes' at critical points. A single PC (server) running the reference station software could control the two reference station receivers ie a two station network.

2) **A simple network of a few stations providing complete RTK coverage for a relatively small, well developed area:** ie for an area of say 60km by 60km, where a relatively simple solution would be to have 4 to 5 reference stations spaced about 30km apart- providing adequate RTK coverage for the area. Dial up lines would connect the stations to a central server running the reference station software. The software would control the receivers, download logged data files and 'push' RINEX files to an FTP server. RTK/DGPS data could be transmitted directly from the receivers by radio and/or phone, with the radios at the stations having to be set on different channels (ie frequencies). A router or bank of phone modems would be needed at each station to allow for several users to dial up simultaneously. This network configuration could be considered as relatively easy to set up, and as there would be no permanently operating lines, the running costs should be relatively low.

3) **A more complex network providing complete RTK coverage for a relatively large, highly developed area:** for a larger area say up to 200km by 200km of required coverage, then there are two possible options or possibilities:
   - **a.** The option as outlined above, but with more stations, and therefore the implied increase in operational and infrastructure supply costing,
   - **b.** Place the stations further apart and use software for continuous network analysis and calculation of network correction parameters – allowing for RTK at longer ranges.

An example of this latter case is for where we have to establish RTK/DGPS services for an area of say 200km by 200km: with about 9 reference stations and a separation distance between the stations of about 70km. RTK rovers will usually be within 35km of a potential station and the maximum distance from a station should not be more than about 50km. For continuous network analysis and calculation of network parameter corrections, raw data will have to be streamed continuously from the receivers to a central server running the reference station software. Permanently open communication links between the receivers and the server are required, with an expedient option being use of the Internet, as running costs (charges) will be lower than with permanently open telephone lines. The software running on the server would control the receivers, download logged data files, and again 'push' RINEX files to a FTP server (Leica Geosystems 2007).

2.13 Results of a Scoping Study Questionnaire investigating CORS potential in Western Australia (2006)

A scoping study and Western Australia spatial industry stakeholder questionnaire on the potential for enhanced GNSS functionality in that state was conducted by Curtin University between 2005 and 2006. some pertinent results and conclusions from this study include the following:

A possible future network of CORS network could complement the existing geodetic network, and service the positional information needs of a wider user community. The current providers of similar services over Western Australia include direct GPS positioning (about 10m accuracy),

Omnistar (commercial provider, 1.0m to 0.1m accuracy, differential GPS, real time, subscriber service), Australian Marine Safety Authority (AMSA Beacon system, coastal coverage, real time about 2.5m, free-to-air) and AusPos (greater than 6 hour GPS observations and post processing of results by Geoscience Australia who operate the AusPos system throughout Australia, 0.05m horizontal and 0.08m vertical, free-to-air). Collectively, these existing GPS based services meet the known needs of a broad range of users (Curtin University 2006).

These include: precision farming, off-shore positioning, asset management, environmental monitoring, exploration and remote project positioning needs.

Most respondents acknowledged that a future network would be based on a CORS strategy, although they saw risks moving to total dependency on an internationally owned and operated system. There were mixed views on the density required, but most believed State coverage (in some form) was necessary. Even with a CORS, users stated they required ground marks to provide redundancy (risk management), reference for re-establishment of position, and calibration of CORS and GPS equipment. Users of the existing network commented that marks must be maintained at an agreed density and location for the foreseeable future, especially for height, and until satisfactory and repeatable accuracy can be generated from CORS positioning (Curtin University 2006).

Interviewees believe that the market for CORS services would increase rapidly in applications such as machine control (earth moving equipment, construction), asset tracking and management, environmental monitoring, mining and mineral exploration, agricultural uses, geotechnical services, expanded survey services, all real time positioning applications, all forms of mapping and for GIS purposes. Survey users foreshadowed demand for higher positional accuracy and certainty will grow as urban density increases, and asset location/ management within service corridors becomes more critical (Curtin University 2006).

These uses have varying accuracy requirements and the market may be substantially satisfied by current GPS services. Current service and equipment providers believe growth will occur as the number of GPS satellites increase (Galileo in Europe, 2008 on) and new frequencies (and hence quality, accuracy) are included. Nonetheless, there was limited feedback on future use, indicating a lack of market knowledge in this State.

Technically, users believed that the data management issues will be complex given the datum (GDA94) is active and constantly changing, albeit slowly. The development of a stronger and more accurate relationship between the AHD height (determined by spirit leveling from tide gauge networks) and geoidal height (from GPS/ CORS) would result in more applications. Traceability of coordinates and integrity monitoring of the CORS were viewed as critical risk management issues, and all users commented that these were the responsibility of government.

The role of the Commonwealth was viewed as that of national coordination, international collaboration for continued involvement in satellite programs such as GPS and more specifically through Geoscience Australia, the operation of reference stations throughout Australia (a national CORS (AusPos), supporting the Australian Fiducial Network for international integrity monitoring of the GPS satellite network), and development of national standards through committees such as the Inter-government Committee on Surveying and Mapping (ICSM) and the AGCC. There was limited appreciation by users of the respective responsibilities of these committees. Victoria indicated they had worked closely with the

Commonwealth to ensure their GPSnet (statewide coverage) was compatible with the national network (Curtin University 2006).

Respondents listing of Applications of perceived benefit
The following applications were identified by Curtin University (2006) as having potential State or National benefit and as being currently unsupported by the existing CORS infrastructure within Western Australia:
• Regional real time kinematic positioning services.
• Geohazard monitoring, including crustal monitoring, mean sea level monitoring, tidal loading determinations and atmospheric sounding.
• Post-processed kinematic surveying, particularly for airborne survey work.
• Precision guidance systems, with application in agriculture and engineering, are currently supported in an ad hoc sense by the commercial sector. Availability of services is restricted in some areas of the State by commercial constraints.

2.14 Conclusions

The literature review has introduced the CORS system of networked GPS base station systems that exist in various configurations across the country, under the management and control of various state government instrumentalities and commercial enterprise organisations.

The chapter has clearly identified that the CORS networks are restricted to major population centres such as State capital cities, or single state coverage, in the situation that exists for the state of Victoria.

The literature review has demonstrated that a clear case for CORS site establishment should be in keeping with recognisable and nationally adopted standards and guidelines to reduce duplication etc as asserted by Hale et al (2005)

The review also details aspects of CORS establishment that were considered important as a basis for standardization, and I will now conduct research into the feasibility of establishment of CORS site in regional NSW as a case study and utilise similar questions to gauge the degree of compliance within the case study area, by assessing spatial industry stakeholders and industry, to determine the degree of compliance and hopefully justify a case for CORS site establishment.

CHAPTER 3 RESEARCH METHOD

3.1 Purpose for Further Research

As detailed in the introductory chapter, Dubbo City Council (DCC) have established that they wish to investigate the potential for enhanced GNSS capabilities and functionality for their own requirements. Also, they wish to investigate the potential of incorporating any potential enhanced spatial systems, that they may establish, within the greater spatial infrastructure that is currently being proposed by the various State and Federal government organisations such as the NSW Department of Lands. However, should this enhanced functionality not be feasible, then DCC wish to investigate realistic alternatives.

DCC also acknowledge that various options for enhanced GNSS functionality now exist, and I have reported this information in the literature review chapter, with a background and investigation into trends in GNSS enhancement, both in NSW and Nationally.

My investigations have revealed that there is limited research on the justification and validation for such infrastructure in regional NSW.

3.2 Aim of this Further Research

Therefore, the aim of this Research will be to investigate the options for DCC to enhance their spatial functionality. This investigation will focus on either:

- the establishment of spatial infrastructure such as a CORS, leading to connection into the proposed DOL NSWNet,
- a standalone GPS Reference Station serving the requirements of DCC only
- a standalone GPS Reference Station serving the requirements of both DCC and the larger geographical location of up to 200km radius from DCC, inclusive of other spatial industry stakeholders within this area, and potentially in a ‘co-operative’ business relationship with other stakeholders
- combinations of the above options.

3.3 Research Method

The specifications of this project required that a Business Model and cost benefit analysis of the proposal to establish a continuously operating, dual frequency GPS base station by Dubbo City Council be made.

To make an acceptable determination of the feasibility and benefits associated with preparing a business case, then accurate up to date data was required on a range of issues related to the proposal to establishing a CORS site.

The Research Approach to this project was based around the development and distribution of a questionnaire to Spatial Data Industry stakeholders ie the users and creators of spatial data such as Local Government Departments, private industry ie land surveyors and earthworks companies, the Roads and Traffic Authority, Department of Agriculture ie Precision and Conservation Farming in and around the NSW Central Western City of Dubbo.

The questionnaire approach was chosen when initial information gathering indicated this was an area that had not previously been the subject of research and even basic information was not readily available in NSW. The completion of the literature review confirmed this lack of available information and reinforced the decision to prepare a questionnaire.

While the questionnaire was developed both for respondent completion and as a guide to conducting an interview, the ability to gather information by interview techniques was severely limited by available time and by the availability of questionnaire participants.

I developed a questionnaire that was both straight forward and relatively short in length so participants did not perceive the completion as a difficult and time consuming task.

This research method describes in detail the questionnaire, its distribution and the collection of other supporting materials. The range of problems encountered in the research process are described to provide a link to the recommendations for further work.

3.4 Questionnaire

To be successful the questionnaire needed to be sufficiently detailed to allow for gathering of information that would not only represent the stakeholder interests for this location, but may also be representative of other regional locations in NSW.

It was also important that the questionnaire contain some background information on the project and myself as the DCC sponsored student, so that the firms receiving it understood this project was a legitimate educational exercise. From initial telephone contact, I was able to determine that many of the participants in the questionnaire process had relatively minimal understanding of the CORS development process in NSW. Thus I had to prepare a brief background to GNSS and CORS developments in conjunction with the questionnaire.

The questionnaire was comprised of two sections. The first part was directed specifically to Survey Practices, and the second part of the questionnaire related to CORS Networks.

In preparing the questionnaire I considered the types of questions I was trying to answer, and used these points as a guide:

1. Is there a correlation between the existing usage of GNSS by a participant and desire for an enhanced utilization? That is, do some stakeholders wish for a greater scope of GNSS service provision by such systems as CORS.

2. Is there a correlation between the status (ie Business, Private Industry, Local Government, farming industry, construction industry etc) of a particular stakeholder and the desire of that group to share the responsibility of combined service provision? That is, what is the stakeholder willingness for the generation of a co-operative Networked Base Station site, to be located at

Dubbo City Council, and what is the breakdown in industry sector that is either for or against a co-operative base station hub.

3. Is there a correlation between industry nature of a stakeholder and their willingness to contribute financially to a co-operative Base Station site?

4. Is there a correlation between the industry status of a particular stakeholder and the philosophical approach to CORS Network Data custodianship ie which level of government should be responsible for custodianship of the relevant data.

5. Is there a correlation between the industry status of a particular stakeholder and the approach to the establishment and management of a CORS Site that would meet the needs of users and stakeholders? Ie does one particular industry support a particular form of CORS establishment and management over another.

6. Is access to electronic data sets important to the products of the firm? What are the main sources?

7. Is sharing of data, both the firms and others, an important part of the business?

8. Where is the traditional surveying firm going in terms of services, staff, IT and the role of the senior surveyor? That is, how do they see their part of the industry changing?

9. Do the respondents make use of enhanced GPS data acquisition facilities ie GNSS ?

10. Do the respondents use RTK or DGPS or both or none?

11. What sort of accuracy is required by the respondent?

3.5 Selection of Participants

The sample size, that was considered representative of the Spatial industry in the NSW Central West, was small, however, it is still representative of the typical sample selection representative of many NSW Regional centers of population.

The questionnaire form had been specifically designed to be emailed to selected spatial industry businesses, local government authorities, state government authorities etc, and could be completed using standard office software for return by email.

As the purpose of this investigation is the feasibility of establishment of a CORS site at Dubbo City Council, being a case study as representative of many other NSW Regional Population Centres, then the selection of participants was as broad based as possible for the particular regional area. I attempted to seek questionnaire responses from as many spatial industry stakeholders as possible in this location.

The representative sample set was determined by reference to the Sensis Company White and Yellow Pages ® listing of land surveyors, conservation and precision farming exponents, State Government Road Authorities, Local Government (City and Shire Councils) and construction

companies in the Dubbo vicinity, specifically inclusive up to 100km radius from the centre of Dubbo.

The Yellow Pages was chosen mainly for the reason that it provides a quick search for those firms that are actively engaged in the surveying and civil construction profession, since the yellow pages is an advertising medium and any surveyor or earthworks company who is not actively seeking business would be unlikely to purchase this advertising space.

The White pages is suitable for the listings of all State and Local Government Authorities such as Local and City Councils, Dept of Agriculture and the Roads and Traffic Authority NSW.

3.6 Questionnaire Distribution

The questionnaire was distributed to seven potential users of CORS infrastructure in the Dubbo area, with respondents coming from Local Government, State Government (Roads and Traffic Authority and Department of Agriculture) and Consulting Surveyors.

3.7 Ethics

An important consideration in collecting information from any private business is maintaining privacy of that information from their commercial competitors. While each questionnaire collected specific details about each firm or organisation, I undertook to ensure that all information was only collated, analysed and summarized in such a way as to ensure that no individual respondent can be identified. This undertaking was published on the questionnaire.

3.8 Other Materials

The questionnaire had specifically requested information on the respondents views about a range of options including the respondents appreciation of GNSS, the potential for enhanced GNSS capabilities for the NSW Central West centred around Dubbo, the degree of potential for the various respondents to participate in enhanced GNSS capability ie CORS co-operative site establishment etc.
Further investigations have revealed that M.Hale, P.Collier and A.Kealy of the CRC for Spatial Information and Department of Geomatics, of the University of Melbourne, Victoria have conducted a study into the Victorian GPSnet CORS network Management Validation via a questionnaire process of which results are available to provide a correlation to my own results. These correlations will be shown in the next chapter of results

3.9 Problems Encountered

There were no intractable problems encountered, just the expected limit on the time available to collect information. With stakeholder respondents being unusually busy for the time of year, responses took more time and effort than originally envisaged.

Despite numerous attempts, getting any response from some of the industry Organizations, specifically civil construction representatives, was impossible. This necessitated the requirement

to carry out less formalized telephone discussions to gain an appreciation of this particular industry's desire for enhanced GNSS capabilities in the local area.

Another unforeseen problem to the data acquisition phase / questionnaire was the very minimal understanding of Spatial industry developments by various respondents particularly to national and state based developments. There wasa very limited understanding in general to CORS based technology development in NSW and this can be considered to be an impediment to the State based rollout of networked GPS Base station functionality.

This problem necessitated the creation of a sizable background 'brief' to the current state of GNSS Development nationally, which was included as a covering document to the questionnaire for all participants.

3.10 Conclusions

The research method I have discussed did generally deliver the results I was expecting. The questionnaire in particular was a successful medium for gathering a range of quantitative and qualitative information that provided indicators to constraints that necessitated further investigation.

Having distributed the questionnaire and received a good range of appropriate responses the next chapter collates these results for analysis.

CHAPTER 4 RESULTS

4.1 Introduction

This chapter will focus on analyzing the results of the Dubbo City Council (DCC) sponsored questionnaire with respect to addressing the purpose and aims as outlined in previous chapters. This involves the case for DCC establishing enhanced spatial functionality in their organization, and their desire to assess the degree of interest in the spatial industry in and around Dubbo. This questionnaire should provide tangible evidence of the compilation of a business case for DCC's proposed spatial infrastructure, and will focus on industry validation for a range of models including:

- the establishment of spatial infrastructure such as a CORS, leading to connection into the proposed DOL NSWNet,
- a standalone GPS Reference Station serving the requirements of DCC only
- a standalone GPS Rreference Station serving the requirements of both DCC and the larger geographical location of up to 200km radius from DCC, inclusive of other spatial industry stakeholders within this area, and potentially in a 'co-operative' business relationship with other stakeholders
- combinations of the above options.

Therefore, this chapter will comprise a dissemination of the questionnaire results particularly with respect to DCC's spatial infrastructure enhancements and lead to the preparation of a business case and report to Council on the preferred options in the analysis and discussions chapter of this dissertation

These options shall be presented as a validation of a particular model, reflective of not only this questionnaire results, but also from prevailing literature research as proposed in my literature review chapter.

4.2 Questionnaire Results

The questionnaire targeted spatial data related organizations, surveying professionals and industry in the NSW Central West only, of which seven tabulated results were available for analysis. Approximately half the respondents represented local government organizations surrounding Dubbo (ie up to 100km from from Dubbo), with an equal proportion of respondents coming from the surveying profession, in state government instrumentalities and private consulting groups in Dubbo. A respondent also came from the conservation farming industry within the NSW Department of Agriculture.
The results as provided for each particular question varied, however there was linearity in results along the side of "like" industries.

The questionnaire was able to produce results in the following broad categories:

- General demand for CORS,
- A background to the types of organizations that would be potential stakeholders in a CORS Network/NSW DLI NSWnet,

- General stakeholder awareness of enhanced GNSS capabilities state-based and nationally,
- Maximizing value of geodetic connection and NSW Cadastral database,
- Role of government,
- Enhanced GNSS and CORS benefits, costs and funding,
- Implementation and transition to future geodetic network,
- Demands, users and needs,

4.2.1 Current Status, demand, users and needs

SydNET - the questionnaire results for this study would indicate that the NSW SydNET network is "known" by the majority of respondents, however minimal usage of it's capabilities is reported. The network is predominantly utilized by local government respondents rather more than the surveyors.

Cadastral Surveying - of the respondents, it is the surveying groups that carry out most of the cadastral work, and also possess survey accurate GPS equipment.

For these surveying groups, it was a case that two of the three respondents utilized total station equipment and techniques for connecting to control, greater than 75% of the time, and GPS for approximately 25% of the time. The other surveying respondent utilized GPS and Total Station in equal proportion to connect to geodetic control. All surveying groups used dual frequency, geodetic quality equipment, and predominantly used RTK when connecting to control, surveying a traverse and picking up detail points in the field.

Leasing or sharing GPS equipment - there existed some ambivalence from all parties to the concept of leasing or sharing GPS equipment as a partnership or consortium, with local government the more willing party to this potential arrangement.

GPS Purchasing - Most parties were reticent in detailing their future GPS equipment purchasing plans. However, almost 50% of the respondents indicated that they would be purchasing GPS equipment in the next 5 years. All parties listed cost as the overriding impediment, however, to future GPS equipment purchases.

Barriers to purchasing GPS equipment – 75% of respondents considered Price as the biggest barrier to purchasing GPS equipment in the future, with Local government respondents particularly sensitive to equipment cost. The next most important barrier was availability of base stations.
For local government respondents, the issues of legal traceability was generally the least concern, followed by lack of GPS applications as also of least concern.

4.2.2 Role of Government

Government involvement - A near majority of respondents felt that the management and operation of CORS networks would be most effectively and appropriately managed by State Government (70%), and a similiar level of agreement was felt amongst the respondents that custodianship of CORS data would also be best managed by State Government (60%), with the NSW Department of Lands the most appropriate organization.

However, respondents view on who should provide CORS network stakeholder consultation was varied, with 60% favouring the Australian GNSS Coordination Committee (AGCC) or similar body to provide consultative information to various stakeholders, a lesser proportion of respondents (30%) favoured a (indirect) State Government led GNSS Reference group and a respondent also favoured the Committee on Surveying and Mapping (ICSM).

No direct State Government based consultative processes were favoured.

4.2.3 CORS networks

Respondents were predominantly in favour of national systems of 'joined up' CORS Networks (70%), that were perceived to be able to benefit the whole of community users.

4.2.4 CORS network contribution to ASDI

A large proportion of respondents (70%) believe that a considerable to significant contribution can be made to the Australian Spatial Data Infrastructure.

4.2.5 Operating Standards

The respondents overwhelmingly considered that it was of high importance for eventual 'joined up' CORS Networks to deliver data in both standardized and internationally accepted formats (100%).

All respondents universally agreed 'somewhat' with the concept of data accuracy at better than +/- 20mm to achieve their positioning (and or navigation requirements). For two respondents this completely exceeded their requirements.

4.2.6 CORS Antenna coordination and control network specification

A larger proportion of respondents felt that the receiver position coordinates network (which depend on CORS antenna coordinates) would be consistent with a local (state based) geodetic network rather than the alternative Australian Regional GPS Network. Interestingly, all Local Government representatives responded affirmatively to the state based network.

Most respondents felt that it was "considerably" important for the proposed network to advise of data quality implications and alert systems, with a minority considering this aspect highly important.

Response was somewhat mixed to the proposal for capability of receiving enhanced GNSS functionality via satellite systems such as GLONASS and GALILEO, with their perceived future demand for these services considered to be similar. In this instance, the surveyors group generally responded with more than considerable requirements for future GNSS enhancements and functionality in comparison to Local Government.

4.2.7 CORS Network Real Time Kinematic (RTK) positioning

The importance of this functionality was particularly emphasized amongst respondents, with 70% of respondents asserting that the nominal accuracy of +/- 20mm that can be achieved with CORS network correction would achieve their requirements.

4.2.8 RTK and Post-Processing functionality

Of the respondents that used survey equipment, all respondents used RTK rather than Post Processing functionality when surveying a traverse, connecting to survey control and picking up

detail in the field, with one respondent using RTK and Post Processing functionality when connecting to control.

4.2.9 CORS Data and Post Processing

70% of respondents considered this functionality as either considerably to highly important. In this response, Local Government representatives felt that this functionality is more important relative to the surveyors group who considered this functionality of lesser importance.

4.2.10 Legal arrangements

Privacy of location was considered 'somewhat' important by the majority of respondents (70%) and 'not important' by 30% of respondents, however, the delineation amongst local government and surveyors was similar.

4.2.11 Legal traceability of Position

40% of respondents considered this functionality as 'somewhat important' with 60% of respondents considering it as 'considerably important' to 'highly important'. The surveying respondents considered this aspect as being of considerable importance, with local government and precision farming respondents considering this functionality of lesser importance.

4.2.12 Commercial – CORS Data distribution

Satellite correction data distribution was favoured by direct distribution from government agencies by a majority of respondents (60%), with a minority favouring distribution by a combination of government and private sector organizations (30%).
Again, the skewing of responses tended to favour the wholly government distribution by local government respondents. However, the combination of private sector/government partnerships was favoured considerably.
No respondent favoured the choice of direct on-selling of data by the private sector (with some value adding).

4.2.13 Commercial – Potential subscribers

Almost 50% of respondents indicated that if a CORS Site was nearby that they would subscribe as users of corrected data, and the other respondents would 'possibly' subscribe. A majority of respondents (70%) considered that there was a possibility of contributing to establishment costs of a CORS site.

For almost all respondents (90%), the case for being able to utilize a geodetic quality, dual-frequency GPS Rover unit to obtain accurate measurements, without the requirement of having to purchase a complete base station and rover system, was considered as a encouraging proposition, however, all respondents would obviously have to weigh up all mitigating factors such as accuracy and cost.

Chapter 5 ANALYSIS AND DISCUSSION

5 Analysis and discussion of questionnaire

5.1 Introduction

The purpose of this chapter is to consolidate the results from the questionnaire and thereby answer the questions posed by the aim and objectives of the project, as described in the Research Method. At this point the other materials collected in support of the project will be discussed in the context of the questionnaire results.

It is acknowledged that the questionnaire provided a relatively small sample size, meaning the analysis and any conclusions drawn may be a simple reflection of the sample and not of the wider spatial industry. However, this analysis still provides a useful starting point for further investigation using a larger sample size more reflective of the state based spatial industry or a larger regional sample size of traditional and non-traditional spatial data stakeholders.

The questionnaire results shall be then used to formulate a Business Model that will best represent the respondents desire for enhanced GNSS functionality in the area centered by Dubbo in the central west of NSW, as well as providing for the aims and objectives of this project.

5.2 Analysis and Discussion

Question 1 – *what is required? Is there a case from spatial industry respondents for enhanced GNSS functionality in this area?*
Almost 50% of respondents in this study of spatial industry respondents in the Central West of NSW indicated that if a CORS site was nearby that they would subscribe as users of corrected data, and that the other respondents would possibly subscribe as users. Most respondents considered that there was a possibility of contributing to establishment costs of a CORS site. This would indicate that there is certainly scope for CORS provision to be considered.

Question 2 – *what are the accuracy requirements and who uses RTK or uses Post Processing functionality?*
Of the respondents that used survey equipment, all respondents used RTK rather than Post Processing functionality when surveying a traverse, connecting to survey control and picking up detail in the field, with one respondent using RTK and Post Processing functionality when connecting to control.
Post Processing functionality – almost three quarters of respondents considered this functionality as either considerably to highly important. In this response, Local Government representatives felt that this functionality is more important relative to the surveyors group who considered this functionality of lesser importance. This would indicate that for the surveying community, RTK functionality is very important, however, for the Local Government organizations who would be utilizing the functionality of asset data mapping etc then Post Processing functionality is very important. However, for many organizations that were both aware of the functionality of SydNET, and have and may start to use SydNET, that the choice for Post Processing services are more broad.

Hale et al 2007 in his study reported that respondents highlighted the ongoing need for CORS network operators to support post-processing functionality even though it was implied that real time applications will eventually dwarf post-processing applications. The Victorian study by Hale et al 2007 also reports that respondents noted the advantages of post processing that inclouded support for legal traceability, science and research applications and providing backup when communication outages disrupt or prevent real time CORS network services.

Question 3 - *Is there a correlation between the status (ie Business, Private Industry, Local Government, farming industry, construction industry etc) of a particular stakeholder and the desire of that group to share the responsibility of combined service provision? That is, what is the stakeholder willingness for the generation of a co-operative Networked Base Station site, to be located at Dubbo City Council, and what is the breakdown in industry sector that is either for or against a co-operative base station hub.*
For almost all respondents, the case for being able to to utilize a geodetic quality, dual-frequency GPS rover unit to obtain accurate measurements, without the requirement of having to purchase a complete base station and rover system, was considered favourable. This does not completely address the level of commitment to a co-operative base station arrangement amongst spatial industry respondents, however, it does leave the door open to DCC for increased discussion amongst potential business partners. Obviously, with the consulting surveying respondents having existing semi-permanent base station functionality, that these services could be combined as a co-operative network model with the proposed DCC Base Station. This would require further investigations and study, inconjunction with analysis of network software.

The questionnaire results of Hale et al 2007, indicate that Network RTK was found to be of high or considerable importance to the majority of respondents in the Victorian GPSnet network validation study. The respondents in this study strongly identified this level of service as important to attracting new users, and addressing the needs of non-traditional spatial information users. The respondents in this survey also felt that the cost of CORS NRTK services are a critical determinant of user uptake. They felt that if a user can run their own base station for less cost, then this will undermine CORS network uptake. However, although cost is an important consideration, factors such as convenience, security and certainty of positioning are also considered of significant benefit to be communicated to potential CORS network users.

Question 4 – *Legal traceability of position* : Hale et al 2007 also points out that legal traceability of position was considered by the majority of respondents to be of high or considerable importance, as was the case with my own study.

Question 5 – *Commercial arrangements :and CORS data distribution*: the DCC study indicates that satellite correction data distribution was favoured by direct distribution from government agencies by a majority of respondents, with a minority favouring distribution by a combination of government and private sector organizations.
The skewing of responses tended to favour the wholly government distribution by local government respondents. However, the combination of private sector/government partnerships was favoured considerably.
No respondent favoured the choice of direct on-selling of data by the private sector (with some value adding).

Hale et al 2007 reports that CORS network users in Victoria strongly supported involvement b ygovernment and the private sector in the management and distribution of CORS networks and service distribution. Responses in Hale et al 2007 study included that CORS networks apply to entire communities and should be controlled by government, or that the private sector is better at

packaging services in an innovative manner and finding customers and that government al all levels should concentrate on building and controlling the CORS infrastructure.

It is worth noting that the Victorian GPSnet approach of splitting infrastructure management to government and service distribution to the private sector satisfied most respondents concerns for the GPSnet study.

5.3 Conclusions and Business Model Report

The discussion in this chapter has drawn together the questionnaire results from the DCC study, and other collected materials to generate justifications for enhanced GNSS functionality and the degree of validation that may exist from other spatial industry stakeholders in this geographic area. This has resolved the tasks as detailed in the Research Method chapter, and provided useful material for the creation of a Business Model and Validation Report for Dubbo City Council.

This Business Model and Report has been prepared from both the current research data on enhanced GNSS infrastructure, as presented in the Literature Review, as well as validation material from this questionnaire analysis, and is now included for review by Dubbo City Council to consider.

5.4 Dubbo City Council CORS Business Model and Report

Dubbo City Council GPS Base Station
Project Assessment

Region: NSW CENTRAL WEST

Project Name: Dubbo GPS Base Station

Project Description: To establish a permanent Global Positioning System (GPS) base station for the Council of the City of Dubbo.

Project Location: Dubbo

Population: approx.45,000

5.5 Executive Summary

The NSW Department of Lands (DOL) is investigating the possibility of establishing a broadened Permanently Operating Network of GPS Base Stations across the State.
Dubbo City Council is considering the placement of it's own GPS Base Station infrastructure, that should be incorporated into the greater State and National network of GPS Base stations. Council considers that the opportunity to integrate with these emerging spatial technologies is to consider it's own requirements for enhanced spatial capability, and will consider such aspects as:

- objectives/vision for the technology;
- its relationship to organizational needs;
- quantification of the benefits and costs of the investment and
- strategy for implementation, as part of a greater business case.

5.6 Purpose

Dubbo City Council (DCC) wishes to enhance it's Spatial Technology capabilities with the provision of Permanently Operating GPS Base station and for it's inclusion into the proposed DOL NSWnet network of Continuously Operating Reference Stations (CORS).

5.7 Background

DCC has been purchasing various survey and mapping GPS equipment and associated software over recent years. As part of the introduction of GPS (and more recently, GNSS) functionality, DCC established a (single frequency) GPS Base Station in 2002, that was primarily utilised for mapping of various Council assets. The functionality proved accessible to all stakeholders and allowed for greater scope and portability of data acquisition. The base station currently is sited on a geodetically placed Trig. Station and is recorded as part of the DOL register of survey control. Council staff have been able to report that the ability to post-process locations that were taken in the field against the known location of the base station increased the relative positional accuracy of GPS derived coordinates to around +/- 200mm in the city and to +/- 500mm in rural areas. This gave the council staff greater capability and sufficient accuracy to capture various asset classes for their GIS database.

The functionality and portability of GPS Base Station derived data became a motivation to other council divisions to adopt and test the systems for their own requirements. Divisions such as construction and utilities quickly adopted the GPS functionality and conducted real world trials of GPS RTK functionality inconjunction with large earthworks projects.

The Council soon acknowledged that a more “rigorous” data capture and data usage system was required to provide greater positional accuracy, that was both accurate and timely ie ‘real time’. This functionality is to be provided by dual frequency, geodetic grade GPS receivers operating as RTK.

In 2007, DCC conducted various trials on construction projects utilising contemporary, dual frequency, geodetic grade GPS receivers. The trials proved beneficial to establishing greater productivity gains for earthworks.

Figure 8 Trimble Precision Guidance infrastructure fitted to DCC grader - GPS Real Time Machine Guidance Trial, Dubbo City Council Effluent Ponds Reconstruction, May 2007

Figure 9 Trimble Precision GPS Real Time Machine Guidance Trial, Dubbo City Council Effluent Ponds Reconstruction, May 2007

Cross-sharing of resources by various divisions of Council has been agreed to and DCC is now in a position to validate the enhanced base station upgrades to a dual frequency grade receiver. Chargeout rates have been calculated by various stakeholders that will justify the increased expenditure requirements for machine guidance equipment, with the council establishing protocols for business units that will incorporate the costs of distributing correction signal.

5.7.1 Background to Global Navigation Satellite Systems (GNSS)

GNSS Infrastructure Types

GNSS infrastructure may involve a single reference station, multiple reference stations or wide area CORS and Virtual Reference Systems (VRS) networks and offers numerous benefits to surveyors and spatial industries in general in various ways including positioning over a large area, a common coordinate reference frame, reference station security, decreased learning curve to achieve precise GPS surveying, cost savings for capital improvement projects (government) or larger profit margin on the same type of jobs (private sector) and reduced costs for field crews for field setup and equipment costs.

Single Reference Station Network
This is an independently operated 'community' reference station providing data for multiple applications. Private firms, municipalities and larger agencies all find single reference stations a suitable starting point to gain network RTK benefits. Generally, a single reference station is connected to one computer for a variety of applications including:

- Post-processed file logging for static surveying,
- Single-base RTK positioning for precision applications within 20km radius from the reference base,
- DGPS corrections for sub-meter accuracy within a 200km radius of the base.

Multiple Reference Station or CORS Network
This is the next stage of GPS infrastructure, being a multi-station network controlled at one central site. Analogous to a wide area network (WAN), these networks cover a larger area. Each station offers single-base RTK positioning but all stations are managed centrally. The GPS infrastructure can be controlled using the same architecture as an IT network. Benefits include expanded geographic territory, increased quality control and enhanced coordinate/data monitoring. All network solutions have access, authentication and accounting so network managers can control who has access to the systems for RTK correction broadcast.

5.7.2 Network establishment specifically for a target industry

Agriculture is a major growth area for positioning services with the majority of agricultural operations in the State now utilising some form of satellite based positioning. Installation of CORS stations for agricultural applications has been, to date, on a strictly ad hoc basis. A number of companies such as Agsystems, Precision Farming Australia, Rinex, Satloc and Trimble Precision Agriculture specialise in supplying positioning solutions to the industry, whilst the OmniSTAR XP product will specifically target the agriculture sector.

As with the mining industry, it is difficult to quantify the number and type of CORS stations installed for agricultural purposes. Cost and economics are a much more significant driving force in agriculture than the mining industry. It may be generalised that Differential GPS (DGPS) CORS are widely operating in agricultural regions whilst a number of farms are running their own RTK systems.

5.7.3 Justification of a CORS Network for Precision Agriculture in the NSW Central West

The ongoing campaign to maintain Australia's on farm profitability and international competitiveness has increasingly put pressure on our agricultural sector (Denham et al 2006 and ABARE 2005).
Australian farmers are under pressure to improve productivity and cut costs to remain competitive. At the same time sustainable agriculture and improved environmental outcomes are increasingly a subject of government and community focus. Agricultural productivity is the product of several factors and in a recent report on the grains industry, the Australian Bureau of Agricultural and Resource Economics (ABARE) concluded that arable land management practices used by farmers was a major determining factor of their productivity (ABARE 2005). The need for improved arable land management practices and associated improved productivity can often be achieved by applying spatial technologies. Contemporary precision agriculture (PA) can support advanced arable land management practices using spatial technology including

satellite navigation techniques, improving productivity and the lives of farm workers whilst simultaneously aiding sustainable environmental outcomes.

5.7.4 NSW Dept of Lands Proposals for a State CORS Network

A proposal to cover all of NSW is currently under review with the release of expressions of interest into a business case for the design and implementation plan for a GNSS CORS network, being tendered by the NSW DOL in 2007.

The NSW DOL assert that with the cost of GPS equipment now having decreased (in real terms), and with advancements in GPS and communications technology, that there has been a greater uptake of GPS technology, especially in State and Local Government organizations. The DOL also acknowledge that some components of the existing conventional geodetic infrastructure such as Trig. station monuments on mountains, are no longer convenient or economical for users of geodetic infrastructure. In addition, the effort and cost of maintaining the physical infrastructure is increasing. These factors, along with increasing efficiency and spatial accuracy demands create a different environment for considering a statewide GPS reference station network (see Figure 10 Potential NSWnet GPS sites).

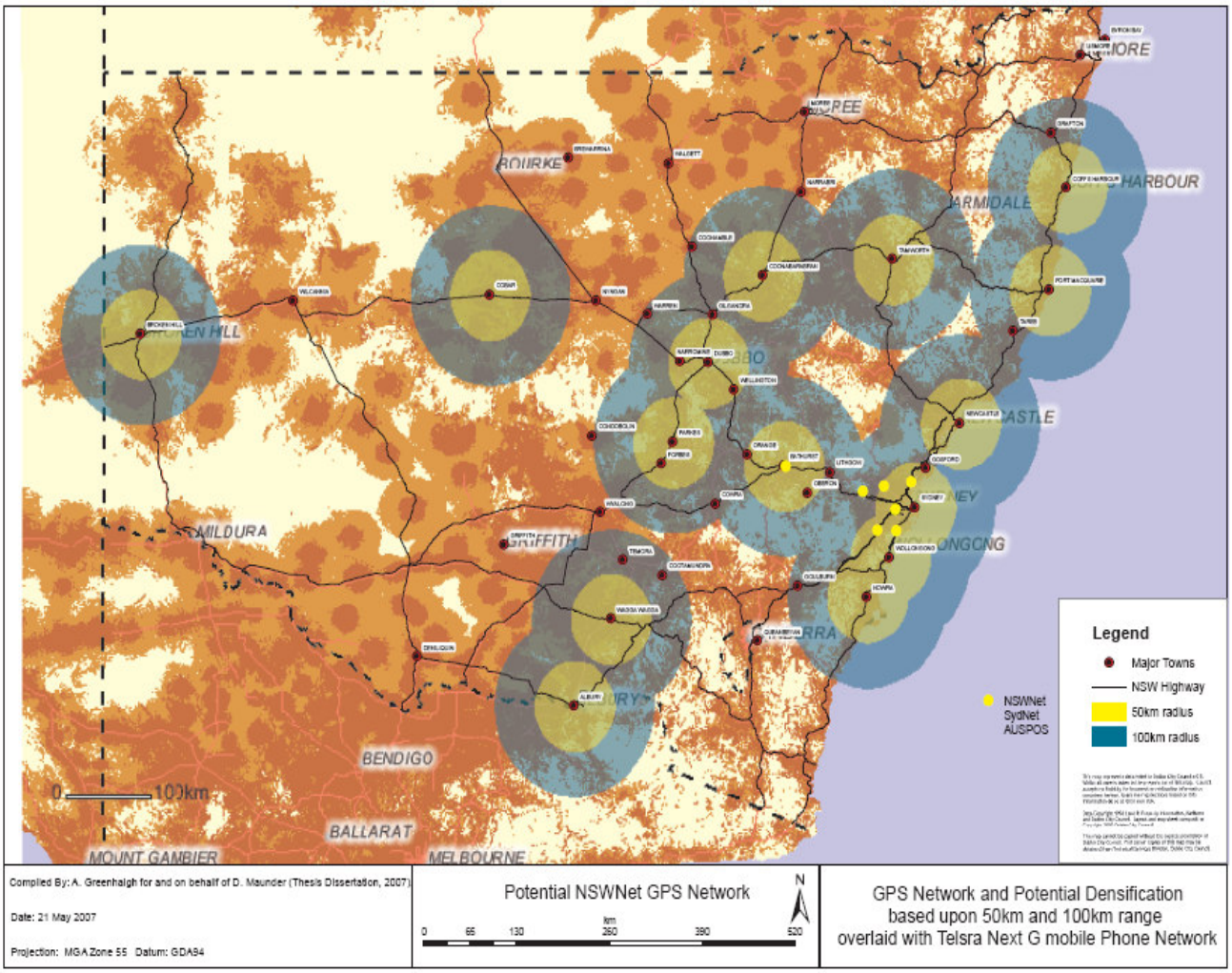

Figure 11 Potential NSWnet GPS Network for NSW (Source A.Greenhalgh, May 2007)

The design and implementation plan and business case for the DOL will take into account the various key spatial aspects:

- The existing build and current plans for the SydNET/Metronet CORS infrastructure,
- Existing Lands Dept. regional offices, facilities, trig stations and reserves,
- GNSS reference stations established by other government agencies in NSW including local government /councils, as well as privately owned and operated GPS reference stations,
- Technical and administrative integration with National (Australian Regional GPS Network), Queensland (Sunpoz) and Victorian(GPSnet) infrastructure,
- Federal augmentation systems such as the Australian Maritime Safety authority (AMSA) beacons,
- The medium and long term requirements of passive geodetic infrastructure (coordinated ground marks) balanced with the requirements of an active geodetic infrastructure (CORS network),
- Emerging GNSS technologies (US based GPS III, European Union based Galileo etc),
- National and international experience and trends (ie Geoscience Australia proposals, UK German and US) in public-private partnerships for building, managing and delivering GNSS CORS infrastructure services.

Anticipated service delivery of the proposed network is dependent on:

- A detailed GNSS CORS design and implementation plan for the NSW CORS infrastructure (which will include – a recommended density of CORS in NSW to enable users to achieve centimeter level positioning across the state by 2015;
- recommended medium and long term locations of all CORS sites as well as the CORS network control centre;
- procurement strategies for all CORS sites ie software, hardware;
- a plan for improving upgrading and building the CORS sites and NSWnet CORS network control centre over the next five years. (Source:NSW DOL - CORS Expression of Interest, 2007).

5.8 Proposal for Independent GPS Base Station at DCC

A convenient proposal for the enhancement of GNSS functionality at Dubbo City Council is to install a permanent Base station at the Council administrative offices, essentially utilising much of the functionality of the existing GPS equipment ie the existing antenna mount and cable.

The proposed base station would comprise a GPS receiver and UHF radio in the building with the antenna mounted on the roof, thus eliminating the requirement for the setup of a field base station for each individual project – thus cost and time savings can be made.

For real time survey corrections only ie RTK, then a commercial type software such as Trimble GPSBase or Leica Spider is not required. However, the proprietary softwares will allow for enhanced functionality to the Base stations such as:

- the ability to log base files for post-processing of survey and mapping receivers, ie stored data can be distributed to users in various DCC departments via Internet or Local Area Network,
- software will allow for configuration to allow broadcast to GPS rovers (survey and mapping grade) using either radio or cellular links via direct internet access, thus allowing for access to real-time corrections using a mobile phone,
- software such as Trimble GPSBase will allow for the positioning of a base receiver on a remote location if required ie for when the required position of roof of admin. Building is considered to have inadequate elevation. The software as loaded on a personal computer in office will allow one to configure, monitor and log base station data from the remotely situated base receiver,
- software can be expanded to allow for interoperability with CORS Base Station operating software

Advantages of logging one's own base data versus using a third party base station
These include the ability to have 'total control' over the data as collected by DCC, and to whom it is made available to, both internally and externally.
The data is able to be acquired by DCC at nil cost, whereas data as obtained from a third party spatial data provider will more than likely incur subscriber fees and charges.
Additionally, the closer the proximity of the base station to the rover receiver, then the more accurate will be the final data. For example, for mapping applications data accuracy loss equates to approximately one millimetre per kilometre (ie ten centimetres in one hundred kilometres) for Standard code post processing which is the system currently in place at DCC at present.
The higher accuracy single frequency Carrier phase post processing that is used to produce positions of a couple of decimetres has a five millimetre per kilometre (or fifty centimetres per one hundred kilometres) error associated with the baseline length. Therefore Carrier phase post processing with mapping receivers is really only viable when one is less than fifty kilometers from the base station (Pers. Comm. Ultimate Positioning, 2nd July 2007)

Dual frequency survey receivers have a one part per million (ppm) error associated with the distance from the Base receiver, thus RTK accuracy is maximised by the utilisation of one's own base station.

Broadcasting of corrections to GPS rovers by UHF radio or via internet
The base station radio can be configured (according to Trimble/Ultimate Positioning representatives) to output the signals as required for correcting both 'survey' type rovers (ie RTK) and 'Mapping' type receivers (ie Differential GPS or DGPS).
The proposed GPS Base station system will allow for real time corrections for all mapping GPS rovers without the expense of adding radio modems to the various DCC units and this is facilitated by the ability of proprietary software to broadcast corrections via the internet and mobile phone coupled to say proprietary dial up networking programs on a datalogger.

5.9 Issues

A suitable model for GNSS Enhancement at DCC can then be reasonably condensed to three infrastructure proposals, including:

(i) Permanently Operating, Networked GPS Base Station

A major issue that exists for the decision making process and GPS Base station validation at DCC is to determine where the project is to provide functionality simply for the Council's own

requirements or to be included as part of a future CORS Network of interconnected Permanently operating base stations both Statewide and Nationally – see Figure 11: Potential NSWnet GPS Network - Potential Densification based on 50km and 100km range.

The proposed DOL NSWnet could involve the establishment of a Virtual Reference Network or System (VRS) to cover the state. This will involve the placement of Global Positioning System (GPS) receivers on specific secure control stations across the State in an array that would hopefully remove potential duplication of receivers and equally provide the maximum coverage for the whole State. The data from the GPS observations will ultimately be loaded directly to a DOL control centre, potentially at Bathurst (DOL CORS expression of interest tender document, 2007).

The VRS system allows for real time, centimetre accuracy positioning through the combination of mobile phone technology and advances in satellite positioning techniques. A common business recovery system for VRS is where VRS corrected spatial data is available to all GPS users for a fee dependent on consumer demand and usage.

Advantages of establishing a VRS are:

- it increases productivity by overcoming limitations in existing GPS real time techniques,
- operators/firms no longer need to research, establish and run their own reference station for each survey, reducing the capital outlay for equipment,
- the use of mobile phone technology overcomes the communication limitations of current radio links,
- it improves the accuracy of results.

(ii) DCC Independent, Semi-Permanently Operating, GPS Base Station

The existing infrastructure at the DCC Administration building serves as a adequate site for proposed GPS Base station, however, radio shadow problems caused by adjacent high buildings may give the opportunity to re-establish equipment ie receiver and antenna at an alternative site ie water tower. This remote equipment will only require a power source and internet connection – ie no computer or software is required for this remote site since it can all be controlled from main administration building office. Other options include the implementation of repeater radio boosters or mobile phone connection for so called ‘dead spots’, thus allowing for the potential to locate all equipment at one hub locality. However, this alternative configuration allows for the optimal satellite and radio coverage at the base site.
The ability to upgrade the DCC site, with this equipment, to a network of base stations is possible, with the infrastructure built in to at least allow for the interconnection to SydNET at some stage in the future.

(iii) Standalone Reference Base Station: comprising a simple network of a few stations providing complete RTK coverage for a relatively small, well developed area: ie for an area of say 60km by 60km, where a relatively simple solution would be to have 4 to 5 reference stations spaced about 30km apart- providing adequate RTK coverage for the area. Dial up lines would connect the stations to a central server running the reference station software. The software would control the receivers, download logged data files and ‘push’ RINEX files to an FTP server. RTK/DGPS data could be transmitted directly from the receivers by radio and/or phone, with the radios at the stations having to be set on different channels (ie frequencies). A router or bank of phone modems would be needed at each station to allow for several users to dial up simultaneously. This network configuration could be considered as relatively easy to set up, and as there would be no permanently operating lines, the running costs should be relatively low.

Therefore, the main issue is whether DCC wishes to facilitate, or be involved with this project?

However, to answer this question appropriately the following question needs to be answered: if DCC endorses participation in this project, how will this affect Council?

- Internal GPS users – Council will no longer be able to set up their own equipment on the base station. If the data observed by DOL is made readily available (free) to Council, survey staff will be advantaged as Council's base station receiver that would have served as a mobile base station inclusion, is now available for use elsewhere ie a second rover. Otherwise, the convenience of downloading the data to Council's computer network for prompt post-processing will be lost.
- External Users – a scoping questionnaire addressing the requirements of external spatial industry stakeholders in the Central West vicinity (ie Dubbo inclusive and up to 120km from Dubbo) has been conducted to gauge the level of interest in a proposed DCC Permanently Operating Base Station / CORS site.
- Building management – access to the DCC Admin building for installation and maintenance of the equipment and services will be required. Suitable arrangements will have to be made with respective building management and infrastructure development stakeholders to facilitate the equipment establishment.
- Logistics – DOL will most likely require :
  - Permanent use of DCC's base station for the siting of a GPS (or GNSS) Receiver. There is no absolute certainty and/or necessity that DOL may utilise DCC's base station. They could establish a base station elsewhere within proximity of the DCC proposed base station or even establish business relationships with existing spatial data stakeholders ie private consulting surveying organisations or existing DOL offices at Dubbo. However, DCC's proposed GPS base station would be very convenient,
  - A small, weatherproof area close to the base station in which to mount some electronic equipment. This currently does not exist for DCC, however, for Council to establish it's own GPS Base Station, then this will still be a consideration,
  - A dedicated telephone line for direct relay of data to the DOL control centre. This does not exist currently at DCC, however this could be installed and maintained by DOL at their cost,
  - A 240 volt power supply. This is already available , and the cost of running this should be minimal and could be offset against the cost of providing data free to DCC,
  - Uninterrupted Power supply and air conditioned space – should not really be required as modern equipment should have own back up power supply and should not require air conditioned environment,
  - Work place health and safety conditions – DCC having already established a single frequency, GPS base station should be complying with any work place health and safety conditions which will provide DOL with significant cost savings

5.10 DCC Conditions for Inclusion in DOL CORS Network

What conditions should DCC place on their participation in this DOL project and what are the options for DCC to establish the GPS base station?

Option 1 - All costs in installing and maintaining the VRS within Council premises will be met by DOL.

Option 2 - All supply, establishment, maintenance and site provision costs to be met by DCC, with DOL to provide datalink for data supply to DOL CORS Network – NSWnet,

Option 3 - All costs to be shared on an equitable basis amongst DOL and DCC.

Option 4 - DCC to be responsible for the purchase and installation of GPS base station, with DOL incorporating the datalink at some stage in the future, with the DOL then assuming all maintenance and running costs,

Option 5 – DCC to facilitate the supply of suitable base station hosting provisions, ie site, power supply, datalink etc, with DOL supplying and installing the Base Station equipment. DCC to provide ongoing maintenance as host site, including personnel and IT equipment.

Option 6 – DCC to establish a 'standalone' permanently or semi-permanently operating, dual frequency, geodetic quality, GPS Base Station, providing RTK and post-processing functionality for itself and potential subscribers.

Option 7 – DCC to enter into a business relationship (as per Option 6 above) with various (local) spatial industry stakeholders with the aim of establishing a 'community' base station. The GPS Base Station infrastructure is purchased by the various stakeholders, whereby corrected data is generated by facilities housed and maintained by DCC, and the corrected data then distributed commercially by a business unit.
This follows from the results from a questionnaire that generated commercial and technical interest from local spatial industry stakeholders to the development of a pilot CORS site at DCC.

5.11 Relationship to Corporate Plan

DCC Strategic Policy is premised on providing and maintaining water, waste services, roads, drainage and support the provision of transport and waterways infrastructure to sustain it's community. The most likely recommendation to support this Corporate Plan is Option 1.
However, if DOL were to indicate a preparedness to commit to future expansion of the CORS network across NSW, then Option 2 to 5 would provide reasonable scope.
If DOL were not to provide a commitment to CORS expansion in the NSW Central West, then obviously Option 2 or 6 would provide primary support.

5.12 Financial Implications

No major cost savings, long or short term, have been identified. However, with Council's existing GPS equipment not only of single frequency grade, and ultimately becoming superseded by superior grade, geodetic quality equipment, the VRS base station proposal or updated dual frequency, geodetic quality GPS Base Station is to be considered imperative.

The optimal consideration is to incorporate a business relationship with DOL, with Option 1 giving Council further functionality when considering the future of it's GPS equipment.

5.13 Options

Preferred – That DCC actively consult with DOL and seek to enter into a business relationship of provision of services as per Option 1 above. That DCC actively participate in the NSWnet proposal and allocate suitable base station site and appropriate office space and datalinks to DOL for the initiation of project.

Alternative 1 – That DCC enter into a business relationship with DOL as per option 4, in exchange for the supply of any GPS survey or mapping data from Council's base station, as required by Council's staff and at an appropriate annual lease/agreement fee.

Alternative 2 – Option 6

Alternative 3 – That DCC enter into a business relationship with local spatial industry stakeholders, as per option 7.

CHAPTER 6 CONCLUSIONS

6 Conclusions

6.1 Introduction

The aim of this project was to investigate the justification and validation of establishment of either a CORS site or a stand-alone GPS Reference Station for the Council of the City of Dubbo in the NSW Central West.

6.2 Research Outcomes

CORS issues – CORS infrastructure is a complex area with many issues that make it challenging to determine a suitable enhancement to an organizations spatial capability. Much research is still being carried out into various aspects of CORS functionality, but it is apparent that a CORS site may not be suitable for all locations.

However, enhanced GNSS functionality via standalone GPS is presenting opportunities for many organizations such as Dubbo City Council to increase their productive output and provide a range of additional services both to within their own functional requirements, but also to other spatial industry stakeholders in the area.

The awareness of CORS and networked GPS Reference functionality amongst the spatial industry stakeholder fraternity is extremely limited and must be sheeted home to State Government infrastructure and service providers in the area of spatial management. The NSW Department of Lands particularly must address the issues of enhanced GNSS functionality for the State of NSW if it does not wish for counter productive spatial infrastructure enhancement by the increasingly variable spatial data users and providers such as Consulting Surveyors and Local Government Organisation, who wish to increase their functionality but do not have sufficient State based direction and guidelines.

6.3 Achievement of Objectives

This has been achieved and the results have been reported in a suitable Business Model and Report.
Validation for enhanced GNSS functionality via the establishment of a DOL CORS site at Dubbo City Council has been demonstrated in this dissertation. Alternatives to this infrastructure have also been presented to Dubbo City Council for their consideration, with appropriate justification, however further research is still required to produce a suitable model for return on investment. Many assumptions have been made with respect to financial implications in the preparation of this Business Model for DCC.

6.4 Further Work

This could include addressing the issues of assessing software for the reference station management, particularly with respect to coordinating a range of existing and proposed GPS Base station in current single station setup, that may be able to be co-ordinated for the greater GNSS and GPS Network functionality of the Dubbo region.
A preparation of suitable cost recovery modeling would be beneficial.
A questionnaire that is more specific in targeting non traditional users of spatial technology would provide a much broader and definitive sample model for this study. The dissertation and subsequent business model provides for a platform of increased business relations amongst the spatial industry stakeholders of the NSW Central West region.

APPENDIX A Project Specification

Appendix A

University of Southern Queensland

FACULTY OF ENGINEERING AND SURVEYING

ENG4111/4112 Research Project
PROJECT SPECIFICATION

FOR: *David MAUNDER*

TOPIC: *GPS usage and infrastructure needs in N.S.W.*

SUPERVISOR: Mr Peter Gibbings

SPONSORHSIP: *Faculty of Engineering and Surveying, USQ.*

PROJECT AIM: The case for an extension of the SydNet Continuously Operating Reference Station (CORS) network or creation of a second tier dual frequency base station cluster, to cater to Global Positioning System (GPS) users within industry, mining and agricultural infrastructure in the Central West of NSW, based at Dubbo.

PROGRAMME: **Issue A, 23rd Mar. 2007**

1. Research the background industry information relating to GPS usage in NSW, particularly with respect to survey and mapping grade data.
2. Evaluate usage of similar systems in other states, particularly Continuously Operating Reference Stations (CORS) in those States.
3. Construct a detailed survey/questionnaire of (current and projected) GPS equipment and technology usage needs of various NSW industry and departmental stakeholders.
4. Assess the potential for extension of the existing NSW CORS infrastructure, with reference to similar projects in other states, based on results from analysis of the questionnaire.
5. Make recommendations on what future infrastructure might be required.
6. An analysis and evaluation of the required infrastructure.
7. Submit dissertation.

As time permits:

8. Assess the viability of a less densified remote GPS cluster in Dubbo (Western NSW) as an alternative to the extension of the existing CORS network, based on analysis of the questionnaire above.
9. Design and prepare a business model for a standalone Base Station cluster in Dubbo, NSW.

AGREED David Maunder (student) Date: 24/04/2007

Co-examiner:

(supervisor) Date: 1/5/2007

APPENDIX B Questionnaire form

Appendix B

Research Project Questionnaire

Topic: The Justification for Establishment of a Continuously Operating GPS Reference Station at Dubbo

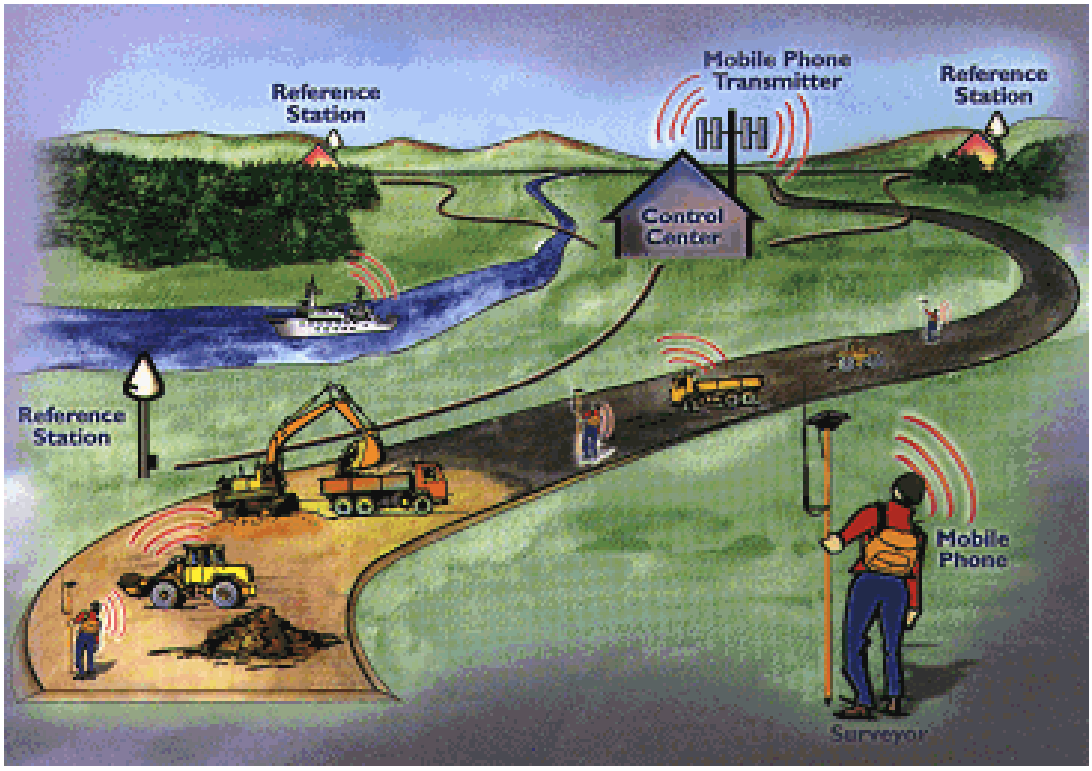

Figure 12 CORS Interpretation (Source: Trimble Navigation)

Introduction

I am a final year Spatial Sciences (Surveying) undergraduate completing an honours based Research Thesis at the University of Southern Queensland, Toowoomba. To this end I am seeking your assistance by asking you to answer an enclosed questionnaire relating to enhanced functionality of a Continuously Operating GPS Base Station in the central west of NSW, based at Dubbo.

You are being invited to participate in this survey as a current GPS user and/or potential CORS network user. Your involvement in the questionnaire is voluntary and you are free to withdraw consent at any time, and to withdraw any unprocessed data previously supplied. The data supplied shall be analysed and used as material for both Dubbo City Council and an undergraduate Honours Thesis.

The preferred method of conducting this questionnaire is to send the complete questionnaire to the interviewee for review, and a subsequent appointment arranged at a mutually agreeable time to conduct a one-on-one interview either by telephone or preferably face-to-face.

My project is investigating the degree of interest in enhanced spatial capabilities for NSW and particularly the NSW Central West geographical location, with respect to the establishment of a Continuously Operating Reference Station (CORS) site at Dubbo City

Council, that is either serving a cluster group in the region or as part of the greater networked system of CORS sites as proposed by the NSW Department of Lands (DOL).

Whilst my project is strictly for academic research purposes, the sponsor of these investigations is Dubbo City Council for whom I am preparing this investigation.
I will be using this and other data sources to produce a business case/model including a cost benefit analysis on behalf of Dubbo City Council.

Purpose of Questionnaire
This exercise will attempt to determine the level and scope of interest from existing and potential users of GPS, particularly with respect to potential users of CORS data, in the Central West of NSW.

Background to GNSS and CORS

The Global Positioning System
The Global Positioning System (GPS) is an all-weather, global, satellite-based, round-the-clock positioning system developed by the U.S. Department of Defense, that became available to the civilian community in the early 1980s. The range of applications of GPS is enormous and encompasses a wide spectrum of hardware and operational procedures principally designed to address varying accuracy requirements. It is the user accuracy requirement that more than anything else differentiates the various GPS equipment and procedures, and is responsible for the enormous differences in the cost (capital and operational) of GPS technology.

Networked Real Time Kinematic (NRTK)
NRTK studies aim to develop a centimeter accuracy RTK system capable of operating over distances up to many tens of kilometers (the distance between a rover receiver and the closest reference station receiver) with equivalent performance to current single base RTK systems over distances up to 10km. The reference stations must be deployed in a dense enough pattern to model distance-dependent errors to an accuracy that residual errors can be ignored. The estimated distance between reference stations should be of the order of 50-100km according to Prof. Chris Rizos of the University of NSW, but is dependent on the geographic location of the network and the level of ionospheric activity, and in addition, the rover must operate within the region defined by the reference station network.

Global Navigation Satellite Systems (GNSS)
GNSS include the United States Global Positioning System (GPS), the Russian Federations's GLONASS and by about 2010, the European Unions's GALILEO. When augmented by ground based continuously operating reference station (CORS) networks GNSS provides satellite-positioning users with improved position, navigation accuracy and integrity. Accuracy in particular is improved by the process of differential correction of autonomous GNSS positions – either in real time or post event.

CORS Networks
Status of CORS Networks in Australia
In the early 1990's, the Australian regional GPS network was established to support geodetic applications, and now consists of 17 reference stations on mainland Australia (with an average spacing of one thousand kilometres) (Roberts et al., 2004). A CORS network to support geodesy, surveying, mapping and high end navigation users was commenced in 1994 when stations of Victoria's GPSnet were first deployed (Hale, 2000). It has since grown to 24 reference stations providing online GPS data access. Users can combine these files with GPS

data collected across Victoria, for both post-processing and real-time positioning (at selected sites) to obtain cm-level accuracy position results – (see figure 2). GPSnet has taken over ten years to fully implement, engage private sector reference station hosts, and is now virtually complete – although some additional stations will be added over the next few years to 'densify' the network in special areas (Asmussen, 2006, GPSnet, 2006). To date, this is the only state-wide CORS network in Australia.

CORS Networks in Victoria

The role of conventional CORS networks has evolved from a predominantly 'passive' network (for data archiving and post-mission positioning applications) to an active network (data broadcasting) where high-precision real-time positioning is made possible across a large area.

The Vicpos and Melbpos services established to cover both metropolitan and rural areas of Victoria consist of 11 'well-distributed' GPSnet reference stations where the GPSnet reference stations from Vicpos stream real time correction data to the GPSnet service cluster (see fig. 1 below). It offers a statewide networked DGPS correction service with sub-meter level positioning via the internet and the GSM/GPRS mobile phone service to users across Victoria. In addition, a number of selected GPSnet sites have single base station real time RTK corrections available to survey accuracy via the internet and local radio broadcast (GPSnet, 2006) to local users. However, the distance dependent aptmospheric biases referred to earlier, restrict the length of GPS baselines, thereby limiting the applications of RTK techniques to within 10-15km of a broadcasting reference station. As the average reference station spacing in GPSnet is of the order of 100km (except in the Melbourne area where the spacing decreases to about 50km), there remain larger areas of Victoria where network RTK cannot be used (Roberts et al., 2004).

Ultimately all GPSnet stations will broadcast DGPS corrections across Victoria using a full NRTK correction solution (Asmussen, 2006, GPSnet, 2006).

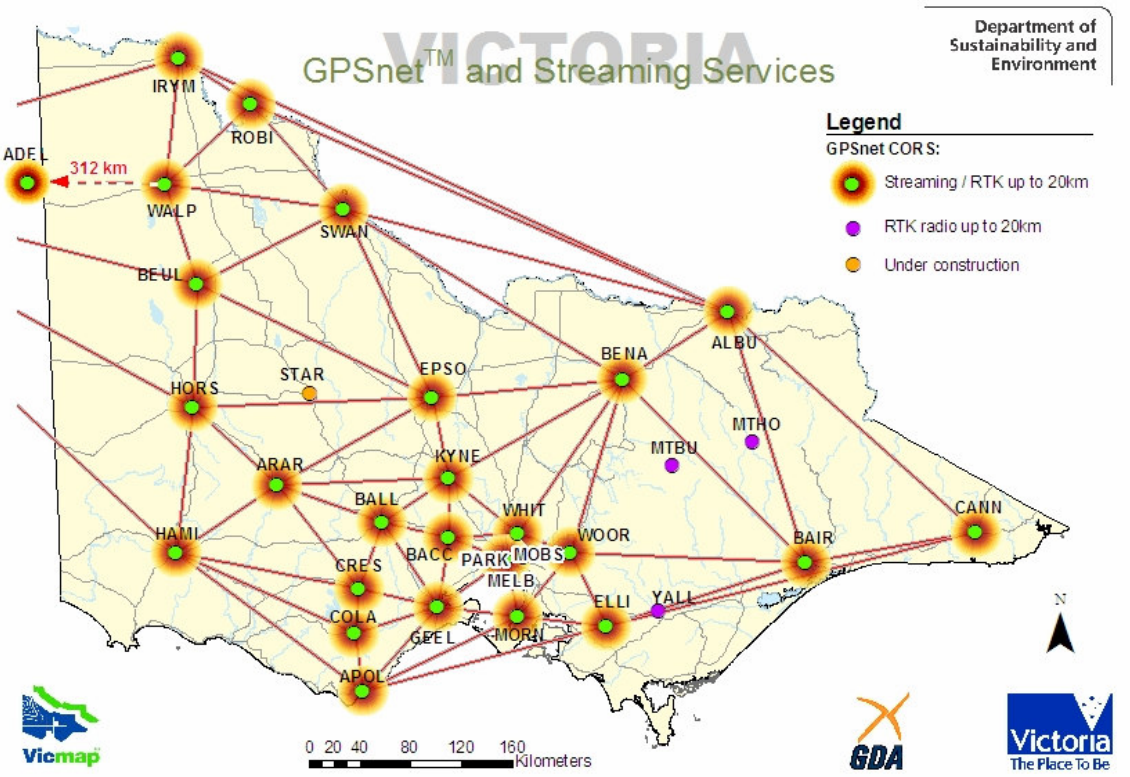

Figure 9 **Victorian GPSnet Base Station Layout (Lands Vic.)**

CORS Implementation in NSW - SydNET

The CORS infrastructure in NSW commenced development as the SydNET project in 2003. SydNET is deployed in the Sydney basin area and is currently being extended to form Metronet which will consist of 10-15 reference stations and will service the eastern seaboard from Nowra to Newcastle and west to Bathurst (the location of the NSW Dept of Lands).

The SydNET real-time CORS network in NSW is being established with network-based positioning capability from the very start, including Network-RTK. The project is funded by the NSW Department of Lands (DOL) as an initiative of State Government infrastructure.

SydNET is a project to establish a permanent real-time GPS network in the Sydney metropolitan area to provide GPS data for post processing and a network-RTK service for users in the region. SydNET has been developed by the DOL in partnership with the School of Surveying and Spatial Iinformation Systems at the University of NSW (UNSW).

Real-time correction data from SydNET will be distributed via the internet. The choice is then given to users to arrange access to the data on the internet. A suggested method is by using general packet radio system (GPRS) service which is available in most parts of Sydney. With a suitable GPRS-enabled device, users can access the data and connect it to their GPS receiver. Other alternatives to the GPRS network are CDMA1x (to be redundant in mid 2008) and 3G which are also available in Sydney and generally across the state of NSW.

SydNET (like the Sunpoz VRS network in QLD) is a CORS network designed from the very beginning to support real-time operations, in contrast to GPSnet (in Victoria), which was migrated to real-time operations.

The first phase of SydNET is only to service the Sydney basin region (see Figure xxx below), but it is planned for expansion over time to cover other areas of NSW. Hence, although SydNET is an ideal test network for proposed research, it is not a blueprint for a state-wide CORS network. The extension of the GPS network across the state of NSW would likely be based on a CORS density ranging from 50 to 200km (Zhang et al 2006)

Figure 10: SydNET Configuration (Rizos et al. 2004)

Appendix B

New CORS Justification in NSW

CORS networks are an accepted means of improving the accuracy and reliability of GNSS for a wide variety of purposes. National and State governments are establishing CORS networks to meet the needs of private users. As the capabilities of CORS networks evolve to provide real time high accuracy services, the user base is expanding beyond spatial professionals and para-professionals and attracting new users. Many of these new users do not have a spatial background or an extensive understanding of satellite positioning.

CORS Networks and Precision Agriculture (PA) - The need for improved arable land management practices and associated improved productivity can often be achieved by applying spatial technologies. Contemporary PA can support advanced arable land management practices using spatial technology including satellite navigation techniques, improving productivity and the lives of farm workers whilst simultaneously aiding sustainable environmental outcomes.

Inevitably, cropping areas are negatively impacted by surface sealing, organic matter decline, soil compaction, soil salinity, soil acidity, unless improvements to agricultural practices are adopted. (ABARE 2005).

There are many challenges associated with changing established agricultural industry practices, however Australian farmers are increasingly adopting high accuracy GNSS correction technology; such as RTK precision guidance using ad hoc reference station technology and management.

A coordinated approach to reference station infrastructure establishment and operation, will optimise capital investment and high accuracy navigation outcomes over cropping districts and other agricultural applications in Australia (Denham et al 2006).

One approach is to try to recruit a core group of users who are prepared to pay for the GPS-RTK services. But this is only feasible if the number of users, and the fees that are charged, are sufficient to generate a reasonable return-on-investment (ROI). This ROI (or at the very least "cost-recovery") is important for many network operators in order that they may provide for the maintenance and upgrade of the CORS infrastructure. On the other hand, there are those who advocate that there is no need to recoup CORS investment, that the installed GPS receivers should be seen as public infrastructure, in a similar manner to roads, bridges, etc (Rizos et al 2006a).

NSW Department of Lands (NDOL) and Increased CORS Coverage in NSW

The NDOL currently are investigating scenarios and models for a major expansion of the spatial capability of the state of NSW. This is being focused in the preparation and release of a tender to provide various plans, models and strategies that include the expansion of the current state coverage of CORS.

NDOL maintain that a publicly owned and managed GNSS, with (or augmented by) CORS, is emerging internationally as an additional form of delivering fundamental survey control and positioning infrastructure to users.

With the advent of Differential GPS techniques, NDOL has actively proclaimed the need for establishing a network of permanent, public accessible GPS reference stations around NSW. (In 1994 a NDOL taskforce considered that the establishment of a State based DGPS service was not feasible based on the case that cost was high compared with the benefits to government and users).

More recently, the NDOL have considered that with the cost of GPS equipment decreasing in real terms, and that GPS and communications technology have advanced significantly, and with the rapidly increasing uptake of GPS technology, particularly in State and Local Government organizations.

Appendix B

- The following trends in spatial information technology underpin the need to develop a reliable, state-wide GPS infrastructure to augment the geodetic framework of the state of NSW:
- GPS hardware costs are anticipated to continue falling leading to mass adoption and use by the community at large;
- Further improvements in receiver and software functionality anticipated;
- Integration of GPS occurring with other positioning technologies;
- Transition of spatial data to the Geocentric Datum of Australia (1st January 2000) which has been adopted due to its direct compatibility with satellite positioning technology and support of objectives to integrate and make compatible, GIS at national/state/regional and local levels;
- Increased adoption of GIS which benefits from the use of GPS technology;
- Improved access to and exchange of increasingly accurate spatial data between business leading to the need for common and reliable spatial referencing; and
- New group of high accuracy spatial users (ie precision farming, transport etc employing satellite positioning equipment and techniques) being added to traditional users (surveyors etc) of geodetic networks.

REFERENCES

ABARE (2005) *Productivity In The Australian Grains Industry*, ABARE eReport 05.3, Prepared For The Grains Research And Development Corporation, Canberra.

GPSnet (2006) *GPSnet*, Department Of Sustainability And Environment, http://www.land.vic.goc.au/gpsnet , accessed in May 2007.

Asmussen, H. (2006) Melbpos Makes It's Mark*, Landmark, Issue 25, 19-21, http://www.land.Vic.gov.au/ca256f 310024b628/0/Fd8afff4c7d7693cca25712c001b3242/$File/Landmark+March+2006_Hi+Res.Pdf*

Rizos, C. & Van Cranenbroeck, J. (2006a) *Alternatives to Current GPS-RTK Services and some Implications for CORS Infrastructure and Operations*, Paper Presented At The FIG Conference, Munich, Germany, 8-13 October.

Roberts, C., Zhang, K., Rizos, C., Kealy, A. And Ge, L. (2004) Improved Atmospheric Modelling For Large Scale High-Precision Positioning Based On GNSS CORS Networks In Australia, Journal Of GPS, 3,(1-2), 218-225.

Hale, M., Collier, P. & Kealy, A. (2005): *Developing a Model for CORS Network Management*, Proceedings of the International Symposium on GPS/GNSS, Hong Kong.

Appendix B

Appendix B

SECTION 1 BACKGROUND

Below, please provide the name of the person completing this questionnaire and/or someone else who may be contacted to obtain any needed follow-up information:

NAME

TITLE

AGENCY

STREET ADDRESS

TOWN/STATE/ZIP

TELEPHONE

FAX

E-MAIL

As you answer questions on the following pages, please feel free to add pages or write on the back of the questionnaire.

QUESTIONNAIRE Part 1 – Survey Practice Related Questions

This questionnaire consists of a series of brief questions with opportunity at the end of each section for additional comments. If there is insufficient room for comments please append additional sheets.
Respond on behalf of your organisation as a whole, by choosing the option which most closely applies. Individual responses will not be publicly linked to the information provider in any way.
Identifying information in section 1 is requested to allow clarification only and is optional.

Where do you practice mostly? - regional city [ ], rural [ ]

Does your organisation conduct cadastral surveys? yes [ ], no [ ]

Do you have access to the Internet from your work premises? yes [ ], no [ ]

Do you own survey accuracy GPS equipment? yes [ ], no [ ]

The techniques and equipment used to connect cadastral survey to the geodetic network (AMG, MGA); leave blank if you do not conduct cadastral surveys

How frequently do you use total station traversing to connect?
0 [ ], 25% [ ], 50% [ ], 75% [ ], >75% [ ]

How frequently do you use GPS to connect? -
0 [ ], 25% [ ], 50% [ ], 75% [ ], >75% [ ]

When you use GPS to connect, do you use? single frequency [ ] dual frequency [ ]
1 receiver [ ] 2 receivers [ ] data from base stations [ ]

d. Do you use RTK or post-processing when a) connecting to control _____
b) surveying a traverse _____

c) picking up detail _____

_____

_____

e. Would your company be willing to contract out connection to control? Why?

_____

_____

_____

f. Would your company consider options of leasing or sharing GPS using partnerships/consortiums? Why?

_____

_____

_____

Additional comments: -

_____

_____

_____

_____

_____

_____

_____

3. Barriers to survey accurate GPS use (complete if you do not own GPS)

a. Do you anticipate purchasing GPS equipment in the next 5 years? yes [ ], no [ ]

b. If you owned GPS equipment would you use it to connect more often? yes [ ], no [ ]

c. Which of the following are barriers to you purchasing GPS equipment?

Cost _____

Complexity _____ score level of significance

Lack of applications for GPS _____ - 6 highest significance

Unfamiliarity _____ - 1 lowest significance

Availability of base stations _____

Issues of legal traceability _____

Additional comments: -

_____

_____

_____

_____

QUESTIONNAIRE Part 2 – CORS Network

Industry Sector (please circle most appropriate selection)

Agriculture
Emergency Services
GIS
Local Government
Mapping
Surveying
Utilities
Other...

Institutional Arrangements

'Joined up' CORS networks between adjoining Australian state and territory jurisdictions can be managed to provide seamless, and potentially high accuracy satellite positioning over significant areas of Australia. To what extent do you see 'joined up' CORS networks of benefit to the Australian community as a whole?

Select one... Not at all
Somewhat Considerable
Significant
Not sure

Additional Comments:

Appropriate category of government management

If CORS networks are to be managed and operated by government bodies in Australia what level of government do you consider the most appropriate to meet the needs of users and stakeholders?

Select one... Local Government
State Government
Federal Government

Additional Comments:

CORS network contribution to ASDI

To what extent do you consider that CORS networks in states and territories of Australia can contribute to the Australian Spatial Data Infrastructure (ASDI)?

Select one... Not at all
Somewhat
Considerable
Significant
Don't know

Additional Comments:

CORS Network Data Custodianship

Which level of government should be responsible for custodianship of CORS data?

Select one... Local Government
State Government
Federal Government

Additional Comments:

CORS network stakeholder consultation

Which organisation/s should be responsible for CORS network stakeholder consultation?

Select one... Australian GNSS Coordination Committee (AGCC) or similar Federal Government body State level.
GNSS Reference Group led by State Government body
Intergovernmental Committee on Surveying and Mapping (ICSM)

Other (please list in additional comments)

Additional Comments:

Operational Standards and Principles

Standard CORS data correction formats available over 'joined up' networks

How important is it for'joined up' CORS networks to deliver CORS data to users in standardised and internationally accepted formats?

Select one... Not important
Somewhat important
Considerably important
Highly important

Additional Comments:

CORS network correction accuracy

Networked real time CORS correction accuracy can achieve nominal horizontal accuracy at better than ±2cm. Does this accuracy meet your positioning and navigation requirements?

Select one... Not at all
Somewhat
Completely Exceeds my requirements

Additional Comments:

CORS antenna coordination and control network specification

Corrected receiver position coordinates depend on the CORS antenna coordinates and the related control network specification. Which level of network, national or state, do you consider to be the appropriate one?

Select one... Compatible with Australian Regional GPS Network
Relative to local state geodetic network
Other (please state below)

Additional Comments:

CORS data quality monitoring and user alerts

CORS networks can be monitored by assessing the raw satellite data received by CORS stations, stability of CORS antennas, latency of correction etc. How important is CORS network data quality and user alerting to you?

Select one... Not important
Somewhat important
Considerably important
Highly important

Additional Comments:

Current CORS network GNSS reception and processing capability

CORS networks can be configured to receive and process multiple satellite systems (ie GPS, GLONASS, Galileo). Please indicate the importance of this capability to you now?

Select one... Not important
Somewhat important
Considerably important
Highly important

Additional Comments:

CORS network GNSS reception and processing capability – next 4 years

CORS networks can be configured to receive and process multiple satellite systems (ie GPS, GLONASS, Galileo). The GLONASS satellite constellation is currently being replenished and the Galileo program has commenced placing satellites in orbit with full operational capacity anticipated to be in 4 years time (2010 approximately). Please indicate the importance of this
capability to you over the next 4 years?

Select one... Not important
Somewhat important
Considerably important
Highly important

Additional Comments:

CORS Network Real Time Kinematic (NRTK) positioning

Real time positioning is now achievable using CORS networks. NRTK horizontal positioning accuracy of ±2 cm using CORS networks is readily achievable. How important is NRTK position correction to you?

Select one... Not important
Somewhat important
Considerably important
Highly important

Additional Comments:

CORS data for Post Processing

Data for post processing can be made available from CORS networks. How important is this form of position correction to you?

Select one... Not important
Somewhat important
Considerably important
Highly important

Additional Comments:

Legal Arrangements

Privacy
To what extent do you consider that privacy of location is important to users of CORS network services?

Select one... Not important
Somewhat important
Considerably important Highly important

Additional Comments:

Legal Traceabiltiy of Position

To what extent is legal traceability of position important to CORS network users?

Select one... Not important
Somewhat important
Considerably important
Highly important

Additional Comments:

Commercial

CORS data distribution

How is satellite correction data best distributed to CORS network users?

Select one... Direct from government agencies
On-sold and perhaps with added value through the private sector organisations
Combination of government and private sector organisations
Other (please state below)

Additional Comments:

Would you subscribe as a user (if you had real world applications and uses) if you did not want to purchase a complete GPS system and there was a CORS site nearby?

Select one…….yes
No
Possibly

Would you contribute to any costs in the establishment of a CORS site?

Select one…….yes
No
Possibly

If it mean't that all you needed was a dual-frequency, geodetic quality GPS rover to obtain accurate measurements without the need or requirement to purchase a complete GPS base station, would this affect your decision to contribute commercially to a CORS network establishment?

Select one…….yes
No
Possibly

General Comments

Appendix B

Please provide any additional comments that you may have on the provision of state sponsored CORS networks in Australia here.

THANK YOU VERY MUCH FOR YOUR HELP

APPENDIX C Questionnaire Results

Appendix C

	Shire Council 1	Shire Council 2	Shire Council 3	RTA Western NSW	Consulting Surveyors 1	Consulting Surveyors 2	West Cons. Farming Assoc.
Where do you practice mostly?							
regional city					x	x	
rural	x	x	x	x			x
Does your organisation conduct cadastral surveys?							
yes				x	x	x	
no	x	x	x				x
Do you have access to the Internet from your work							
yes	x	x	x	x	x	x	x
no							
Do you own survey accuracy GPS equipment?							
yes			x	x	x	x	
no	x	x					x
how frequently do you use total station traversing to							
0%							
25%							
50%				x			
75%							
>75%					x	x	
how frequently do you use GPS to connect?							
0%							
25%					x	x	
50%				x			
75%							
>75%							
when you use GPS to connect, do you use:							
single frequency							
dual frequency				x	x	x	
1 receiver							
2 receivers				x		x	
data from base stations							

do you use RTK or post-processing when : connecting to control							
RTK				x	x	x	
PP				x			
surveying a traverse							
RTK				x	x	x	
PP							
picking up detail							
RTK				x	x	x	
PP							
would your company be willing to contract out connection to control?							
yes				x			
no							
possibly					x	x	
Would your company consider options of leasing or sharing GPS using partnerships/consortiums?							
yes	x						
no				x	x		
possibly		x	x			x	
Barriers to survey accurate GPS use (complete if you do not own GPS)							
Do you anticipate purchasing GPS equipment in the next 5							
yes	x					x	x
no							
If you owned GPS equipment would you use it to connect more often?							
yes	x						
no						x	
Which of the following are barriers to you purchasing GPS equipment?							
score level of significance: 6 highest significance & 1 lowest significance							
Cost	6	6				5	6
Complexity	3	3				3	
Lack of applications for GPS	2	2				1	
Unfamiliarity	4	4				1	

Availability of base stations	5	5				1	
Issues of legal traceability	1	1				1	
Are you aware of SydNet?							
yes		x	x	x	x	x	
no	x						
Have you used SydNet?							
yes		x	x				
no	x			x	x	x	
If there were more GPS base stations would you use the information more often?							
yes	x	x		x	x	x	
no			x				
QUESTIONNAIRE Part 2 – CORS Network							
Industry Sector (please circle most appropriate selection)							
Agriculture							x
Emergency Services							
GIS							
Local Government	x	x	x				
Mapping							
Surveying				x	x	x	
Utilities							
Other...							
Institutional Arrangements							
'Joined up' CORS networks between adjoining Australian state and territory jurisdictions can be managed to provide seamless, and potentially high accuracy satellite positioning over significant areas of Australia. To what extent do you see 'joined up' CORS networks of benefit to the Australian community as a whole? Select one...							
Not at all							
Somewhat Considerable		x				x	
Significant			x	x	x		x
Not sure	x						
Appropriate category of government management							
If CORS networks are to be managed and operated by government bodies in Australia what level of government do you consider the most appropriate to meet the needs of users and stakeholders?							
State Government		x	x	x	x	x	
Federal Government							x
Local Government	x						
CORS network contribution to ASDI							
To what extent do you consider that CORS networks in states and territories of Australia can contribute to the Australian Spatial Data Infrastructure (ASDI)? Select one...							
Not at all							
Somewhat							
Considerable	x	x	x			x	
Significant				x	x		x
Don't know							
CORS Network Data Custodianship							
Which level of government should be responsible for custodianship of CORS data? Select one...							
Local Government	x	x					
State Government			x	x	x	x	
Federal Government							x
CORS network stakeholder consultation							
Which organisation/s should be responsible for CORS network stakeholder consultation? Select one...							
Australian GNSS Coordination Committee (AGCC) or similar body			x			x	x
State level.							
Federal Government							
GNSS Reference Group led by State Government body				x	x		
Intergovernmental Committee on Surveying and Mapping (ICSM)	x						
Operational Standards and Principles							

Standard CORS data correction formats available over 'joined up' networks							
How important is it for'joined up' CORS networks to deliver CORS data to users in standardised and internationally							
Not important							
Somewhat important							
Considerably important							
Highly important	x	x	x	x	x	x	x
CORS network correction accuracy							
Networked real time CORS correction accuracy can achieve nominal horizontal accuracy at better than ±2cm. Does this accuracy meet your positioning and navigation requirements? Select one...							
Not at all							
Somewhat	x	x		x	x	x	
requirements			x				x
don't know							
CORS antenna coordination and control network							
Corrected receiver position coordinates depend on the CORS antenna coordinates and the related control network specification. Which level of network, national or state, do you consider to be the appropriate one? Select one...							
Compatible with Australian Regional GPS Network				x		x	
Relative to local state geodetic network	x	x	x		x		
don't know							x
CORS data quality monitoring and user alerts							
CORS networks can be monitored by assessing the raw satellite data received by CORS stations, stability of CORS antennas, latency of correction etc. How important is CORS network data quality and user alerting to you? Select one...							
Not important							x
Somewhat important							
Considerably important	x	x		x	x		
Highly important			x			x	
Current CORS network GNSS reception and processing							
CORS networks can be configured to receive and process multiple satellite systems (ie GPS, GLONASS, Galileo). Please indicate the importance of this capability to you now?							
Not important			x				
Somewhat important	x	x				x	
Considerably important				x	x		x
Highly important							
CORS network GNSS reception and processing capability – next 4 years							
CORS networks can be configured to receive and process multiple satellite systems (ie GPS, GLONASS, Galileo). The GLONASS satellite constellation is currently being replenished and the Galileo program has commenced placing satellites in orbit with full operational capacity anticipated to be in 4 years time (2010 approximately). Please indicate the importance of this							
Not important				x			
Somewhat important		x	x			x	
Considerably important	x				x		x
Highly important							
CORS Network Real Time Kinematic (NRTK) positioning							
Real time positioning is now achievable using CORS networks. NRTK horizontal positioning accuracy of ±2 cm using CORS networks is readily achievable. How important is NRTK position							
Not important							
Somewhat important		x					
Considerably important			x				x
Highly important	x			x	x	x	
CORS data for Post Processing							
Data for post processing can be made available from CORS networks. How important is this form of position correction to							
Not important							x
Somewhat important					x	x	

Appendix C

Considerably important	x	x	x				
Highly important				x			
Legal Arrangements							
To what extent do you consider that privacy of location is important to users of CORS network services?							
Not important		x			x		
Somewhat important	x		x	x		x	
lerably important Highly important							
don't know							x
Legal Traceabiltiy of Position							
To what extent is legal traceability of position important to CORS network users?							
Not important							
Somewhat important	x	x	x				
Considerably important					x		
Highly important				x		x	
don't know							x
Commercial							
CORS data distribution:							
network users?							
Direct from government agencies		x	x	x		x	
On-sold and perhaps with added value through the private sector							
Combination of government and private sector organisations	x				x		
don't know							x
Additional Questions							
Would you subscribe as a user (if you had real world applications and uses) if you did not want to purchase a complete GPS system and there was a CORS site nearby?							
yes	x	x		x			
no							
possibly			x			x	x
would you contribute to any costs in the establishment of a							
yes							
no					x		x
possibly	x	x	x	x		x	
if it mean't that all you needed was a dual-frequency, geodetic quality GPS rover to obtain accurate measurements without the need to purchase a base station, would this affect your decision to contribute commercially to a CORS network establishment?							
yes							
no				x			
possibly	x	x	x		x	x	x

REFERENCES

ABARE (2005) *Productivity In The Australian Grains Industry*, ABARE eReport 05.3, Prepared For The Grains Research And Development Corporation, Canberra.

AGCC (2002) Positioning For The Future – Australia's Satellite Navigation Strategic Policy, Australian GNSS Coordination Committee, ISBN 0-642-50214-5, August.

Albaredes, G. (1992) *A New Approach: User Oriented GIS*, in Proceedings Of eGIS 1992, Munich, pps 830-837.

Ashkenazi, V. (2005) *GNSS: Benefits, Risks And Misconceptions*, Key Note Address, International Symposium On GPS/GNSS, The Hong Kong Polytechnic, Hong Kong.

Asmussen, H. (2006) Melbpos Makes It's Mark*, Landmark, Issue 25, 19-21, http://www.land.Vic.gov.au/ca256f 310024b628/0/Fd8afff4c7d7693cca25712c001b3242/$File/Landmark+March+2006_Hi+Res.Pdf*

AuScope (2006) *Geospatial Infrastructure Component*, Draft Proposals on Working Groups to AuScope Steering Committee - Version5_5_2006, viewed at Http://Www.Auscope.Org.Au/Pdf/Geospatial_Plan_Final2.Pdf on the 21st May, 2007.

Berterreche, J. (2005) *Users Can Locate Themselves On The Ground In Real Time – Realtime GPS Network France Enters Its Rollout Phase*. Geo-Informatics, 23rd December, 2005.

Bootle, B.J. (2001) *Precision Agriculture*, Final Report To The Australian Nuffield Farming Scholars Association, NSW.

Cislowski, G.J. and Higgins, M.B. 2006 SunPOZ: *Enabling centimetre accuracy GNSS applications in Queensland.* Proceedings fron the International Global Satellite Systems Society IGNSS Symposium, 17-21 July 2006, Surfers Paradise, Australia.

CRCSI (2005) *Quality Control Issues for Real-time Positioning*, http://www.crcsi.com.au/pages/programs.aspx?programid=44, web site accessed may 19th, 2007.

Curtin University (2004) *Issues Surrounding the Establishment of Continuously Operating Reference Station (CORS) Networks in Western Australia* (Featherstone, et al. WA Centre for Geodesy, Curtin University of Technology

Curtin University (2006) *Continuously Operating Reference Stations (CORS) And A Future Geodetic Framework For Western Australia*, Report And Technical Documentation Prepared By Curtin University On Behalf Of Landgate Western Australia, July 2006.

Denham, J.L., Whitlock, A.K. & Yule, D. (2006) *Contemporary Position And Navigation Needs Of Precision Agriculture And Victoria's GPSnet Cors Network*, Paper Presented To International Global Navigation Satellite Systems Society IGNSS Symposium, Surfers Paradise, 17-21 July.

Gandonou, J., Dillon, C.R., Stombaugh, T.S. & Shearer, S.A. (2001) *Precision Agriculture: A Break-Even Acreage Analysis*, 2001 ASAE Annual International Meeting, USA July 30 To Aug 1, 2001, Paper Number 01-1029.

References

Glowacki, T.J., Penna, N. & Bourke, W. (2006) Validation of GPS Based Estimates of Integrated Water Vapour for the Australian Region and Identification of Diurnal Variability, Australian Meteorological Magazine, in press, 2006.

Gordini, C., Kealy, A.N., Grgich, P.M. & Hale, M.J. (2006) *Testing And Evaluation Of A GPS CORS Network For Real Time Centimetric Positioning – The Victorian GPSnet.* Papers Presented At The International Navigation Satellite Systems Society Symposium, 17-21 July 2006, Surfers Paradise, Qld, Australia.

GPSnet (2006) *GPSnet*, Department Of Sustainability And Environment, http://www.land.vic.goc.au/gpsnet , accessed in May 2007.

Hale, M., Collier, P. & Kealy, A. (2005): *Developing a Model for CORS Network Management*, Proceedings of the International Symposium on GPS/GNSS, Hong Kong.

Hale, M.J., Collier, P.A., Kealy, A.N., Ramm, P.J., & Millner, J.C. (2006) Validating A Model For CORS Network Management, Paper Presented At The International Global Navigation Satellite Systems Society, Surfers Paradise, Australia, 17-21 July.

Hale, M. & Ramm, P. (2005) *Positioning Victoria For The Future*, Paper Presented At The SSC 2005 Spatial Intelligence, Innovation And Praxis: The National Biennial Conference Of The Spatial Sciences Institute, Melbourne, September, 2005.

Hale, M., Collier, P. and Kealy, A. 2007 GPSnet CORS Network Management Validation Through User Feedback, non-peered paper. CRC for Spatial Information and Department of Geomatics, the University of Melbourne.

Higgins, M.B. And Talbot, N. (2001) Centimetres For Everyone: Initial Results From An Australian Virtual Reference Station Network Pilot Project, Proceedings From The 5th International Symposium On Satellite Navigation Technology and Applications, 24-27 July 2001 Canberra, Australia.

Higgins, M. (2001) *An Australian Pilot Project for a Real Time Kinematic GPS Network using the Virtual Reference Station Concept, Paper Presented At New Technology For A New Century Conference, Fig Working Week, Seoul, Korea, 6-11 May.*

Higgins, M. (2002) *Australia's Changing Surveying Infrastructure from Marks in the Ground to Virtual Reference Stations, FIG XXII International Congress, Washington, 19-26 April, Ts5.6.*
ICSM (1991) *Report of the Working Party on the Need for a GPS Network*, Intergovernmental Committee On Surveying And Mapping.

HNTB 2004 *Survey Grade GPS Reference Station technology for the Missouri Department of Transport* (technical paper), viewed September 2007.

Houghton, H.J., (2005) *Scoping Paper For 2005 Review Of Western Australia's Geodetic Framework And Priorities For Positioning Information*, Paper Prepared For The Department Of Land Information WA, Viewed 1st May 2007.

References

Hu, G.R., Khoo, H.S., Goh, P.C. & Law, C.L. (2003) *Development And Assessment Of GPS Virtual Reference Stations For RTK Positioning*, Journal Of Geodesy, Vol. 77, No. 5/6, Pp. 292-302.

ICSM (2000) *The Australasian geodetic infrastructure: 10 years and beyond discussion paper*, http://www.crcsi.com.au/icsm/geodesy/gifv2-2-1.pdf, web site accessed 25th may 2007.

Kallweit, T. (2003) Exacting A Toll: GPS, Microwaves Precise Swiss System, GPS World, June, 16-22.

Kinlyside, D.A. & Yan, T.S. (2005) *SydNET – First Results*, Paper Presented At APAS2005, Association Of Public Authority Surveyors Conference, Batemans Bay, March 2005.

Koniditsiotis, C. (2003) Intelligent Access Program (IAP) – Using Satellite Based Tracking To Monitor Heavy Freight Vehicle Compliance, Paper 93, Proceedings Of SatNav 2003, Melbourne Australia, 22-25 July.

Kumar-Mills, D., Homer, J., Kubik, K. And Higgins, M. (2005) *Efficient RTK Positioning By Integrating Virtual Reference Stations With WCDMA Network*, Journal Of Global Positioning Systems, Vol. 4, No. 1-2:48-55.

Lachapelle, G., Alves, P., Fortes, L.P., Cannon, M.E. And Townsend, B. (2000) *DGPS RTK Positioning using a Reference Network*, Paper Presented To 13th International Technical Meeting Satellite Division US Instrument Navigation, Salt Lake City, Utah, 19-22 September.

Landau H.; Vollath U.; Chen X. (2002), 'Virtual Reference station' Journal of Global Positioning System, Vol. 1, No. 1 pp 137-143.

Landau H.; Vollath U.; Chen X. (2003a): *Virtual reference stations versus broadcast solutions in network RTK - Advantages and Limitations.* GNSS, Graz, Austria, Apr.

Landau H.; Vollath U.; Deking A.; Pagels C. (2003b): *Virtual reference station networks - recent innovations by Trimble*. Trimble, Terrasat GmbH.

Leica Geosystems 2007, GPS *Reference Stations and Networks – An Introductory Guide,* web site viewed On 20th August, 2007.
www.leicaadvantage.com/support/referencestations1200/referencestationquickguides.cfm

Liu G.C. (2004): *GPS RTK positioning via internet-based 3G CDMA2000/1X wireless technology.* GPS Solutions, 7(4):222-229

NESPAL (2006) Precision Agriculture (Internet), Available From Http://Nespal.Cpes.Peachnet.Edu/Precag/ > Viewed 20th May 2007.

NSW Department of Lands Tender Document (2007) Request for Quotation: Business case, design and implementation plan for a Global Navigation Satellite System (GNSS) Continuously Operating Reference Station (CORS) Network for NSW Department of Lands, Issue date 5th April 2007.

References

Ong, G.K.S. & Gibbings, P. (2005) *How well does the Virtual Reference Station (VRS) System Of GPS Base Stations perform in comparison to conventional RTK*, A paper published in Spatial Science Magazine, Vol. 50, No. 1, June 2005.

Pugh, N. (2005) *Scalable GPS Infrastructure*, Article From Professional Surveyor Magazine (U.S.A.), Feb. 2005, (ISSN 0278-1425, CPC IPM No. 1183346) Reed Business Geo, Inc, Publishers.

Queensland Dept of Natural Resources and Water (2006) *Satellite Positioning in Queensland*, The State of Queensland Government, Queensland.

Ramm, P., Hale, M. & Jones, C. (2000): 'Geodetic Infrastructure – A Co-operative Future', Trans Tasman Surveyor, Volume 45, Number 2, 29-34.

Ramm, P. & Hale, M. (2004) Realisation Of The Geodetic Datum In Victoria, Proceedings Of The International Symposium On GPS/GNSS, Sydney: GNSS/GPS Society.

Razza, B. (2005) *Recent Developments In The Sector Of Navigation Satellite System Reference Stations (GNSS) And Possible Links With The Typical Surveying Measurements Carried Out By Surveyors.* Paper Presented At Pharaoh To Geoinformatics FIG Working Week 2005 And GSDI-8, 16-21 April 2005 Cairo Egypt.

Retscher G. (2002): *Accuracy performance of virtual reference station (VRS) networks.* Journal of Global Positioning Systems, 1(1): 40-47

Rizos, C. (1999) *Principles And Practices Of GPS Surveying*, GPS Tutorial Notes Sourced Online At The UNSW SNAP Site, First Published In 1997 As Monograph 17, By The School Of Geomatic Engineering, UNSW (ISBN 0-85839-071-X).

Rizos, C. (2001) *How can my Position on the Paddock help my Future Direction*? Paper Presented at Geospatial Information and Agriculture Conference, Sydney, Australia, 16-19 July.

Rizos (2002) *Making Sense of GPS Techniques*, Chapter 11 In Manual of Geospatial Science and Technology, J. Bossler, J. Jenson, R. McMaster And C. Rizos (Eds), Taylor and Francis Inc. ISBN 0-7484-0924-6, 146-161.

Rizos, C. and Han, S. (2003) *Reference station network based RTK systems – Concepts and Progress*, Wuhan University Journal of Natural Sciences, 8(2B), 566-574.

Rizos, C., Kinlyside, D., Yan, T., Omar, S., & Musa, T.A. (2003) *Implementing Network RTK : The SydNET CORS Infrastructure*, 6th International Symposium On Satellite Systems Navigation Technology Including Mobile Positioning And Location Services, Melbourne, Australia, 22-25 July.

Rizos, C., Yan, T.S. & Kinlyside, D.A. (2004) *Development of SydNET Permanent Real-Time GPS Network*, Journal Of Global Positioning Systems, Vol. 3, No. 1-2 : 296-301.

Rizos, C, Higgins, M, & Hewitson, S. (2005a), 'New GNSS Developments and their Impact on Survey Service Providers and Surveyors', Proceedings of SSC2005 Spatial Intelligence and Praxis:

The National Biennial Conference of the Spatial Sciences Institute, Melbourne, Australia, 1100-1113.

Rizos, C., Higgins, M. & Hewitson, S. (2005b) New GNSS Developments and Their Impact On CORS Service Providers, Paper Published By University Of NSW SNAP

Rizos, C. & Van Cranenbroeck, J. (2006a) *Alternatives to Current GPS-RTK Services and some Implications for CORS Infrastructure and Operations*, Paper Presented At The FIG Conference, Munich, Germany, 8-13 October.

Rizos, C. & Cranenbroeck, J. (2006b) *The Future of GNSS RTK Services and Implications for CORS Infrastructure – Making GNSS-RTK Services Pay*, A Paper Presented At The FIG Conference, Munich, Germany, 8-13 October.

Roberts, C., Zhang, K., Rizos, C., Kealy, A. And Ge, L. (2004) Improved Atmospheric Modeling For Large Scale High-Precision Positioning Based On GNSS CORS Networks In Australia, Journal Of GPS, 3,(1-2), 218-225.

Roberts, C. (2004) GPS for Cadastral Surveying – Practical Considerations*, Paper Presented At Proceedings of SSC 2005 Spatial Intelligence, Innovation and Praxis: The National Biennial Conference of the Spatial Sciences Institute, September 2005, Melbourne.*

Roberts, C. (2006) GNSS and the Convergence of Geodesy and the Cadastre in Australia*, Paper Presented At XXIII FIG Congress – Shaping The Change, Munich, Germany, October 8-13.*

Sinnott, D.H. (2004) *GNSS Coordination at The National Level: The Australian Experience*, Journal Of Global Positioning Systems, Vol. 3, No. 1-2:242-250.

SMMF (1994) *Proceedings of a Public Sector Symposium on Collaboration in Establishing and Managing Permanent DGPS Base Stations for NSW*, Surveying And Mapping Managers Forum, Sydney, 1994.

Styles, J.S., Costa, N. & Jenkins, B. (2003) In The Drivers Seat: Location Based Services Power GPS/Galileo Market Growth, GPS World, October, 34-40.

Swinton, S.M. & Lowenberg-de-boer, J. (1998) evaluating the profitability of site specific farming, journal of production agriculture, vol. 11, no. 4, pps 439-446.

Takac, F. (1997) Base Station Densification Project, Report To Department Of Natural Resources And Environment.

Talbot, N., Lu, G., Allison, T. & Vollath, U. 2002, '*Broadcast Network RTK- Transmission Standards and Results*', Proceedings of the 15th International Technical Meeting of the Satellite Division of the Institute of Navigation, Portland, Oregon, USA, 24-27 Sept. 2002.

Wanninger, L. (2006) *Introduction to Network RTK*, IAG Sub-Commission 4.5: Next Generation RTK, http://www.network-rtk.info/.

Wübbena G.; Bagge A.; Schmitz M. (2001): *Network-based techniques for RTK Applications.* GPS Symposium, Tokyo, Japan, 14 Nov.

References

Wübbena G.; Bagge A.; Seeber, V., Hankemier, P. (1996): *Reducing distance dependent errors for real-time precise DGPS applications by establishing reference station networks.* Proceedings of ION GPS, 17-20 September 1996, Kansas City, Missouri, USA, pp 1845-1852.

Zhang K. and Roberts C. (2003): *Network-based real-time kinematic positioning system: current development in Australia.* Geoinformatics and Surveying Conference, Malaysia, 7 Apr.2003.

Zhang, K., Rizos, C., Kealy, A., Ge, L., Ramm, P., Hale, M., Kinleyside, D. & Harcombe, P. (2004): "Improved Atmospheric Modelling for large scale high-precision positioning based on GNSS CORS Networks in Australia", International Symposium on Satellite Navigation Technology including GNSS/GPS, Sydney, Australia.