CORSnet NEW SOUTH WALES

Guidelines for CORSnet-NSW Continuously Operating Reference Stations (CORS)

NSW GOVERNMENT | Land & Property Information

A division of the Department of Finance & Services

25 June 2012

DOCUMENT CONTROL SHEET

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Approved by:

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LPI welcomes feedback on these guidelines. For details, see Maintenance of Guidelines on page 7.

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Terms and Definitions

For the purpose of these guidelines, the following terms and definitions shall apply:

Term/Acronym	**Definition**
AFN	Australian Fiducial Network – eight permanent, continuously operating, geodetic GNSS receivers on the Australian mainland and Tasmania, initially observed during the International GNSS Service 1992 campaign. The coordinates of the AFN sites, based on ITRF92 at epoch 1994.0, were published in the Government Gazette as the official realisation of the GDA94 datum.
APC	Antenna Phase Centre – the point inside a GNSS antenna to which all GNSS signals are measured. As this point cannot be physically measured to, measurements are then referred to the Antenna Reference Point (ARP) using known offsets between the APC and the ARP.
APREF	Asia-Pacific Reference Frame – a project to create and maintain an accurate and densely realised geodetic framework in the Asia-Pacific region, based on continuous observation and analysis of GNSS data (http://www.ga.gov.au/earth-monitoring/geodesy/asia-pacific-reference-frame.html).
ARP	Antenna Reference Point – the physically accessible point on a GNSS antenna to which all measurements related to that antenna are referred.
CMR^+	Compact Measurement Record (Plus) – manufacturer's proprietary format for real-time data developed by Trimble Navigation. It is the default industry standard in precision agriculture and machine guidance, and widely accepted by third-party GNSS manufacturers.
AHD71	Australian Height Datum 1971 – the national vertical datum of Australia (http://www.ga.gov.au/earth-monitoring/geodesy/geodetic-datums/australian-height-datum-ahd.html).
CORS	Continuously Operating Reference Station – a permanent, continuously operating GNSS receiver and antenna, mounted on a stable monument with reliable power supply and communications infrastructure.
CORSnet-NSW	A rapidly growing network of GNSS CORS providing fundamental positioning infrastructure for New South Wales (NSW) that is accurate, reliable and easy to use (http://www.corsnet.com.au/).

Term/Acronym	Definition
DGPS/DGNSS	Differential GPS / Differential GNSS – a sub-metre, code-based, real-time positioning technique or service.
DOMES	Directory of MERIT Sites – historically, the DOMES numbering system was designed at the start of the MERIT campaign in the early 1980s in order to give an unambiguous identifier to all instrument reference points and markers involved in the campaign. This information was first published by the Bureau International de l'Heure (BIH). Since the official start of the International Earth Rotation and Reference Systems Service (IERS) in 1988, a DOMES number has been issued for all stations contributing to the ITRF.
elevation mask	A GNSS receiver setting that determines whether GNSS signals are not recorded below a certain angle above the horizon.
GDA94	The Geocentric Datum of Australia 1994, realised by the coordinates of the Australian Fiducial Network (AFN) geodetic stations, referred to the GRS80 ellipsoid and determined within the International Terrestrial Reference Frame 1992 (ITRF92) at the epoch of 1994.0 (http://www.ga.gov.au/earth-monitoring/geodesy/geodetic-datums/GDA.html).
geodetic datum	An official, fully-defined, spatial reference system to which coordinates are referred in either one, two, three or four dimensions.
GNSS	Global Navigation Satellite System – the family of current and future satellite navigation systems, including GPS, GLONASS, Beidou/Compass, Galileo and others.
IGS	International GNSS Service – an international federation of agencies that pool resources to operate a global CORS network whose data is used, amongst other purposes, to generate precise GNSS products in support of Earth science research, as well as multi-disciplinary applications (http://igs.org/).
ITRF	International Terrestrial Reference Frame – a realisation of the International Terrestrial Reference System (ITRS), produced by the International Earth Rotation and Reference Systems Service (IERS). A new ITRF, based on the latest data and analysis, is published every few years (http://itrf.ensg.ign.fr/).

Term/Acronym	Definition
LPI	Land and Property Information – a division of the NSW Department of Finance and Services. LPI builds, owns and operates CORSnet-NSW and is responsible for the maintenance of this document.
multipath	Errors in GNSS observations caused by one or more reflected GNSS signals interfering with the direct GNSS signal because of their common time origin but different path lengths.
NCC	Network Control Centre – location that houses all communication and IT infrastructure and software systems to operate, monitor and manage a CORS network.
NMS	Network Management System – a combination of hardware and software that monitors physical hardware (e.g. modems, UPS, batteries) within a CORS network.
NRTK	Network Real Time Kinematic – centimetre-level, carrier phase-based, real-time positioning technique or service, relative to a network of GNSS reference stations.
NTRIP	RTCM-SC10410 - *Networked Transport of RTCM via Internet Protocol* (NTRIP) is an application-level protocol for streaming RTCM-10403 formatted GNSS data over the Internet. Details of this standard can be found at http://www.rtcm.org & http://igs.bkg.bund.de/ntrip/about.
PDU	Power Distribution Unit – a device that manages the distribution of power to network components.
reference frame	A geodetic reference system is a set of definitions and mathematical models that allow geodetic measurements to be related to each other in a systematic fashion. A reference frame is the physical realisation of a reference system. Current global reference frames basically consist of a set of point coordinates at a reference epoch and constant velocity vectors for each point.
Reg 13	Regulation 13 – The process of verification of a reference standard of a position-measurement in accordance with Regulation 13 of the National Measurement Regulations 1999 and the National Measurement Act 1960. Through this process, Geoscience Australia certifies the position of a GNSS CORS, stated on the Regulation 13 certificate (http://www.ga.gov.au/earth-monitoring/geodesy/regulation-13-certificates.html).

Term/Acronym	Definition
RFI	Radio Frequency Interference – interference of GNSS signals in the presence of other radio frequency signals, causing an adverse effect on the GNSS signals recorded at a site. Common sources of RFI can include radio and television towers, microwave data links, power lines or transformers, and mobile phone towers.
RINEX	Receiver INdependent EXchange – an internationally accepted format for the exchange of GNSS data between software applications and for GNSS data archiving (ftp://ftp.unibe.ch/aiub/rinex).
RTCM	Radio Technical Commission for Maritime Services – Special Commission 104 is responsible for international standards of radio communication and navigation using differential GNSS. Details of these standards can be found at http://www.rtcm.org.
RTK	Real Time Kinematic – centimetre-level, carrier phase-based, real-time positioning technique or service, relative to a single GNSS reference station.
SCIMS	Survey Control Information Management System – database containing coordinates and related metadata for survey marks established under the direction of the NSW Surveyor General. SCIMS is maintained by Land and Property Information (LPI) for the purposes of cadastral boundary definition, engineering surveys, mapping and a variety of other spatial applications (http://www.lpi.nsw.gov.au/surveying/scims_online).
SNR	Signal-to-Noise Ratio – an assessment of the strength of a signal as a ratio compared against background noise.
survey control mark	A mark, with associated coordinates, uncertainties and relevant metadata that is a physical realisation of one or more of the recognised Australian geodetic datums.
tier	A term used to differentiate GNSS CORS sites based on their primary purpose, reliability, stability, permanency and GNSS products/services.
UNAVCO	University NAVSTAR Consortium – a non-profit, membership-governed university consortium facilitating geoscience research and education using geodesy (http://www.unavco.org/).
UPS	Uninterruptible Power Supply – an electrical device that provides short-term power to devices when the primary power supply fails.

Foreword

Introduction

The introduction of "active" Continuously Operating Reference Stations (CORS) based on Global Navigation Satellite System (GNSS) technology has revolutionised the delivery of the geodetic datum in Australia, shifting away from traditional "passive" ground marks. The use of GNSS CORS for datum delivery is discussed in Active GPS and Survey Marks (ICSM, 2008).

In a geodetic context, GNSS CORS form an integral component of the State's and the nation's geospatial infrastructure. The primary purpose of geodetic GNSS CORS is to collect data to measure and monitor the movement of the continent so that a "millimetre" accurate reference frame and datum for geoscience and spatial datasets can be defined and maintained.

GNSS CORS also support a multitude of downstream applications such as major infrastructure projects, asset management, resource and emergency management, machine guidance, intelligent transport systems, precision agriculture and environmental research. Both government and the private sector are establishing GNSS CORS, often as part of a network, to provide real-time positioning services offering timely, reliable and accurate positioning for these and other applications.

CORSnet-NSW is a rapidly growing network of GNSS CORS providing fundamental positioning infrastructure for New South Wales (NSW) that is accurate, reliable and easy to use (Janssen et al., 2011). The network also provides stimulus for innovative spatial applications and research using satellite positioning technology. It offers Differential GNSS (DGNSS/DGPS), single-base Real Time Kinematic (RTK) and Network Real Time Kinematic (NRTK) positioning services, and RINEX data for post-processing applications. CORSnet-NSW is built, owned and operated by Land and Property Information (LPI), a division of the NSW Department of Finance & Services.

Acknowledging that other reference station providers (both government and private) may need to establish and operate CORS and co-exist in the State, CORSnet-NSW forms the backbone of datum realisation for all spatial applications in NSW, ensuring seamless, consistent and accurate positioning across the State. LPI encourages the inclusion of all other suitable reference stations in its network, including in areas already serviced by CORSnet-NSW, to ensure redundancy and continuation of services.

It is recognised that clear guidance and practical coordination is required to build an effective partnership model for technical cooperation in GNSS CORS networks across the State. This document provides such technical guidance. CORSnet-NSW user guidelines and additional information on best practice can be found in the Technical Information section of the CORSnet-NSW website (LPI, 2012a).

Purpose of Guidelines

These guidelines provide recommendations for the technical design, installation, operation and maintenance of GNSS CORS used in CORSnet-NSW with the objective of ensuring interoperable GNSS CORS across New South Wales. It is anticipated that these guidelines may be adopted by other CORS network operators.

The provision of these guidelines demonstrates LPI's commitment to the national positioning infrastructure (NPI) policy, and supports its goal to "*ensure the sustainable, nationally compatible deployment of GNSS CORS infrastructure capable of accommodating a variety of providers and ensuring an efficient and effective Australia-wide coverage and service for the positioning needs of a diverse user community*".

In this context, it is necessary to define the terms compatibility and interoperability. LPI has adapted the definitions given by Hein (2006): "Compatibility" refers to the ability of GNSS CORS network services to be used separately or together without interfering with each individual service or signal. "Interoperability" refers to the ability of GNSS CORS network services to be used together in order to provide better capabilities at the user level than would be achieved by relying solely on one service or signal.

It is acknowledged that separate guidelines may exist for other Ground Based Augmentation Systems (GBAS) in Australia. One such GBAS is the GPS beacon system of the Australian Maritime Safety Authority (AMSA), which transmits differential GPS (DGPS) signals approximately 150 nautical miles out to sea. A second example is an aviation-specific GBAS operating at Sydney airport as one of the first such systems in the world. These standalone systems are not part of CORSnet-NSW and are beyond the scope and intention of this document.

Brief History of Guidelines

This document contains guidelines initially published in July 2011. The current version (Version 1.1) contains additions regarding GNSS CORS network design, antenna replacement and metadata, new appendices, and updated web links.

Acknowledgements

These guidelines are based on invaluable initial work undertaken by the Intergovernmental Committee on Surveying and Mapping (ICSM) Geodetic Technical Sub-Committee (GTSC). In particular, Darren Burns (Department of Environment and Resource Management, Queensland) and Robert Sarib (Department of Lands and Planning, Northern Territory) are gratefully acknowledged for their contribution to the early development of a generic, national document. This ICSM-GTSC document has since developed into a draft guideline as part of the proposed new SP1 version 2.0 standard (the draft guideline is available from http://www.icsm.gov.au/icsm/publications/).

The initial, generic ICSM-GTSC document has been revived, extensively reviewed, modified and expanded to meet the needs of CORSnet-NSW by the following LPI staff:

- Mr Simon McElroy
- Dr Volker Janssen
- Mr Russell Commins
- Mr Thomas Yan

Maintenance of Guidelines

The maintenance of these guidelines is the responsibility of Land and Property Information (LPI), a division of the NSW Department of Finance and Services. Updates will be required when Initial Operational Capability (IOC) is declared for new GNSS and GPS modernisation. In the future, it is intended to include CORSnet-NSW guidelines regarding reliability and service levels. Please direct feedback and report any broken links to Simon McElroy at Simon.McElroy@lpi.nsw.gov.au.

Referencing of Guidelines

These guidelines are available on the CORSnet-NSW website and should be referenced as follows:

LPI (2012) Guidelines for CORSnet-NSW Continuously Operating Reference Stations (CORS), version 1.1, available via http://www.lpi.nsw.gov.au/surveying/corsnet-nsw/education_and_research (accessed Month Year).

1 The GNSS CORS Hierarchy

In order to distinguish Global Navigation Satellite System (GNSS) Continuously Operating Reference Station (CORS) networks in regards to their purpose, the concept of a tiered hierarchy of permanent GNSS reference stations was proposed by Rizos (2007) and has since been widely accepted across Australia (Burns & Sarib, 2010). This original hierarchy has been adopted and expanded as the basis for differentiating between GNSS CORS throughout this document, with the addition of Tier 4 and 5. The tier status of a GNSS CORS is principally determined by:

- The primary purpose for which the station has been established.
- The expected reliability and services from the station.
- The expected stability of the station monument.
- The expected permanency of the station.

The ultimate responsibility for the assignment of a tier classification to a station included in CORSnet-NSW must remain within the subjective judgement of LPI as the relevant authority. CORSnet-NSW currently (at the date of issue of these guidelines) consists of GNSS CORS classified as Tier 1-3. LPI may consider inclusion of Tier 4 and 5 classified GNSS CORS where appropriate.

1.1 Tier 1 GNSS CORS

Tier 1 GNSS CORS require high-stability monuments to support long-term, geoscientific research and global reference frame definition. These sites are established to support the International GNSS Service (IGS) or other equivalent ultra-high accuracy networks. The IGS site guidelines (IGS, 2009), and their proposed major revision (draft document available at http://igs.org/network/guidelines/proposed.html), provide guidelines for all GNSS CORS sites contributing data to IGS, and additional requirements for the IGS reference frame sites, which are a subset of IGS sites used to determine the International Terrestrial Reference Frame (ITRF). Data from Tier 1 GNSS CORS should be submitted to IGS for global geodetic science and research purposes.

Tier 1 GNSS CORS are owned and operated by the federal government (primarily Geoscience Australia). Their operation tends to be focused on post processing (RINEX data). Tier 1 GNSS CORS are included in CORSnet-NSW if additional, primarily real-time focused, requirements are met.

1.2 Tier 2 GNSS CORS

Tier 2 GNSS CORS require high-stability monuments, usually established by national (i.e. Geoscience Australia) and/or state geodetic agencies for the purpose of maintaining national geodetic reference frames. These sites are operated long term and form the primary national GNSS network. It should be noted that Tier 2 GNSS CORS provide a tie between the national geodetic datum and the global ITRF. The design and construction methodology across Tier 2 sites is very similar. Data from Tier 2 GNSS CORS is made available to the relevant national, state or territory jurisdiction for the purpose of national geodetic reference frame realisation/improvement and satellite positioning services.

Tier 2 GNSS CORS located in NSW are built, owned and operated by LPI to support the federal Collaborative Research Infrastructure Strategy (NCRIS). They are included in CORSnet-NSW if additional, primarily real-time focused, requirements are met and to ensure a link to the national datum.

1.3 Tier 3 GNSS CORS

Tier 3 GNSS CORS require stable monuments and are established by national or state government agencies, commercial agencies and companies specialising in CORS service provision. They are established for the purpose of densification of the national GNSS CORS network and supporting real-time positioning applications. These stations generally operate in, and provide access to, the datum rather than defining it. The design and construction methodology across Tier 3 sites is similar.

NSW Tier 3 GNSS CORS make up the majority of the CORSnet-NSW infrastructure. They are predominately built, owned and operated by LPI, and are often located or "hosted" at local government buildings.

1.4 Tier 4 GNSS CORS

Tier 4 GNSS CORS are established by local government, smaller government agencies and smaller commercial agencies operating up to a few GNSS reference stations in the medium term (3-7 years) for the purpose of supporting satellite-positioning needs to a group of local users with similar requirements. Monumentation, service levels, reliability and backup systems satisfy the internal user group. The design and construction methodology across Tier 4 sites can be varied.

Tier 4 GNSS CORS may be included in CORSnet-NSW to provide densification and avoid the duplication of service that would occur with the establishment of a new Tier 3 site by LPI. They can provide vital, independent backup to primary stations (Tier 3 GNSS CORS).

1.5 Tier 5 GNSS CORS

Tier 5 GNSS CORS are established by small private business or individuals, providing an "ad-hoc" service for short-term project (<5 years), seasonal or local use only. Monumentation and reliability satisfy the owner's internal requirements. Permanent backup systems are generally not considered, and availability may be irregular. The design and construction methodology across Tier 5 sites is highly variable.

Tier 5 GNSS CORS are generally not included in CORSnet-NSW. However, under certain circumstances, Tier 5 sites may be used as integrity monitoring stations (i.e. simulating users and measuring performance) or to support unique local user requirements.

Table 1 summarises the specifications for GNSS CORS tiers in CORSnet-NSW.

Table 1: Summary of specifications for GNSS CORS tiers in CORSnet-NSW.

Specification for	Tier 1	Tier 2	Tier 3	Tier 4	Tier 5
Life Span					
• Operational life and site tenure	■ (>50 yrs)	■ (>30 yrs)	■ (>15 yrs)	□ (>5 yrs)	□ (>1 yr)
Primary Purpose					
• Datum definition (global), international GNSS services and geodynamic studies	■	□	X	X	X
• Datum definition (regional/national/state)	■	■	□	X	X
• Datum densification – spine/sub-spine survey mark (state)	□	■	■	□	X
• "Active" control station/reference station (e.g. LGA)	□	■	■	□	□
• Real-time positioning services – CORS network covering area (e.g. state or LGA)	□	■	■	□	X
• Real-time positioning services – single CORS covering localised area (e.g. port, airport, mine, construction site, farm)	□	□	■	■	□
• Geodynamic monitoring (tide gauges)	□	■	□	X	X
• Other (timing, monitoring, applied research, etc.)	□	□	□	□	□
Typical Ownership					
• Federal government	■	□	□	N/A	N/A
• State government	□	■	■	□	N/A
• Local government	X	□	■	■	□
• CORS service provider	X	□	■	■	□
• Large business	X	□	■	■	□
• Small business or individual	X	X	□	■	■
Service Level					
• Data complete and continuous – post processing (raw or RINEX)	■ (>99%)	■ (>99%)	■ (>95%)	■ (>90%)	□ (>75%)
• Data complete and continuous – real time (raw or RTCM)	□ (>90%)	■ (>95%)	■ (>95%)	■ (>90%)	□ (>75%)
Service Type					
• Provision of "centimetre" network-based services (NRTK and/or Virtual RINEX)	■ (primary)	■ (primary)	■ (primary)	□ (backup)	X
• Provision of "sub-metre" network-based services (DGPS)	■ (primary)	■ (primary)	■ (primary)	□ (backup)	X
• Provision of "centimetre" single-CORS-based services (RTK and/or RINEX)	■ (primary)	■ (primary)	■ (primary)	□ (backup)	□ (backup)
• Provision of "sub-metre" single-CORS-based services (DGPS)	■ (primary)	■ (primary)	■ (primary)	■ (primary)	□ (backup)

Specification for	Tier 1	Tier 2	Tier 3	Tier 4	Tier 5
• Monitoring service performance	□	□	□	□	□
Foundation					
• Permanently fixed to bedrock or deep (>3m) concrete base	■	■	□	□	□
• Permanently keyed into more competent rock through layers of soil / fractured rock	■	■	□	□	□
• Permanently mounted on concrete base (>0.5m^3) or solid building that is only subject to minimal seasonal movement	X	X	■	■	□
• Permanently mounted on semi-rigid structure (e.g. steel shed, hangar, tower) that may be subject to some shorter-term movement or vibration	X	X	X	■	■
Monumentation					
• Dual reinforced concrete pillars or dual braced deep-drilled frames (i.e. dual antenna mounts)	□	□	N/A	N/A	N/A
• Single reinforced concrete pillar or braced deep-drilled frame	■	■	□	□	□
• Rigid stainless steel or galvanised steel mounts permanently attached to building or concrete plinth	X	X	■	■	□
• Adjustable, semi-rigid, long (braced if >2m), temporary or "ad-hoc" mount subject to vibration movement of <5mm	X	X	X	X	■
Mount (Mark) Definition and Traceability					
• Unambiguous definition of survey mark	■	■	■	■	□
• 5/8th Whitworth thread spigot	■	■	■	■	□
• Zero or minimal (<2mm) height of antenna	■	■	■	□	□
Signal Reception and Interference					
• Skyview clear of obstructions	■ (>0-5° elev)	■ (>0-5° elev)	■ (>5-15° elev)	■ (>15° elev)	■ (>20° elev)
• Minimal multipath at site	■ (~ zero)	■ (~ zero)	■ (minimal)	□ (low)	□
• Minimal RFI at site	■ (~ zero)	■ (~ zero)	■ (minimal)	□ (low)	□
Security					
• Access to antenna restricted (e.g. elevated site, roof, locked fence)	□	□	□	□	□
• Access to receiver and peripheral devices restricted (e.g. locked cabinet, secure IT server room)	■	■	■	■	□

Specification for	Tier 1	Tier 2	Tier 3	Tier 4	Tier 5
Power					
• Ensured continuous operation of GNSS receiver	■	■	■	■	□
• Ensured continuous operation of all communications devices	□	■	■	■	□
• Alternate power supply providing operation for specified time period (office location)	■ (>20 days)	■ (>20 days)	■ (>5 hours)	■ (>5 hours)	□
• Alternate power supply providing operation for specified time period (remote location)	■ (>20 days)	■ (>20 days)	■ (>40 hours)	■ (>10 hours)	□
Communications					
• Remote control and data access supported	□	■	■	■	■
• Sufficient dedicated link bandwidth of approx. 400 bytes/s for non-redundant design or 800 bytes/s for redundant design	■	■	■	■	■
• Reliable and continuous, with a latency of less than 2 seconds from CORS to end user (for real-time positioning services)	■	■	■	■	■
• Backup/alternate communications device installed	□	■	■	□	□
GNSS Receiver					
• Geodetic/CORS grade quality	■	■	■	□	□
• Survey/Construction/Precision Agriculture grade quality	X	X	X	■	■
• Ability to store and remotely download raw 1-second GNSS data for at least a specified number of days	■ (>60 days)	■ (>60 days)	■ (>30 days)	□ (>15 days)	□
• Ability to store and remotely download at least a specified number of days of raw meteorological data	■ (>60 days)	■ (>60 days)	□ (>30 hours)	N/A	N/A
• RTCM 10403.1 or suitable alternative data format for real-time data streaming at 1-second or better	□	■	■	■	□
• Tracks existing GPS observables (L1 & L2)	■	■	■	■	■
• Tracks, or is upgradable to track, GPS L2C	■	■	■	□	□
• Tracks, or is upgradable to track, GPS L5	■	■	■	□	□
• Tracks existing GLONASS observables	■	■	■	■	□
• Tracks, or is upgradable to track, proposed GLONASS observables	□	□	□	□	□
• Tracks, or is upgradable to track, free-to-air Galileo observables	□	□	□	□	□

Specification for	Tier 1	Tier 2	Tier 3	Tier 4	Tier 5
• Tracks, or is upgradable to track, Beidou/Compass observables	□	□	□	□	□
• Tracks, or is upgradable to track, QZSS observables	□	□	□	□	□
• Dedicated network (Ethernet) port supporting multiple data streams simultaneously	■	■	■	■	■
• Receiver bias model available in CORS network management software	■	■	■	■	■
GNSS Antenna					
• Geodetic/CORS grade quality	■	■	■	□	□
• Survey/Construction/Precision Agriculture grade quality	X	X	X	■	■
• Choke ring antenna with high-quality (e.g. Dorne Margolin) element	■	■	□	□	□
• Multipath mitigation	■	■	■	■	■
• IGS “individual” calibrated absolute antenna phase centre model available	□	□	□	N/A	N/A
• IGS “type” calibrated absolute antenna phase centre model available	■	■	■	■	■
• Antenna orientated to True North (±5°)	■	■	■	■	□
Weather Station					
• Pressure measurement accuracy better than ±0.1hPa	■	■	□	□	□
• Temperature measurement accuracy better than ±1°C	■	■	□	□	□
• Relative humidity measurement accuracy better than ±2%	■	■	□	□	□
Coordinates					
• Provisional coordinates in national geodetic datum, derived by 24-hour datasets processed via AUSPOS	■	■	■	■	■
• Final coordinates in national geodetic datum, derived by Geoscience Australia via Regulation 13 certification	■	■	■	■	■
• Final local GDA94(1997) and AHD71 coordinates, derived by LPI approved survey and available in SCIMS	□	■	■	■	□
Position Monitoring					
• Periodic (6-24 month) high-precision, local terrestrial reference mark surveys	□	■	□	□	N/A

Specification for	Tier 1	Tier 2	Tier 3	Tier 4	Tier 5
• Continuous (daily solutions) monitoring with scientific software	■	■	■	■	□
• Continuous (real-time) monitoring within CORS network management software	■	■	■	■	■
Hardware Monitoring					
• Continuous GNSS receiver monitoring within CORS Network Management System (NMS)	■	■	■	■	■
• Continuous peripheral device monitoring with Network Management System (NMS), e.g. UPS, modems, battery status, alarms	N/A	□	□	□	□
Accepted Data Format (Post Processing)					
• Raw proprietary (unsmoothed) format for archiving	■	■	□	□	□
• RINEX (via receiver memory) for ultra-precise post processing	■	■	□	□	□
• RINEX (via decoded RTCM stream) for general post processing	■	■	■	■	□
Accepted Data Format (Real Time)					
• RTCM 10403.1 or suitable alternative data format for real-time applications	■	■	■	■	■
• Access to real-time data stream (no antenna model applied)	■	■	■	□	□
• Access to real-time data stream (null antenna model applied)	X	X	X	□	□
• Access to real-time data stream (directly from receiver)	□	□	□	□	□
• Access to real-time data stream (relayed via a third-party NCC)	□	□	□	□	□
Metadata					
• Complete and current IGS site log	■	■	■	■	■
• Readily available site metadata	■	■	■	■	■
• DOMES number assigned	■	■	■	■	□
• Unique 4-character site ID (global)	■	■	□	□	□
• Unique 4-character site ID (Australasia)	■	■	■	■	□
• Antenna photos showing N,E,S,W horizon	■	■	□	□	□

Legend

■ – Mandatory

□ – Optional (preferred if possible)

X – Not permitted

N/A – Not applicable

2 GNSS CORS Network Design

There are a number of major principles to consider when designing GNSS CORS networks:

- Inter-station distance or station density.

- Connection to the reference frame through the GNSS CORS tiers.

- The reliability and integrity of services to be provided and the risk of systems failure that is acceptable, i.e. the effect of station(s) outage on the delivery of a service.

- Type of service(s) to be provided. These range from sparse CORS networks for DGPS applications, to clusters of 5-6 CORS for NRTK, to those specifically designed to monitor a structure (e.g. bridge, freeway construction) or natural feature (e.g. earthquake fault line).

- The area over which the service(s) are required. Existing high-population areas, regions experiencing rapid population growth or rural locations adopting precision agriculture may require a different sub-network design to that portion of a network that may cover low population areas and/or offer low commercial returns (e.g. remote regions, national parks and offshore waters).

- Whether the network is post-processing or real-time orientated. Real-time networks that use Ultra High Frequency (UHF) radio as the primary communications to rovers will need to consider Line of Sight (LOS), hence terrain and radio ranges, during network design. Real-time networks relying on the Internet for data transfer will need to consider the availability of mobile communications coverage.

- Networks designed for NRTK often require multiple CORS far beyond the desired area of operation to allow the modelling of atmospheric effects. Overseas (UK) studies indicate that NRTK services designed for mountainous regions may require CORS to be established at different altitudes, requiring the installation of further CORS (Edwards et al., 2010).

- The level of rover monitoring that is desired. Additional CORS that mimic a rover (i.e. that do not contribute to actual service delivery) are routinely established throughout a network to allow the CORS operator to monitor typical service performance being experienced by users.

- Networks providing dual or triple constellation services may opt for technological solutions (e.g. "sparse GLONASS") that allow them to alternate between the use of single and multiple constellation GNSS receiver hardware in their network design.

- The proximity to existing CORS operated by other providers and the level of infrastructure sharing that is available.

- The desired lifetime over which the CORS network is required to operate, i.e. short term for a project (e.g. freeway build) or permanent (e.g. datum realisation).

- The collocation of CORS hardware with other geodetic (e.g. tide gauges, gravity sites or seismic stations), meteorological (Bureau of Meteorology) or research infrastructure. Similarly, the potential for government operators to use regional offices, local councils or state government office blocks and the private sector to use partner and dealer offices.

Based on the current status of GNSS technology, indicative inter-station distances of GNSS CORS are as follows:

- Tier 1 GNSS CORS should have a typical inter-station distance of between 500 and 1500 kilometres or less.

- Tier 2 GNSS CORS should have a typical inter-station distance of between 90 and 500 kilometres or less.

- Tier 3 and Tier 4 GNSS CORS should have a typical inter-station distance of between 20 and 90 kilometres or less.

- Tier 5 GNSS CORS are established on an opportunity basis, either as an autonomous (standalone) CORS located central to the intended area of operation or as a cluster of several CORS. A suggested inter-station distance is therefore not applicable.

These inter-station distances assume negligible outages. Operators requiring greater reliability or redundancy should decrease these values, hence increasing network density.

A nominal 10% of stations in a GNSS CORS network should be constructed to the standards of the next highest tier to provide a stronger link between sites in the GNSS CORS network and the national and international reference frame, and to improve national geodetic datum accuracy.

Modern real-time positioning software is generally able to tolerate a single GNSS CORS outage in the middle of a network and continue to function, albeit with a possible small accuracy deterioration. However, when a site on the perimeter of a real-time positioning network suffers a hardware, communications or power failure, service in that area may be disrupted. To reduce the possibility of service disruption, a greater density of GNSS CORS sites around the network perimeter should be considered. Alternatively, the area with guaranteed continuous NRTK coverage can be reduced.

Particular care should be taken to increase the power and communications reliability at sites that form the perimeter of any GNSS CORS network offering real-time services.

Furthermore, it is important to consider the organisational issues related to the establishment and operation of the GNSS CORS network and how these may relate to the National Positioning Infrastructure (NPI) policy and plan.

Higgins (2008) outlined a model to specify the roles that a given organisation may play in the delivery of GNSS CORS network services. This model breaks up the process into five discrete roles:

- *Specify the network and services*. This may include consideration of station density, coverage area, service accuracy, reliability and availability, as well as technical issues (e.g. geodetic reference frame).
- *Own the reference stations*. This may incorporate site selection, site construction, equipment purchasing, data communications, hosting the equipment, site maintenance, and equipment replacement cycles.
- *Network the data*. This may involve running the Network Control Centre (NCC) and associated information technology and communications, and carrying out the quality control and archiving of raw data.
- *Process the network*. This may include processing the raw data from the GNSS CORS, producing correction data streams, and distributing these to users.
- *Deliver the services*. This may involve retail sales and marketing of data products, support to end users and their rover equipment, and liaison with communications providers for end users.

If different organisations play these different roles, it will be necessary to have strong governance processes in place to provide clarity and transparency in regards to business and legal issues. Good governance mechanisms also ensure that end users have confidence in the GNSS CORS network services offered. Typical governance mechanisms required would include agreements on responsibilities of each organisation.

3 GNSS CORS Establishment

The tier status of a GNSS CORS will determine the minimum criteria for many aspects of the site selection process, and accordingly aspects of the following establishment guidelines are divided into tier categories.

Every potential GNSS CORS will have site-specific issues to resolve. This document recognises seven general principles for the location and design of a GNSS CORS:

- Safety first – Occupational Health and Safety (OH&S) considerations during installation and maintenance.
- The role of the CORS, e.g. a primary station located at the hub of a "spoked" network, an auxiliary backup station, a CORS on the fringe of a network or an integrity monitoring station.
- Stability of the GNSS antenna foundation, monument and mounting device.
- Quality and completeness of the recorded GNSS signals.
- A continuous and reliable power supply.
- A reliable communications system (primary and backup) with acceptable latency and sufficient bandwidth.
- GNSS CORS infrastructure that resists the ambient environmental and security conditions.

Following an initial desktop design process, a site visit to evaluate the potential GNSS CORS site is essential. Good reconnaissance will allow the evaluation of candidate sites, identify and record any significant signal obstructions and suspected multipath and Radio Frequency Interference (RFI) sources. It will also investigate site access, power, measure cable runs, test communications availability, and consider general issues of site security, ownership and arranging local hosts or nominated contact officers. Reconnaissance should also investigate the potential for future changes to sky visibility from tree growth and development at adjacent sites. Where there is a concern about the site foundation, this initial reconnaissance may also help determine whether additional geophysical or structural analysis is required to determine site suitability.

3.1 Pre-installation Data Quality Assessment

Ideally, prior to construction, an initial data acquisition process should be undertaken to test data from a proposed GNSS CORS site. The data should be analysed for signal reception suitability using GNSS quality assessment software such as TEQC (UNAVCO, 2012a). Data should be analysed for signal quality parameters on all observed frequencies. At a minimum, the analysis should include multipath, the ratio of available to recorded observations, the number and length of loss-of-lock or cycle-slip events, and the variation of the Signal-to-Noise Ratio (SNR) with satellite elevation.

At proposed Tier 1 and 2 sites, a minimum of 48 hours of data observed at 30-second epochs should be recorded and analysed.

At proposed Tier 3 and 4 sites, a minimum of 24 hours of data observed at 30-second epochs should be recorded and analysed.

Where the GNSS CORS site is to be used as part of a real-time positioning network, data should be recorded at 1-second epochs.

The initial data acquisition process should be undertaken as closely as possible to the intended final antenna location. If possible, the equipment to be used at the GNSS CORS site should be used for the initial data acquisition process. Equipment settings such as enabled tracking options and elevation masks should be set the same as those intended for the GNSS CORS installation.

3.2 Signal Quality

3.2.1 Sky Visibility

GNSS CORS sites should have as few obstructions as possible above the local horizon. Some obstructions to the South (southern hemisphere operators) can be tolerated.

Tier 1 and 2 GNSS CORS should have an elevation mask set to 0°.

Tier 3 (and lower) GNSS CORS sites should have an elevation mask set to match the sky visibility at the site, but not more than 10°.

During initial site reconnaissance, potential future obstructions affecting sky visibility, e.g. likely tree growth and nearby development, should be considered and recorded.

3.2.2 Multipath

Multipath is the term used to describe GNSS satellite signals that arrive at the GNSS antenna having travelled via a number of paths. The signal arrives once directly from the satellite and then a number of additional times having reflected off other surfaces.

For all CORS, it is recommended that suspected multipath sources be a minimum of 20 metres from the GNSS antenna and below 5° elevation.

Sources of multipath can be manmade or natural. Reflective surfaces such as metal panels and roofing, building walls, metal and mesh fencing, signs and water bodies are known to provide high levels of multipath. Trees, especially when the canopy is wet, can also increase the effect of multipath. These reflective bodies should be avoided at GNSS CORS sites as much as possible.

CORSnet-NSW uses Trimble Navigation's VRS^{3}Net CORS network management software to provide site multipath indicators. Alternatively, the TEQC software (UNAVCO, 2012a) can be used. Suitable sites will have pseudorange multipath values less than 0.5 metres, and preferably less than 0.3 metres. Phase multipath values should be 5 millimetres or less. These values are indicative only. Valid multipath values may take a week or more of observations.

3.2.3 Radio Frequency Interference (RFI) Sources: GNSS and Communications

The GNSS signals received at a GNSS CORS site may suffer interference in the presence of other radio frequency signals. This interference causes an adverse effect on the GNSS signals recorded at the site. Common sources of Radio Frequency Interference (RFI) may include radio and television towers, microwave data links, power lines and transformers, and mobile phone towers. Directional transmitters, particularly microwave data links that point toward the GNSS CORS site, should be avoided. A simple field test that involves attempting to obtain a navigation solution and monitoring abnormal GNSS signal strengths at the candidate site, on a low-cost handheld GPS receiver, can often identify and rule out heavy RFI environments (e.g. "radio tower farms"). Integer multiples of lower radio frequency may cause harmonic interference with a GNSS signal. Any proposed radio frequency system should be checked to minimise RFI. RFI is difficult to identify and a function of radiated power, amongst other parameters. Defining a safe distance from a given RFI source is therefore not appropriate. Low-cost, handheld, battery-operated devices are commercially available to detect the presence of non-GPS signals and interference broadcasting on the L1 frequency.

RFI may also hamper communications, and hence effective data flows, from a CORS to the Network Control Centre (NCC) or users (e.g. direct communication systems employing UHF or mobile phone technology). Most transmitting antennas utilise the E-plane radiation pattern, which generally projects the highest signal strength horizontally, not vertically. Consequently, adding vertical separation between the GNSS antenna and the transmitting UHF radio antenna will have a much greater impact on noise reduction than horizontal separation alone (lowering a transmitting antenna by 1 metre has a similar effect to moving it away 10 metres).

For all GNSS CORS, it is advisable that a potential site be tested to confirm that RFI sources and transmission paths will not undermine GNSS performance. Analysis of the test observation data is recommended. Specialist advice may be required if RFI is suspected at a site.

3.3 Authorisation to Build

CORS construction, even pre-build geophysical bore hole sampling, may be governed by a range of state and local planning policies, regulations and acts including State Environmental Planning Policies (SEPPs) and Local Environmental Plans (LEPs). In some instances, a Development Application (DA) may be required. Careful scrutiny of the appropriate and any associated legislation may include special arrangements for survey marks, navigation aids and multiple antenna installations.

In NSW, CORS operators are required to exercise the due diligence code of practice for the protection of Aboriginal objects, i.e. it needs to be confirmed that a proposed CORS in a remote area is not located in an Aboriginal place and does not disturb a nearby Aboriginal site or object. This should be done well before geophysical testing and construction begins.

3.4 Site Access

Arrangements regarding emergency and periodic access (e.g. maintenance) to the GNSS CORS site should be agreed before construction. Details should include contact officers, contact details (business and/or after hours), access times (business and/or after hours), costs involved, notification times required and any special local requirements (e.g. site briefings/inductions, visitors to hold valid Maritime Security Identification Cards, visitors to be supervised whilst on site).

The need for emergency site access can be significantly reduced by equipping the site with appropriate auxiliary support devices such as remote web relay, Virtual Private Network (VPN) tunnel allowing direct and secure access to CORS receivers through the firewalls of the host organisation, Uninterruptible Power Supply (UPS), backup communications link and surveillance camera. CORS network operators should have appropriate IT administrative rights to CORS equipment and peripheral devices.

3.5 Site Security

Site security includes protecting the GNSS CORS from theft, vandalism, weather, lightning and animals. It also includes ensuring long-term tenure. When a government Tier 1 or Tier 2 GNSS CORS site is established, the preferred form of land tenure is a survey or trigonometrical station reserve. However, freehold title, a long-term lease, and easements for access are effective ways of registering a long-term interest, particularly for privately owned and government Tier 3 GNSS CORS. Any formal arrangement with a landowner to secure tenure should ensure the agreement includes an option for continuance and extension if there is a change of land ownership. Furthermore, requirements regarding insurances covering both parties should be clearly noted.

By its nature, a GNSS CORS will be exposed to the weather and the natural environment. Electronic equipment not contained in a secure building may require a locked and sealed enclosure (Figure 1) or be placed in a building enclosure (Figure 2). Enclosures should be rated to industry standards for protection against ambient conditions. The Bureau of Meteorology (http://www.bom.gov.au/) should be consulted on the seasonal weather patterns expected at the proposed GNSS CORS site. Sealed enclosures may need to include insulation or air conditioning equipment to control temperature and humidity. Equipment should generally be installed such that the equipment that is least tolerant of temperature extremes is located lower in the enclosure.

Solar panels, and other externally mounted equipment, should be designed and certified to withstand local conditions. Solar panels can also be mounted and orientated to provide an effective shade awning to protect equipment cabinets from direct sunlight (see Figure 1). Any antenna, power and communications cables between the enclosure and the monument should be enclosed in durable conduit and, preferably, buried for protection. Installers must always "Dial-Before-You-Dig" (http://www.1100.com.au/) to avoid costly damage to underground pipes and cables. The layout of the equipment should also be designed to prevent inadvertent disruption during maintenance.

Ideally, a GNSS CORS site should be as unobtrusive as possible to reduce attracting unwanted attention. If fencing is used to minimise the risk of vandalism, theft, stock damage or inadvertent disturbance, the fence should be below the level of the antenna, or at least 20 metres from the GNSS antenna, to minimise multipath.

Figure 1: Enclosure with solar panel doubling as a shade awning at a CORSnet-NSW site (Tier 2).

Figure 2: Building enclosures at CORSnet-NSW sites (Tier 3).

3.6 Site Stability

The primary factors that will affect the stability of the GNSS CORS antenna are the site foundation, monument and mounting device.

3.6.1 Site Foundation

Tier 1 and 2 GNSS CORS antenna monuments should be structurally affixed to sound bedrock to provide data on tectonic plate motion, related tidal forces, inner plate distortions (i.e. within Australia) and a precise realisation of the national geodetic datum. Locations with exposed bedrock are preferred, though bedrock is often under layers of soil. In cases where bedrock is at a depth of greater than 3 metres beneath the surface, a large mass concrete foundation may be created. Sites with mine subsidence, landfill, reactive (i.e. black) soils and excessive surface cracking indicating large amounts of soil expansion and contraction due to water should be avoided. On sites where there is concern about the foundation, some form of geophysical analysis is recommended which usually involves bore hole drilling.

Lower-tier GNSS CORS do not have as stringent foundation requirements, allowing them to be installed anywhere close to available resources such as proximity to existing power and communications infrastructure, site security and site tenure. Tier 3 and 4 GNSS CORS sites may be affixed to bedrock or placed on load-bearing components of structures, preferably near the intersection of two walls. Concrete or brick structures such as buildings of two or less storeys in height are preferred to minimise foundation instability due to variable thermal and wind loading.

Structures with the potential for variable loading, such as water towers, may be used for Tier 5 GNSS CORS. Foundation structures with a metal roof or nearby reflective surface should be avoided where possible to reduce the effect of multipath.

Buildings less than five years old may still be undergoing post-construction settlement. These structures should be avoided where possible, and if they are used, monitoring surveys to nearby reference marks could be undertaken until settlement has stabilised. Historical buildings which have heritage issues should be avoided where possible.

Structural analysis by an engineer will help identify the best monument mounting point and fixing method for buildings or similar structures used as Tier 3 (or lower) foundations.

3.6.2 Antenna Monument

Antenna monuments are the devices that secure the GNSS antenna mount to bedrock, the building or the object being used. Reinforced concrete pillars and deep-drilled braced monuments are generally recognised as the most stable and economic GNSS CORS structures acceptable and are required for Tier 1 and Tier 2 GNSS CORS sites. In Australia, the reinforced concrete pillar is the preferred monument.

These monuments should be designed to incorporate additional reference marks such as benchmarks to allow local reference mark surveys to be undertaken (see section 5.4).

Typical antenna monuments for CORSnet-NSW Tier 2 sites are shown in Figure 3. A sample monument design for CORSnet-NSW Tier 1 and Tier 2 GNSS CORS is shown in Appendix 2.

Figure 3: Typical CORSnet-NSW Tier 2 antenna monuments.

Typical antenna monuments for CORSnet-NSW Tier 3 and 4 sites include:

- Free standing pole.
- Clamp style mount.
- Wall mount.
- Pad style mount.
- Department of Sustainability and Environment, Victoria (DSE) rooftop style mount.

These antenna monument types are depicted in Figure 4. Sample monument designs for CORSnet-NSW Tier 3 and 4 GNSS CORS are shown in Appendix 3.

For all GNSS CORS, the required characteristics of the monument include:

- Longevity.
- Sufficient elevation of the antenna to minimise obstructions occurring above the elevation mask.
- Stability in regards to short-term (e.g. vibration), medium-term (e.g. daily or seasonal movement) and long-term (e.g. subsidence and geophysical deformation) movements.
- Minimal thermal expansion.
- Low maintenance.
- Corrosion and erosion resistance.

- Multipath minimisation.
- Simple design for ease of fabrication, installation and maintenance.
- True verticality (within 2 mm) at the apex.
- Load-bearing capability (e.g. choke ring antennas typically weigh in excess of 4 kg).
- Light weight to minimise stress and damage to non-structural parts of the building (Tier 3, or lower, building mounts only).
- Aesthetics.
- Overall footprint.
- Safety harness attachment points (Tier 3, or lower, building and tall mounts).
- Tamper-proof design.

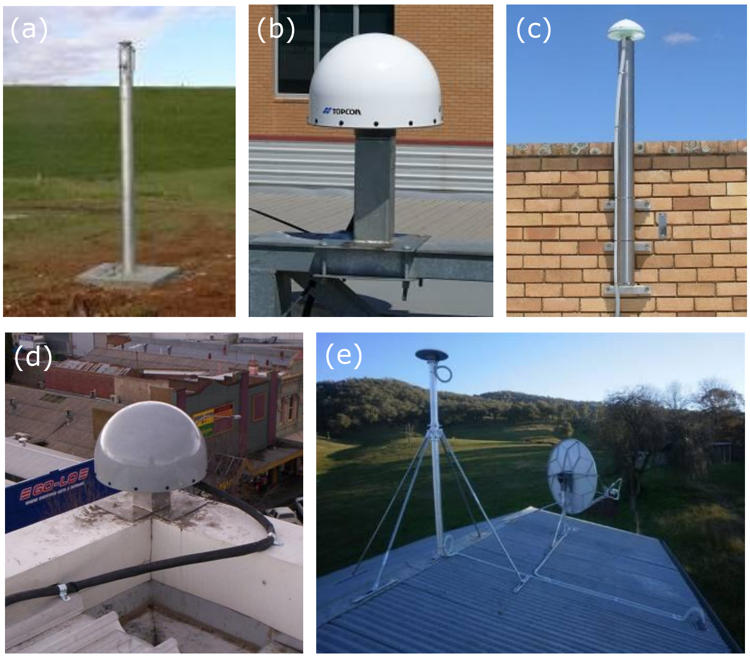

Figure 4: Typical CORSnet-NSW Tier 3 and 4 antenna monuments: (a) free standing pole, (b) clamp style mount, (c) wall mount, (d) pad style mount, (e) DSE rooftop style mount.

Ground-based Tier 3 (or lower) GNSS CORS sites may use pillars, deep-drilled braced monuments or other purpose-built monuments that provide suitable stability. Tier 3 (or lower) GNSS CORS mounted on structures require stainless steel (preferred) or galvanised steel brackets, posts, or mast and brace monuments. Aluminium monuments should be avoided due to the increased thermal expansion of aluminium. If galvanised steel monuments are used, scratching or modifying these should be avoided. If it is necessary to touch up any exposed steel, a cold gal paint or similar should be used. Whilst this is good practice in the short term, cold gal tends to break down over time and eventually rust may form in these areas. The aesthetics of the monument will need to be considered when located in prominent locations or on high-profile buildings. Powder-coating monuments to match building colour schemes is often advantageous or a requirement in pre-installation negotiations (Figure 5).

Figure 5: Powder-coated antenna monuments at CORSnet-NSW sites (Tier 3), also showing the use of steel ties, waterproof connectors and partial drip loops.

Monuments may vary in dimension and material, and whilst they may appear sturdy, consideration to having structural certification in terms of compliance with operational specifications (e.g. < 2mm horizontal deflection under normal wind loading) is an option.

Building-based GNSS CORS monuments should be designed specifically for the site and directly affixed at a minimum of three points to a load-bearing component of the foundation, ensuring that the foundation structure is not damaged by the monument.

Roof mounts increase options in terms of site mounting and improve Occupational Health and Safety (OH&S) considerations. Fixings in roof sheeting should be placed in the ridges only.

On wall mounts, only one bolt or other anchor device should be placed per brick. On single-width brick walls the bolts or other anchors should, at minimum, penetrate the centre of the brick. Bolts or other anchors must never be anchored through the mortar between bricks. Anchoring through foundation structures with a double-brick cavity wall must be avoided as this will damage the wall by pulling the two brick skins together.

Chemical anchors (e.g. Chemset) used with stainless steel bolts are preferred for masonry attachment and where the foundation structure is constructed of hollow or fragile bricks. Chemical anchors give a much more enduring attachment than expansion fittings. Expansion fittings also have decreased effectiveness in any form of hollow masonry (e.g. hollow brick or besser block). One or two of the anchors can be stainless steel expanding type bolts (e.g. Dynabolts) or thread-forming anchors (e.g. Anka screws) if required to hold the monument in position while the chemical anchors cure (Figure 6). It is not necessary to replace these anchors. If possible, the highest attachment point should be four or more brick courses down from the top course and around 500mm in from any edge or window. All anchors should be tightened after curing of the adhesive. A thread-locking compound (e.g. Lock Tight) should be used to stop nuts loosening over time. The use of chemical anchors should be as per the manufacturer's specifications (generally a minimum of 90mm depth for 10mm threaded rod in a 12mm hole; inserts must be used for hollow bricks).

Figure 6: Using Anka screws (top) to hold the monument in position while the chemical anchors (bottom) cure at a CORSnet-NSW site (Tier 3).

At sites that do not accommodate a monument from a proven range, a structural engineer could be employed to confirm the appropriateness of the fixings, embedment depths, materials and structures in regards to attaching the mount.

For pillared and deep-drilled braced monuments, a monument height of between 1.2 and 1.7 metres is preferred to minimise the effect of multipath off ground surfaces. Bracketed roof monuments should extend a minimum of 0.5 metres above the roof surface. Post or mast and brace monuments should extend a minimum of 1.2 metres above the roof surface. Tall mounts are susceptible to wind vibration and swaying. Bracing may help stabilise these mounts. Where a site foundation has a metal roof or other reflective surface, monument heights that are multiples of GNSS carrier phase wavelengths (e.g. 19-25 centimetres for GPS) should be avoided.

Antenna monuments should have widths that are less than the antenna diameter to minimise multipath off the top surface of the monument and to ensure that antenna cables can be easily connected. The distance between the top of the antenna monument and the base of the GNSS antenna should be less than 5 centimetres or greater than one GNSS carrier phase wavelength (NGS, 2006). For some GNSS antennas (e.g. LEIAR10 NONE), the monument tops either need to have a diameter of less than 85 millimetres or have a bevelled edge to allow space for the antenna cable to pass (Figure 7).

All monuments should be designed or signed off by a structural engineer, and be installed by professionals to ensure structural stability. All relevant building codes should be observed and permits obtained where required.

When installed by contractors, engineer-certified drawings with fixing details should be issued to the installers. Compliance can be qualified by having relevant photos of the fixings and other aspects of the installation returned once the job is complete. Spot checks should be conducted.

Figure 7: Antenna monument with bevelled edge at a CORSnet-NSW site (Tier 3).

Additional information on GNSS CORS antenna monuments is available from the IGS Monumentation Design and Implementation web page (IGS, 2010), the UNAVCO Station Monumentation web page (UNAVCO, 2012b) and the United States National Geodetic Survey's National Continuously Operating Reference Station Monumentation Report (NGS, 2000).

3.6.3 Antenna Mounts

Antenna mounts are the devices used to connect the GNSS antenna to the monument. For all GNSS CORS, the required characteristics of the antenna mount include:

- Unambiguous definition of the survey mark, i.e. supporting a clear definition of the Antenna Reference Point (ARP) location.
- 5/8th Whitworth thread spigot.
- True verticality of the spigot.
- Zero or minimal (< 2mm) height of the ARP where possible.
- Ability to orientate the antenna to True North.

Given the nature of metal and its tendency to warp when heat is applied through welding or galvanising, there is a possibility that some mounts are not straight in terms of the mast itself and the thread on which the antenna must fit.

A number of institutions around the world perform calibrations on GNSS antennas (relative, absolute "type" and absolute "individual") to improve the accuracy of GNSS signals the antenna receives (see section 4.2). For these calibrations to be effective, antenna mounts must allow the GNSS antenna to be accurately levelled and oriented to within ±5° of True North. For non-North orientated antennas, the potential exists to modify the contents of the absolute "individual" antenna model file for each CORS (i.e. the azimuth values are changed to reflect the actual antenna orientation).

The mounting device must be capable of being locked in place to ensure that the antenna does not move once mounted. If an antenna is removed and replaced, the antenna mount should enable the antenna to return to exactly the same location and orientation. The use of shims or thin washers (0.2-1.0mm thickness) allow antennas to be orientated while ensuring that they are screwed down firmly onto the 5/8th Whitworth thread. Hand tightening is sufficient; tools or a thread-locking compound (e.g. Lock Tight) must not be used. As the rotating levelling screws on standard survey tribrachs cannot be fixed, tribrachs are not suitable as antenna mounts for GNSS CORS sites.

In Australia, the antenna mount used with Tier 1 and Tier 2 GNSS CORS pillar monuments is a pillar plate concreted into place when the pillar top is built. This mount is oriented by placing the intended antenna on the mount, and orienting the mount such that the antenna is correctly aligned to True North. The mount is then secured, the antenna removed, and the mount concreted in place (Figure 8). The four reference pins visible on the pillar top are used for the reference mark (RM) survey (see section 5.4).

Figure 8: Construction of the GNSS CORS antenna mount at a CORSnet-NSW site (Tier 2).

A number of other GNSS CORS antenna mounts exist, including the Southern California Integrated GPS Network (SCIGN) mount, the SECO 2072-series mount and the UNAVCO fixed-height mount (Figure 9). These mounts need to be installed on top of the antenna monument, hence having the disadvantage of introducing an antenna height. In most cases, these mounts also contain removable parts, negatively affecting legal traceability of the Antenna Reference Point (ARP).

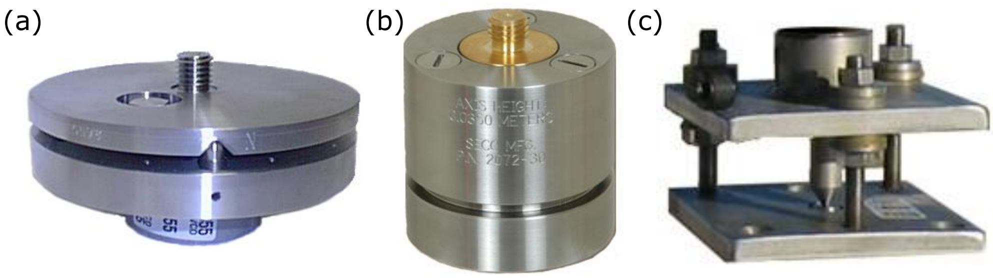

Figure 9: GNSS antenna mounts: (a) SCIGN mount, (b) SECO 2072 mount, (c) UNAVCO mount (UNAVCO, 2012c).

In order to provide a legally traceable survey monument that allows the GNSS antenna to be oriented to True North without the need to introduce an antenna height, the CORSnet-NSW Adjustable Antenna

Mount (CAAM) was developed by LPI (Figure 10). A patent has been issued (Australian Patent No. 2012200770). For CORSnet-NSW Tier 3 sites, this antenna mount is used as an integrated, non-removable part of a free-standing pole or wall-mounted GNSS CORS monument. Using three adjustment screws, the vertical position of the 5/8th Whitworth thread spigot can be adjusted slightly to ensure the antenna is oriented to True North without the introduction of an antenna height (Figure 11). CAAM design sketches are shown in Appendix 4.

Generally, a compass is used to orient the antenna to True North. In this case, the magnetic declination (i.e. difference between True North and Magnetic North) must be applied. Additional information and a worked example of this calculation can be found in Appendix 5.

Figure 10: Internal workings of the CORSnet-NSW Adjustable Antenna Mount (CAAM), Australian Patent No. 2012200770.

Figure 11: CORSnet-NSW Adjustable Antenna Mount (CAAM), integrated into the GNSS antenna monument.

3.7 Occupational Health and Safety

Safety first – safety is the most important part of any installation and maintenance program of physical CORS infrastructure. GNSS CORS monuments are often on rooftops and high on building walls. State and federal regulations have a requirement in terms of how far up and how close to an edge a person can work before fall protection is required. A compliant installation of ladder bracket and harness point, which ensures the installer can attach the harness from the point of entry, is shown in Figure 12.

Multiple harness points may be required per installation dependent on the nature of the site. Many GNSS CORS monument locations pose an ongoing maintenance issue as they are on or close to an edge or drop that exceeds the industry and regulatory guidelines (e.g. within 2m of a 2m drop) and as such would require, at the minimum, a trained and harnessed operator to install and maintain the GNSS CORS site and the existence of a suitably certified anchor point in the vicinity onto which to connect the harness.

Figure 12: (a) DSE-style harness attachment point and ladder bracket, and (b) elevated pole monument with harness attachment point and ladder rest at a CORSnet-NSW site (Tier 3).

All parties are responsible for fulfilling their obligations under Occupational Health and Safety (OH&S) legislation, including undertaking risk assessments, implementing safe work practices and providing material safety data sheets. Harness attachment points and ladder hangers must be installed as required and precautions must be taken to mitigate any potential risk (Figure 13). Unsafe sites, regardless of their GNSS suitability, must be rejected. Documented safety processes and related site infrastructure along with mechanisms to ensure compliance to avoid risk of harm or exposure to liability are essential.

Figure 13: Handrail installed around the base of a CORSnet-NSW site (Tier 3).

3.8 Power and Communications

3.8.1 Power

All GNSS CORS have a fundamental need for a continuous and reliable power supply. Dual (primary and backup) power supplies are required for Tier 1-4 sites, and highly recommended for Tier 5 sites.

Solar power and mains power are the most suitable primary power sources. Choosing between solar or mains primary power at a site is a decision based on hours of available sunlight, the power requirements of the equipment and installation/operation cost. The amount of available sunlight is a function of season, latitude, local climate conditions (e.g. cloud cover) and the area available (i.e. ground footprint). If mains power is readily available, this is likely to be the most cost effective primary power source. CORS operators should note that significant power fluctuations occur in regional power grids. In the absence of readily available mains power, the cost of bringing mains power to the site against the cost of installing a solar/battery array may determine the preferred power solution. Solar power also provides an effective backup power supply for sites with a primary mains power source.

Consideration should be given to installing a dedicated General Power Outlet (GPO) circuit to reduce the risk of another load on the same circuit as the CORS equipment tripping the circuit breaker or Residual Current Device (RCD) and thereby bringing down the CORS site. All new works or extensions to existing systems must have compliance certificates completed in accordance with state electrical regulations.

Tamperproof covers or GPOs should be installed to prevent accidental or wilful disconnection of power to the GNSS CORS equipment. Surge protection against power spikes should be considered – spikes are the most common and harmful power problem, particularly in country areas where supplies can be poorly regulated.

Tier 1 and Tier 2 GNSS CORS require continuous power backup by way of 12V DC power supplying the GNSS receiver, powered inline amplifiers and automatic weather station at a minimum. Backup power, e.g. using solar panels, batteries and an Uninterruptible Power Supply (UPS) unit (see Figure 1, section 3.5), should be able to power the site for a minimum of 20 days.

The Tier 1 and Tier 2 requirements are also recommended for Tier 3 (or lower) sites. The length of time that backup power keeps the site operating is a risk mitigation issue for the CORS operator. The impact of office closures over weekends and during extended public holiday breaks (e.g. Christmas and New Year period) should be considered carefully. If the environment (e.g. IT server room) in which the site is being installed is itself power protected or critical, then the likelihood of being offline for extended periods is further reduced.

The power system should include "conditioning" (e.g. surge protection and filtering) with automatic fall-over/fall-back mechanisms between primary and backup supply. The power system should be analysed to balance peak and total power consumption with supply. Including a safety margin in the designed power supply is recommended. A number of site power calculators that will help determine power draw are available on the Internet, including the UNAVCO GNSS CORS power calculator (UNAVCO, 2012d).

Consideration should be given to the final site design as to what additional load/devices may be incorporated (now or in the future) and the UPS and batteries sized around that requirement. While the power demand of most GNSS CORS is very low, including a switch and fan or other devices as part of the standard installation will have a dramatic impact on the load and run-time calculations.

The use of a Network Management System (NMS) is recommended, particularly for GNSS CORS sites on an IP (Internet Protocol) network. The NMS monitors and manages all network-attached equipment installed on site. The functionality of the NMS is dependent on the configuration. If the NMS detects that a piece of equipment is not working, it can run diagnostics, perform analyses, provide alerts, and, if necessary, attempt to restart a device that is not responding. This is particularly useful at remote sites when the communications equipment is not responding correctly and may remove the need for site visits to restart communications equipment.

The use of an NMS to bring all site devices into one platform that can then alert, control and provide reporting on the GNSS CORS site as a whole rather than relying on a number of limited interfaces to connect to separate sections of the site is highly desirable. As the network grows, the effectiveness of managing the site through a common interface will yield significant benefits not only from a user perspective but also technically through the ability to integrate and automate actions on site involving a number of pieces of equipment (e.g. "self healing").

A Power Distribution Unit (PDU) combined with a UPS is recommended for Tier 1-4 GNSS CORS. The PDU manages the power supply at the site and provides increased protection against power fluctuations. A remotely managed PDU controls the power distribution within pre-set limitations and provides system tools, reports and alerts. In the event of primary power failure, the PDU manages the switch from the primary power source to the secondary power source, ensuring that the secondary power supply is brought online automatically and that the power reverts to the primary power source when service resumes. The PDU can also be scripted to switch non-critical equipment off when the temperature in an equipment enclosure reaches a pre-defined critical level, and turn this equipment back on when the enclosure temperature is within acceptable limits again. The use of web relays adds "self healing" capabilities to the site where communication equipment "hangs" and cannot be reached remotely.

An Uninterruptible Power Supply (UPS) provides a short-term backup power supply to site equipment. The UPS, through the PDU, can also provide short-term power in the short time period between primary power failure and alternate secondary power provision. Some UPS units have onboard temperature sensors and contact closures, which could eliminate the requirement for additional devices such as temperature and battery monitors. Ultimately, the choice of UPS is one of risk and reward.

The typical battery life of a sealed battery is 3-5 years. Batteries in UPS units for the purpose of standby power prefer to be maintained in an environment of around 28°C for optimal life expectancy. Every 7°C rise in temperature loosely equates to halving the battery life. Inside a cabinet enclosure that does not include an active cooling mechanism, the temperature can be significantly higher than the ambient air temperature.

If GNSS receivers and auxiliary equipment are powered via a standard power plug pack, then the operating temperature of the "unit" is reduced to that of the power supply, which for any plug-pack style power supply is typically around 40°C. The use of industrial-grade, high-temperature power components will increase the thermal capability of these devices to above the 40°C limitation and thereby reduce risk.

In the event of low power supply, an integrated NMS, PDU and UPS arrangement can also ensure that critical equipment such as the GNSS receiver maintains power at the expense of powering less critical equipment. The reports from the site NMS and PDU can alert operators to equipment that is not performing as expected, providing an opportunity for replacement prior to failure.

It is important to ensure that any solar panels and other equipment on site do not create multipath or sky obstructions at the GNSS antenna (Figure 14). For all GNSS CORS, specialist advice is recommended for the design of the power sub-system.

Figure 14: GNSS CORS pillar, automatic weather station and solar power with backup battery power installation at a CORSnet-NSW site (Tier 2).

3.8.2 Communications

All GNSS CORS require reliable communications for data transmission. The range of communication options and service providers available is constantly changing and improving. Systems that are currently (at the date of issue of these guidelines) popular with streaming data between a CORS and the Network Control Centre (NCC) include:

- ADSL (Asymmetric Digital Subscriber Line).
- Cellular 3G/4G network.
- Corporate WAN (Wide Area Network).
- Satellite link for remote locations, e.g. VSAT (Very Small Aperture Terminal).

GNSS CORS sites require communications infrastructure for real-time data transmission (data streaming) and/or periodic download for data archiving. The particular communications requirement for a GNSS CORS is more a function of whether the site is used to provide real-time positioning than the tier of the site. Coverage, reliability, cost, latency and bandwidth are all primary considerations.

In determining bandwidth requirements, the following factors need to be considered:

- Normal download operations (i.e. data streaming, regular downloads and web cam images).
- Irregular downloads (i.e. retrieving data stored on the receiver's memory during a communication outage). It is important to ensure that the download of such data does not affect the latency of any real-time streams.
- Uploads for receiver firmware upgrades.
- GUI (Graphical User Interface) support for GNSS receivers and other devices (e.g. web cams, met stations, battery monitors).
- An increase in overall data volumes due to GNSS modernisation (i.e. extra signals, extra satellite launches and new satellite systems).

A comprehensive and future-proof IP map needs to be developed during the initial design of the network. The architecture needs to sufficiently accommodate additional IP addresses per site for future development and additional subnets for future sites. A thoughtful and careful design process will minimise the pain of remapping IP ranges and making changes to existing equipment. Such additional IP addresses allowed per site may include a network switch, UPS, redundant communications devices and a technician's laptop (for local testing and fault finding).

To minimise the amount of site-specific support required, a common approach to bringing the sites into the network, such as using Virtual Private Network (VPN) technology, is advised. With the correct design, VPN technology can provide a homogeneous and unified configuration for all CORS sites and hence reduce the amount of support required. It also provides a secure method of connection via the Internet, in accordance with the network security policies of most hosts.

The data link needs to have sufficient bandwidth to carry the data traffic. On average, a real-time stream from a CORS in RTCM 3 format will require approximately 400 bytes/s. In a redundant design, two streams may be running simultaneously, doubling the bandwidth requirement to approximately 800 bytes/s. These figures are based on the tracking of current GPS and GLONASS constellations with standard dual-frequency observations.

The overall latency of data from a GNSS CORS to the user for real-time positioning services should **not exceed two seconds**. In general, a good wire connection between CORS site and NCC should exhibit latency of no more than 100ms. A good wireless connection between site and NCC should exhibit latency of no more than 300ms.

Latency can vary when there is contention with other competing services or the provider reprioritises users. A secondary communications capability is essential for GNSS CORS used for real-time positioning, especially for sites that form the perimeter of a real-time positioning network where a communications outage may lead to a loss of service.

The two primary methods of broadcasting real-time GNSS CORS data to users are via the Internet or radio transmission (typically UHF). Determining a communications method requires assessment of data bandwidth, the communications protocols, signal strength, wattage (radios only), services available at the site, terrain and black spots.

Radio transmission of data should only be used to provide real-time data services and is not recommended as the primary communications method for Tier 1-3 GNSS CORS. In Australia, radio broadcast is regulated by the Australian Communications and Media Authority (ACMA, see http://www.acma.gov.au/). Any transmissions in the licensed frequency spectrum require a license from ACMA. Any transmissions in the unlicensed spectrum must follow the guidelines set by ACMA.

Mixed (bridged) mode communications may be undertaken at a GNSS CORS site if necessary. For example, data may be sent from the receiver site via a radio link to a remotely located reliable Internet connection. However, mixed mode connections may increase data latency to end users.

In some remote areas, satellite communications (e.g. VSAT) may be the only communications platform that can be deployed. Compared to the other options, satellite communications will require higher power requirements and introduce higher latency (typically 700-800ms) to the data stream.

For all GNSS CORS, specialist advice is recommended for the design of the communications sub-system, including suitable devices to secure network access and data traffic. Clear and consistent labelling of all components and cables involved is very helpful for maintenance and trouble shooting (Figure 15).

Figure 15: Labelled circuit breakers at a CORSnet-NSW site (Tier 2).

3.9 Standardisation

Significant efficiencies during build, operation and maintenance can be achieved if a standard approach and bill of materials is developed in relation to the design and construction of sites. Tier 1-3 GNSS CORS have a large component of the design and construction methodology well established and documented. An example of a briefing document for Tier 3 GNSS CORS installation can be found in Appendix 6. Checklists are a very useful tool to ensure a consistent quality of CORS installations. Sample checklists for the installation of Tier 3 GNSS CORS antenna mounts and cabinets are shown in Appendix 7 & 8. Tier 4 GNSS CORS operators should develop similar procedures during the initial planning phase of any large rollout.

3.10 Redundancy

As the number of users and applications relying on the availability of data from GNSS CORS increases, the negative impact of downtime and risk of system failure also increases. Possible forms of redundancy in a GNSS CORS network may include:

- Spare GNSS hardware to replace faulty equipment.
- Use of GNSS equipment from different manufacturers.
- Additional GNSS CORS sites.
- Installation of dual antenna cables.
- Dual independent communications systems (hardware and/or providers).
- Backup power supply.
- Dual GNSS antenna and/or receiver installations at each CORS site.
- Dual Network Control Centres.
- Independent monitoring via multiple analysis centres.

3.11 Site Maintenance

Once built, GNSS CORS will require some form of maintenance being either pro-active or reactive.

Pro-active maintenance constitutes any element of preventative measure necessary to ensure continuing operation of the site and may include:

- Firmware upgrades.
- Inspection and/or changing of batteries.
- Run-time testing of standby power sources.
- Routine checking of the GNSS antenna installation and cables for spurious emissions caused by cable/connector corrosion.

- Tensioning of mount fixings.
- Inspection of water penetrations.
- Cleaning or changing of fan filters and filter cartridges.
- Inspection of external structures for rust, damage or deterioration.
- Stocktakes.
- Updating Point of Contact details.

Reactive maintenance includes the availability of spare GNSS receivers, spare parts and the annual update of local host contact details. Options for the CORS operator are to simply service the break-fix requirements of the network themselves or contract out maintenance and repairs.

CORS operators should determine and document the importance of each site in terms of up-time and response time with respect to site failures. This benchmark will guide the site template chosen from a design perspective (particularly in relation to redundancy options, run times, sparing levels, etc.) as well as the frequency and extent of preventative maintenance measures and response times to trouble calls.

4 GNSS Equipment

GNSS CORS technology is evolving at a rapid rate. New GNSS signals, new GNSS systems, revised data formats and improving communications options all tend to shorten the equipment replacement cycle. The current replacement cycle is approximately 5-7 years. CORS operators need to carefully consider future-proofing their investment by thorough consideration of current and anticipated GNSS modernisation and its impact on both GNSS receiver and antenna choice. A sustainable GNSS CORS operation is a balance between changing technology, capital and operating costs, efficiency and demand.

4.1 GNSS CORS Receiver

Many CORS operators intentionally choose to use a mix of different GNSS receiver makes and models within a network to add vital redundancy. In extreme scenarios, should a fault develop with a certain make or brand of receiver, which has happened to networks throughout the world in a few instances to date, then only a proportion of the network is lost.

Operationally, many CORS operators intentionally choose to avoid using the latest receiver firmware release, but use the preceding and proven version instead. Any immediate switch to the latest firmware version is only considered to either fix critical bugs directly impacting on service provision or if there is a substantial operational improvement. All new firmware should be thoroughly tested before adoption. Many CORS operators install permanent and dedicated dual receivers somewhere in their network for the sole purpose of conducting side-by-side tests on current and new firmware releases.

Additional communication ports are often required for receivers at shared sites. These either support other CORS networks, e.g. at state borders, or are used at sites that also provide UHF radio broadcasts to local users. The need for both primary and backup communications for each CORS provider can result in GNSS receivers needing four or more communication ports.

In regards to environmental considerations, the stated operating temperature of a GNSS receiver may well be the internal temperature of the device's Central Processing Unit (CPU) and not the external ambient air temperature. If so, then the CPU reading may be around 12°C hotter than the ambient air temperature, and appropriate cooling may have to be installed.

Typical specifications for a geodetic/CORS quality GNSS receiver to be used in CORSnet-NSW are provided in Table 2. These recommendations are valid at the date of issue of these guidelines.

Table 2: Specifications of a geodetic/CORS quality GNSS receiver.

Component	Recommended Capability
Signal Tracking	• A minimum of 12 channels per frequency per system tracked. • Recording all available carrier phase, pseudorange, Doppler, and Signal-to-Noise Ratio (SNR) data per tracked frequency. • Ideally simultaneous GPS L2C and P2 tracking. • Pseudorange measurements should not be smoothed for RINEX. • Smoothing may be a default for real-time streams. • Minimum of GPS and GLONASS tracking. • Capability to observe future signals when available is an advantage preferably by firmware (not hardware) upgrades. • Receivers capable of tracking space-based augmentation services should have this function turned off.
Internet Communications	• Dedicated network (Ethernet) port. • Serial/USB port. • Static IP address. • HTTP/S interface. • ftp over Transfer Control Protocol (TCP). • IP configurable LAN/WAN connectivity.
Radio Communications	• Radio output port capability (Tier 4 and 5 only) where required to support these conventional users. • 4,800 – 115,200 baud rate.
Power	• Nominal 12V DC input. • Extended operational range between 10.5 and 28V DC. • Dual power inputs and/or internal power pack.
Input	• Ideally external frequency, i.e. atomic clock (Tier 1 and 2 only). • Meteorological sensor. • Tilt sensor (desirable for Tier 1 and 2).
Output	• Current RTCM 10403.1 at 1Hz or better on multiple streams. • NMEA-0183. • Proprietary raw data streaming.
Logging	• Ideally onboard continuous logging of raw unsmoothed data. • Onboard logging of data stored as 1-second hourly and 30-second daily RINEX files simultaneously. • Onboard logging of input sensor data.

Component	Recommended Capability
Internal Memory	• Capability to store at least 60 days (Tier 1 and 2) or 30 days (Tier 3) of raw and/or RINEX data onboard as per the logging specification. • Internal file memory management. • USB storage devices may be used to extend the receiver's logging capability.
Environment	• Operating temperature of -40°C to +65°C. • Dustproof/waterproof to IP67. • Humidity as per MIL-STD 810F. • Shock resistant to 1m drop on hard surface.
Remote Control Settings	• Full control of receiver functions, via a HTTP-based GUI, including: ○ data protocols and logging rates ○ data transfers ○ quality settings ○ power cycling and remote reboot ○ general system management ○ client access authentication ○ firmware upgrades

4.2 GNSS CORS Antenna and Models

Once installed, a GNSS CORS antenna should not be removed or replaced unless it is absolutely necessary (e.g. due to hardware failure). If data from the site is being submitted to an analysis centre (e.g. IGS or APREF), the analysis centre should be notified of the change as soon as practicably possible, via an updated IGS site log. The CORS operator would also need to apply for a new Regulation 13 certificate with new Recognised Value Standard (RVS) coordinates, issued by Geoscience Australia (see section 5.1). Previous data analysis has shown that there is a noticeable change in the position of the GNSS antenna when it is removed or replaced at a GNSS CORS site (e.g. Wanninger, 2009; Wanninger et al., 2009). This can occur even when the same antenna is returned to the site with the same orientation. Therefore, especially in the case of Tier 1 and Tier 2 GNSS CORS that provide information on geophysical processes, the antenna should not be removed for any reason other than hardware failure.

By choosing an antenna that is capable of tracking as many planned GNSS signals as possible at the time of purchase (i.e. "future proofing"), the need to remove an antenna to track newly available GNSS signals is reduced. Overseas, some CORS operators have started installing dual antennas (and mounts) at GNSS CORS to allow the observation of overlapping time series during the upgrade or replacement of individual antennas at the site.

If an antenna needs to be replaced, a temporary reference station (e.g. a mobile CORS) should be set up close by on an arbitrary mark and collect data for at least one week before the antenna change and for at least one week after the antenna change (Figure 16). This will provide the necessary information to ensure that a consistent long-term coordinate time series of the GNSS CORS site is maintained. The described procedure is mandatory for CORSnet-NSW Tier 1 and Tier 2 GNSS CORS and optional for Tier 3 (or lower) GNSS CORS.

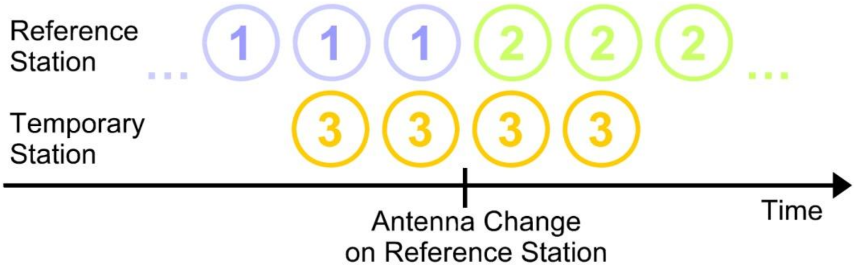

Figure 16: Basic principle of monitoring the effects of an antenna change at a reference station with three antennas involved: (1) old antenna at reference station, (2) new antenna at reference station, and (3) antenna of temporary station (Wanninger et al., 2009).

Antenna calibrations provide a link between the point where GNSS signals are measured within the antenna (the Antenna Phase Centre or APC) and the point to which these measurements are referred (the Antenna Reference Point or ARP). As "individual" antenna calibrations are not economically feasible in most instances, several organisations have also undertaken model or "type" specific antenna calibrations. For these antenna models to be valid, the GNSS CORS antenna must be orientated to within ±5° of True North.

Choke ring antennas with high-quality (e.g. Dorne Margolin) elements have very stable and well understood properties, with high multipath mitigation. Therefore, they are required for Tier 1 and Tier 2 GNSS CORS and optional for Tier 3 GNSS CORS. An antenna with a ground plane is recommended for Tier 3 and 4 GNSS CORS that do not have choke ring antennas to minimise multipath from ground-based signal backscatter.

The use of a radome has been shown to alter the location of the APC, which can also vary over time as ultraviolet light changes the material properties of the radome. The use of radomes is therefore not recommended by IGS. There are, however, environmental conditions that may require the use of a radome. These conditions include areas of high snowfall, prone to dust storms or sites where birds are likely to perch on top of an unprotected antenna. In these cases, only antenna and radome pairs with an existing combined IGS antenna calibration model should be used. To date, LPI has installed radomes at all Tier 2 sites in NSW. Conical radomes should not be used for Tier 1 and Tier 2 GNSS CORS. Existing radomes should not be removed.

Typical specifications for a geodetic/CORS quality GNSS antenna to be used in CORSnet-NSW are provided in Table 3. These recommendations are valid at the date of issue of these guidelines.

In order to avoid confusion, the IGS standard GNSS receiver and antenna naming convention (IGS, 2012b) must be used in site logs and metadata. This format has a very strict case and space format. The individual formats used by manufacturers are generally non-IGS compliant.

Table 3: Specifications of a geodetic/CORS quality GNSS antenna.

Component	Recommended Minimum Capability
Antenna Type	• Tier 1 and 2 GNSS CORS must have choke ring antennas with high-quality (e.g. Dorne Margolin) elements. • Choke ring antennas are optional for Tier 3 GNSS CORS, though other forms of geodetic antennas may be used. • Antenna satellite signal tracking capabilities should be matched with or exceed the satellite signal tracking capability of the GNSS receiver at the site.
Antenna Phase Centre (APC) Calibration	• All GNSS CORS antennas must have a valid IGS "type" absolute antenna calibration (IGS, 2012a).
Antenna Reference Point (ARP)	• The ARP is the external measurement point of the antenna and must have a prescribed offset from the APC as part of the IGS antenna calibration.
Radome	• The use of radomes on GNSS antennas is discouraged by IGS unless required due to local environmental conditions. • If radomes are necessary, the radome must be hemispherical, and the antenna/radome combination must have a valid IGS absolute "type" antenna calibration. • Conical radomes are not to be used at Tier 1 & 2 sites.
Antenna Orientation	• The antenna must be oriented to ±5° of True North (Tier 1 & 2). The same is mandatory for new Tier 3 GNSS CORS installations and strongly recommended for all other tiers. • If the deflection from True North is greater than ±5°, the actual alignment should be measured and recorded in the station site log and metadata.
Environmental	• Weatherproof and corrosion resistant.

CORS operators should take extreme care to avoid mixing "relative" and "absolute" antenna modelling in operational systems. Similarly, users must be notified of the antenna model philosophy employed and use a similar system at their GNSS rover.

CORS operators should note that GNSS antenna modelling is dealt with differently for post-processing and real-time services, by most CORS management software packages. For post-processing services, under the

RINEX standard, observations refer to the APC and the antenna type is specified in the RINEX header. For real-time services, observations and correction signals are reduced to the ARP (i.e. the effects of antenna offset and APC variations are removed) and the antenna is specified as a null antenna (Janssen & Haasdyk, 2011).

4.3 GNSS Antenna Cable

The antenna cable is a key element of the core system and connects the GNSS antenna to the receiver. It also typically carries power to the active elements of the antenna from the receiver.

Cables are vulnerable to weather, pests and fire. Within buildings, the use of dedicated cableways will reduce the risk of forming hazards to occupants. An extra few metres should always be added (and stored in an expansion loop) to the length of any antenna cable run to allow for the possible future relocation of the GNSS receiver or to replace corroded ends. Cables external to buildings are best protected when run through UV-stabilised PVC conduits, which provide protection from weathering, rodents and birds. All external conduit joints should be glued. Conduits should be buried where practical on outdoor installations (Figure 17). To reduce the risk of leaks, conduit ends should be either facing downwards or sealed with the appropriate gland to stop the inflow of moisture. Filling the end of conduits with silicon must be avoided. Silicon is not suitable for waterproofing as it tends to break down. This may cause rain to run down the cable and into the roof of the building, potentially leading to damage occurring. A drip loop (partial drip loop preferred) should be left before the cable/conduit enters a building/mount. Water will follow a cable until gravity intervenes, therefore partial drip loops or similar should always be installed prior to any vertical entry point.

Figure 17: GNSS antenna cable and conduit being buried at a CORSnet-NSW site (Tier 3).

Cable connectors are potential points of failure through water infiltration and rust. The use of self-amalgamating or abuttal-based tape (electrical tape is not appropriate) will assist in protecting against water intrusion. Sites that exhibit regular pre-dawn outages on cold days may be suffering from poor/corroded connectors with water intrusions that are freezing.

Cables should be neatly run, parallel or perpendicular to building lines where possible, and properly secured for the length of their run. Stainless steel cable ties should be used on outdoor installations (where cable ties are needed). Loose cabling must be avoided as it creates a trip hazard on roofs or can lead to a number of other issues such as increasing the stress on the connectors as the wind buffets the free length of cable. Penetrating a roof to pass cables through should be avoided. The use of steel ties, waterproof connectors and partial drip loops is depicted in Figure 5 (section 3.6.2).

GNSS antenna cables are graded. The higher the grade, the less signal loss occurs per linear metre of cable. To date, LMR400 has proven popular, with LMR600 used for longer runs and LMR240 for "pig tails", i.e. short flexible leads of lower gauge cable used between the receiver and the main antenna cable that place less weight stress on the receiver ports. Higher-grade cables are, however, more expensive and less flexible than lower grade cables. The inclusion of in-line amplifiers will reduce the signal loss along the cable run. However, these amplifiers provide additional potential points of failure in the system. Where practical, a higher-grade antenna cable is recommended over the inclusion of an in-line amplifier.

The minimum bend radius of LMR400 coaxial cable should not be smaller than 30mm. Tension in the cable at the receiver and antenna connection will place stress on the connection, which may cause failure. At the GNSS antenna, this tension may also cause the antenna to rotate from the orientation to True North. As much as practical, a (partial) stress relief loop should be left at all connector termination points, particularly the antenna attachment point.

Every connection in a cable run increases the signal loss through the cable run. Therefore, the number of connections in the run should be minimised. However, the inclusion of an antenna splitter during installation at Tier 2-4 GNSS CORS is recommended in order to provide more flexibility in regards to operating an additional (redundant) GNSS receiver. Adding in-line amplifiers, antenna splitters and other such devices in the antenna cable run after installation should be avoided, as these will result in jumps or steps in any high-precision time series analysis.

The insertion of an in-line lightning protector may help protect the GNSS receiver and associated equipment in the event of a direct lightning strike on the antenna, though the antenna itself is not protected. While a lightning protector requires an additional connection in the cable run, and therefore will increase signal loss, it is a recommended inclusion at GNSS CORS sites (see section 4.7).

Handheld, battery-operated GNSS interference meters can be used to confirm that no signals are accidentally rebroadcasted from any point between antenna and receiver, e.g. due to an inferior or corroded cable/connector/antenna assembly.

Recommended GNSS antenna cable specifications for use in CORSnet-NSW are provided in Table 4. These recommendations apply to all tiers and are valid at the date of issue of these guidelines.

Table 4: Specifications of a standard GNSS CORS antenna cable.

Component	Recommended Minimum Capability
Cable Protection	• The antenna cable should be protected from weather, pest and fire using suitable conduit. Antenna cable connectors should be sealed with self-amalgamation tape for protection against water infiltration.
Cable Tension	• Tension in the antenna cable should be avoided, particularly at the interfaces with the receiver and antenna.
In-line Amplifiers	• In-line amplifiers should only be used where necessary. If an in-line amplifier is used, it should be noted in the station site log and metadata.
Cable Splitters	• Antenna splitters are standard for CORSnet-NSW Tier 2 and 3 GNSS CORS. The splitter must be DC blocked to the backup receiver. Splitters should be recorded in the station site log and metadata.
Lightning Protection	• A grounded lightning arrestor can be placed in the antenna cabling between GNSS antenna and receiver in lightning prone areas.
Cable Type	• The type of antenna cable used should be sufficient for the length of the intended cable run between antenna and receiver, including some spare length. The selected cables and components should have a total signal loss of less than 9db over the length of the cable run.

From a Quality Assurance perspective, CORS operators should document a cabling standard, issued to all installers, and use a checklist and/or photo system to confirm compliance (see Appendix 6, 7 & 8).

A definitive published standard for the installation of GNSS antenna cables does not exist. However, the Australian Communications Industry Forum (ACIF) has created the Australian standard AS/ACIF S009:2006 *Installation Requirements for Customer Cabling (Wiring Rules)*. This standard includes requirements intended to ensure the safety of equipment users, cabling providers and the general public and is relevant to both coaxial and data cable installations.

Some examples of relevant requirements listed in the standard, which are often faced when installing GNSS CORS, include:

- Cables shall be supported/secured for their entire length.
- Cabling should not be placed on ceiling tiles or be attached to ceiling hanger rods. Instead, cabling should be secured to independent supports (e.g. a tray, trough, hook or catenary wire within the ceiling space) or attached directly to the floor above.

- Cabling should be independently attached to support points. A Cable can share a catenary wire and/or support attachments with other services as long as it is *individually* attached to the support. Cables should not be attached directly to another service such as a power cable, conduit, or water pipe.

- Fixed cables should be separated from other services, e.g. a permanent separation from low-voltage (i.e. 240V) power cables should be achieved by one of the following:

    - Minimum distance of 50mm (no conduit or barrier) and a minimum distance of 150mm at terminations (e.g. power point).

    - A barrier of durable insulating material (i.e. conduit).

    - A wall stud, nogging, joist or rafter.

  This will prevent damaged or incorrectly installed cables from picking up a 240V charge.

- Buried cables may share a trench with low-voltage power (no separation) as long as the power cable is in an orange, heavy-duty conduit marked *ELECTRICAL* and the communications cable is in a separate, white conduit marked *COMMUNICATIONS*.

4.4 Meteorological Sensors

External dedicated meteorological sensors are required at Tier 1 and 2 GNSS CORS, providing continuous meteorological data at the site. The inclusion of meteorological sensors at GNSS CORS provides information that aids in understanding the site environment, thereby improving GNSS processing and the development of scientific weather models.

Meteorological sensors should be installed on monuments other than the GNSS antenna monument, and in a location that does not increase the multipath environment or reduce sky visibility for the GNSS antenna. The meteorological sensor should be connected to the GNSS receiver to allow meteorological data to be recorded in RINEX format for archiving.

Meteorological sensors at GNSS CORS have the following requirements:

- Atmospheric pressure measurement accuracy of better than ±0.1 hPa.

- Temperature measurement accuracy of better than ±1°C.

- Relative humidity measurement accuracy of better than ±2%.

- Ideally, the meteorological sensor should be installed at the same height as the GNSS antenna.

- The height difference between the pressure measurement reference mark of the meteorological sensor and the GNSS CORS antenna reference point should be determined to better than 10 millimetres.

4.5 Tilt Sensors

Tilt sensors are currently not required at any CORSnet-NSW sites.

4.6 Remote Control

Remote control is generally provided through a web relay, a device that can be installed as part of a standard GNSS CORS site to:

- Monitor temperature.
- Monitor contacts (e.g. door opening).
- Provide remote "switching" of DC power sources.

These devices have the ability to be scripted, programmed and to run events. As such, they can be used for rebooting a device remotely, as long as communications are available. If the device is in the communications path, then the ability to reboot is denied. Web relays can be programmed to automate this process so that if communications are lost, the web relay will wait a period of time before rebooting all communications devices locally (i.e. "self healing"), thereby reducing the need for a site visit.

4.7 Lightning Protection

Lightning protection is akin to insurance, it is paid for in the hope that it will not be needed but when it is needed, it must work. Based on probability of strike, it could be argued for many CORS sites that the cost of installing lightning protection is higher than the potential cost if no protection was installed at all and the occasional device was damaged. Despite the above, given the sensitivity of the equipment, it cannot be guaranteed that even if installed properly, a strike would not destroy the GNSS antenna, receiver and peripherals.

There are two general approaches to lightning protection:

- Build a sacrificial system to take the strike and divert the energy away from your system.
- Allow your system to be struck and attempt to manage the discharge of the strike.

Sacrificial systems or Lightning Protection Systems (LPSs) are well defined in the Australian standard AS/NZS 1768:2007 *Lightning Protection*. They can be complex and costly to build and, typically, they extend to become the highest point in a given area and discharge to a separate grounding system. Given the CORS site strives to have an unimpeded skyview, such large lightning devices elevated above the GNSS CORS antenna are generally not desirable and are an additional expense.

Alternatively, when attempting to manage the discharge of a lightning strike, generally only one surge device is used per installation, which is typically placed near the GNSS receiver end of the cable. For systems that have active devices at both ends of the antenna cable, it is recommended that an arrestor is installed at both ends, i.e. one at the GNSS antenna and one at the GNSS receiver end.

Earthing requirements of these systems are detailed in Australian standard AS/NZS 3000:2007 *Wiring Rules*. Essentially, it is required that earthing is made at the Multiple Earthed Neutral (MEN) using the appropriately sized conductor. Earth installations should not contradict electrical wiring rules.

For all GNSS CORS, specialist advice is recommended for the design of any lightning protection system.

4.8 Pre Assembly

Experience has proven that all components should be preassembled and validated, in a test rig or cabinet imitation, before installation takes place. This investment often ensures easier and quicker field installation and provides Quality Assurance.

5 GNSS CORS Site Coordinates

GNSS CORS sites claiming to be coordinated on the national geodetic datum need to be coordinated in a consistent and unified manner. Connection to local survey control is not sufficient. A review of coordinate systems, datums and associated transformations in the Australian context can be found in Janssen (2009a).

5.1 Regulation 13 Certification

In Australia, the coordinates of all GNSS CORS should be obtained through assessment against the Recognised Value Standard (RVS) of measurement for position in accordance with the National Measurement Regulations 1999 and the National Measurement Act 1960. The Geocentric Datum of Australia (GDA94) (ICSM, 2006) positions of the Australian Fiducial Network (AFN) have been adopted as that Recognised Value Standard of measurement. In order to obtain coordinates of a GNSS CORS assessed against the Recognised Value Standard, a request needs to be made to Geoscience Australia, a facility accredited by the National Association of Testing Authorities (NATA), for Regulation 13 certification for position.

In order to obtain a Regulation 13 certificate for a GNSS CORS in Australia, Geoscience Australia requires the following information (GA, 2011a):

- A cover letter (on letterhead) requesting a "*Certificate of Verification of a Reference Standard of a Position-Measurement in Accordance with Regulation 13 of the National Measurement Regulations 1999 and the National Measurement Act 1960*". This letter should include an outline of the stations submitted and clearly state your name, address and contact details. This letter should be addressed to:

  Laboratory Contact
  National Geospatial Reference Systems Project (NGRS)
  Geoscience Australia
  GPO Box 378
  Canberra ACT 2601
  Australia

- GNSS CORS site metadata (on CD/DVD for legal traceability) including:
  - Antenna and radome type (using the IGS standard naming convention).
  - Antenna serial number.
  - Receiver type (using the IGS standard naming convention).
  - Receiver serial number.
  - Antenna offset measurement (antenna height), i.e. the vertical distance from the Antenna Reference Point (ARP) to the station mark, including an annotated diagram clearly showing the relationship between ARP and station mark.

- GNSS CORS site photographs showing the installation as a whole as well as close-ups, including the equipment's serial and model numbers. Ideally, but only if it is safe to do so, photographs of the GNSS antenna showing the horizon to the north, east, south and west are also included. The naming convention of these digital photographs should clearly indicate the view direction (see section 6.4).

- 24-hour GNSS RINEX files (on CD/DVD for legal traceability) containing one complete GPS week of data (Sunday to Saturday inclusive), observed at 30-second epochs. The information in the RINEX header should be fully consistent with the metadata supplied.

Upon assessment, analysis and verification, which may take up to a few months, Geoscience Australia will provide:

- A Certificate of Verification of a Reference Standard of a Position-Measurement in Accordance with Regulation 13 of the National Measurement Regulations 1999 and the National Measurement Act 1960 for each GNSS CORS. This certificate states the verified ellipsoidal coordinates of the GNSS CORS in the national datum (see Appendix 1 for an example).

- The certificate applies to the station mark and is valid for five years.

- The certificate is only valid if the GNSS CORS continues to operate with identical equipment to that assessed in the original Geoscience Australia analysis. If the GNSS antenna or receiver is replaced, then a new Regulation 13 certificate must be applied for. LPI retains but does not publicise old Regulation 13 certificates – these are available on request.

In the interim, *provisional* coordinates of each GNSS CORS should be determined through a single 24-hour AUSPOS solution (GA, 2011b). Rapid Orbit solutions are sufficient. This should be confirmed by a second 24-hour solution. The use of ellipsoidal heights determined by adding AUSGeoid09 N-values to orthometric (AHD71) heights is not acceptable.

The coordinates provided by Geoscience Australia through the AUSPOS solution (provisional) and the Regulation 13 process (final) are the coordinates that must be used internally in any CORS management software. In this way, all GNSS CORS claiming to be operated on the national geodetic datum will be unified on a common realisation of the datum, and will therefore be interoperable, from a datum perspective, with other GNSS CORS, including GNSS CORS operated by other parties. Homogeneous GNSS CORS coordinates are also essential in order to provide network services such as NRTK and Virtual RINEX. In NSW, the realisation of GDA94 stemming from AUSPOS solutions and the Regulation 13 process is referred to as GDA94(2010) (Janssen & McElroy, 2010). For CORSnet-NSW sites, these coordinates are only available from the CORSnet-NSW website (LPI, 2012a).

5.2 Differences between GNSS CORS Coordinates and Ground Mark Coordinates

The coordinates of ground control survey marks held in the Survey Control Information Management System (SCIMS) are the result of a series of least squares adjustments based on measurements from episodic campaigns. Experience has shown that the longer time series observations at GNSS CORS, and their direct connection to the AFN through the Regulation 13 process, provide greater measurement accuracies than the process of propagating coordinates through many layers of measurements and adjustments on ground control survey marks. The result of this increased accuracy is that there may be apparent differences (Haasdyk et al., 2010) between the datum as realised by GNSS CORS published coordinates, referred to as GDA94(2010) in NSW, and the datum as realised by the published coordinates of the surrounding ground control survey marks in SCIMS, referred to as GDA94(1997) in NSW (Janssen & McElroy, 2010).

As GNSS CORS are tied to appropriate ground marks through appropriate measurements (i.e. GNSS-based local tie survey, see section 5.3), and the coordinates of the ground marks will be readjusted to include the effect of GNSS CORS measurements, these differences will become less visible in the future. However, until datum realisation through GNSS CORS and ground marks is harmonised, GNSS CORS operators need to understand why these datum realisation differences exist. The GNSS CORS operator should also be able to inform users of the reasons for the differences and provide practical methods of reconciling surveys undertaken using GNSS CORS with the local datum as realised by ground mark coordinates. In order to account for these differences when connecting to the local ground control network using CORSnet-NSW, users are required to perform a "site transformation", also termed site calibration or localisation (Haasdyk & Janssen, 2012).

5.3 Connecting to Local Control Marks on the National Geodetic Datum

A local tie survey should be performed to establish a connection between the GNSS CORS and surrounding local survey control marks. Details of the full survey requirements must be discussed with LPI *prior* to commencement of the survey if the resulting coordinates are intended to be included in SCIMS. In such instances, LPI will process and adjust the collected GNSS data and arrange inclusion into SCIMS at an appropriate Class and Order in accordance with SP1 requirements (ICSM, 2007).

LPI requirements for local tie surveys include the following:

- Dual-frequency, static GNSS survey.
- Connection to a minimum of three (preferably four) of the closest 2A0 and/or A1 horizontal survey control marks, preferably determined by GNSS techniques.
- Connection to a minimum of three (preferably four) of the closest vertical survey control marks, preferably LAL1.

- The overall network geometry must be "fit-for-purpose".
- The minimum session length must be 60 minutes.
- All marks must be double-occupied.
- Clearly defined (and checked) antenna height measurement at all sites.
- The IGS naming convention must be adopted for all GNSS receivers and antennas used (i.e. CORS and rovers).
- GNSS data must be supplied in raw proprietary or RINEX format (with complete and fully consistent RINEX header information).
- Field notes or logsheets must be completed in compliance with Surveyor General's Direction No. 12: Control Surveys and SCIMS (LPI, 2012b).
- IGS absolute "type" antenna models and final precise orbits must be used in the data processing.

5.4 Stability Monitoring

There are three principal methods of determining station stability and integrity. The first involves sending regular data to an analysis centre to determine the stability of the GNSS CORS relative to other GNSS CORS distributed across Australia. This provides long-term, high-accuracy, weekly monitoring in a global context. An effective way of undertaking this task is to make data from the GNSS CORS (Tier 1-3 only) available for ongoing monitoring and analysis to Geoscience Australia, an organiser and analysis centre for the Asia-Pacific Reference Frame (APREF) project (GA, 2012). Advantages of participation in APREF include independent monitoring of the stability of the GNSS CORS relative to other GNSS CORS in the region, and the GNSS CORS contributing to the maintenance and a more dense continuous realisation of the regional geodetic framework.

In addition to contributing data to APREF, all CORSnet-NSW sites are monitored by LPI via high-precision daily coordinate solutions using highly sophisticated scientific software in an automated process (Haasdyk et al., 2010). Figure 18 illustrates an example of the resulting coordinate time series, which are made available on the CORSnet-NSW website (LPI, 2012a).

The second method of monitoring site stability and integrity is through network monitoring and stability modules in CORS network management software. This provides short- to medium-term, medium-accuracy but near real-time monitoring. Once satisfactory coordinates (e.g. RVS, see section 5.1) are assigned to the GNSS CORS, these modules monitor the relative position of the CORS in the network and can be configured to issue alarms or email warnings to the network operator if the software detects relative movement of a GNSS CORS outside a specified level. This method of monitoring is the best way of determining station movement in real time, although the monitoring is limited to sites that are included in the CORS network managing software.

The third method involves periodic terrestrial monitoring against a series of at least three local reference marks (Janssen, 2009b). For Tier 1 and 2 GNSS CORS, these local reference mark (RM) surveys should be undertaken during installation, 6 and 18 months after installation, and every 2 years thereafter.

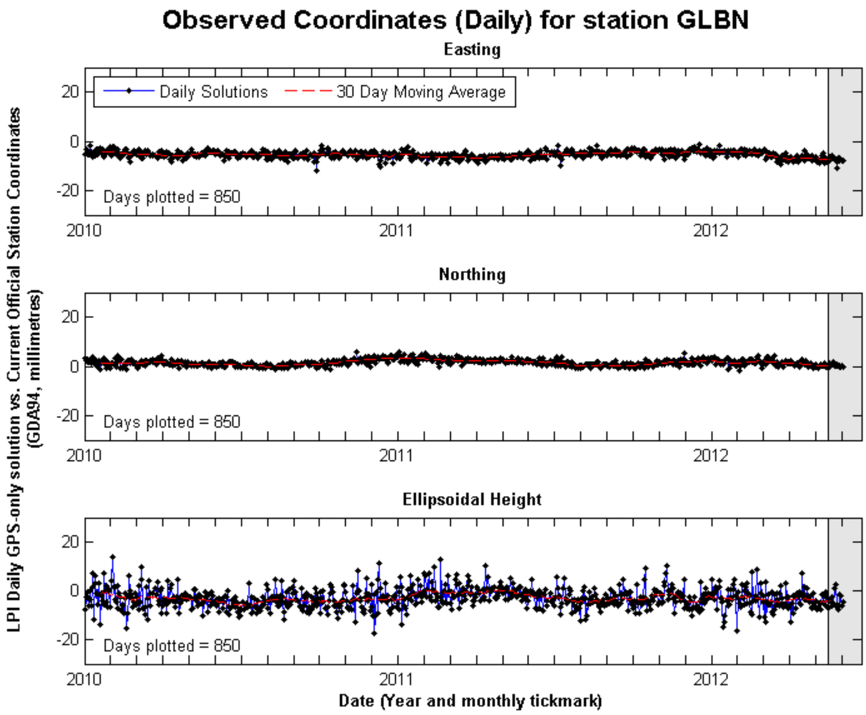

Figure 18: Observed position vs. official position for Goulburn CORS (Tier 3).

Figure 19 illustrates how an RM survey (epoch 0) is conducted during CORS installation before the GNSS antenna is installed. Once installed, the GNSS antenna must not be removed. The four reference pins on the pillar top used for future RM surveys are clearly visible. One of the three reference marks placed around the pillar is also shown, in this case a stainless steel rod driven to refusal and decoupled from surrounding soil (a mark drilled in bedrock is preferred). A cover box is used for protection, and the RM number should be stamped on the brass ID tag for easy identification.

The aim of RM surveys is to check that the GNSS CORS antenna has not moved relative to the immediate environment. These local monitoring surveys should be precise to better than 1 millimetre in position and height. If differences in survey results approach 1-2 millimetres, there is likely a need to investigate the cause further, or to undertake more regular monitoring. RM surveys should be undertaken to specifications provided by Geoscience Australia, including the equipment used and the survey practice followed. More information on RM surveys at GNSS CORS in NSW can be obtained from LPI and Geoscience Australia.

Figure 19: (a) RM survey being conducted during installation of a CORSnet-NSW site (Tier 2) before the GNSS antenna is installed, and (b) one of the reference marks placed for Tier 2 sites.

6 GNSS CORS Operation

Tier 1 and 2 GNSS CORS contribute to international and national geodesy programs and their operation must conform with the requirements of those geodetic programs. Tier 1 GNSS CORS operational requirements are outlined in the IGS site guidelines (IGS, 2009) and their proposed major revision (see draft at http://igs.org/network/guidelines/proposed.html). The following guidelines provide advice on the operational requirements of Tier 2 and lower GNSS CORS.

6.1 Operational Status

Users of GNSS CORS data need to know whether a GNSS CORS of interest was operating, is operating, or is likely to be operating during their period of interest. An effective method of providing this information is through a website that provides the current status of GNSS CORS sites and the history of the site. This website may be open to the public or available to registered users through a secure connection. It is recommended that this access point provide a method to download GNSS data and metadata for the GNSS CORS for post-processing applications. If data from the GNSS CORS is being distributed to an analysis centre for monitoring, that analysis centre should be informed of any proposed changes to the site including (but not limited to) cable, receiver or antenna changes prior to the change occurring. Once the change has occurred, the analysis centre should be informed of the extent and timing of that change through an update of the site log.

6.2 Reliability

In practice, the following factors should be considered in regards to GNSS CORS reliability:

- Multipath (pseudorange and carrier phase).
- Stability of the Antenna Reference Point (ARP).
- Availability and completeness of RINEX data for archiving.
- Availability and completeness of real-time data streams.
- Quality of GNSS services provided (e.g. ambiguity resolution success rate and time-to-fix-ambiguities).
- User feedback.

Reliability guidelines are currently beyond the scope of this document and may be included in future revisions.

6.3 Data Formats

6.3.1 Post-Processed Data Formats

GNSS data for post processing should ideally be archived in raw (native binary) format and be made available in the Receiver INdependent EXchange (RINEX) format or compact RINEX (Hatanaka) format.

The use of proprietary formats may increase the functionality of a site for applications that use a consistent brand of equipment. These formats, however, may not be able to be used by equipment and software from other brands, and the use of the RINEX format for data distribution is therefore strongly recommended.

RINEX is an open standard format allowing data to be used for GNSS post-processing applications irrespective of the receiver or software used. RINEX files include observation, navigation (separate files for GPS and GLONASS orbits) and meteorological files.

The data in the header of each RINEX file derived from a GNSS CORS should be complete and fully consistent with the site log and metadata.

A standard RINEX data file naming convention exists, which is detailed in section 4 of each RINEX format definition file, with Version 3.01 being the current version (e.g. available at ftp://ftp.unibe.ch/aiub/rinex). This naming convention is recommended for all GNSS CORS and is required when data is submitted to LPI or Geoscience Australia. In general, the standard naming format for RINEX data is:

SSSSDDDF.YYT

where:

- SSSS is a unique 4-character identifier for the site (see section 6.5).
- DDD is the GPS Day of Year, e.g. day 9 is denoted "009".
- F is the file sequence number within a day (i.e. "0" for a 24-hour file, "A" for a 1-hour file from 00h-01h, "B" for a 1-hour file from 01h-02h etc.). The file sequence number can also be used to indicate multiple sessions observed in one GPS day (e.g. "1" for the first session and "2" for the second session observed at a site).
- YY is the last two digits of the year, e.g. 2012 is denoted "12".
- T is the type of file, denoted as follows:
    - "o" – observation file
    - "n" – GPS navigation file
    - "g" – GLONASS navigation file
    - "m" – meteorological data file
    - "d" – Hatanaka compressed observation file

For instance, the 24-hour RINEX observation file of the CORSnet-NSW station at Bathurst (4-character ID "BATH") for 9 March 2012 has the file name BATH0690.12o.

When archiving 15-minute high-rate GNSS data, the RINEX data file naming convention is extended to include the starting hour and minute within the GPS hour:

SSSSDDDHMM.YYT

where:

- H is a character for the n-th hour in the GPS day (i.e. 0 hours GPS is denoted "A", 1 hours GPS is denoted "B" etc.).
- MM is the starting minute within the GPS hour (e.g. 00, 15, 30, 45).
- The remaining characters are as defined above.

Further information on the RINEX format is available at the IGS Formats webpage (IGS, 2012c).

6.3.2 Real-Time Data Formats

GNSS data for real-time positioning services should be made available according to the Radio Technical Commission for Maritime Services – Special Committee 104 (RTCM-SC104) standards.

The Special Committee 104 of the Radio Technical Commission for Maritime Services (RTCM, 2012) publishes standards for real-time GNSS data transmission:

- RTCM 10402.3 *RTCM Recommended Standards for Differential GNSS (Global Navigation Satellite Systems) Service – Version 2.3 + Amendment 1*; a standard used to distribute real-time differential GNSS data from a single reference station directly to a user.
- RTCM 10403.1 *Differential GNSS (Global Navigation Satellite Systems) Services – Version 3 + Amendments 1-5*; a standard used to distribute real-time differential GNSS data including GNSS network corrections to a user.
- RTCM 10410.1 *Standard for Networked Transport of RTCM via Internet Protocol (NTRIP) – Version 2 + Amendment 1*; a standard for transmitting RTCM 10403.1 and RTCM 10402.3 messages to multiple Internet-enabled devices.

RTCM 10402.3 messages are not compatible with the more recently developed RTCM 10403.1 messages. Many existing legacy GNSS receivers have been designed for use with RTCM 10402.3 messages and may not be able to decode RTCM 10403.1 messages. Therefore, both standards are being maintained as current standards.

Further information on NTRIP is available from the GNSS Data Centre NTRIP homepage of the Bundesamt für Kartographie und Geodäsie (BKG), the German Federal Agency of Cartography and Geodesy (BKG, 2012).

Proprietary data formats (e.g. CMR^{+}) may be preferred in some sectors (e.g. precision agriculture or Controlled Traffic Farming) as they may provide additional functionality and speed when a single brand of equipment is used. Proprietary data formats, however, may not be able to be used by equipment and software from other brands. Therefore, if proprietary data formats are to be used, additional open format distribution is strongly recommended to provide services to the maximum number of users.

6.4 Metadata

GNSS CORS metadata contains information about the site. Metadata includes site ownership, contact details, monument information, tier status and site coordinates.

GNSS CORS metadata is as important as the GNSS data the receiver is recording. The metadata aids operators in managing the GNSS CORS site, and allows users to make decisions on the suitability of the data from the site for their purpose. The metadata must be kept up to date and should include a site log detailing the history of changes (using GMT/UTC date and times) at the GNSS CORS.

IGS provides an IGS site log template (IGS, 2012d) that records most of the important metadata related to a GNSS CORS site and includes a link to instructions on how to complete the site log. An advantage of the IGS site log is that historical information about a site is recorded in a single file.

An IGS site log is mandatory for all CORSnet-NSW sites as it allows GNSS CORS metadata to be recorded and distributed in a consistent manner. Up-to-date Tier 1 and 2 GNSS CORS site logs should be submitted to Geoscience Australia, while up-to-date Tier 3 and 4 site logs should be made available on the CORS operator's website. CORSnet-NSW site logs for GNSS CORS operated by LPI are available via the CORSnet-NSW website (LPI, 2012a), and links are given to information provided by third-party CORS operators.

LPI takes metadata provided by third parties for CORSnet-NSW sites not operated by LPI at face value. Because LPI is not the primary source, it accepts no responsibility for the currency of this information. It is the responsibility of the GNSS CORS operator to notify LPI and provide updated metadata when a change has occurred at any site included in CORSnet-NSW.

The GNSS CORS operator may need to keep additional metadata relating to the site for their own management purposes, e.g. contact details of a person holding the keys to access the GNSS CORS on a building. This type of additional metadata is required for the good management of the GNSS CORS site but may not need to be distributed to users of data from the site.

During installation of a new GNSS CORS, checklists are a very useful tool to collect relevant metadata. As an example, Appendix 7 provides a checklist for the installation of Tier 3 antenna mounts, and Appendix 8 contains a checklist for the installation of Tier 3 cabinets.

Digital photographs are an important part of GNSS CORS metadata and are required for Regulation 13 certification (see section 5.1). These photos should show the installation as a whole (e.g. to clearly identify the building the CORS antenna is mounted on) as well as close-ups, including the equipment's serial and model numbers. If an antenna height is present, an annotated photo diagram should clearly show and state the vertical offset between the monument and the antenna's ARP. Ideally, photos of the antenna showing the horizon to the north, east, south and west should also be taken. This is a requirement for Tier 1 & 2 GNSS CORS (if it is safe to do so) but is generally not possible for lower tiers mounted on buildings.

The file naming convention for digital photographs should clearly state important information such as the CORS site the photo refers to, the equipment shown, the view direction and the date the photo was taken. A few examples are given in Table 5.

Table 5: Examples of naming digital site photographs of GNSS CORS.

File Name	Explanation
CNBN_ant_270_09APR12.jpg	View of the antenna at CNBN looking west. Image taken on 9th April 2012.
CNBN_ant_sn_09APR12.jpg	View of the antenna serial number at CNBN. Image taken on 9th April 2012.
CNBN_dome_sn_09APR12.jpg	View of the radome serial number at CNBN. Image taken on 9th April 2012.
CNBN_rec_sn_09APR12.jpg	View of the receiver serial number at CNBN. Image taken on 9th April 2012.
CNBN_cabinet_09APR12.jpg	View of the cabinet at CNBN. Image taken on 9th April 2012.

GNSS CORS metadata maintenance is the responsibility of the GNSS CORS operator. Where the metadata for a site is spread across a number of documents, it is important to ensure that the data contained in these metadata files is consistent.

6.5 Station Naming and Identifiers

GNSS CORS names must be unique, unambiguous and should be based upon their geographical location, e.g. suburb name in larger cities, and town name or locality name in remote regions. Company or institution names should be avoided for GNSS CORS of all tiers. Reference to existing survey mark numbers should also be avoided. All names should end with the "CORS" acronym, e.g. Dubbo CORS. GNSS CORS shared between organisations must use exactly the same name, and any local alias should be noted in the metadata. For instance, Bathurst CORS is also known as TS Mulley 5517-1 (eccentric station 1).

It is recommended to install a monument inscription plaque on or very close to the GNSS CORS antenna monument. This plaque should state the name of the GNSS CORS and provide brief contact details of the CORS operator (Figure 20).

At locations that have replacement CORS or multiple operating CORS, names should include a numerical character, e.g. Cowan 2 CORS, Cowan 3 CORS, etc. Renaming the original station with a numerical character is not required, e.g. Cowan CORS indicates the first CORS at the site. Replacing the equipment (i.e. GNSS antenna or receiver) or changing the antenna height does not warrant a new site name, unless the original monument is moved.

Figure 20: Monument inscriptions for Tuross Head CORS (Tier 2) and Narrabri CORS (Tier 3).

The IGS site log (see section 6.4) refers to a 4-character identifier in its metadata requirements. The GNSS CORS operator should check with the appropriate authority (e.g. LPI, Geoscience Australia) that the proposed 4-character identifier of a new GNSS CORS is not in use by another GNSS CORS.

Generally, the 4-character identifier should avoid or use a minimum number of vowels, e.g. PTKL (Port Kembla CORS) and TBOB (Tibooburra CORS). Identifiers that may be offensive should be avoided, e.g. DKSN is preferred to DICK for Dickson CORS. Numerical characters must be included to denote replacement or multiple CORS at the same site, e.g. CWAN was replaced by CWN2. A non-exhaustive list of currently used 4-character IDs for GNSS CORS can be found on the SOPAC website (SOPAC, 2012).

A unique 9-digit DOMES (Directory of MERIT Sites) number should also be obtained for Tier 1-4 GNSS CORS. Applications for IERS DOMES numbers (Tier 1 & 2) and APREF DOMES numbers (Tier 3 & 4) should be made via Geoscience Australia.

For example, the IERS DOMES number for Tibooburra CORS (Tier 2) is 59963M001, where:

- 599 is the 3-digit country code for Australia.
- 63 is the site number within Australia.
- M indicates that the tracking point is a monument point (e.g. pillar, pole or brass mark).

- 001 is a sequential point number, indicating that this is the first CORS at the site.

Similarly, the APREF DOMES number for Bathurst CORS (Tier 3) is AUM000102, where:

- AU is the 2-digit country code for Australia.
- M indicates that the tracking point is a monument point (e.g. pillar, pole or brass mark).
- 000102 is the site number within the APREF network.

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Appendix 1: Sample Regulation 13 certificate

Australian Government

Geoscience Australia

Certificate of Verification of a Reference Standard of a Position-Measurement in Accordance with Regulation 13 of the National Measurement Regulations 1999 and the National Measurement Act 1960

Name of Verifying Authority:

Name: National Geospatial Reference Systems
Organisation: Geoscience Australia
Address: Corner Jerrabomberra Ave and Hindmarsh Drive, Symonston ACT 2609 Australia
Telephone: (02) 6249 9111
Facsimile: (02) 6249 9969
Email: geodesy@ga.gov.au

Client detail:

Name: Dr Volker Janssen
Organisation: Survey Infrastructure and Geodesy, Land and Property Management Authority,NSW
Address: 346 Panorama Avenue, Bathurst NSW 2795
Telephone: (02) 6332 8426
Facsimile: (02) 6332 8479
Email: Volker.Janssen@lpma.nsw.gov.au
Date of request: 30 March 2011

Description and denomination of standard of measurement:

The measurement was undertaken using an antenna `LEIAR10 NONE` (International GNSS Service antenna naming convention) with the serial number 13110-023 and refers to a point located 0.0000 m below the antenna reference point. This antenna is attached to a stainless steel mast via a 5/8 inch spigot thread. The station (4 character ID: MREE) is located at the Moree Plains Shire Council Sewage Treatment Works building, Gwydir St, Moree.

Permanent distinguishing marks:

Exempt under Regulation 16 (4)

Date of verification:

08 April 2011

Date of expiry of certificate:

06 April 2016

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Value of standard of measurement:

South Latitude and its uncertainty of value:

29° 27' 27.82467" ± 0.0315 m

East Longitude and its uncertainty of value:

149° 49' 31.97397" ± 0.0315 m

Elevation above Ellipsoid and its uncertainty of value:

245.9715 ± 0.0544 m

Geocentric Datum of Australia (GDA94) coordinates referred to the GRS80 ellipsoid being in the ITRF92 reference frame at the epoch 1994. The uncertainties are calculated in accordance with the principles of the ISO Guide to the Expression of Uncertainty in Measurement (1995), with an interval estimated to have a confidence level of 95% at the time of verification. The combined standard uncertainty was converted to an expanded uncertainty using a coverage factor, k, of 2.

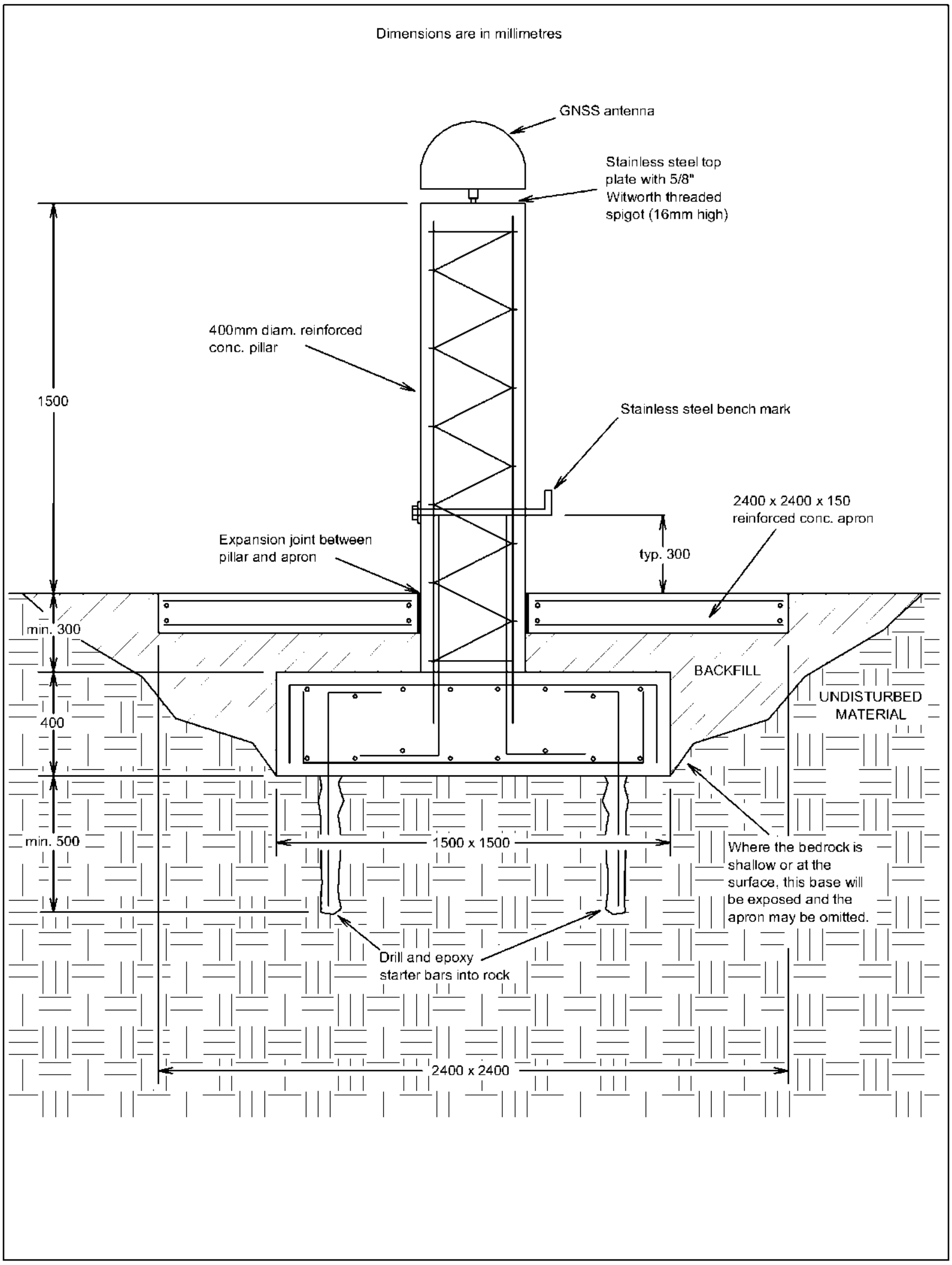
Details of any relevant environmental or other influence factor(s) at the time of verification:

Uncertainty of the coordinates of the recognized-value standard of measurement of position (i.e. GDA94); and Uncertainty due to instability of the GPS antenna mounting and modelling of the antenna phase centre variations.

Signature: ______________________	**Signature:** G Johnston ______________________
08 April 2011	08 April 2011
Dr John Dawson NATA approved signatory	Mr Gary Johnston Geoscience Australia approved signatory
Senior Research Scientist National Geospatial Reference Systems Project Geoscience Australia	Project Leader National Geospatial Reference Systems Project Geoscience Australia

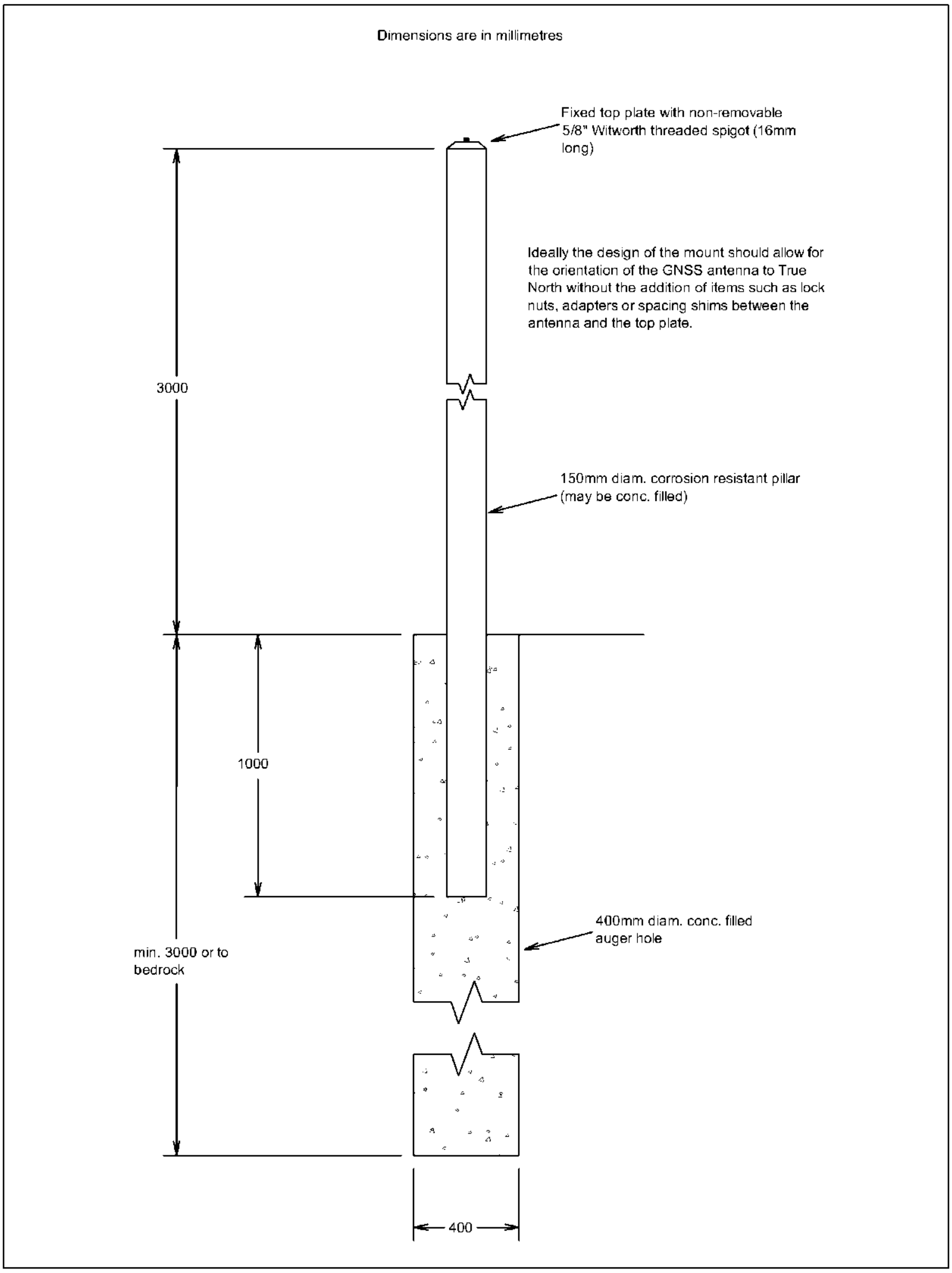
Being a person, or a person representing a body, appointed as a verifying authority under Regulations 71 and 73 of the National Measurement Regulations 1999 in accordance with the National Measurement Act 1960, I hereby certify that the above standard is verified as a reference standard of measurement in accordance with the Regulations, by the above-named authority.

Appendix 2: Sample monument design for CORSnet-NSW Tier 1 and Tier 2 GNSS CORS

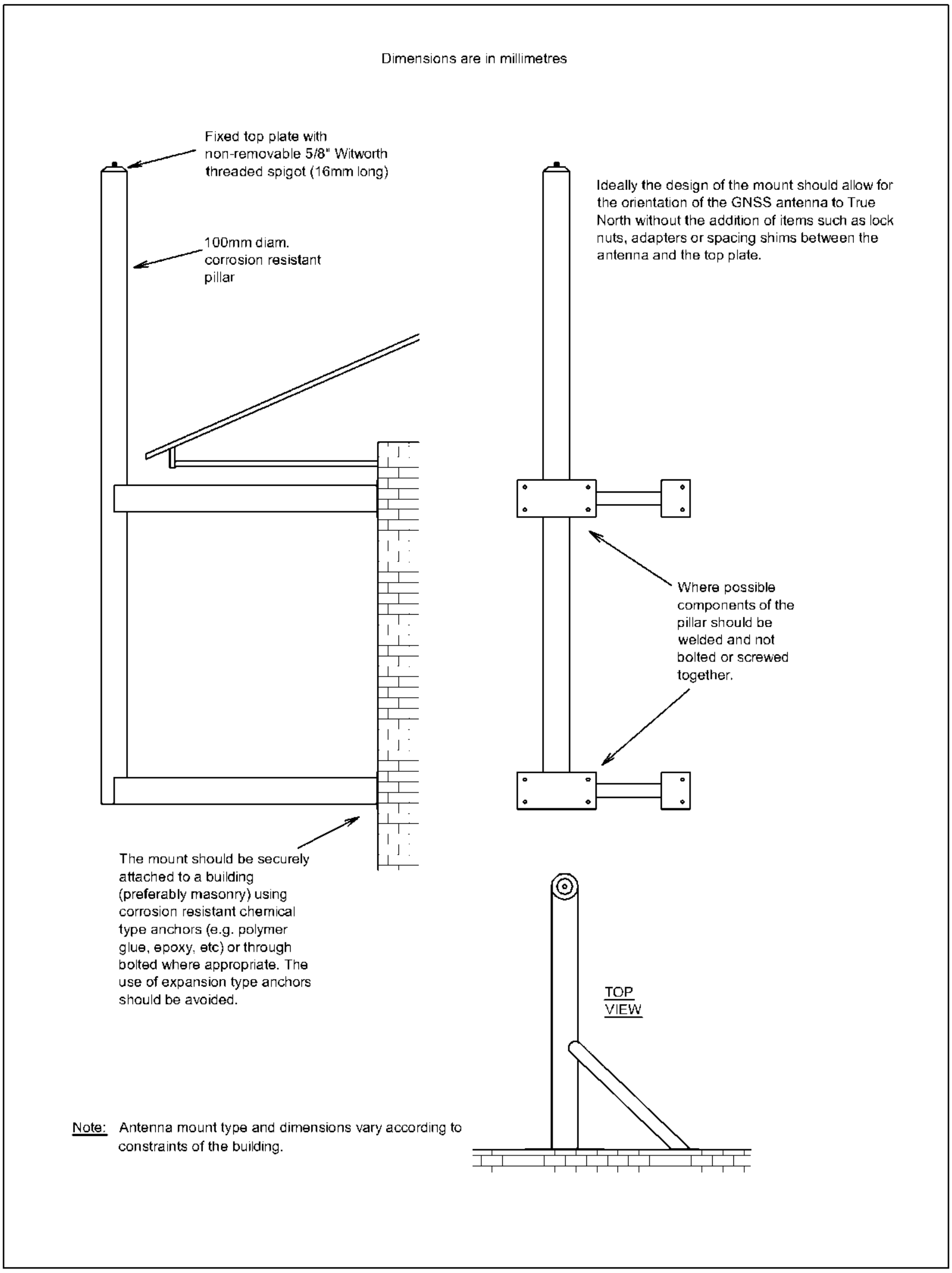


Appendix 3: Sample monument designs for CORSnet-NSW Tier 3 and Tier 4 GNSS CORS

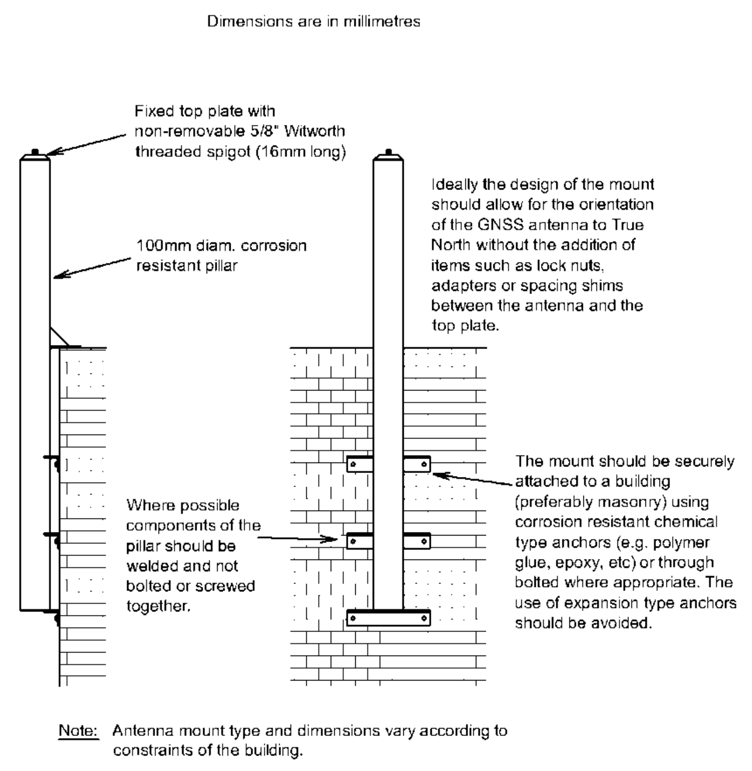
Free standing pole monument design:



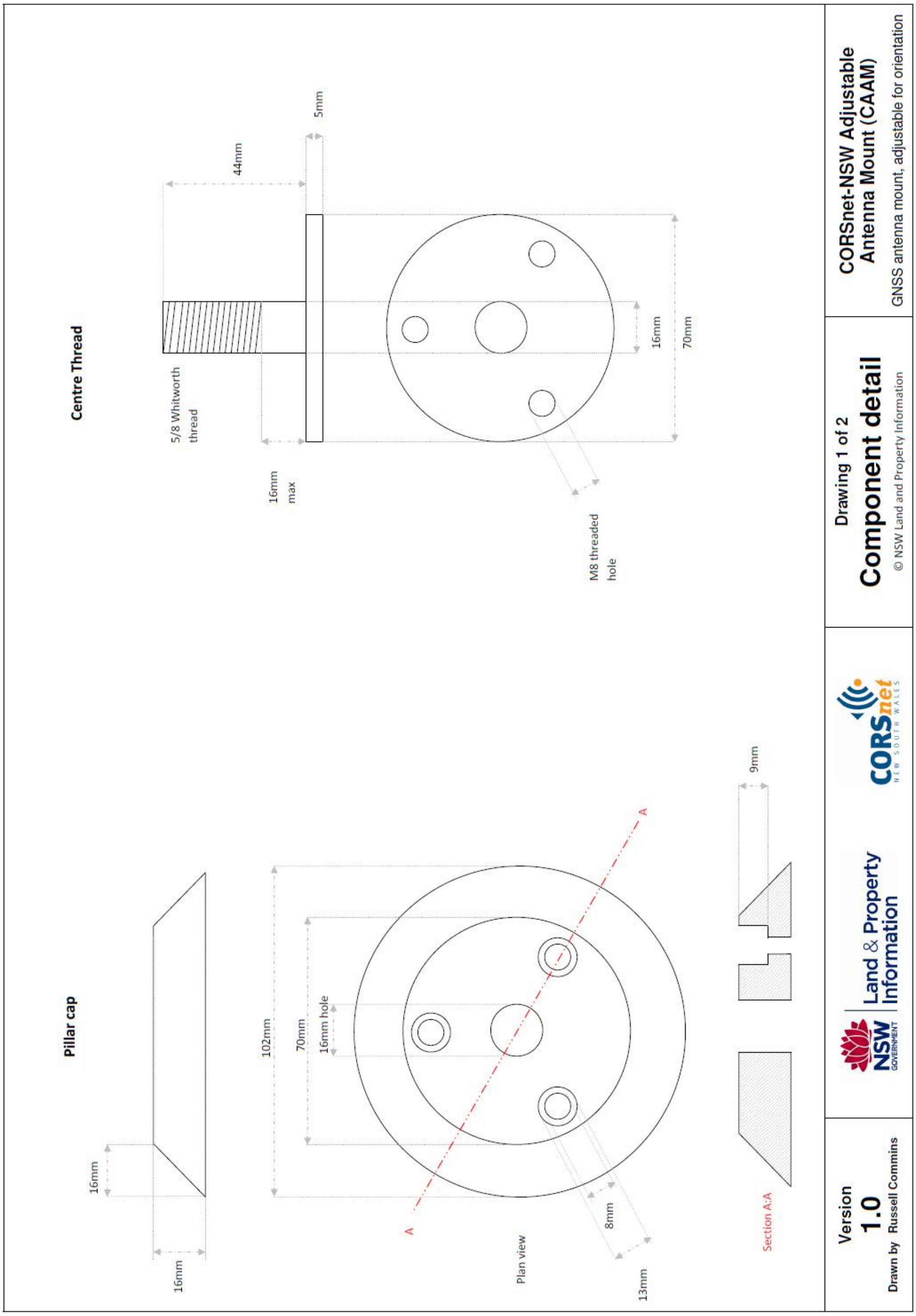
Wall-mounted monument design (building with eaves):

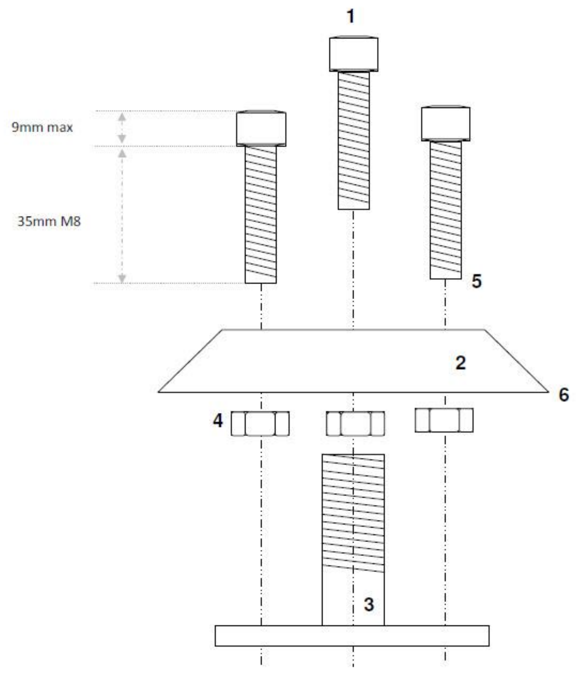


Wall-mounted monument design (building without eaves):



Appendix 4: CORSnet-NSW Adjustable Antenna Mount (CAAM) design (Australian Patent No. 2012200770)





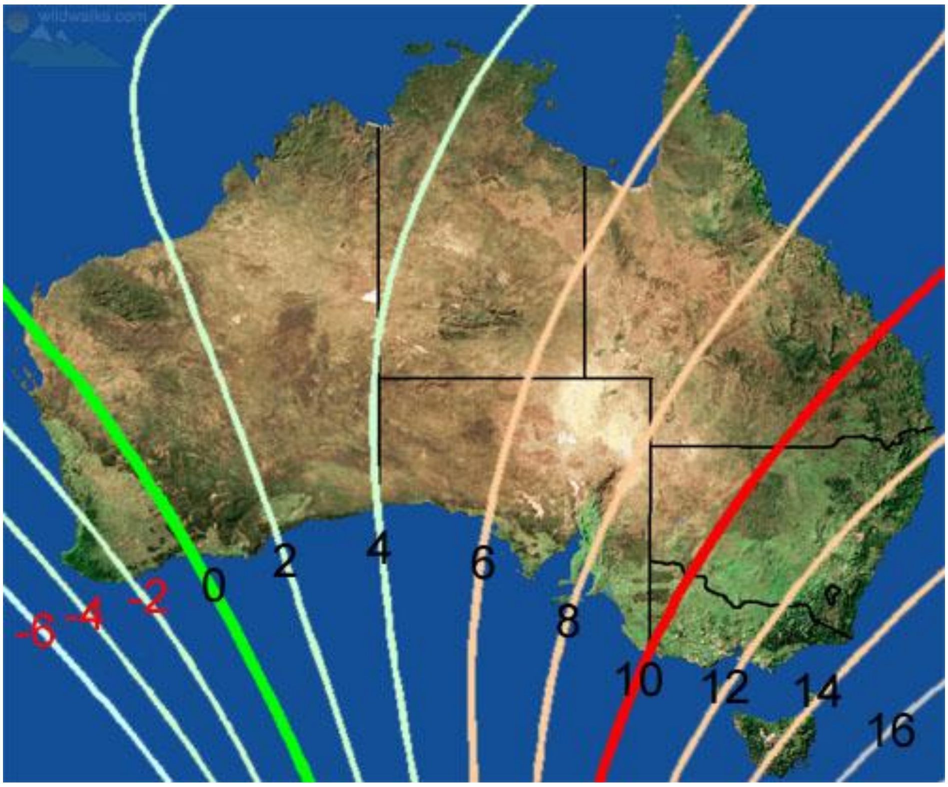
Note	All components stainless steel
1	M8 Allen Head bolt (socket head)
2	Pillar cap
3	Centre thread
4	M8 nut (tighten to allow easy bolt rotation then hold in place with thread locking compound)
5	Small spot weld on the end of each bolt after assembly to prevent the centre thread component from being removed
6	To be welded to the top of 100mm (OD) CORSnet-NSW stainless steel antenna pole, mast or pillar

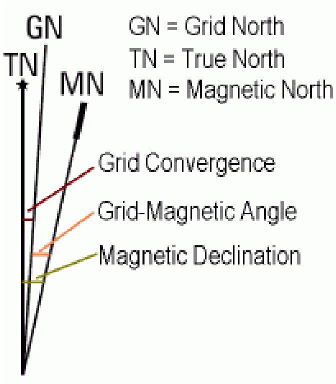
Version 1.0 Drawn by Russell Commins	NSW Government – Land & Property Information; CORSnet New South Wales	Drawing 2 of 2 **Assembly** © NSW Land and Property Information	**CORSnet-NSW Adjustable Antenna Mount (CAAM)** GNSS antenna mount, adjustable for orientation

Appendix 5: Magnetic Declination over Australia

Magnetic Declination is the difference between True North and Magnetic North. Compass bearings must be corrected in order to determine true bearings. For a full description of Magnetic Declination, or to compute official values, visit http://www.ga.gov.au/oracle/geomag/agrfform.jsp (accessed June 2012).

Magnetic Declination *does* change over time, but quite slowly (less than 0.1°/yr in NSW). These changes are small enough that the values shown in the map below (valid for 2005), obtained from http://www.wildwalks.com/bushcraft/technical-stuff/magnetic-declination.html (accessed June 2012), will still apply up to 2015 for manual compass readings.





<u>Example for Lithgow, NSW</u>

Lithgow (approx. -33° 28' S, 150° 09' E)
has a Magnetic Declination of 12 degrees.

A magnetic compass bearing of 100 degrees in Lithgow converts to a true bearing of 112 degrees (100°+12°).

True to Magnetic, subtract (the Magn. Declination)

Magnetic to True, add (the Magn. Declination)

Therefore, to orient to True North (360°), you must observe a magnetic bearing of 360°-12° = 348°.

Appendix 6: CORSnet-NSW Antenna Mount Installation Briefing

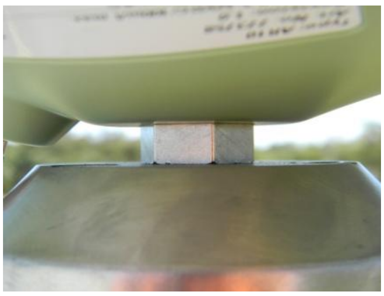
The CORSnet-NSW antenna mount will be a registered survey mark surveyed to the highest accuracy. It is important that the installer makes the mount as secure/rigid as possible.

Attaching the Mount:

Safety first. Antenna mounts used for CORSnet-NSW are often on rooftops and high on building walls. If you are a contractor, you are responsible for fulfilling your obligations under NSW OH&S legislation incl. undertaking risk assessments, implementing safe work practices and providing material safety data sheets. Your safety is the most important part of this installation, so if you need extra harness attachment points, ladder hangers, etc. to safely access the mount, please contact your LPI contact person.

Stainless steel through bolt or Chemset (or similar) type anchors. For single-brick or single-skin concrete walls, bolting through is the preferred method using stainless steel threaded rod. If the wall is too thick, has an internal cavity or the inside of the wall cannot be reached, the mount should be attached using stainless steel Chemset (or similar) type anchors. Two of the anchors can be stainless steel expanding type bolts (e.g. Dynabolts) or thread forming anchors (e.g. Ramset Anka) if needed to hold the mount in position while the chemical anchors cure. There is no need to replace these two expanding anchors. If possible, the highest attachment point should be 4 or more standard brick courses down from the top course. All anchors should be tightened after curing of the adhesive.

Use thread-locking compound. A thread-locking compound (like Lock Tight) should be used to stop the nuts loosening over time. Alternatively, use Nylock nuts or similar (Nylock nuts will be supplied).



Screw the antenna on firmly and face it True North. The antenna will screw down onto the 5/8th Whitworth thread on top of the mount. It is important that the antenna screws down firmly (hand tight is sufficient; do not use Lock Tight). The North point will be marked on the antenna (if not, the coax attachment point faces North). If the antenna does not face True North when first screwed on, adjust the spigot as follows:

1) Take note of approximately how far the antenna needs to rotate (clockwise or anti-clockwise) before it faces the correct direction.

2) Remove the antenna.

3) Turn each of the three adjustment screws using a hex key. If the antenna needs to rotate approximately 30° clockwise, turn each of the three screws about 30° clockwise.

4) Screw the antenna on firmly again and check for direction.

5) Repeat this adjustment process until the direction is correct.

Make sure that you turn all three hex screws the same amount, and do not try to go more than half a turn in one go. Turning the screws clockwise raises the centre spigot a tiny amount, allowing the antenna more rotation before it tightens. The change is so small you probably will not even see it move.

Antenna Cable Run:

Protect the cable. Any exposed cable should be housed in UV stabilised conduit. All outdoor exposed cable connections should be waterproofed using self-amalgam tape or similar (electrical tape is not appropriate).

Reduce the risk of leaks. Conduit ends should either be facing downwards or be sealed with the appropriate cable gland to stop the inflow of moisture. A drip loop should be left before the cable/conduit enters the building.

Neat and secure. The cable should be neatly run and properly secured for the length of its run. Stainless steel cable ties should be used on outdoor installations (where cable ties are needed). The minimum bend radius of LMR400 coaxial cable should not be smaller than 30 mm. As much as practical, a stress relief loop should be left at the antenna attachment point.

Earth for lightning protection. Earth for lightning protection should be a minimum of 6 mm^2 returning to the earth stake, main or floor distributor or line tapped to earth of 6 mm^2 or greater which returns to the MD or FD as per AS S009:2006. Earth installation should not contradict electrical wiring rules.

This antenna will be used as an official government monument, therefore it is imperative that:

- **The antenna faces TRUE NORTH.**
- **Clear digital images of at least 1600 x 1200 pixels are provided of the mount in place. These images should clearly show:**
  - **The base of the antenna (where it meets the mount).**
  - **The serial number of the antenna once it is in place.**
  - **The mount and the supplied name plate.**
  - **The mount and its position on the building.**

Appendix 7: CORSnet-NSW Antenna Installation Checklist

Site Name ___________________________

CORS Antenna Installation

Items checklist (completed by LPI)	Packed	N/A	Photographed
Antenna mount	☐	☐	
Antenna: TYPE (S/N)	☐	☐	☐
Radome: TYPE (S/N)	☐	☐	☐
Antenna cable (Length ____________) (Cable Type ___________)	☐	☐	
Conduit and gland	☐	☐	
Amalgam tape	☐	☐	
Threaded rod (through bolting)	☐	☐	
Chemset	☐	☐	
Threaded rod (Chemset bolting)	☐	☐	
Chemset sleeves for hollow bricks	☐	☐	
Nylock nuts and washers	☐	☐	
Stainless steel cable ties	☐	☐	
Name plate	☐	☐	☐

Signed_____________________________

Install checklist (completed by installer)	Done	N/A	
Chemset sleeves used for hollow bricks	☐	☐	
Antenna mount flush, level and firm	☐	☐	
Amalgam tape used over antenna connections	☐	☐	
External coax protected with conduit	☐	☐	
Drip loop before entering building	☐	☐	
Antenna orientated to True North (348° magnetic)	☐	☐	
Antenna photographed (incl. serial number)	☐	☐	(NB: Photos should
Antenna photographed (incl. radome serial number)	☐	☐	be at least 1600 x 1200)
Cable secured with stainless steel cable ties	☐	☐	
Earth wire installed to cabinet (as per RFQ)	☐	☐	
Name plate installed at antenna	☐	☐	
GPO installed (as per RFQ)	☐	☐	
Site cleanup	☐	☐	

Signed_____________________________

If you have any issues during the installation which need clarification please contact your LPI contact person.

Appendix 8: CORSnet-NSW Cabinet Installation Checklist

Site Name:

Rack/Cabinet Build Checklist

			Photographed	N/A
Receiver	Model: Serial No.:		☐	☐
Router	Model: Serial No.:		☐	☐
UPS	Model: Serial No.:		☐	☐
Cable (section 1, i.e. antenna end)	Type:	Length:	☐	☐
Cable (section 2, i.e. main length)	Type:	Length:	☐	☐
Lightning arrestor	Model:		☐	☐
Antenna splitter	Model:		☐	☐
Cable (section 3, i.e. receiver end)	Type:	Length:	☐	☐
Modem	Model: Serial No.:		☐	☐
Web relay #1	Model: Serial No.:		☐	☐
Web relay #2	Model: Serial No.:		☐	☐