Stakeholder Requirements for Modernising Australia’s Geocentric Datum

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Next Generation Australian and New Zealand Datum

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Executive Summary

In February 2015 the Intergovernmental Committee on Mapping and Surveying (ICSM), Permanent Committee on Geodesy (PCG) proposed a revised Roadmap to modernise the Geocentric Datum of Australia 1994 (GDA94), Australia's current national geocentric datum. This report describes the information considered by the PCG prior to its determination of the revised proposal and develops recommendations for the implementation process for consideration by ICSM.

The first version Datum Modernisation Roadmap was released in 2011 in response to an assessment by PCG that GDA94 would eventually be unable to satisfy the requirements of all Australians. Simply, it was envisaged the reference system would need to be able to support the ability for spatial data sets on the national datum to be closely aligned with Global Navigation Satellite System (GNSS) derived International Terrestrial Reference Frame (ITRF) locations in real-time and ultimately this would require implementation of a national time dependent reference frame.

Information taken into account by the PCG and outlined in the report includes feedback from consultation with the spatial sector between 2012 and 2014 on the first version Roadmap, lessons learnt from an analysis of the GDA94 implementation that may be applied to current modernisation efforts, and the anticipated impact of the inevitable spread of ubiquitous accurate positioning within society. Consideration of current international responses to the provision of time dependent reference frames is also included.

Consultation with the spatial sector revealed general support for the effort to modernise GDA94 with the majority of stakeholders expressing the view that "Do Nothing" was not a realistic option. Respondents identified a range of issues associated with implementation of a modernised datum and emphasised the need for a nationally coordinated process. Overall, the feedback highlighted the importance of project and change management processes in ensuring a successful outcome, leading to the inclusion of a section specifically addressing these aspects in this narrative.

The report indicates that availability of ubiquitous accurate GNSS positioning is inevitable within Australia, driven by the natural evolution of GNSS systems and the presence of GNSS and other measurement sensors in smartphones and vehicles. A 'tsunami' of adoption is predicted whereby literally millions of Australians may utilise the technology within several years of its development. Failure to satisfy the requirements of these users is likely to result in confusion and conflict, as well as lost opportunities.

Seventeen general recommendations for the implementation process are developed and include:

- That ICSM and ANZLIC should determine and clearly document the intended datum modernisation pathway to provide a mandate for change.
- The formation of a project team to manage the implementation at a national level, using project and change management techniques and specifically addressing technical and practical aspects.

- Implementation should aim to enable spatial datasets to be readily represented in close alignment with the GNSS measurement frame (ITRF) at around 2020.
- The importance of targeted and general communication, including the provision of 'soft' educational resources to complement the 'hard' technical resources.
- The necessity to engage with commercial off-the-shelf software providers to facilitate the introduction of software tools that perform the appropriate datum transformations.

This report does not include a benefit-cost assessment of particular options for datum modernisation nor does it deal with the explicit content of the technical tools that will need to be provided.

1. Introduction

1.1. Background to the Report

During 2010 the Intergovernmental Committee on Surveying and Mapping (ICSM), Permanent Committee on Geodesy (PCG) undertook an assessment of the Geocentric Datum of Australia 1994 (GDA94) which concluded that eventually the datum would be unable to meet the requirements of all Australian spatial stakeholders. Simply, it was envisaged the reference system would need to be able to support the ability for spatial data sets on the national datum to be closely aligned with Global Navigation Satellite System (GNSS) derived International Terrestrial Reference Frame (ITRF) locations in real-time and ultimately this would require implementation of a national time dependent reference frame.

This led PCG to develop the first version Datum Roadmap in 2011, which proposed a two stage process to implement a new national datum. The first stage, with an anticipated implementation in 2015, involved the development of a fully national geodetic adjustment that would be projected forward in time and referenced to the static epoch 2020. By 2020 it was anticipated that the necessary tools and resources would be available to enable the adoption of a time dependent Australian reference frame. Donnelley *et al* (2014) outlines additional details of the first version Datum Roadmap [1].

Between 2012 and 2014, PCG and researchers in the Cooperative Research Centre for Spatial Information (CRCSI) worked on the technical components of the first version Datum Modernisation Roadmap. During this period both parties also promoted the key elements of the Roadmap in Australian jurisdictions in a variety of workshops and forums.

In 2013 ICSM requested that at an appropriate time PCG, in conjunction with CRCSI participants, develop an implementation proposal for the next generation Australian Datum for formal endorsement by ICSM and the Australian and New Zealand Land Information Council (ANZLIC).

To inform the development of the proposal, CRCSI participants undertook an analysis of user requirements of the next Australian datum, engaging with spatial sector users before preparing two papers relating to user requirements [2], [3].

PCG met in Canberra in February 2015 to consider the Roadmap and following a lengthy review of user feedback, the current progress of the technical implementation tasks and anticipated stakeholder requirements, agreed to a revised Roadmap proposal for ICSM and ANZLIC endorsement.

PCG also resolved to authorise this report summarising the material that informed the February 2015 proposal.

1.2. Purpose of the Report

The report objectives are to (1) describe the information considered by the PCG in February 2015 prior to its determination of the revised proposal for Australia's modernised geocentric spatial reference system, articulated in *Statement on Datum Modernisation – version: 25 March 2015* [4], and (2) develop recommendations for the implementation process.

1.3. Assumptions

For the purposes of this report it is assumed that:

- Australia aspires to become a 'spatially-enabled society' as defined by FIG Report No. 58 [5].
- The current GDA94 datum is unable to meet the future spatial referencing requirements in a spatially-enabled society.
- Australian jurisdictions will support a nationally coordinated implementation plan and change management process delivering a 21st Century geocentric reference system.
- The first version Datum Modernisation Roadmap is the model for the proposed national datum against which stakeholder feedback is compared.

1.4. Report Content

The report:

- Reviews the GDA94 execution timeline to look for lessons that may be applied to implementation of a modernised Australian datum.
- Summarises the feedback received from the geospatial community during the promotion of the first version Datum Modernisation Roadmap between 2012 and 2014.
- Considers the impact of technology trends and their implication for all present and future datum users.
- Reviews the international environment for examples of current datum modernisation initiatives.
- Highlights some practical management strategies applicable to the process for changing the national datum.

Each section concludes with a summary of the lessons learnt or issues identified in an indexed table.

A particular option regarding the form of the national reference system is not prescribed. However, in response to issues identified, recommendations concerning the attributes of a new spatial reference system and its implementation are provided at the end of the report.

The report includes references to publications that post-date the February 2015 decision by PCG. These more contemporary references to concepts, issues and trends accepted by the PCG have been used to provide a snapshot of the latest circumstances.

1.5. Interpretation of 'Accurate'

Much of the discussion in the report focuses on the anticipated widespread ability for stakeholders to measure 'accurate' locations and compare those locations to spatial datasets at some nominated 'accuracy' level.

The phrase 'X metre accurate' in relation to a GNSS navigated or measured position is intended to mean a two dimensional location that is within 'X' metres of its true position determined in real-time in the current International Terrestrial Reference Frame (ITRF) at the epoch of the day of measurement at the 95% confidence level. For example, it is anticipated that affordable GNSS will be able to deliver 0.5 metre accurate (or better) positioning by 2020 (refer **Section 4 Ubiquitous Positioning**).

Similarly, a spatial data set that is nominated as having 'X metre accuracy" is intended to mean that 95% of the horizontal positions in the dataset have an error with respect to true ground position that is equal to or less than 'X' metres with respect to the nominated national datum or reference frame. For instance, some of the ANZLIC Foundation Spatial Data Framework (FSDF) themes refer to a desired 'accuracy' of one metre in urban areas [6]. This is referred to as a requirement for '1.0 metre accuracy' which in 2015 would be with respect to GDA94.

1.6. Statement on GDA94 and ITRF / WGS Equivalency

GDA94 was coincident with the ITRF in January 1994. However, GDA94 is defined so that it is 'fixed' to the Australian tectonic plate and therefore moves along with the plate at around 7 centimetres a year in a north easterly direction. In contrast, the reference frames used by GNSS (ITRF and WGS84) are global spatial reference systems co-rotating with the Earth and referenced to celestial objects – they are effectively fixed to the centre of mass of the earth [3].

At the official adoption of GDA94 on 1 January 2000 the difference in coordinates of any feature measured in the plate-fixed GDA94 and earth-fixed ITRF/WGS84 was approximately 40cm. In 2015 the difference is about 1.5 metres and by 2020 the difference will be approximately 1.8 metres.

On 1 January, 2000 the achievable accuracy of autonomous Global Positioning System (GPS) receivers was approximately 100 metres due to the implementation of the Selective Availability (SA) policy by the US government (autonomous GPS refers to the receivers determining their position without application of an external augmentation or correction service). Only professional users with expensive GNSS equipment using appropriate techniques could achieve GPS positional accuracy at sub-metre level in real-time - literally only thousands of Australian users with specialised training and knowledge. Typically, these users were applying Real-time Kinematic (RTK) techniques whereby the position of a roving GPS receiver was determined relative to another GPS receiver on an accurately surveyed reference station with 'known' GDA94 coordinates. Accordingly in 2000 ICSM issued the advice that, for practical purposes and the vast majority of users, the difference between GDA94 and ITRF/WGS84 could be ignored.

In May 2000 the Clinton Administration cancelled the Selective Availability policy [7]. This resulted in the majority of GPS users being able to achieve positional accuracy of approximately 10 metres but the difference between GDA94 and ITRF/WGS84 could still be ignored. In this regard it is relevant to note that most users of autonomous GPS typically related their GPS measured location to datasets represented on hard copy maps at scales ranging from 1:25,000 (one millimetre on the map represented twenty-five metres on the ground) to 1:100,000 (one millimetre on the map represented one hundred metres on the ground).

The advent of multiple GNSS constellations and improvements in GNSS technology has resulted in cheap autonomous GNSS receivers currently routinely determining ITRF positions within two to three metres of their true value under good GNSS observing conditions.

Commercial Wide Area Differential GNSS systems (WADGNSS) such as OmniSTAR™ and StarFire™ allow users of professional grade GNSS units enabled to access position correction services, known as Differential GNSS (DGNSS) receivers, to achieve positional accuracies of between 0.5 metres and 0.05 metres in real-time. By default, these DGNSS locations are reported to the user in the current ITRF although some Australian service providers do provide alternatives that output GDA94 locations.

For instance, subscribers to StarFire™ supported by Australian spatial industry reseller *4D Global* have the transformation to GDA94 installed in the receiver at the point of sale (P Terrett, personal communication March 2015). Some OmniSTAR™ subscribers also employ a process to enable location to be reported in the receiver in GDA94 coordinates but this involves manual intervention by the user on a regular basis and the procedure is not employed by all subscribers (R Box, K. Dyer personal communication, March 2015). DGNSS units are very popular in agriculture and there is no evidence that these users are alerted to the difference between WADGNSS ITRF locations and Australian GDA94 locations.

The increasing usage of sub-metre accurate DGNSS services operating in ITRF, the approximate 1.5 metre difference between ITRF and GDA94 locations, and widespread adoption of digital data and maps over hardcopy maps, resulted in ICSM clarifying the advice regarding the equivalency of GDA94 and WGS84 / ITRF in April 2015. The *Geodetic Datum of Australia Technical Manual Version 2.4* advises that where users require accuracy better than 5 metres GDA94 and WGS/ITRF cannot be considered equivalent and a transformation must be applied [8].

1.7. Acronyms

AHD Australian Height Datum

AGD66 Australian Geodetic Datum 1966

AGD84 Australian Geodetic Datum 1984

ANZLIC Australian and New Zealand Land Information Council

CORS Continuously Operating Reference Station

COTS Commercial Off-The-Shelf

CRCSI Cooperative Research Centre for Spatial Information

DCDB Digital Cadastral Data-Base

DGNSS Differential Global Navigation Satellite System

EGNOS European Geostationary Navigation Overlay Service

GDA94 Geocentric Datum of Australia 1994

GNSS Global Navigation Satellite System

GSA European Global Navigation Satellite Systems Agency

GPS Global Positioning System

ICSM Intergovernmental Committee on Surveying and Mapping

IAG International Association of Geodesy

ITRF International Terrestrial Reference Frame

NGS National Geodetic Survey

NRTK Networked Real-time Kinematic GNSS

PCG ICSM Permanent Committee on Geodesy

RTK Real-time Kinematic (GNSS)

TASSIC Tasmanian Spatial Information Council

2. Review of GDA94 Implementation

To assist with understanding the process required to successfully modernise the Australian datum a desktop review of the GDA94 implementation process was undertaken. ICSM Minutes from 1988 to 2004 were examined to determine the tasks associated with GDA94 rollout as well as the scheduling of those tasks. A basic timeline of the rollout is developed based upon ICSM resolutions and other significant events. Feedback or observations on the adoption process noted in the Minutes were reviewed.

2.1. ICSM Resolutions

The major Resolutions in the ICSM minutes relating to GDA94 are listed in the Table 2-1. There are numerous Actions and Recommendations associated with GDA94 implementation recorded in the minutes which are not included in this summary for the sake of brevity. The 'Resolution' column reproduces the identification number as it was recorded in the minutes whilst the text in normal font in the 'Detail' column is the heading for the resolution as it was recorded. Information in italic font is some or all of the descriptive content of the resolution, provided here to clarify the purpose.

Meeting	Resolution	Detail
1st Meeting 1988 July	Resolution 2	Adoption of a Geocentric Datum *The Committee noting recommendations contained in the March 1987 Report of the National Mapping Council Working Party on the Global Positioning System resolves to recommend the adoption of an appropriate geocentric datum on 1 January 2000 and agrees to further consider the impact on the range of datum users throughout the community with a view to advising respective governments to effect appropriate implementation action. In the meantime members will make appropriate transitional arrangements.*
2nd Meeting 1990 March	Resolution 6	Commitment to Adoption a Geocentric Datum *The Committee noting the recommendations in the March 1990 Report of the Working Party on the Adoption of a Geocentric Datum reaffirms its commitment to both the spirit and the content of Resolution 2 of 1988 where the adoption of a geocentric datum on 1 January 2000 is recommended.*
10th Meeting 1994 November	R94/11/01 R94/11/02 R94/11/03 R94/11/04 R94/11/05	Earth centred Cartesian Co-ords for AFN & ANN adopted Lats & Longs adopted for GDA94 GDA94 converted to UTM to be MGA94 GDA94 & MGA94 to be used for implementation of GDA Combined adjustment constrained by AFN & ANN to be undertaken
16th Meeting 1997 November	R97/11/01	Funding for Promotion of GDA *ICSM resolves to make available to AUSLIG a sum of up to $10,000 to assist with the short term employment of a marketing type person to develop GDA promotion campaign suitable for all ICSM jurisdictions.*

Meeting	Resolution	Detail
17th Meeting 1998 May	R98/05/02 R98/05/03 R98/05/04	ToR of new Working Group on Legal Implications of GDA *There are urgent reasons to clarify the legal status of offshore and onshore; mineral and petroleum tenure boundaries and the need for legislative changes to allow conversion to the GDA.* ToR of new Working Group on Geocentric Datum of Australia (GDA) Promotion (GDAWG) *ICSM resolves to establish a Geocentric Datum of Australia (GDA) promotions coordination group comprising of a representative of each jurisdiction. The purpose of the group shall be to co-ordinate a nationally orchestrated user responsive promotion/education program, supporting the implementation of the Geocentric Datum of Australia (GDA).* *This working group was disbanded in November 2001.* ICSM support for converting to GDA
18th Meeting 1998 December	R98/012/01	Legal Implications of GDA *Resolution archived May 1999 – see R99/05/05.*
19th Meeting 1999 May	R99/05/05	GDA Legislation
20th Meeting 1999 October	R99/10/01 R99/10/09 R99/10/10 R99/10/13	Dual NTv2 Transformation Grids between AGD and GDA94 ***ICSM resolves** to develop a national transformation product consisting of a national coverage NTv2 transformation grid from AGD66 to GDA94, and a separate NVTv2 transformation grid from AGD84 to GDA94 for all AGD84 jurisdictions, and communicate these outcomes to the industry and user communities.* Common Map References Grid Reference Systems Geocoding
23st Meeting 2001 May	R00/11/05	ToR of new Working Group for GDA Implementation *ICSM resolves to establish a GDA Implementation Working Group comprised of a representative of each jurisdiction. The purpose of the group shall be to monitor and facilitate the implementation of GDA to ensure a nationally consistent approach.*
28th Meeting 2003 Wellington	R03/11/02 R03/11/04	Horizontal Datum (GDA94 be retained for 5 years) Disbandment of the GDA Implementation Working Group

Table 2-1 ICSM Resolutions Concerning GDA94 Implementation

The GDA94 implementation process is visualised in the timeline shown in Figure 2-2:

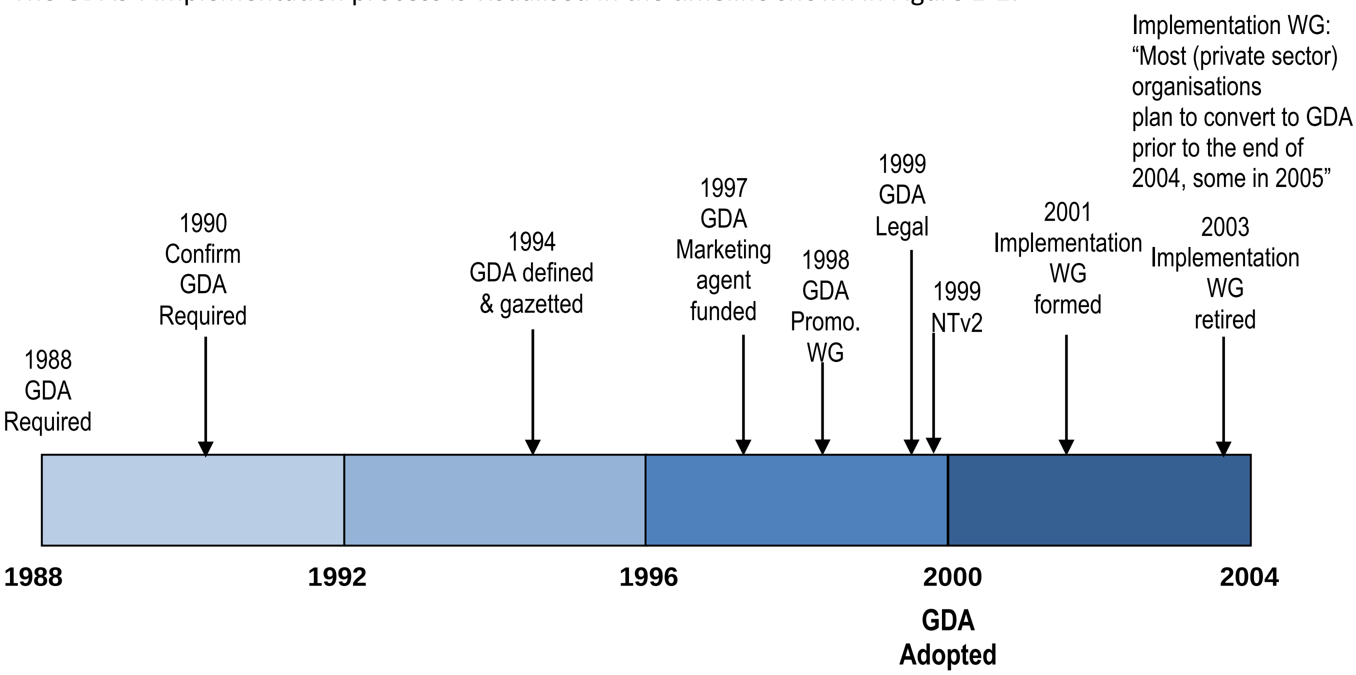

Figure 2-2 GDA94 Implementation Timeline

2.2. GDA94 Implementation Working Group

The GDA Implementation Working Group (GDAIWG) was established in May 2001. Its primary function was to facilitate a consistent approach to the implementation of GDA94 across all jurisdictions and monitor public and private sector uptake of GDA94. Essentially, it was focused on the process of adoption rather than promotion, although this latter aspect was a minor function. A review of the Minutes and GDAIWG reports to ICSM reveals:

- In November 2002 jurisdictions did not have a predetermined list of 'standard' public datasets that should be transformed to GDA94.
- A classification system of 'standard' datasets was never developed. Instead a list of 'major' datasets was adopted and conversion compliance measured against this list in 2003.
- It does not appear there was ever a project plan developed to achieve GDA94 compliance of 'major' public datasets by a certain date, nor broad jurisdiction agreement as to nomination of a target date, or a coordinated communication program to advise on the national progress ('GDA94 compliant' was defined as meaning data was stored with GDA94 coordinates, or in a system that was capable of both importing and exporting data based on GDA94).
- Some jurisdictions did not achieve GDA94 compliance for a large percentage of 'major' datasets until 2003. It was recognised organisations (public and private) may choose not to ever transform some data to GDA94.

- A jurisdiction reported issues with a major software vendor successfully implementing the NTv2 Transformation Grids – the preferred method for high accuracy transformation between AGD66/84 and GDA94 – in mid-2003.
- Jurisdictions were developing "stand alone" software to undertake the NTv2 transformations in 2003.
- In 2003, ICSM requested GDAIWG investigate how users of transformation software could be advised of its performance. The GDAIWG advised the onus should be on users to satisfy themselves software met their requirements.
- Also in 2003, ICSM requested GDAIWG investigate slow uptake of GDA94 in resource based and social economic datasets. GDAIWG determined that is was primarily due to lead agencies still being in the process of converting all their datasets to GDA94 and the spatial accuracy of these datasets was so low, or boundaries so fuzzy, that datum was irrelevant.
- Polling of private sector organisations in 2003 revealed most planned to convert to GDA94 prior to the end of 2004, some in 2005; that many would move to GDA94 on an incremental basis, e.g. as new projects started or upon client request; and conversion did not occur until after GDA94 adoption by lead agencies.

2.3. Summary of GDA94 Implementation Review

The key learnings revealed by the desktop review of GDA94 implementation, indexed with the DR prefix, are described in Table 2-3.

DR Index	Description
DR1	**Clear statement of intent** There were clear statements about the intent to adopt a new datum at the commencement of the process.
DR2	**GDA94 implementation project plan not developed** There was never a formal project team established and national project plan developed for the implementation of GDA94. The national implementation was achieved by deploying tasks amongst the existing ICSM permanent committees supported by the creation of ad hoc working groups.
DR3	**Measureable implementation targets not developed** There does not appear to have been any formal GDA94 compliance targets on the major datasets or a strategic approach to measuring this and conveying progress to all spatial stakeholders ('GDA94 compliant' was defined as meaning data was stored with GDA94 coordinates, or in a system that was capable of both importing and exporting data based on GDA94).
DR4	**Early focus on technical functions** The initial focus was in relation to a range of the core technical tasks – the backbone of the GDA94 was established by 1994 and the defining parameters gazetted.
DR5	**GDA94 promotion Working Group established** A working group solely focussed on the promotion of GDA94 was established approximately eighteen months prior to its formal 'adoption'.

DR Index	Description
DR6	**Important legal and technical functions not settled until just prior to GDA94 adoption** Shortly before the formal adoption of GDA94, ICSM was undertaking important deliberations on critical legal considerations and essential technical aspects. For instance, the decision to develop dual national NTv2 Transformation Grids between AGD and GDA94 was decided in October 1999.
DR7	**GDA94 adoption effectively commenced on 1 January 2000** The 'adoption' date of 1 January 2000 was effectively the commencement date of the implementation of the datum. For instance, some jurisdictions did not make 'major' datasets GDA94 compliant for three years or more.
DR8	**Promotion and Implementation Working Groups not linked** The GDA Promotion Working Group (GDAPWG) and GDAIWG were two distinct entities, whose operations did not overlap. The operations of the GDAPWG did span the period either side of the 'adoption' date. In contrast, the GDAIWG, whose focus was on the process and success of implementation, was not established until fifteen months after the formal adoption of GDA94 as the national datum of Australia.

Table 2-3 Key Learnings from Desktop Review of GDA94 Implementation

3. Feedback from Australian Spatial Sector

3.1. Background

PCG and CRCSI members publicised the first version Datum Modernisation Roadmap at numerous national and international spatial sector events between 2012 and 2014. There were presentations in all Australian jurisdictions.

New South Wales Land and Property Information (LPI) held a datum user workshop in October 2012. Invitees representing a broad cross section of the spatial professional met for two days with an objective of determining feedback for ICSM on the first version Roadmap. The Office of Surveyor General Victoria held a similar one day event in September 2013, whilst the Northern Territory Department of Lands, Planning and Environment held an open invitation workshop in May 2013 that recorded a series of responses to pre-advised questions about ‘datum change’. The proceedings at these events were recorded in individual unpublished summaries forwarded to the PCG.

Presentations followed by an open forum soliciting feedback were conducted at the Association of Public Sector Surveyors (APAS) conference in Canberra in March 2013, the national Surveying and Spatial Science Conference in Canberra in April 2013, and the TASSIC Spatial Information day in Hobart in October 2013.

The full list of formal events is outlined in Appendix A.

PCG and CRCSI members also sought feedback informally through discussions at conferences and meetings and via email.

3.2. Comment on User Feedback

The different methods adopted to gather feedback resulted in a wide variety of opinions being expressed and the level of detail in responses varying considerably. For example, during the Victorian Office of Surveyor General workshop participants commenced consideration of where certain types of spatial data should be transformed – at the repository by the custodian or on-the-fly by the client application. In contrast, responses at some information presentations consisted of a simple acknowledgement of the work being undertaken followed by a request to be kept fully informed of all developments. However, a number of themes did emerge and they are summarised in **Section 3.3**.

An important observation about the feedback on user needs is that it is only derived from the spatial sector. **Section 4 Ubiquitous Positioning** looks at the requirements of other users.

3.3. Summary of Feedback

The important messages and queries arising from the consultation with the spatial sector on the first version Datum roadmap are summarised in Table 3-1 and indexed with the CS prefix.

CS Index	Description
CS1	**Do-Nothing was not seen as a viable option.** There was strong agreement that GDA94 in its current form was incapable of meeting the requirements of all future positioning stakeholders, since it includes large distortions when realised by traditional survey ground control, lacks rigorous accuracy estimates and will be offset from ITRF by around 1.8 metres in 2020.
CS2	**A statement about the necessity for datum modernisation was needed.** Feedback indicated a clear statement outlining the need for datum modernisation and the reasons behind the proposal chosen should be developed by ICSM and ANZLIC, and government decision makers at all levels should be alerted to the statement to provide a 'mandate' for datum change. It was noted the technical requirement for a modernised datum was unlikely to be sufficient to facilitate immediate change within some organisations without a high level policy and / or business driver.
CS3	**Concern was expressed about the cost associated with a datum change – who pays?** There was considerable concern expressed about how the costs associated with datum change would be met by organisations, particularly given the noted disconnect between technical requirements and business drivers (CS2). The main source of these costs was considered to be general education, staff training and software / database upgrades. However, there was little acknowledgement that many of these costs would be an issue irrespective of datum change due to the need to respond to the effects of ubiquitous accurate GNSS positioning (see **Section 4 Ubiquitous Positioning** and **Section 6.3 Comment on Costs Associated with GDA94 Modernisation**).
CS4	**Implementation should be coordinated and driven at a national level.** A consistent and authoritative national approach to the implementation of the datum modernisation process was requested. This included a comprehensive promotion and awareness campaign to complement the development of the technical resources.
CS5	**The level of understanding relating to the technical elements of datum and reference system implementation was noted as highly variable across the spatial sector and general education resources were required.** An education program about datums, reference frames and coordinate systems - specifically the creation of soft resources explaining concepts in non-technical terms - was viewed as a fundamental element of the implementation of a new spatial reference system. Feedback indicated it was required in support of a new static epoch datum but was noted as particularly critical for implementation of a time dependent reference frame. This observation reflects the distribution of spatial data across a large population of spatial data managers with varying levels of geospatial training, in particular with regard to geodetic theory. In contrast, for GDA94 implementation custodianship of spatial data was concentrated in relatively few organisations.

CS Index	Description
CS6	**Concern was expressed over the use of "GDA" in the name of a modernised datum and "MGA" for the projection of the modernised datum.** The varying level of understanding about datums, reference frames and coordinate systems (CS5) combined with the historical tendency to use these acronyms without a date qualifier resulted in a body of opinion that retention of "GDA" and "MGA" for the new plate-fixed datum was dangerous and would result in widespread confusion of GDA94 coordinates with GDA2020 coordinates.
CS7	**Current Commercial Off-The-Shelf (COTS) software support for a time dependent reference frame was virtually non-existent.** Most GIS and CAD software does not currently allow for transformations to a time dependent reference frame where 1.0 metre accurate data sets are concerned. The typical approach in relation to time dependent reference frames such as WGS84 or ITRF has been to apply "constant" transformation parameters that generally ignore the time dependency. For small scale mapping and thematic GIS products this approach is satisfactory as the time variations are insignificant in relation to the resolution of the data.
CS8	**Software support for transformation from GDA94 to a new datum and/or reference frame regarded as essential to maximise adoption rates.** It was noted COTS software must support officially developed transformation techniques if there was to be widespread adoption of a new datum or reference frame. Engagement with software developers should be included in the implementation process and technical tools developed by ICSM must be on code base or grid format that is supported by COTS software.
CS9	**Spatial stakeholders need to address the metadata held with spatial information.** In an era where location information from high accuracy, time dependent location systems (e.g. GNSS) proliferates, managers of geospatial data need to specifically include metadata concerning the reference frame (or datum) and epoch of measurement as well as a statement or classification of its accuracy. This metadata needs to be considered an integral attribute of all location datasets. Awareness of this issue needs to be immediately addressed as it not only relates to spatial data captured in the future – the attributing of legacy datasets will need to be undertaken for society to properly realise the benefits of accurate location data.
CS10	**Proposed 2015 adoption date regarded as overly optimistic.** When first canvassed in 2012 and 2013 the nomination of 2015 for adoption of a new plate-fixed datum was regarded as unachievable. In part, this stemmed from the misconception that 2015 was intended as the year in which a new national datum should be fully 'adopted', rather than the starting date for implementation of a new datum that would be adopted over a period of time.
CS11	**The timing of implementation of a modernised datum will vary.** It was stressed that the timing of change to GDA2020 for each and every organisation or entity would be driven by a variety of factors. Technological capacity and datum availability were two key aspects but human resourcing, budget, types and scale of data managed, client requirements, the stage of projects and general attitude to change were some others.

CS Index	Description
CS12	**Level of understanding of the implications of 'ubiquitous positioning' was mixed.** Feedback indicated that knowledge of the practical implications of the widespread availability of 0.5m accurate (or better) real-time GNSS positioning was varied. This possibly reflected variation in the level of understanding of datum related technicalities as well as an absence of knowledge about the predicted availability, and adoption rate, of accurate positioning (refer **Section 4 Ubiquitous Positioning)**.
CS13	**How will legal traceability be achieved for a time dependent reference frame?** Stakeholders were satisfied with the response that the National Measurement Institute (NMI) did not foresee any technical issue given velocity is an SI unit.
CS14	**What are the legal implications of adopting a new time dependent reference frame?** Questions were raised on how time dependent reference frames will be described in legislation, regulations or policies and whether impacts on existing legislation, regulations and policies had been considered.
CS15	**What are the plans for the Australian Height Datum (AHD)?** As the proposed new plate-fixed datum and subsequent reference frame were three dimensional, queries were raised about future intentions for AHD. In particular, long term retention of the AHD was seen as undesirable given the increasing use of GNSS for determining relative height differences. Deformation modelling was nominated as an important inclusion in the technical considerations for a modernised height reference system.
CS16	**What is happening internationally in relation to the adoption of time dependent reference frames by other nations or regions?** Spatial stakeholders inquired as to whether there were any other examples of existing or proposed national or regional time dependent reference frames.

Table 3-1 Key Spatial Sector Messages and Queries on First Version Datum Modernisation Roadmap

4. Ubiquitous Positioning

The modernised national positioning reference system must cater for the requirements of the new classes of users envisaged due to the forecast emergence of 'ubiquitous' positioning. This section provides a brief outline of those predicted requirements.

4.1. Spatial Technology Trends

The emergence of 'ubiquitous' positioning is inexorably linked to the general trend towards a complete digitisation of society, summarised by Woodgate *et al* (2014) [9]. Digital technology developments such as Big Data, the Internet of Things (IoT), crowd sourcing, smart cities, 3D printing, Augmented Reality (AR), Virtual Reality (VR), Artificial Intelligence (AI) and Machine-to-Machine (M2M) communication will transform virtually every aspect of civilisation. Iansiti and Lakhani (2014) illustrate the impacts of this so called 'digital ubiquity' using a number of commercial examples [10]. The smartphone and its ability to provide mobile, real-time connectivity is central to this digital revolution.

Impacts of digitisation on the geospatial world resulted in the United Nations Committee of Experts on Global Geospatial Information Management (UN-GGIM) releasing a report titled ***"Future trends in geospatial information management: the five to ten year vision"*** in July 2013 [11]. The report collates the predictions of a range of experts from across the geospatial community on those future trends. Some that particularly affect delivery of a national datum or reference frame include:

- Increasing real-time positional accuracy availability and demands.
- Integrated positioning solutions available to a broad user community.
- Mobile mapping systems becoming greatly enhanced.
- Open source solutions for spatial software and data becoming a viable substitute to proprietary alternatives.
- Widespread reliance on M2M communication of spatially linked data - for instance, to enable the realisation of the IoT.
- Increasing use and reliance on real-time data in the decision making process across multiple sectors, including the general public.

The trends are also examined by the European Global Navigation Satellite System Agency (GSA) "***GNSS Market Report***" series which provide a comprehensive review of global GNSS trends and applications and include market analyses by use sector and world region [12]. The report methodology notes that assumptions are based upon expert opinions and model predictions are checked against the most recent independent market research before being validated iteratively through consultation with sector experts and stakeholders.

The first report was published in October 2010 and the predicted GNSS market by sector in the latest report (Issue 4, published in March 2015) is consistent with earlier versions [13]. Real-time applications in the Location Based Services (LBS) and transport segments are expected to contribute over 93% of GNSS market revenues in the period 2013 to 2023. The predicted market revenues are illustrated in Figure 4-1 and reflect the dominance of smartphones and in-vehicle devices supporting location aware applications.

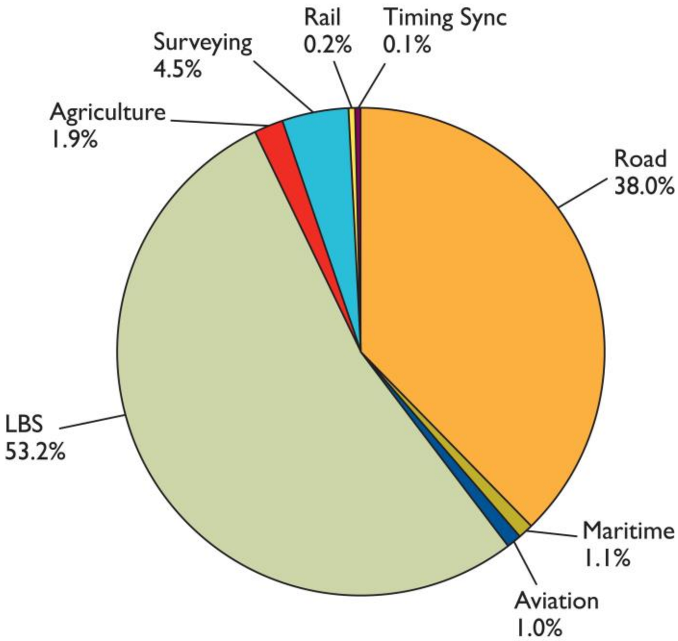

Figure 4-1 Cumulative Core Revenue 2013 - 2023 (European GNSS Agency, 2015) [13]

Notable predictions from the report that will impact national reference frames include:

- GNSS, most commonly via smartphones, will remain the main source of outdoor positioning information and by 2019 it is estimated there will be one GNSS device per person on the planet. That ratio is estimated to be reached in Australasia by 2023.
- As the main source of outdoor positioning GNSS will be increasingly combined with an array of other sensors to deliver an earth-located ubiquitous position no matter which technology was involved in its determination.
- Autonomous (driverless) vehicles, utilising in-vehicle GNSS systems in conjunction with other sensors, are close to being realised in the production environment and this will grow the accurate GNSS market.
- App downloads that rely on positioning data will reach 7.5 billion by 2019, up from 2.8 billion in 2014 and there is high potential for start-up and Small Medium Enterprise (SME) application developers using location data.
- Smartphones will enable users to become map creators and it is envisaged that the focus will soon shift to high accuracy smartphone uses. This will benefit a wide range of enterprise users including those in traditional spatial sector roles like surveying and mapping but also less traditional and now mainstream functions including agriculture, construction and land management.

- In particular, it was observed that high-end smartphones utilising the new signals from multi-constellation GNSS will actually replace some specialised devices dedicated to professional measurement applications.
- Real-time Precise Point Positioning (PPP-RT) in low priced GNSS receivers will soon emerge as an alternative to Network Real-time Kinematic (NRTK) or RTK GNSS positioning for surveyors and others seeking decimetre or better accuracy.

The relevance of the PPP-RT prediction is highlighted by a recent CRCSI announcement. Issue 47 of the CRCSI EDM bulletin outlines the ongoing research collaboration between Australia and Japan, funded entirely by the Japanese government, which has recently demonstrated the Japanese Quasi-Zenith Satellite System (QZSS) could soon deliver sub-decimetre PPP-RT services anywhere, anytime across the Australian continent [14]. Currently there is only one operational QZSS satellite which provides part day coverage but the QZSS launch schedule published by the Japanese indicates three additional satellites will be launched in 2017. This will potentially lead to 24/7 QZSS PPP-RT coverage over the whole of Australia during 2018.

The RTK GNSS market is also undergoing significant change in response to the entry of Chinese manufacturers and users. Divis (2014) from *Inside GNSS* reported on an expert panel discussion from ION GNSS+ 2014 in Tampa, Florida where the CEO and President of Chinese manufacturer *Wuhan Navigation and LBS, Inc* predicted that the price for high precision RTK modules would fall to $100 by 2020 [15].

The combination of modernised, multi-constellation GNSS, technological improvements in GNSS receivers and market growth will inevitably lead to the development of 0.5m accurate GNSS positioning and subsequently 0.1m accurate (or better) positioning in consumer priced GNSS receivers. Based upon the current trends, expert predictions suggest delivery of these capabilities sometime before 2023, possibly as early as 2020.

The presence of GNSS in smartphones and vehicles will quickly result in accurate GNSS positioning becoming an omnipresent utility within society. The default reference frame for these GNSS real-time positions will be ITRF.

4.2. Demands on the Australian Spatial Reference System 2020-2023

Hausler (2014) estimated that there were no more than five thousand subscribers to NRTK services in Australia and by extrapolation deduced that the total of GNSS centimetre accurate positioning users was unlikely to exceed twenty three thousand, or one percent of the Australian population, in 2014 [16]. Recent enquiries affirmed this number as a reliable upper estimate of Australian centimetre accurate positioning users and also that the total number of DGNSS users achieving sub-metre accuracy was unlikely to exceed this figure. For the purpose of the following comparison it is therefore assumed that no more than fifty thousand Australians are currently utilising GNSS technology that determines locations with accuracy equal to or better than 0.5 metre and that perhaps half are employed in the spatial sector. The majority (but not all – refer to **Section 1.6**) are estimated to have sufficient knowledge, or be using particular techniques, to ensure these locations are relative to GDA94 datum.

Smartphone market analyses may be utilised to estimate the potential population of Australian consumers using positioning capability in smartphones. Research company Telsyte identified there were 16 million smartphones in Australia at the end of June 2014 and estimated that 5.6 million new units would be sold in the last 6 months of 2014 [17]. Deloitte also conducted an Australian mobile consumer survey in 2014 that showed 58% of smartphone owners changed their device twice in the previous 5 years and 26% switched three times whilst 73% indicated that they would move to a more frequent upgrade cycle in the next five years [18]. Numerous national and international studies estimate that smartphones will be in common usage by 80% of the Australian population by 2020.

Accepting this research, it is realistic to predict that approximately five million Australians will replace their smartphones with a new model within six months of accurate GNSS becoming a standard feature – for instance by PPP-RT. If 50% of new models had this feature and only 2.5% of users adopted accurate positioning (refer to **Section 6.2 Diffusion of Innovation** for a discussion outlining the significance of the 2.5% value) this could result in over sixty thousand Australian smartphone users utilising 0.5m (or 0.1m) accurate GNSS ITRF locations within six to twelve months.

The raw numbers predicted for smartphone users, without specific consideration of other market sectors such as transport, occasions the inescapable conclusion that the spatial sector (or 'expert community') will be a minority user group of the reference frame for accurate global positioning soon after accurate consumer priced GNSS is realised.

It follows that the majority of accurate positioning will be undertaken by stakeholders with no knowledge of datums, reference frames, coordinates or projections. Consumers, and indeed most non-expert users of positioning services, are typically interested in 'location' rather than the 'coordinates' of their location, which may be relative to other user measured 'locations' and / or features represented in spatial data sets on national or global reference frames. This characteristic is illustrated by the trend for on-line mapping services to not display coordinates on the map interface.

Smartphone Apps that rely on positioning data are consistently amongst the most popular App downloads. The truly international nature of App development combined with the increasing availability of open source, non-enterprise solutions indicates it is unrealistic to expect the coding of transformations between plate-fixed datums and time varying reference frames to be appropriately dealt with for every national datum by every App.

For Australia's national spatial reference system to meet the requirements of the majority of GNSS users the clear implication is that by around 2020 it should be capable of relating accurately measured locations in ITRF to accurate datasets in the national datum in real-time for users with no knowledge of, or interest in, spatial reference systems.

4.3. Australian Initiatives Utilising Accurate Positioning

The availability of accurate GNSS supported positioning in consumer devices will result in a cavalcade of ad-hoc uses but there are also current Australian programs that rely upon accurate positioning and virtual world models for their full potential to be realised.

ANZLIC's Foundation Spatial Data Framework (FSDF) is an initiative aimed at improving the efficiency and effectiveness of spatial data management that will help facilitate a location enabled society. Spatial data with similar characteristics has been grouped into ten themes that include a dataset profile and a roadmap for future development [6]. Themes with a current long term goal for 1.0 metre accurate location in urban areas include *Administrative Boundaries* and *Land Parcel and Property Boundaries.*

In December 2014 ICSM's Spatial Information and Delivery and Access (SIDA) working group conducted a survey to understand jurisdictional readiness for access to the FDSF data sets. Jurisdictions were requested to estimate the percentage of their land parcel and property boundary data sets in several positional accuracy categories. The nationally aggregated percentage estimates from the SIDA survey are as follows [19]:

- Survey accurate coordinates 25%
- Transformed with estimated position accuracy +/-1 metre 10%
- Transformed with estimated position accuracy +/-5 metre 8%
- Transformed with estimated position accuracy +/-10 metre or greater 16%
- Digitised map representation 19%
- Other 22%

An existing example of online delivery of property boundary lines attributed with positional accuracy is the *Boundary Lines with Accuracy* layer within the Land Information System Tasmania (LIST) service. The layer indicates the origin of boundary lines using colour coded categories which provide a general indication of the positional accuracy – Figure 4.2 shows the layer legend from LISTmap.

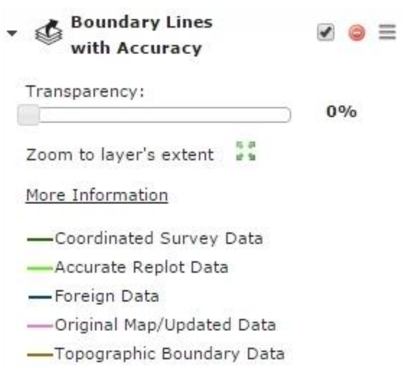

Figure 4-2 Legend for LISTmap *Boundary Lines with Accuracy* Layer

Figure 4-3 is a LISTmap screen capture of the *Boundary Lines with Accuracy* layer in the Tasmanian suburb of Midway Point.

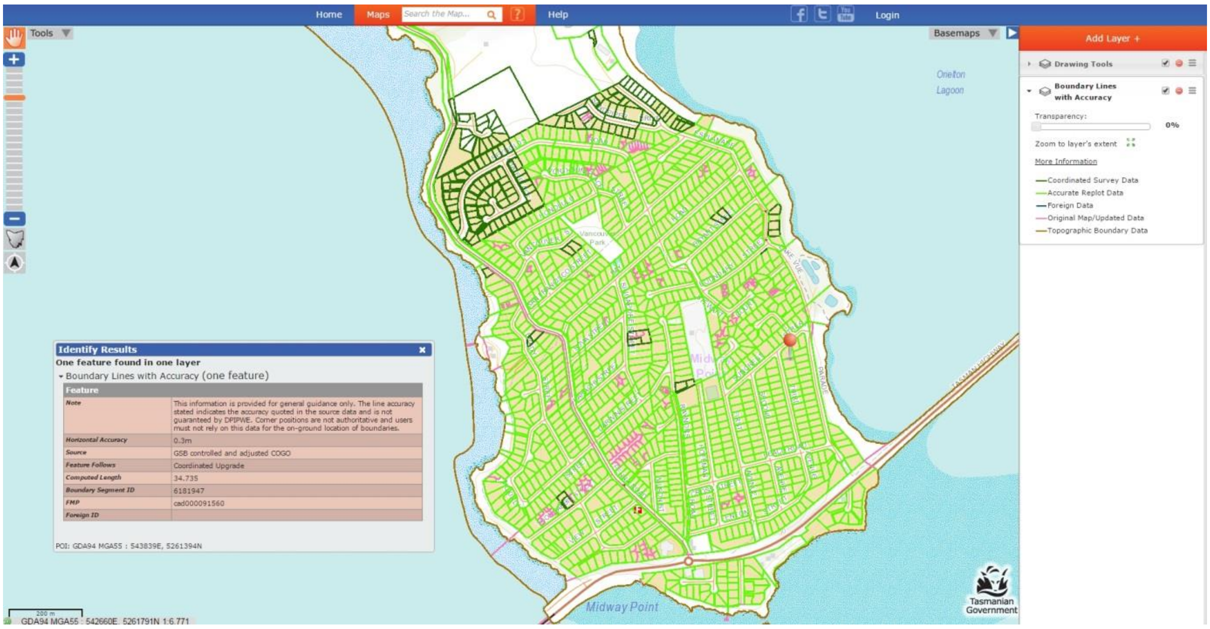

Figure 4-3 Tasmanian Boundary Lines with Accuracy Layer, LISTmap

The estimated horizontal location accuracy of each individual boundary line is one of the attributes of the layer, demonstrated in the Identify Results query window displayed in Figure 4-4.

Identify Results

One feature found in one layer

Boundary Lines with Accuracy (one feature)

Feature	
Note	This information is provided for general guidance only. The line accuracy stated indicates the accuracy quoted in the source data and is not guaranteed by DPIPWE. Corner positions are not authoritative and users must not rely on this data for the on-ground location of boundaries.
Horizontal Accuracy	0.3m
Source	GSB controlled and adjusted COGO
Feature Follows	Coordinated Upgrade
Computed Length	36.298
Boundary Segment ID	6183340
FMP	cad000091581
Foreign ID	

Figure 4-4 Query Result from LISTmap *Boundary Lines with Accuracy* Layer

These examples indicate there is already opportunity for professional and consumer users to utilise survey accurate *Land Parcel and Property Boundaries* spatial data in conjunction with accurate real-time GNSS positioning. Ongoing jurisdiction efforts to upgrade Digital Cadastral Data-Bases (DCDB's) will result in an increase in these opportunities.

Cadastre 2034 released by ICSM in 2015 describes a vision for cadastral systems, including DCDBs, in Australia and outlines a high level strategy to guide jurisdictions in meeting that vision. It explicitly acknowledges the requirement for Australian datum modernisation to accommodate time dependent positions [20].

In addition, other FSDF themes that will include large amounts of data where accurate GNSS locations are readily utilised include *Elevation and Depth* (in support of the increasing availability and applications of regional LiDAR data), *Transport* (in support of Intelligent Transport Systems and automated parking) and *Imagery* (to maximise benefit from high resolution capture programs).

An attempt to develop uniform, national datum referenced locations of underground assets via Australian Standard *AS 5488-2013 Classification of Subsurface Utility Information,* is an example of a current non-FSDF initiative that will benefit from widespread availability of accurate GNSS positioning.

The reference system for spatial data within Australia is the GDA94 datum and so mapped feature locations – hardcopy or digital - are normally delivered to consumers in GDA94 coordinates. In the above instances failure to resolve the differences between real-time ITRF GNSS positions and GDA94 based spatial data sets in an automated fashion (no user involvement) is likely to result in confusion, frustration and potential conflict amongst stakeholders but more importantly realise an unquantified opportunity cost.

4.4. National Positioning Infrastructure

The Australian Government is developing a strategy for improving the national Positioning, Navigation and Timing capability (PNT). The Position, Navigation and Timing Working Group (PNT-WG), chaired by Geoscience Australia (GA), and reporting to the Space Coordination Committee, has been established. It is responsible for a coordinated, whole of government approach to achieve a vision of "..instantaneous, reliable and fit-for-purpose PNT anywhere and anytime across the Australian Landscape and beyond." [21]. In December 2014, the National Positioning Infrastructure (NPI) Advisory Board (NPI-AB), consisting of ten permanent members from government (outside of GA), industry and academia was established to advise GA on aspects associated with developing and implementing a NPI. This new governance structure and coordination effort can only improve the prospect of an Australia wide accurate positioning paradigm.

For instance, following on-going discussions with the Australian and New Zealand governments, Thales Australia and Thales Alenia Space co-sponsored a workshop during March 2015 for invited Australian and New Zealand participants to outline the potential for an Australasian Space Based Augmentation System (SBAS) that would satisfy aviation, and other sector requirements [22]. It does not appear unreasonable to predict an SBAS service under sovereign control similar to EGNOS in Europe will eventually operate in Australia. Such a service would inevitably operate in ITRF to comply with aviation requirements.

4.5. Summary of Ubiquitous Positioning Implications

The implications of ubiquitous positioning outlined in the preceding sections are summarised in Table 4-4, indexed with the UP prefix.

UP Index	Description
UP1	**Once accurate positioning is available in consumer level technology it will become widely utilised extremely quickly.** The abundance of smartphones (and ultimately in-vehicle guidance) in Australian society will ensure that an adoption 'tsunami' of accurate positioning will transpire.
UP2	**The majority of 0.5m – 0.1 m accurate real-time positioning undertaken between 2020 and 2023 is likely to be performed in the time varying ITRF.** Consumer devices will inherently measure locations, either by GNSS directly or via GNSS in combination with other linked measurement sensors, in ITRF.
UP3	**Ideally a system that resolves the non-equivalence between the national datum (currently GDA94) and ITRF/WGS84 for accurate spatial datasets should be implemented before accurate positioning becomes ubiquitous.** As a consequence of the estimated number of stakeholders who will utilise accurate location services, it is desirable to implement a modernised spatial reference system before accurate consumer positioning becomes available. In practice this means real-time GNSS measured positions and accurate spatial datasets are either in reference frames that are in very close alignment or are able to be easily related to one another in the same reference frame.
UP4	**Machine to Machine (M2M) communication of accurate locations with little or no manual intervention will become extremely common and will require well developed protocols and techniques.** Protocols and tools that correctly apply the transformations between datums and / or reference frames and also support M2M communication are essential before a time dependent reference frame would be successfully implemented by the majority of spatial stakeholders.
UP5	**The process developed to accommodate ITRF real-time locations and GDA94 spatial data sets should generally resolve the issues at the point of supply for consumers.** The general user must be protected from the complexity associated with transforming data between reference frames, i.e. assume the overwhelming majority of positioning stakeholders will have a need to accurately locate themselves in relation to mapping data sets but will have minimal awareness of datums and the techniques needed to transform between plate-fixed datums or time varying reference frames. The number and varied origin of Apps, tools and hardware predicted to be developed in the next ten years means it is unrealistic to assume the majority of consumer devices will appropriately handle these transformations.

Table 4-3 Ubiquitous Positioning Implications

5. International Datum Modernisation Considerations

The emergence of ubiquitous positioning is an international phenomenon and accordingly it is useful to consider some other current responses by national, regional and standards bodies as to the implications for modern spatial reference frames.

5.1. ISO/TC 211 Standards

The International Standards Organisation Technical Committee 211 Geographic information / Geomatics (ISO/TC 211) is responsible for the ISO geographic information series of standards.

ISO/TC 211 aims to establish a structure for information concerning the location of objects or phenomena relative to the Earth. In particular, the series includes standards for data management (including definition and description) as well as specifications for accessing, presenting and transferring the data in digital/electronic form between different users, systems and locations [23].

A number of ISO/TC211 projects are underway or planned that aim to modernise the relevant ISO geographic series of standards so that they easily accommodate reference frames with time varying coordinates. The main projects relate to:

- ISO/IS19135 Geographic Information – Procedures for item registration.
- ISO/TR19161 Geodetic References.
- ISO/TS19127 Geographic Information – Geodetic codes and parameters.
- ISO/IS19111 Geographic Information – Spatial referencing by coordinates.

International Standard (IS) 19135 specifies procedures to be followed in establishing and maintaining registers of unique identifiers and their meanings relating to geographic information - for instance, a register of datums and reference frames. IS19135 is currently under revision and the target date for completion of the revised standard is June 2015 [25].

Technical Report (TR) 19161 is a project investigating issues concerning standardisation of requirements related to geodetic references as viewed by various user communities. The Technical Report is due in June 2015.

Technical Standard (TS) 19127 defines rules for the creation and maintenance of a register, or database, of geodetic codes and parameters that comply with IS19135 and IS19111. These registers provide simple, uniform descriptions of geodetic datums or reference frames that are utilised by software to support spatial referencing by coordinates and the transformations between different reference frames. The EPSG registry is an example of a free database maintained on a best effort basis by the Geomatics Committee of the International Association of Oil and Gas Producers (OGP).

ISO TC/211 has a current project to create a validated, authoritative ISO registry of international scope under TS19127. Australia is a permanent member of the Control Body for the Registry of Geodetic Codes and Parameters formed to validate the content of the ISO register under construction and ISO compliant sections of external registers. A review of TS19127 was recently commenced and according to the ISO/TC 211 Programme of Work IS19127 is scheduled for release in June 2017 [24].

The Control Body for the Registry of Geodetic Codes and Parameters has also identified that ISO/IS19111 – Spatial Referencing by Coordinates will require revision to enable it to readily describe time varying horizontal and vertical reference systems. The Control Body recently recommended that a group of international experts meet in June 2015 to workshop the requirements before a new work item to revise IS19111 is proposed to ISO/TC 211 (J Dawson, personal correspondence April 2015).

Modernisation of relevant ISO/TC211 standards will enable time dependent reference frames to be included in COTS software products in a straightforward manner and provide the basis for their legal implementation. Modernisation will also deliver a framework for the development of resource and educational material that supports the implementation of modern reference frames.

Based upon the current status of the ISO/TC work programme, it seems likely that this group of projects will be completed prior to 2020, although COTS software providers may require a further period of time to implement these new standards.

5.2. New Zealand

The official geodetic datum of New Zealand is NZGD2000. Land Information New Zealand (LINZ) is the agency responsible forNZGD2000 which is a ‘plate-fixed’ datum. However, in order to address the movement and deformation that occurs within New Zealand (since it straddles the Australian and Pacific tectonic plates) deformation models are developed and applied to the datum to accommodate the movement and trace positions back to a common epoch (2000) [25].

LINZ has been progressively modernising NZGD2000, largely in response to earthquakes that result in significant land movements. Accordingly there have been several versions of NZGD2000. LINZ considers that this gradual approach to modernisation is working well and that the datum is able to meet the needs of users in a dynamic environment. (N. Donnelly, personal communication April 2015).

LINZ is planning to modernise the New Zealand vertical reference frame with the collection of a national airborne gravity dataset which will be used to compute an improved geoid model. Modernisation of both the horizontal and vertical reference frames will continue in the coming years, driven by the ten-year goals of the New Zealand Positioning Strategy released in 2014. (N. Donnelly, personal communication April 2015).

5.3. United States of America

2010 Federal Geospatial Summit

In 2010 National Geodetic Survey (NGS), the agency responsible for America's National Spatial Reference System (NSRS), held a federal geospatial summit to outline high level plans to replace the existing American horizontal (NAD83) and vertical (NAVD88) datums in 2022 [26]. These plans have since been developed in accordance with the NGS Ten-Year Strategic Plan 2013-2023 [27].

The proceedings of the 2010 summit include extensive detail of the actual discussions in order to convey the nature of the interactions between NGS and the stakeholders to provide greater context to the feedback [28].

During the summit NGS articulated a proposal for a new datum described as a 'semi-dynamic' where control coordinates were fixed at an epoch (a 'plate-fixed' datum) but whose velocities were known and available to the community to use if desired and distortions detected in the control network would be corrected on an ad-hoc basis.

The main themes to emerge from the 2010 summit were:

- Stakeholders should understand why the datums needed to change.
- NGS should expect to expend considerable effort to implement new datums – both in a technical and organisational sense.
- Most spatial stakeholders (circa 2010) cared more about 'relative' location accuracy than 'absolute' (global) accuracy.
- NGS should develop and provide support tools in advance of adoption of the new datums.
- It must be understood that there will always be slow (no) adopters of the new datums.
- The key criterion to successful implementation would be communication.

Similar sentiments were expressed during the Australian workshops in 2012 and 2013 and in subsequent feedback to PCG.

2015 Federal Geospatial Summit

NGS held a second summit in April 2015 where it was confirmed that the USA will adopt new national horizontal and vertical reference frames in 2022. The 2022 adoption date accommodates the projected completion of a significant project associated with the definition of the vertical reference frame - the Grav-D project.

The replacement for NAD83 will be a USA-specific reference frame defined by a national CORS network linked to the ITRF that will allow for both plate-fixed coordinates and time varying coordinates depending upon user requirements [29].

The exact detail concerning the new horizontal reference frame (for instance, a recommended epoch for the plate-fixed component) was not confirmed during the summit. NGS advised that this detail was still under consideration.

One summit session included a range of spatial stakeholders delivering brief presentations outlining their thoughts on the NGS proposals, including impacts on their organisations and plans for adoption [30]. The feedback indicated acceptance of the future requirement for time dependent reference frames and attention was focussed on what was necessary to facilitate a successful implementation for each organisation. A presentation from international spatial software provider ESRI indicated they have already commenced development of functionality to support time dependent transformations accommodating secular and episodic motion.

5.4. Europe

In 1990 EUREF, the International Association of Geodesy (IAG) Reference Frame Sub-Commission for Europe, adopted the European Terrestrial Reference System of 1989 (ETRS89) so that it was fixed to the stable part of the European continental plate and coincident with the International Terrestrial Reference System (ITRS) at epoch 1989.0 [31]. Under its definition, for each $ITRF_{yy}$ release, a corresponding frame in ETRS89 can be defined and labelled $ETRF_{yy}$. Thus there are multiple possible realisations of ETRS89, but the ETRF2000 frame is now recommended as the conventional frame for use by European countries [32]. The European plate is moving approximately 2.5 centimetres per year, meaning the coordinate displacements between the current ITRF epoch and ETRS89 realisations are much smaller than those for GDA94.

Europe wide or regional initiatives generally use ETRS89 for all geo-referencing but the approach of individual nations to the use of ETRS89 has varied. Some still use historic national static datums and transform to various realisations of ETRS89. Others have adopted a realisation of ETRS89. The CRS_{EU} web portal describes the European national coordinate reference systems and the transformation parameters between those national systems and ETRS89 [33].

ETRS89 is the current mandated coordinate reference system for the European INSPIRE directive [35]. The INSPIRE Thematic clusters platform, the on-line collaboration portal designed to enable information sharing in support of INSPIRE implementation, includes a Coordinate Reference Systems cluster and the information page summary observes that the current version of ISO/IS19111 does not include an explicit mechanism to readily support exchange of accurate, time dependent geographic information [35].

EUREF is currently addressing technical elements associated with a more accurate time varying reference frame through its working group on deformation models. Established in 2012, the group intends to model inter-plate and intra-plate deformations with a goal that this modelling could ultimately be used to overcome the time dependent accuracy limitations in the current realisations of ETRS89 [36].

5.5. Summary of International Considerations

The key points to note from the scan of some current international efforts to address issues associated with datum modernisation, indexed with the IE prefix, are outlined in Table 5-1.

IE Index	Description
IE1	**ISO/TC 211 Geographic information / Geomatics is currently undertaking a series of projects to modernise the ISO geographic information series of standards to support modern reference frames.** Modernisation of relevant ISO/TC211 standards will enable time varying reference frames to be included in COTS software products in a straightforward manner and provide the basis for their legal implementation. Modernisation will also deliver a framework for the development of resource and educational material that supports the implementation of time varying reference frames. Based upon the current status of the work programme it seems likely that this group of projects will be completed prior to 2020 although COTS software providers may require a further period of time to implement these new standards.
IE2	**The international community is aware of the implications of ubiquitous positioning for national datums and spatial reference systems.** Agencies responsible for national or regional datums are considering modernisation plans – development status is varied and reflects the circumstances applying in each instance.
IE3	**The NGS is well advanced in its preparations for the adoption of time varying reference frames in 2022.** The USA has confirmed its intention to simultaneously implement new time dependent horizontal and vertical frames in 2022. The horizontal reference frame will allow for both plate-fixed coordinates and time varying coordinates depending upon user requirements. A notable element of the NGS implementation is the focus on communication with stakeholders – an often repeated mantra is "communicate, communicate and communicate".
IE4	**Feedback from spatial stakeholders in the USA delivered at the 2015 summit indicated acceptance of the need for time dependent reference frames.** Stakeholder attention was focussed on what was required to facilitate a successful implementation for each organisation. A presentation from international spatial software provider ESRI indicated they have already commenced development of functionality to support time dependent transformations accommodating secular and episodic motion.

Table 5-1 Key Points from International Environment Scan

6. Implementation Considerations

The feedback from the spatial sector highlighted many concerns associated with the process needed to change the national datum and how it would be managed. Datum modernisation will require people to accept new ideas and adopt significant changes to their conventional practice. Specifically, when considering accurate datasets, the non-equivalence of GDA94 and ITRF/WGS84 requires a fundamental change in practice for spatial sector stakeholders ingrained by fifteen years of routine application. Implementation of a new time dependent reference frame will require the acquisition of new knowledge and application of new techniques and tools that are not currently available in most COTS software packages or readily available generally.

It is appropriate that the body of knowledge and techniques relating to project management and change management are utilised for the datum modernisation process. Project management is the application of techniques, tools and processes to implement a change to meet requirements whilst change management is the application of techniques, tools and processes to manage the people-side of change and enable them to more readily accept and adopt the change being implemented.

6.1. Datum Change Essentials

There are many models of change management that may be adopted to assist with implementation of a modernised Australian datum. Factors routinely considered when implementing change include clarity of purpose, transparency, allowing sufficient time, the need to provide resources supporting the change and the requirement to ensure individuals have a feeling of empowerment concerning the future plans.

All models identify that successful communication is critical when implementing change. Tribus (2001) outlines three basic elements for a communication strategy during the change process [37]: *"For change to be successful there needs to be a compelling reason to change, a clear vision of what the change will be, and, a sensible first step."* That is, the communication strategy must address the 'why', 'what' and 'how' of datum modernisation.

Specific conclusions drawn from the spatial sector feedback (see **Section 3.3**) considered in terms of the basic framework above re-inforce the following stakeholder requirements:

- Clarity – communication must address a large range of spatial stakeholders and the message will need to be refined for each (see **Section 6.2**). The initial focus should be on articulating the 'why' to all audiences.
- Transparency – communication should outline the benefits <u>and</u> the problems as well as be specific about the progress.
- Time – sufficient time for implementation must be allowed, accepting that change is generally a process and not a single event. A carefully considered project plan will optimise the utilisation of available time.

- Resources / support – this not only refers to the technical resources providing straightforward implementation but also the provision of 'soft' resources explaining the change. It is important to achieve 'early victories' in relation to the provision of these resources.
- Empowerment – stakeholders need inclusivity.

6.2. Diffusion of Innovations

Those responsible for implementing an 'innovation', defined as a new idea, behaviour or technology, are generally interested in maximising its adoption rate. Fundamental to that aim is the need to understand the factors that influence adoption. The process of adoption of innovations by a population group is a social theory that has been studied and applied for over forty years. Rogers' (2003) diffusion of innovation theory, first proposed in 1962, is one of the most popular for understanding how new ideas and technology are adopted by a society [38]. This framework can be applied to identify how the adoption rate of a new national reference system is maximised in the spatial sector.

Rogers (2003) identifies five adopter categories based upon their tendency to adopt an innovation: innovators, early adopters, early majority, late majority and laggards [38]. The categories may be applied to understand adoption by individuals or organisations. These measures of the 'degree of innovativeness' have been proven to commonly follow a normal distribution when cumulative adopter numbers are plotted over time. Rogers' Innovation Adoption Curve, shown in Figure 6.1, overlays the adopter categories on the normal distribution, applying the accepted relationships between the mean and the standard deviation to estimate approximate percentages of each population category [38].

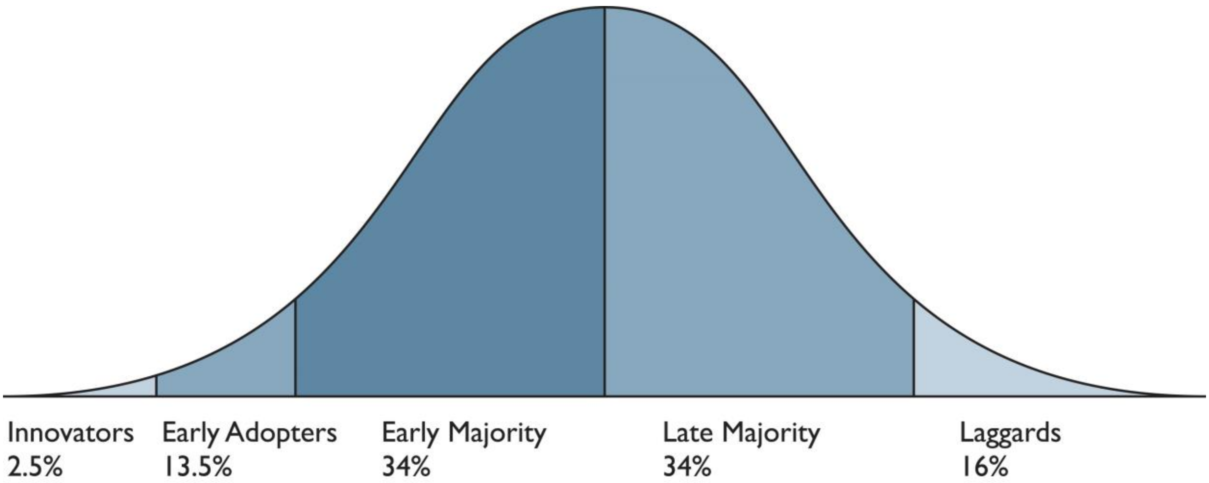

Figure 6-1 Innovation Adoption Curve, adapted from Rogers (2013) [38]

Each adopter category or group has defined characteristics that determine its attitude to adoption of a particular new idea or innovation, whereby an innovation is adopted by a successive group only after it evolves to meet the needs of that group - that is, the membership of each category should be thought of as static. This principle indicates that an attempt to maximise adoption rates by trying to convince the entire population to adopt a new idea or technology is unlikely to succeed. Rather, adoption rates are more readily increased by addressing the different categories of adopters in sequential fashion, using targeted communication and techniques that satisfy their requirements as determined by previous learnings.

For example, according to Rogers (2003) and others the adoption process begins with 'innovators', the small proportion of a population who are risk takers able to cope with a high degree of uncertainty, setbacks and difficulty and do not require any particular support to try new innovations [38]. Adoption rates can be maximised by targeting 'innovators' with early versions and publicising their successes.

'Early adopters' will embrace the innovation when its benefits become apparent. For Rogers (2003), 'early adopters' were generally leaders in their social system and so their experiences were vital to the adoption process, since other members looked to their opinion for confirmation of an innovation [38]. Examples of techniques targeting 'early adopters' include offering face-to-face support for trial resources, and maintaining the relationships, in order to obtain feedback and improvement advice with regular feedback. Successes should also be publicised.

Similar descriptive characteristics and possible approaches to maximise adoption are described for all groups, including the role of 'change agents'. It is particularly useful to note that the final category of adopter, the 'laggards', can be a formidable and vocal opposition to early adoption efforts.

6.3. Comment on Costs Associated with GDA94 Modernisation

Spatial stakeholders indicated that cost of implementation of a new spatial reference system was a major concern. This is understandable since it is normal for there to be an up-front cost associated with change. A benefit-cost assessment is not a component of this report but it is possible to provide two general comments relating to the apparent cost of datum modernisation.

Firstly, it is obvious that there will be an implementation cost associated with the ubiquitous positioning paradigm regardless of any official change to the national datum. Spatial stakeholders will need to fund staff training and software/database upgrades to respond to the requirements of ubiquitous accurate GNSS positioning regardless of any action in relation to the national datum (see **Section 4 Ubiquitous Positioning)**.

Secondly, many stakeholders recalled there was a 'significant' cost accompanying the implementation of GDA94 and undoubtedly associated modernisation of GDA94 with this previous experience. Feedback from spatial stakeholders indicated that the expressed 'significant' cost of GDA94 implementation often related to amendments to hard copy maps and updates to data held only in this form. Differences in relation to the proposal to modernise GDA94 are twofold, namely small scale datasets and cartographic maps will be virtually unaffected by the process since the magnitude of the transformation distance required is not readily detectable and digitisation of society is resulting in the removal of many hardcopy mapping products from production.

6.4. Summary of Considerations

Consideration of project and change management techniques along with strategies to encourage adoption outlined in the preceding sections are summarised in Table 6-2 (indexed with the IC prefix).

IC Index	Description
IC1	**Datum modernisation is not just about a change in technology and technical requirements – first and foremost it concerns change in human knowledge, behaviour and practices.** The datum modernisation project involves implementing change in conventional practices and techniques that requires people to accept and apply new ideas. In particular, implementation of a time dependent reference frame will require the acquisition of new knowledge and application of new techniques and tools that are not currently available in most COTS software packages or even readily available generally.
IC2	**Apply project and change management techniques to datum modernisation implementation.** The body of knowledge and techniques relating to project management and change management should be utilised for datum modernisation. Project management is the application of techniques, tools and processes to implement a change to meet requirements whilst change management is the application of techniques, tools and processes to manage the people-side of change to enable them to more readily accept and adopt the change.
IC3	**Communication is critical to the successful implementation of a change project.** Communication should address the "why", "what" and "how" of datum modernisation for all stakeholders. A simple framework to apply to communication efforts is that it should provide clarity and transparency, address timelines, deliver resources / support and afford stakeholders with a feeling of empowerment. The basic delivery principle to follow is "communicate, communicate and communicate. Upon completion of that communication effort, communicate a bit more."
IC4	**Adoption of a new idea or technique spreads sequentially through a population.** Under well-established social theory members of a population may be grouped based upon their degree of innovativeness. It has been demonstrated that an "innovation" or new idea moves sequentially through a population, passing from group to group. Strategies to increase acceptance of an innovation and therefore adoption rates must therefore target each "group" sequentially.
IC5	**Targeted communication is required.** Different stakeholder or adopter "personalities" require different communication. It is very difficult to successfully address all the adopter groups at the one time with the same message. For example, restricting communication efforts to large assemblies at multi-discipline conferences or other events is problematic as the same message will not resonate with all attendees. These events should only be viewed as an opportunity to provide general information and updates.

IC Index	Description
IC6	**GDA94 implementation and current modernisation efforts are not directly comparable in relation to cost.** The change in data storage and representation from hardcopy to digital between GDA94 implementation and today, the different magnitude of the transformation distance and the inevitable need for change to accommodate the ubiquitous positioning paradigm means care must be taken when using GDA94 implementation as a basis for comparison of cost associated with the current modernisation effort.

Table 6-2 Key Points from Implementation Considerations

7. Concluding Remarks

The primary objectives of the report were to summarise the information considered by the PCG in February 2015 prior to its determination of the revised proposal for Australia's modernised spatial reference system and to develop recommendations for the implementation process.

The disruptive effects synonymous with the digital age may be observed in areas as diverse as business methods or products through to Government regulation and service provision. The availability of ubiquitous accurate positioning will impact all these areas and the report outlines how its anticipated development is driving the requirement for Australia to modernise the national spatial reference system. The future system must support the ability for spatial data sets on the national datum to be closely aligned with GNSS derived ITRF locations in real-time for literally millions of users, with the majority being incapable of manually intervening to enable this. Ultimately this will necessitate the use of time dependent reference frames.

In addition to the impact on the National Spatial Reference System due to the change in distribution of accurate GNSS technology the anticipated rate of that change is an essential consideration in the implementation process. For instance, twenty years after GPS became fully operational and fifteen years since GDA94 was introduced it is estimated there are no more than fifty thousand commercial users of sub-metre accurate GNSS within Australia, many of whom would have been trained in spatial technology and / or have access to a support network of some kind. Realisation of the ubiquitous positioning paradigm is likely to result in this number being surpassed in a time period measured in months by new commercial and consumer users that have negligible formal technical support and little or no training in spatial technology and techniques. This rate of change is problematic given it has been demonstrated that it is likely to require several years for a new national reference system to become widely adopted.

It is evident the spatial sector is absolutely critical to the successful, rapid transition to a modernised Australian spatial reference system. This group will implement the modernised system to enable accurate GNSS ITRF locations to be related to accurate spatial datasets on the national datum and so allow the seamless evolution of a ubiquitous positioning paradigm. Accordingly, the implementation process must encourage the broader spatial community to 'buy in' to its development and execution.

Recommendations for the implementation of an Australian spatial reference system that will meet all stakeholder requirements and minimise the disruptive effects associated with the anticipated rate of change in those requirements are outlined in Section 8.

8. Recommendations

Consideration of the issues and learnings outlined in this report leads to the development of the recommendations in Table 8-1. The "matters addressed" column relates the recommendation to the indexed issues identified in the summary tables in the report.

Index	Recommendation	Matters addressed
R1	ICSM and ANZLIC should determine and clearly document the intention for Datum Modernisation as soon as possible. Stakeholders must be provided with a clear vision including why a particular option was chosen.	DR1, CS1, CS2, CS3
R2	Implementation must be regarded as a process and not an event.	DR3, DR7, CS10, CS11,
R3	The implementation process should be coordinated **and** driven at the national level.	DR2, DR3, CS4, UP1, UP3, IC1, IC2,
R4	The implementation should be treated as a change management process.	CS5, CS6, CS7, CS9, CS11, IC1, IC4
R5	The implementation process should be the subject of a project team and plan.	DR2, DR6, CS4, UP1, UP3, IC1, IC2, IC3
R6	The implementation project should be split into two sub-sections – one dealing specifically with the technical elements and another addressing the practical aspects.	DR4, CS5, CS6, CS10, CS11, CS12, UP1, UP3, IC3, IC4.
R7	The overarching project plan should include conventional project management elements but in particular: • Clear timeframes (start and end points) for the implementation by jurisdictions should be nominated. • Nationally agreed implementation targets for identified key jurisdiction datasets that are measurable and reportable (for example, the FSDF themes).	DR3, CS10, CS11, UP1, IC6
R8	The implementation should aim to enable spatial datasets to be easily represented in close alignment with the GNSS measurement frame (ITRF) by the majority of spatial data managers and custodians at or around 2020 (or prior to the expected introduction of accurate consumer grade GNSS).	UP1, UP2, UP3
R9	Preparation of an overarching communication strategy for the implementation must be a project priority once the intention for datum modernisation is documented.	DR8, CS3, CS4, CS5, CS9, CS12, CS13, CS15, CS16, UP1, UP2, IE3, IE4, IE5, IC3, IC4, IC5, IC6
R10	A general education program incorporating "soft" or non-technical resources is an essential element of the communication strategy.	CS5, CS6, CS12, CS16, UP1, UP2, UP3
R11	The communication strategy should outline how innovation "adopter" categories will be individually addressed.	CS5, CS11, CS12, IC4, IC5
R12	Communication should consider and develop specific implementation guidelines for particular stakeholder types such as cartographers, surveyors, data managers (utilities and mapping data sets) and data custodians.	CS5, CS12, CS9, CS11, IC1, IC2, IC3, IC5

Index	Recommendation	Matters addressed
R13	The use of "GDA" and "MGA" in the new spatial reference system should be a specific item of consideration for the group addressing practical implementation aspects. If used, a communication program outlining how potential confusion will be avoided should be developed.	CS5, CS6, UP4, IC1, IC4
R14	Australia should proactively support ISO/TC 211 efforts to modernise the ISO/TC 211 standards to support time dependent reference frames.	CS5, CS7, CS8, UP1, UP2, UP3, UP4, IE1, IE3
R15	Australia should be proactive in its engagement with software suppliers both before and during the implementation process and technical tools developed by ICSM must be on code base or in a format that is readily supported by software.	CS5, CS7, CS8, UP1, UP2, UP5, IE1, IE2
R16	A review of the legal and regulatory implications of the adoption of a modernised Australian datum should be undertaken prior to the commencement of implementation.	DR6, CS13, CS14, UP1, UP2
R17	The long term future of the AHD should be addressed during the datum modernisation process.	CS15, UP1, UP2, UP4, IE3

Table 8-1 Implementation Recommendations

Appendix A – Workshops, presentations and forums on the Next Generation Australian Datum

Location	Event	Date
FIG	Presentation – FIG reference frames in practice, Italy	May 2012
ACT	Presentation - SSSI ACT seminar	Jun 2012
TAS	Presentation - SSSI state conference	Sep 2012
QLD	Presentation – QLD Surveying and Spatial Conference	Sep 2012
NSW	Workshop – NSW Next Generation Datum Event	Oct 2012
TAS	Presentation – Tasmanian Spatial Industry Council	Feb 2013
TAS	Presentation – Tasmanian Government Spatial Committee	Mar 2013
ACT/NSW	Presentation / forum – APAS Conference	Mar 2013
AUS	Presentation / forum – SSSC National Conference Canberra	April 2013
NT	Workshop – NT Next Generation Datum Event	May 2013
TAS	Workshop – DPIPWE Information and Land Services Division	May 2013
WA	Presentation – SSSI State Conference	May 2013
TAS	Presentation – SSSI State Conference	Jun 2013
FIG	Presentation – FIG Reference Frames in Practice, Philippines	Jun 2013
ASIA	Presentations – South East Asian Survey Congress, Philippines	Jun 2013
QLD	Presentation – Annual conference of Far Nth QLD GIS Group	Jun 2013
VIC	Presentation – iGNSS Seminar	Jul 2013
VIC	Presentation – Regional ISV Seminar	Aug 2013
SA	Presentation – AIMS National Conference	Aug 2013
SA	Presentation - SA Spatial Information Day	Aug 2013
ACT	Presentations – SSSI Regional Conference	Aug 2013
VIC	Workshop – VIC Next Generation Datum Event	Sep 2013
TAS	Presentations / forum – TASSIC Spatial Information Day	Oct 2013
NZ	Presentations – CRCSI Annual Conference	Nov 2013
VIC	Presentation - Regional ISV Seminar	Nov 2013
VIC	Presentation - Regional ISV Seminar	Dec 2013
Webinar	Dynamics in the Next Generation Datum Webinar – NSW SSSI	Dec 2013
VIC	Presentation - Joint SSSI and ISV Seminar	Jan 2014
NSW/ACT	Presentation – APAS Conference	Apr 2014
AUS	Presentation – Locate 14 Conference, Canberra	Apr 2014
ACT	Presentation - ANU Geodesy Workshop	Jul 2014
VIC	Presentation - ISV Surveying Expo	Jul 2014
NSW	Presentation – SSSI North Coast Conference	Jul 2014
VIC	Presentation - Local Govt Spatial Reference Group (Vicmap Info Seminar)	1 Aug 2014
ACT	Presentation – SSSI Regional Conference	Aug 2014
SA	Presentation – SA Spatial Information Day	Aug 2014

Location	Event	Date
VIC	Presentation - Local Govt Spatial Reference Group (Vicmap Info Seminar)	15 Aug 2014
TAS	Presentation – SSSI State Conference	Aug 2014
VIC	Presentation - Local Govt Spatial Reference Group (Vicmap Info Seminar)	22 Aug 2014
VIC	Presentations - SSSI Summit	Sep 2014
IAG	Presentations – REFAG Symposium, Luxembourg	Oct 2014
QLD	Presentation – QCON 2014	Oct 2014
VIC	Presentation - ISV Seminar	Nov 2014
WA	Presentations – CRCSI Annual Conference	Nov 2014
SA	Presentation – SSSI Cadastral Workshop	Nov 2014
NSW	Presentation – ISNSW Australia Day Seminar	Feb 2015
AUS	Presentations – Locate 15	Mar 2015
NSW	Discussion – ISNSW Committee Meeting	Apr 2015

Table A-1 Workshops, Presentations & Forums on the Next Generation Australian Datum

Appendix B – Interviews and other respondents

The author thanks the following people who contributed their time and knowledge to assist the preparation of this report.

Name	Organisation
Robert Walch	Walch Optics – Tasmanian Leica Dealer
Dave Collett	Smartnet Australia
Keith Dyer	Omnistar
Peter Terrett	4D Global
Russell Box	Ultimate Positioning Group
Dr John Dawson	Geoscience Australia
Dr Grant Hausler	Geoscience Australia
Richard Stanaway	Quickclose
Prof Chris Rizos	University of NSW
Dr Craig Roberts	University of NSW
Dr Joel Haasdyk	Land and Property Information, NSW
Simon McElroy	Land and Property Information, NSW
Assoc Prof Matt Higgins	Department of Natural Resource Management, QLD
Darren Burns	Department of Natural Resource Management, QLD
Peter Todd	Department of Natural Resource Management, QLD
Linda Morgan	Landgate, WA
Michael Giudici	Department of Primary Industries Parks Water and Environment, TAS
Mark Chilcott	Department of Primary Industries Parks Water and Environment, TAS
Dr Roger Fraser	Department of Environment, Land, Water and Planning, VIC
Nic Donnelly	Land Information New Zealand
Steve Turner	Department of Transport Energy and Infrastructure, SA
Andrew Falkenberg	Department of Transport Energy and Infrastructure, SA
Dr Nic Brown	Geoscience Australia
Amy Peterson	Department of Lands Planning and Environment, NT
Gavin Evans	Office of Surveyor-General, ACT
Dr Don Grant	Royal Melbourne Institute of Technology

Table B-1 Persons Consulted in the Preparation of this Report

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