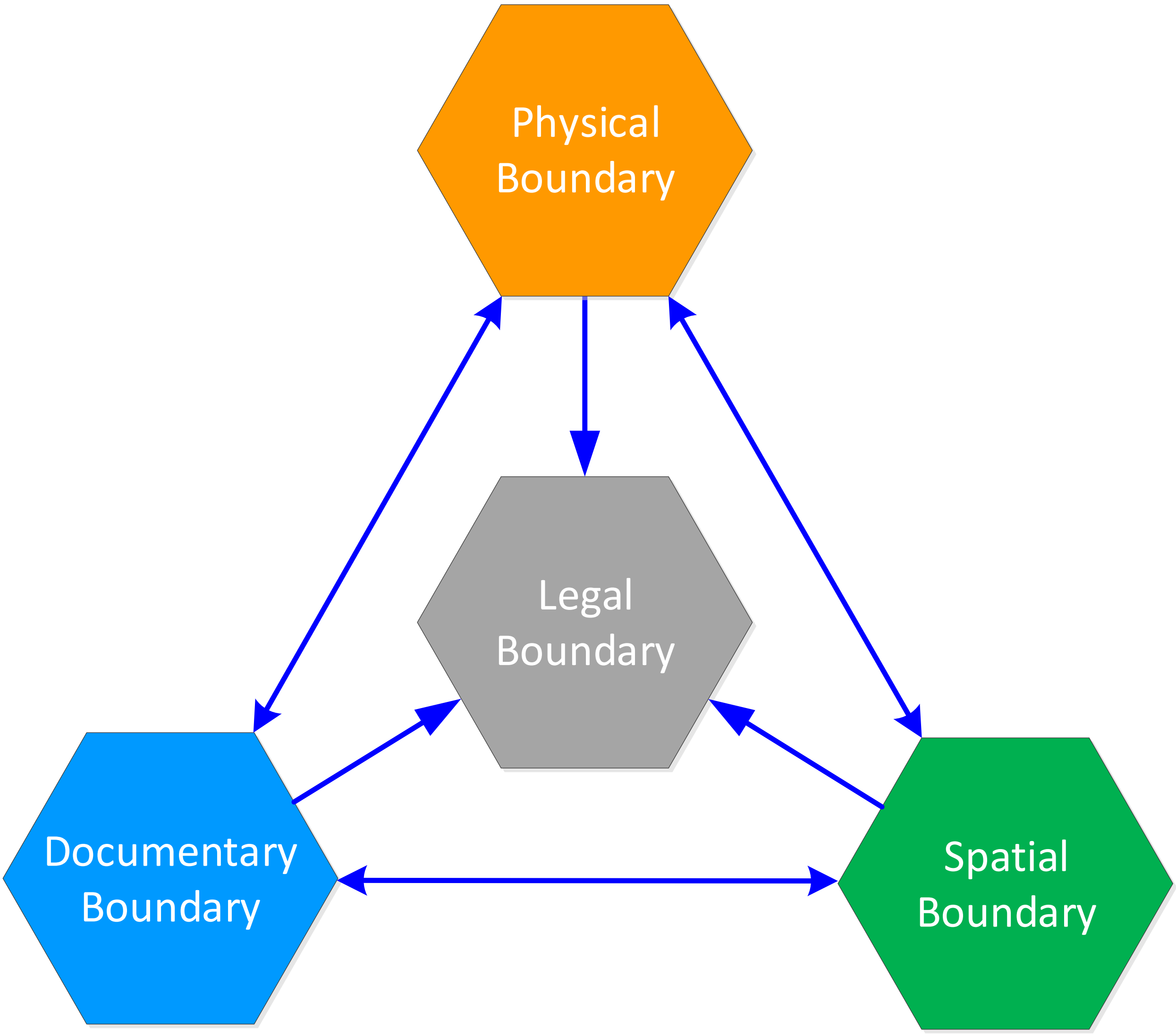
CRCSI Research Report

Upgrading Spatial Cadastres in Australia and New Zealand: Functions, Benefits & Optimal Spatial Uncertainty

D.B Grant, G McCamley, D Mitchell, S Enemark, J Zevenbergen

August 2018


Physical Boundary
Legal Boundary
Documentary Boundary
Spatial Boundary

Authorship and Affiliations

This work has been supported by the Cooperative Research Centre for Spatial Information, whose activities are funded by the Business Cooperative Research Centres Programme.

Members of the Intergovernmental Committee on Surveying and Mapping (ICSM) Permanent Committee on the Cadastre (ICSM-PCC) have also contributed to this report.

The project team members comprise:

- Associate Professor Donald Grant (RMIT University)
  Principal Researcher/Investigator
- Dr Geoffrey McCamley (RMIT University)
- Associate Professor David Mitchell (RMIT University)
- Professor Stig Enemark (Aalborg University, Denmark)
- Professor Jaap Zevenbergen (University of Twente, Netherlands)

The project team gratefully acknowledges the time and contribution from all interviewees across Australian jurisdictions and New Zealand.

Table of Contents

Authorship and Affiliations 2

Executive Summary 6

Definition of Key Terms 13

1 Introduction 18

1.1 Fit-For-Purpose and Cadastral Survey Outcomes 18

1.2 Spatial Cadastre 21

1.3 Problem Statement/Research Questions 22

1.4 Project Scope 24

2 Project Approach 27

2.1 Methodology 27

2.2 Data Collection 28

2.3 Data Analysis 29

3 Discussion and Analysis 31

3.1 Fundamental Concepts of Boundaries and Coordinates 31

3.1.1 The nature of boundaries 31

3.1.2 Moveable natural boundaries 34

3.1.3 Adverse Possession 35

3.1.4 Surveyor vs Landowner perspectives of boundaries 36

3.1.5 Functions of boundary coordinates 38

3.1.6 Boundary Coordinates and Earth Deformation 41

3.1.7 Discussion on Boundaries and Coordinates 46

3.2 Cadastral Triangular Model 49

3.2.1 Evolution of Model complexity 49

3.2.2 Spatial Cadastral Triangular Model 52

3.2.3 Application to the Research Question ... 54

3.3 Spatial Cadastral Improvement Levels ... 56

3.3.1 Level 0 – Graphical Paper Map ... 58

3.3.2 Level 1 – Digitised Spatial Cadastre ... 58

3.3.3 Level 2 – Survey-maintained Spatial Cadastre ... 59

3.3.4 Level 3 – Spatially-Aligned Cadastre ... 61

3.3.5 Level 4 – Survey-improved Spatial Cadastre ... 61

3.3.6 Level 5 – Survey-compliant Spatial Cadastre ... 62

3.3.7 Level 6 – Survey Coordinate Cadastre ... 62

3.3.8 Level 7 – Legal Coordinate Cadastre ... 63

4 Results ... 64

4.1 Spatial Cadastre Users and Functions ... 64

4.2 Findings and Recommendations ... 67

4.2.1 Optimal Positional Uncertainty of the Spatial Cadastre ... 67

4.2.2 Maintenance of the Spatial Cadastre ... 68

4.2.3 Legal Coordinate Cadastre ... 70

4.2.4 Visualisation or Representation of Positional Uncertainty ... 76

4.2.5 Context and Alignment with Other Relevant Lines ... 77

4.2.6 Completeness of the Spatial Cadastre ... 79

4.2.7 Mandate Government Usage after Improvement ... 80

5 Business Case Framework ... 81

5.1 Analysis of Benefits ... 82

5.2 Benefit and Cost dependency on Accuracy/Uncertainty ... 84

5.3 Business Case Options ... 90

5.3.1 Business case option A 93

5.3.2 Business case option B 93

5.3.3 Business case option C 94

5.3.4 Business case option D 96

5.3.5 Summary of Business Case Options 97

6 Future Research 98

6.1.1 Three-Dimensional Tenure 98

6.1.2 Attribute data and completeness of the Spatial Cadastre 98

6.1.3 Legal role of Spatial Cadastre 98

6.1.4 Natural Boundaries 99

6.1.5 Future Technology Advancements 99

7 References 100

8 Appendices 105

8.1 Appendix A – Interview questions 105

8.1.1 Spatial Cadastre - Stakeholders 105

8.1.2 Spatial Cadastre - Users 109

8.2 Appendix B – Contributing interviewees 111

8.3 Appendix C – Draft Observations Presented to Workshop 113

Executive Summary

Successful economies rely on effective land administration and cadastral systems.

The Cadastre 2034 strategies of Australia and New Zealand jointly seek to provide "a cadastral system that enables people to readily and confidently identify the location and extent of all rights, restrictions and responsibilities related to land and real property". An important component of each jurisdiction's cadastral system is the 'Spatial Cadastre'; being a geo-located spatial representation of cadastral boundaries in that jurisdiction. This is delivered online to an increasingly wide variety of users and serves multiple purposes. Spatial Cadastres that are fit-for-purpose will be critical to achieving the Cadastre 2034 strategies.

Australian and New Zealand cadastral systems can be classified as AAA (Accurate, Assured, Authoritative) (Williamson, Rajabifard, Kalantari, & Wallace, 2012). This means that they are fit-for-purpose to the extent that they support the role of cadastral surveyors to reliably define boundaries for landowners or other interested parties. However, with some exceptions, the Spatial Cadastres are not considered fully fit for broader public-good purposes.

Spatial Cadastres vary considerably in the positional uncertainty of their depiction of boundaries. Many users of the Spatial Cadastre are not expert in the technical details of cadastral boundaries or of geodetic coordinates and can therefore misinterpret or be misled by the variable quality of this information. The opportunities for misinterpretation by the public (the "people" referred to in the Cadastre 2034 strategies) affects the confidence with which they can readily identify boundaries.

There have been significant changes in technology over recent decades and issues arise for user interpretation when there are misalignments between the Spatial Cadastre and other datasets often used in conjunction with it. For example: when parcel dimensions calculated from the Spatial Cadastre differ from surveyor's measurements or boundary dimensions in title documents; or when disputes between neighbours are exacerbated by misinterpretation of the boundary shown in the Spatial Cadastre. Such issues can lead to:

- a loss of public confidence in the cadastre and land tenure systems;
- operational inefficiencies within land administration agencies; and
- costs and delays in land development processes.

These effects result in costs to land agencies as well as the broader society, land owners and those transacting in land.

This research project has identified the key functions that the Spatial Cadastre serves for the community and the optimal positional uncertainty required of the Spatial Cadastre to best fulfil these functions. A framework has been established for developing business cases for upgrading Spatial Cadastres to meet this optimal positional uncertainty. All Australian and New Zealand jurisdictions were investigated. The research focused on primary parcel ownership, i.e. excluding 3D strata parcels and secondary interests in land.

The principal source of data for this project was interviews with stakeholders and users of the Spatial Cadastre across Australia and New Zealand. A total of 80 individuals, including 2 international experts in land tenure, were interviewed to provide the project with a unique, semi-empirical, qualitative data source.

The functions of the cadastral system as a whole, and the Spatial Cadastre as a sub-system, can be expressed in terms of a model of cadastral outcomes, or purposes, which has previously been accepted by all nine jurisdictions. This outcomes model provided a sound framework for analysis of the functions of the Spatial Cadastre.

To support the interviews, a conceptual model was developed to help understand the different representations of boundaries within cadastral systems. This is the Cadastral Triangular Model which depicts the relationships between:

- the physical manifestation of boundaries;
- the documentary record of boundaries;
- the spatial depiction of boundaries in the Spatial Cadastre; and
- how each of these three representations relate to the true legal boundaries.

The Cadastral Triangular Model proved to be a powerful tool for allowing all interview participants to reach a common understanding of the complex concepts explored in the interviews. Each of the interview participants brought their own unique perspectives and user requirements to the interviews. Without the Cadastral Triangular Model, generating a coherent synthesis from these many viewpoints would have been challenging.

The Cadastral Triangular Model was developed expressly for this project, but it is believed it will prove useful for investigations into other aspects of other cadastral systems around the world.

Another framework used for analysis is a hierarchy of Spatial Cadastral Improvement Levels describing options for upgrade of Spatial Cadastres. This proved valuable as a means of describing and aligning the nine different Spatial Cadastres and the aspirations and options for further improvement of each.

This hierarchy of Spatial Cadastral Improvement Levels will also have applicability to other Spatial Cadastres around the world.

A topic which has been given some attention is the impact of earth deformation on boundaries and boundary coordinates. This topic is often overlooked in Australia when describing spatial cadastres and boundary coordinates because:

- the current localised nature of cadastral survey methods for boundary determination, and the current hierarchy of boundary evidence, are almost entirely impervious to the effects of earth deformation[1]
- strain rates within Australia are very low - almost below the level of being measurable by survey – so in a local sense it seems reasonable to discount them.

However, technology provides opportunities to significantly change the way that cadastral surveys are conducted and the information they rely on. An assumption that earth deformation will continue to have no impact on boundaries in Australia may not be correct – particularly if relying on coordinates defined in a continental scale geodetic datum. This is separately investigated in a related CRCSI Project 3.20 led by Adrian White, NSW Department of Finance Services & Innovation which is considering the implications of a dynamic datum on the cadastre (van der Vlugt, 2018b).

Analysis of the interviews highlighted the need to clarify and document a fundamental conceptual understanding of the nature of boundaries, coordinates and how coordinates are affected by earth deformation. Regulatory and operational systems for managing cadastres have been challenged in recent decades by significant changes in technology, public use of that technology, and public expectations. Conceptual certainties that have held for centuries have more recently been questioned. Some concepts and public needs have changed, while others remain sound. A clarification of the fundamental needs and expectations of cadastral systems and boundaries has been necessary to draw together findings relating to the broad scope of this project and the broad range of user perspectives provided by interviewees.

Following analysis of the interviews, draft findings were workshopped with representatives from the jurisdictional land agencies prior to finalisation in this report. Despite differences between the nine jurisdictions, an encouraging level of consensus was achieved on the findings.

[1] The exception is boundaries lying across or close to a major earthquake rupture. This is more readily apparent to surveyors in New Zealand than Australia.

The results of this project identify a wide variety of users of the Spatial Cadastre, including: utility companies, councils, government departments, property developers, surveyors and the public. Surveyors are a key user group for the cadastral system as a whole, but interviews indicated that they are not significantly more demanding of the Spatial Cadastre than other user groups.

The key findings identified by this research project are:

- The optimal positional uncertainty for Spatial Cadastres is 0.1 – 0.2m in urban areas, 0.3-0.5m for rural areas and up to 1m in more remote areas. At this level of positional uncertainty Spatial Cadastres may be described as "spatially-aligned" with other spatial datasets. This level of positional uncertainty readily supports:

    - correct parcel identification;
    - the location of physical assets in relation to boundaries;
    - searching for survey marks and buried services within an accuracy range sufficient to result in discovery in most cases[2];
    - the representation of boundaries in reasonable relation to fence posts or walls;
    - supporting 'quiet title' between neighbours;

  Some jurisdictional Spatial Cadastres have already achieved better positional uncertainty than these optimal levels. In this case they should continue to support the maintenance of these higher accuracy levels.

- A clear plan for on-going maintenance of the Spatial Cadastre should be part of any business case for accuracy improvement. Opportunities exist for automation of some maintenance tasks but also improved positional uncertainty can result in additional costs to maintain that improved level. A strategy to require digital lodgement of cadastral surveys; mandatory connections between cadastral surveys and control marks; and alignment of all cadastral survey bearings to the national geodetic datum should be considered.

- All spatial cadastres necessarily allocate coordinates to boundaries in order to represent them spatially. However, the highest level of legal coordinate cadastre is one in which those coordinates are awarded a legal evidential status which makes them virtually irrefutable evidence of boundary location. Such a **legal** coordinate cadastre is not considered appropriate for any

[2] A hole dug for buried marks will generally be at least 0.3m across – the width of a spade.

jurisdiction in Australia or New Zealand – especially not for urban, peri-urban or intensive rural land. There is an inherent inconsistency in assigning <u>fixed</u> coordinates (those that remain unchanging over time due to their protection under the law and their role in defining enduring property rights) to features that move with the dynamic surface of the Earth. This inherent inconsistency is more noticeable in New Zealand but also applies in Australia over time periods matching the lifetimes of boundaries (many decades to a few centuries.)

- Spatial Cadastres should include a system for clear visualisation of the uncertainty of the determination and maintenance of the boundaries they display. If positional uncertainty is visually displayed with links to uncertainty attribute data, then better risk-based decisions by land managers, landowners and the general public are achievable.

- The most important boundary lines shown in the Spatial Cadastre should be the title boundaries – typically being the boundary lines defined by the most recent approved survey. However, for the Cadastre 2034 strategy to be fully realised for rights, restrictions and responsibilities other than title ownership, other relevant lines such as long-term occupation and up-to-date positions of moveable boundaries should be considered.

- To justify the expenditure required to upgrade the accuracy of jurisdictional Spatial Cadastres, their use by government agencies in the jurisdiction should be mandated by government policy as the single authoritative dataset across local and jurisdictional government.

- A finding raised by interviewees, although peripheral to the scope of this project, is the importance of providing a complete topological coverage of the Spatial Cadastre in each jurisdiction and improvement of the completeness of attribute data (e.g. secondary interests) contained within or linked to the Spatial Cadastre.

Developing acceptable business cases for upgrading Spatial Cadastres in line with the above will be challenging. Four business case options are considered by this project:

A. All Australian and New Zealand Spatial Cadastres are currently maintained and continuously improved by the inclusion of new cadastral surveys. The positional uncertainty achieved by project-based upgrades and/or on-going inclusion of new cadastral surveys is varied. Eventually, ongoing integration of modern surveys into the Spatial Cadastre will result in achievement of the optimal positional uncertainty in many areas. However, without a project approach to improvement, the timescale for this *laissez faire* approach will be a century or more. Business case option A is the 'business as usual' or 'do nothing' business case option for upgrading Spatial Cadastres.

B. At the optimal levels of positional uncertainty identified above, economic benefits in land administration and land management will be realised by the widest range of users. These recommended levels of positional uncertainty could be achieved cost-effectively through a focus on least squares adjustment of the Spatial Cadastre, supported by a control network (improved where required), but without parcel resurvey or full back-capture of previous surveys.

   This is the recommended business case option for upgrading the Spatial Cadastre.

C. Going beyond the optimal positional uncertainty is not likely to realise significant additional economic benefits to the wider base of users of the Spatial Cadastre. The justification for advancement beyond the optimal positional uncertainty will be primarily based on the fiscal benefit to jurisdictional land agencies, e.g. by supporting automated processing and validation of surveys and Spatial Cadastral maintenance. To achieve these lower levels of positional uncertainty, redefinition of boundaries and/or back-capture of previous surveys will be necessary – incurring significant cost. Individual land agencies may be able to progress beyond the proposed optimal level where the additional costs can be justified by internal processing efficiencies.

D. This option represents a staged approach whereby improvement of the Spatial Cadastre would commence with the recommended business case option B. Subsequently a second stage business case would be developed for further improvement based on back-capture of historical survey observations and boundary dimensions, strongly connected to a geodetic control network (improved where necessary). The result would be the same as business case option C but achieved in two stages. This staged approach would deliver maximum economic benefits quickly for most spatial data users through option B. A staged approach may reduce the project risks of cost-over-runs through better estimates of second stage project costs based on lessons learned from the first stage, as well as from reduced project complexity. The second stage may deliver fiscal benefits from improved opportunities for automation in the capture, validation and adjustment of the captured survey observations – particularly because the starting point for this improvement will be a Spatial Cadastre which has already been raised to the optimal level.

If improvement beyond the optimal level of business case option B can be justified, this is the next preferred business case option.

(Note that, in accordance with recommendations above, progress to a fully legal coordinated cadastre is not recommended for Australian or New Zealand jurisdictions and a business case for this option is not proposed.)

The evolution of Spatial Cadastres is on-going in response to technology and the changing needs of society. This will result in new opportunities and challenges for management of Spatial Cadastres, e.g. 3D representations of boundaries, application of dynamic datums, etc. Further research is thus expected and will be necessary as Spatial Cadastres continue to evolve.

This report is structured as follows:

- The background and scope are discussed in Chapter 1.
- The project's methodology is discussed in Chapter 2.
- The fundamental concepts and frameworks for addressing the research questions, based on a review of literature, are in Chapter 3.
- The results of the project derived from analysis of interviews and the recommendations are in Chapter 4.
- A framework for business cases is presented in Chapter 5.
- Opportunities for further research are proposed in Chapter 6.

Definitions of Key Terms

One objective of this research project is to define common terminology. Terminology and acronyms used are defined in-situ within the body of this report when first introduced. However, critical terms used in this report are also listed in the table below.

Term	Meaning
Digital Cadastre	A database of cadastral survey data relating to cadastral boundaries within a jurisdiction. It may include: • A spatial model of boundaries as well as coordinates and related attributes for boundary points, lines and polygons, and their topology, i.e. the Spatial Cadastre referred to below which is included in all Australian and New Zealand jurisdictional Digital Cadastres. • Cadastral survey observations and boundary dimensions held as structured data in database tables. • Links to images of analogue cadastral survey plans, record sheets, and other relevant cadastral documents. The Digital Cadastre is also often referred to as the Digital Cadastral Database (DCDB) or the Spatial Cadastral Database (SDCB) in the case of Western Australia.
Spatial Cadastre	A spatial representation of cadastral boundaries within a jurisdiction. It provides a spatial view or digital map view of the coordinated geo-located information contained in the digital cadastre (see above). It also may be referred to as the spatial cadastral map or digital cadastral map. For this report, all these terms are considered synonymous. The official jurisdictional spatial representation of cadastral parcels and their boundary points and lines will be referred to as the 'Spatial Cadastre'.

Term	Meaning
Improvement[3] Levels	Spatial Cadastres may be described by their levels of development or "maturity" (Todd, Higgins, & Williams, 1998). Each action undertaken to improve the accuracy of the Spatial Cadastre can build on previous actions and can provide a foundation for future actions. A revised and expanded range of "maturity levels" (here called Spatial Cadastral "Improvement Levels") is developed by this project and discussed in section 3.3.
Accuracy	"The level of closeness of an estimated value – measured or computed – of a quantity to its true or accepted value" (ICSM, 2014b). As the "true" value is never known, the accuracy can only be estimated.
Uncertainty	The level of "doubt about the validity of a measurement or result of a measurement (e.g. a coordinate)" (ICSM, 2014b). It acts as an estimate of the accuracy. Uncertainty is expressed as a standard deviation in the International System of Units expanded to the 95% confidence level.

[3] The word "improvement" here only refers to a reduction in the positional uncertainty of boundary coordinates. The highest level of "improvement" (lowest positional uncertainty) is not necessarily cost-justified, desirable, or even practically achievable.

Term	Meaning
Positional Uncertainty	In the context of geodetic control surveys (ICSM, 2014b) this is "the uncertainty of the horizontal and/or vertical coordinates of a survey control mark with respect to datum." Positional uncertainty (rather than 'accuracy') is the most commonly used term in this report for coordinates. The term, originally applied to geodetic networks by (ICSM, 2014b) is adapted here to apply to boundary points. It is a measure of the uncertainty of a boundary coordinate with respect to the axes of the geodetic datum. This becomes particularly relevant when aligning boundaries in the Spatial Cadastre with related features in other spatial datasets on the same geodetic datum.
Relative Uncertainty	In the context of geodetic control surveys (ICSM, 2014b) this is "the uncertainty between the horizontal and/or vertical coordinates of any two survey control marks." In this report, relative uncertainty is used for the uncertainty between a boundary point and other nearby boundary points or local survey control marks used to reference boundary points.
Survey Uncertainty	In the context of geodetic control surveys (ICSM, 2014b) this is "the uncertainty of the horizontal and/or vertical coordinates of a survey control mark independent of datum. That is, the uncertainty of a coordinate relative to the survey in which it was observed, without the contribution of the uncertainty in the underlying datum realisation." In this report, survey uncertainty is used for the uncertainty between a boundary point and the geodetic control marks used to connect the boundary survey to the geodetic datum and allow geodetic coordinates to be generated.

Term	Meaning
End Outcome	A broad and high-level result achieved for the community. Not to be confused with “outputs” (specific products or services). The end outcome of a system is effectively the “purpose” of that system – particularly in relation to the phrase fit-for-purpose.
Fiscal benefit	A benefit expressed in terms of money in relation to government revenue or expenditure. Where the Spatial Cadastre is provided to the public at no cost, fiscal benefits will relate more to cost savings than revenue.
Economic benefit	A benefit that can be expressed in terms of money saved or revenue generated. This can be anywhere in the economy and, unlike fiscal benefit, is not confined to government expenditure or revenue.

1 Introduction

This chapter provides a high-level description of cadastral systems in Australia and New Zealand in the context of a "fit-for-purpose" approach to defining the community or government requirements for those systems. The purposes for the cadastral systems are described by end-outcomes. The jurisdictional cadastral systems are assessed in terms of how well they currently serve these purposes or outcomes. A component of the cadastral system in each jurisdiction is the 'Spatial Cadastre' which is described and problems associated with it are explored. The research questions and of scope of this project are then outlined.

1.1 Fit-For-Purpose and Cadastral Survey Outcomes

Enemark, Bell, Lemmen, and McLaren (2014) describe a proposal to implement fit-for-purpose Land Administration for developing countries. This proposal is based on a joint FIG – World Bank statement that includes the following high-level principle:

> *"When assessing technology and investment choices, the focus should be on a "fit-for-purpose approach" that will meet the needs of society today and that can be incrementally improved over time."* (Enemark et al., 2014)

Although this principle was put forward for land administration systems in developing countries, it is also valid in jurisdictions with advanced cadastral systems where we should also have a clear understanding of the purposes of a land administration system (including the cadastral component of it). This will allow us to design the appropriate level of government intervention and investment in the Spatial Cadastre to best meet the needs of society.

The fit-for-purpose approach also fits well with modern regulatory best practice – as outlined by D. B. Grant and Haanen (2006) for cadastral regulation. It is to identify:

- the end outcomes (high-level purposes) government wants to achieve for the benefit of society,
- the risks to achieving those end outcomes, and
- the level of intervention appropriate to manage those risks – i.e. the intervention that is fit-for-purpose.

Australia and New Zealand have similar political, economic and social histories, both being British colonies that have inherited much of the English legal system. The system of Torrens Title was introduced in the mid-1800's in Australian jurisdictions and New Zealand. The land administration systems have developed a high level of integrity (Hirst, 2010) and may be described as AAA (Accurate, Assured, Authoritative) (Williamson et al., 2012). Both countries have sound economies and stable governments. Successful economies rely on effective land administration systems and at the core of land administration is the cadastre (Krelle & Rajabifard, 2010).

Jurisdictions such as Australia and New Zealand have cadastral systems that can also be described as multi-purpose (McLaughlin, 1975) and which have evolved over time to serve many complex land administration and public information purposes. Therefore, the question of what will be "fit-for-purpose" for an improved cadastral system is a complex one – requiring a clear understanding of the purposes or end outcomes expected of the cadastral system.

The two main purposes or end outcomes for the cadastral survey systems in Australia and New Zealand have been documented and accepted by all the government surveyors boards of the jurisdictions covered by this research (CRSBANZ, 2009). These boards form the Council of Reciprocating Surveyors Boards of Australia and New Zealand (CRSBANZ). The end outcomes, depicted in Figure 1, are:

A. Holders of rights, restrictions and responsibilities in land confidently know the boundaries to which they apply so that they can efficiently identify, trade and use their rights.
B. Other parties can rely on and efficiently use the cadastre for achieving other public good outcomes (e.g. electoral boundary definition, resource management, emergency management, land administration).

The end outcomes are the high-level results achieved for the community and do not directly tell us what outputs are required or the technical standards that those outputs should achieve.[4]

End outcome A is the core purpose of the cadastral survey system – the definition of boundaries. This outcome is well achieved across the AAA cadastral systems of Australian and New Zealand jurisdictions. Therefore, these cadastral systems <u>are</u> fit-for-purpose as far as End Outcome A is concerned.

End Outcome B is an additional purpose which has come to be increasingly important for government and society over the last two or three decades. Cadastral

[4] Outputs and standards can be derived by the analysis of the risks of not achieving end outcomes (D. B. Grant & Haanen, 2006). However, an assessment of the regulatory standards for cadastral surveys is outside the scope of this research.

information presented in the form of the Spatial Cadastre, and able to be combined with other related spatial land information, contributes to End Outcome B.

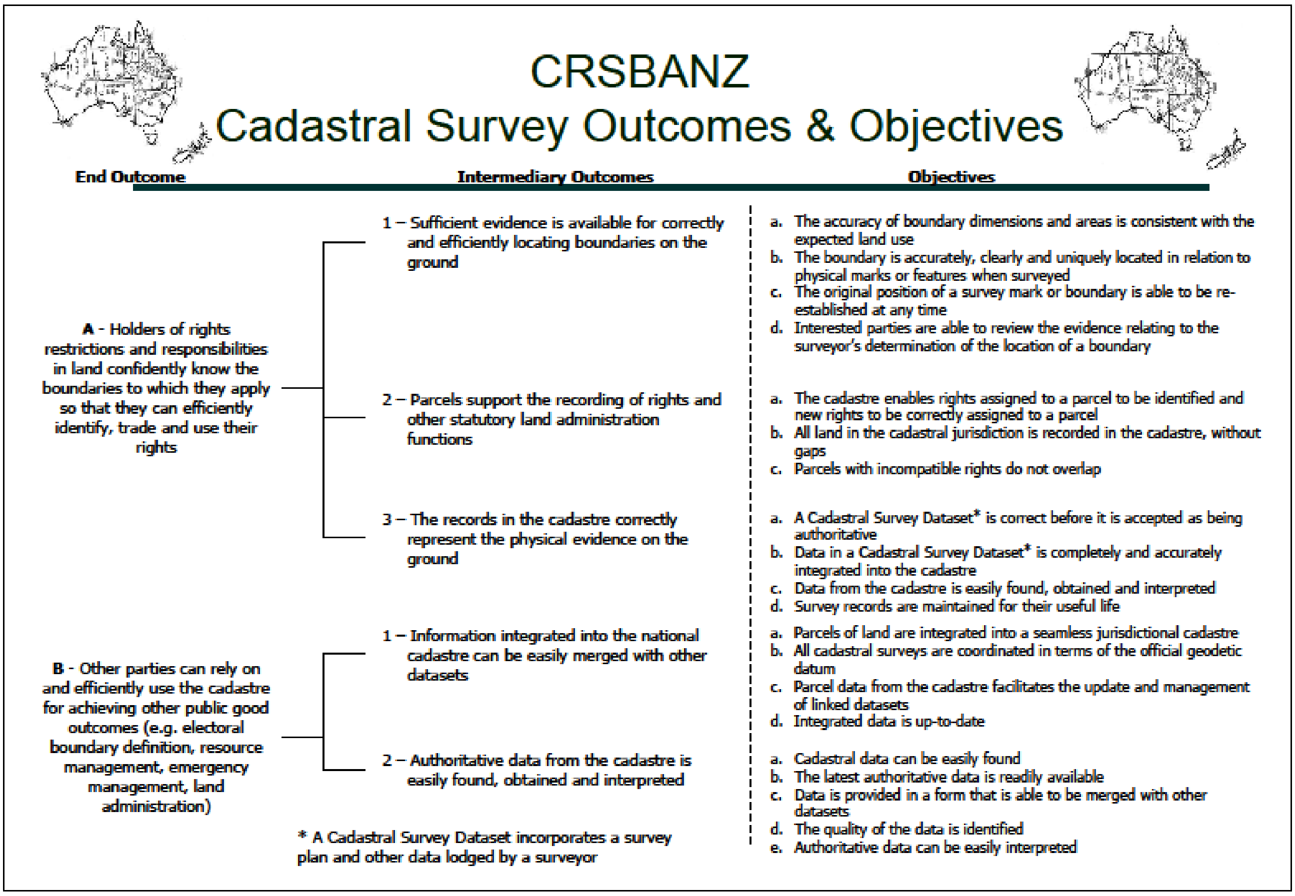


Figure 1. CRSBANZ Cadastral Survey Outcomes and Objectives (CRSBANZ, 2009)

This research is driven by widespread acceptance that within Australia and New Zealand, the achievement of End Outcome B is, at best, highly variable from place to place within jurisdictions and between jurisdictions. The cadastral system is therefore not considered to be currently fit-for-purpose in relation to End Outcome B.

The Fit-For-Purpose Land Administration approach also proposes incremental system enhancement over time – with a focus on initial development or upgrade to meet the most urgent purposes, followed by further improvement as the needs of society evolve (Enemark et al., 2014; Enemark, McLaren, & Lemmen, 2016). This approach matches the history of cadastral systems in Australia and New Zealand which were initially of poor quality in the late 18th and early 19th centuries but which proved sufficient to allow the respective colonies to develop. Incremental improvements were required later from the late 19th century as the needs of the established colonies became more complex.

1.2 Spatial Cadastre

The Cadastre 2034 strategies for New Zealand (D.B. Grant, 2014) and Australia (ICSM, 2015) identify many common issues and opportunities for Australian, New Zealand and international land management agencies. Whilst all Australian jurisdictions and New Zealand have common origins for management of their cadastres, there are also specific historic, geographic and legislative differences which makes consideration of all jurisdictions as a single homogeneous system difficult or unhelpful. For example: the impact of earthquakes in New Zealand (D.B. Grant, Crook, & Donnelly, 2014); differences in adverse possession laws (Park & Willlamson, 1999); different recognition of indigenous land rights; variations in jurisdictional land areas and population densities; etc. These differences mean that the evolution and positional uncertainty within Spatial Cadastres varies between jurisdictions.

Spatial Cadastres emerged in the 1990's with the digitisation of paper based cadastral maps and parish plans, some boundaries having originated without an accompanying survey. Initially, Spatial Cadastres were principally used by the cadastral surveyors as an index map to land records and parcel abuttals. For example, based upon a street address, titles for the underlying and neighbouring parcels could be located, relevant survey plans could be identified and sourced along with locations of nearby permanent marks as necessary to conduct a re-establishment or a subdivisional survey.

To progressively improve the Spatial Cadastre, lodged survey plans were updated within the Spatial Cadastre and local areas within the Spatial Cadastre were upgraded to fit with incoming survey data by respective land agencies. However, much of the data contained in Spatial Cadastres still contains unadjusted and even unsurveyed parcels. Additional data layers, attributes and improved online presentations have been added to enhance the utility of the data (Sinclair Knight Merz, 2011; Williamson & Enemark, 1996).

The Spatial Cadastre now serves multiple purposes and outcomes, e.g. legal land tenure and land administration functions. Users of Spatial Cadastres now extend beyond traditional users of paper-based maps (e.g. cadastral surveyors and the land agency) and include other government agencies, utility companies, property developers, third party on-sellers/aggregators of the data, landowners and the public.

1.3 Problem Statement/Research Questions

There have been significant changes in technology over the last few decades (and further changes are expected) that have resulted in international and national debate on the role that coordinates could or should play in the definition of boundaries. Even within the relatively coherent cadastral systems across Australia and New Zealand, a single preferred model is not yet clear.

The technology disruptions that have occurred include:

- Geodetic quality global positioning which has an accuracy close to being independent of distance or location. The potential accuracy approaches 1 part per billion with a resolution of a few millimetres. This has resulted in periodic redefinition of national geodetic datums to accommodate tectonic plate motion. Measurable tectonic plate motion and earth deformation also raises questions about the management of boundary coordinates over time.
- Public access to global positioning on hand held devices. The accuracy on these devices is currently a few metres but is expected to achieve decimetres in the next few years with Satellite Based Augmentation Systems and improved devices. This will enable the public to capture reasonably accurate coordinates and compare these to boundary positions in the Spatial Cadastre.
- Public access to spatial datasets including the Spatial Cadastre. In 2005 Google Maps was released to the public providing GIS tools for the public. A few years later it was released on smartphones. The public can now locate boundaries in relation to imagery depicting fences, walls, etc.
- On paper-based maps and survey plans, cadastral boundaries were historically shown as an inked line and the width of the ink line, intentionally or not, prevented inappropriate expectations of low spatial uncertainty. In the digitised Spatial Cadastre, boundary lines may appear to have a zero-width where the zoom-in capability of the GIS tools effectively has no practical limit. This can lead to public misunderstanding of the positional uncertainty of the Spatial Cadastre. This misunderstanding may lead to reputational risk for land administration agencies responding to queries and concerns.

All spatial data exhibits some positional uncertainty, i.e. the difference between the true position of a measured feature in the world, and the coordinates that represent that feature in terms of a geodetic datum or coordinate reference frame. Whilst uncertainty in geodetic measurements has reduced significantly in recent times, the uncertainty of the geodetic datum itself, and the associated network of control reference marks, also contribute to positional uncertainty (ICSM, 2014a, 2014b; Steed & Lutton, 2014).

Historical and recent cadastral survey plans prepared by surveyors are based on physical monuments and the local/relative measurement of angles and distances. These measurements contain errors which propagate into the Spatial Cadastre. The limits of uncertainty of survey measurements are governed by the measurement technology employed and the jurisdictional survey standards or survey regulations. The positional uncertainty within the Spatial Cadastre cannot be better than that which propagates through from the source measurement data. Positional uncertainty also includes the uncertainty of the connection to the geodetic datum via geodetic control marks – and the positional uncertainty of those control marks. Surveyors are generally aware of these contributions to positional uncertainty, but many users of the Spatial Cadastre are not.

In part this lack of user knowledge may result from the fact that positional uncertainty is often not published, or not readily available, and is certainly not easily interpreted by non-experts. The positional uncertainty of the Spatial Cadastral may vary geographically both within and between jurisdictions. Positional uncertainties are known to vary from centimetres in urban areas to hundreds of metres in remote rural areas. The positional uncertainty of the Spatial Cadastre is widely believed to be not fit-for-purpose although this varies from place to place. Issues include:

- An overlay with other spatial datasets (e.g. remote sensing, imagery, asset management databases) onto the Spatial Cadastre may show a false or misleading misalignment.
- The use of other locational services (e.g. GPS) may not correctly align with coordinates within the Spatial Cadastre.
- Parcel dimensions or areas calculated from coordinates in the Spatial Cadastre may differ from those measured on the ground or appearing on survey or title documents.
- Boundary disputes between neighbours may develop arising from, or exacerbated by, misinterpretation of the boundary representation in the Spatial Cadastre.

Additionally, some jurisdictions have multiple versions of the Spatial Cadastre and this can create issues when data in these versions is not maintained in alignment. The distribution of updates and the timeliness of data available may also be problematic to users.

When the Spatial Cadastre does not meet users' expectations, this can lead to a loss of public confidence in the cadastre and land tenure systems, operational inefficiencies within land administration agencies, unnecessary boundary disputes, and lost opportunity costs and delays in land development processes. These effects result in an economic cost to the broader society, land owners and land transactors. The potential loss of public confidence is a serious concern.

This project will address the following research questions for jurisdictions in Australia and New Zealand:

- What functions or purposes does the Spatial Cadastre serve?
- What is the optimal positional uncertainty required of the Spatial Cadastre to best fulfil these functions?
- How should business cases for upgrading Spatial Cadastres be framed to meet the optimal positional uncertainty.

This research will identify how the positional uncertainty in the Spatial Cadastre affects functions that the data can be used for and how the realisation of benefits is dependent on positional uncertainty. Common terminology will be developed. A framework will also be developed for considering relationships between the physical, documentary and spatial representations of boundaries and the evidentiary role these play in legally defining boundary locations.

1.4 Project Scope

This project considers the eight Australian jurisdictions as well as New Zealand. International experiences in upgrading the accuracy of their respective Spatial Cadastres are also considered ensuring project recommendations are consistent with the directions being taken internationally.

The project only considers the current legal framework for land tenure in each jurisdiction, i.e. the project is not seeking to include recommendations for changes in property law or survey regulations.

The focus of the project is on the primary parcel ownership layer within the Spatial Cadastre. The project does not directly consider the uncertainty of, or proposals for spatial improvement of, secondary interests such as units, 3D strata parcels, or secondary registered or unregistered rights, responsibilities and restrictions in land tenure, e.g. easements, covenants, planning zones, electoral and administrative boundaries.

However, where the positional uncertainty of the primary parcel in the Spatial Cadastre results in problems in relation to such secondary interests, then this misalignment is within the scope of the project. Similarly, the project does not focus on jurisdictional surveying regulations or uncertainty in survey measurements as recorded on survey plans, except (and to the extent) that these are the specific cause of positional uncertainty and where this causes the Spatial Cadastre to not be fit-for-purpose.

The project is focused on positional uncertainty rather than other 'attribute' inaccuracies/omissions within the Spatial Cadastre, e.g. the correctness and updating of parcel ownership details or land status. The project's scope is summarised and depicted in Figure 2.

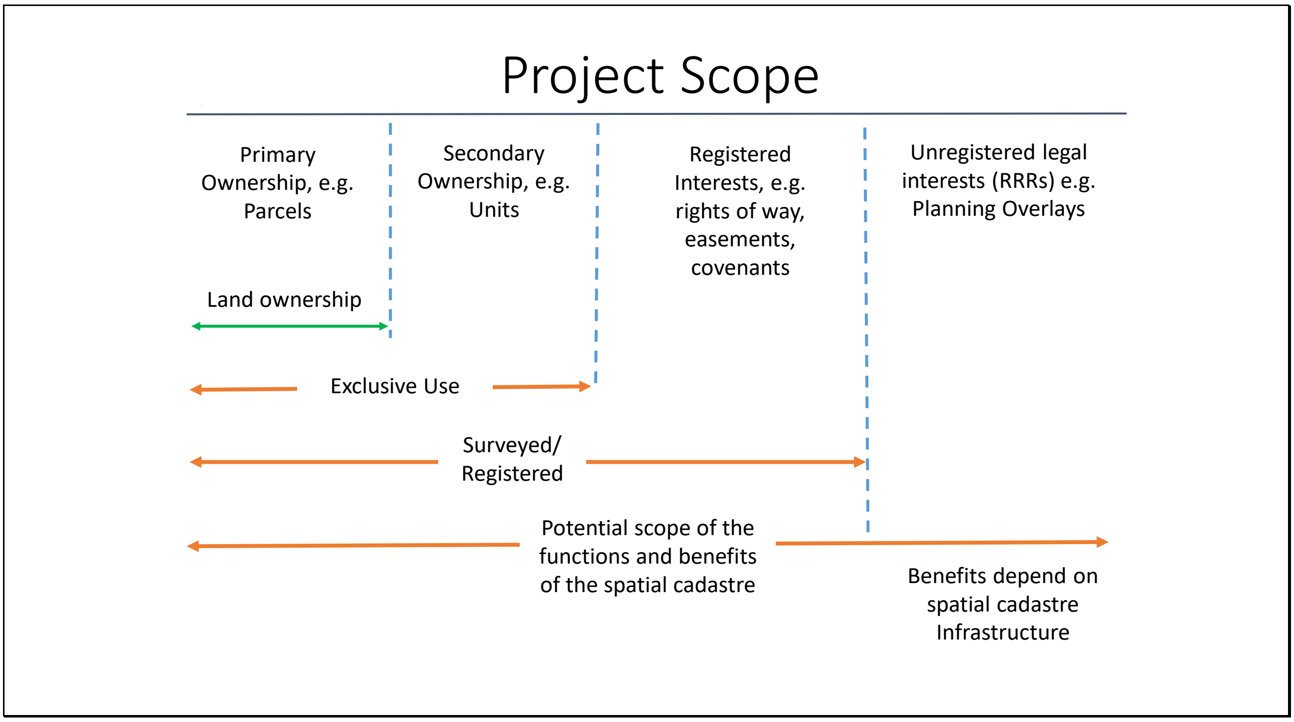


Figure 2. The main area of scope is the spatial representation of primary (ownership) parcel boundaries represented by the green arrow. Secondary interests and other interests, represented by the orange arrows, are not within the main scope but their utility is not independent of the spatial certainty in primary parcel ownership. Where the benefits of spatial upgrade would extend beyond the primary ownership layer (green arrow) and assist with the benefits delivered by other layers (orange arrows) then these indirect benefits are also considered.

This project is one of four current initiatives of the Cooperative Research Centre for Spatial Information (CRCSI) and the ICSM Permanent Committee on the Cadastre (ICSM-PCC). The other initiatives are:

- A pilot project investigating the feasibility of using LIDAR and imagery to upgrade the Spatial Cadastre (Priebbenow, Fraser, & Karki, 2018).

- Implications of a dynamic datum on the cadastre (van der Vlugt, 2018a).
- a PCC review of the cadastral representation of 3D parcels (Collier, 2018).

Recommendations of this project aim to be consistent with these other CRCSI and PCC initiatives.

2 Project Approach

For research projects to successfully address their objectives they adopt a structured method or approach. Ideally this method should be well established and proven successful by previous research projects. This chapter describes the theoretical method adopted by this project, the project's adherence to RMIT research protocols and summarises the implementation of the project plan.

2.1 Methodology

The principal source of data for the project was from interviews with stakeholders and users of the Spatial Cadastre in Australian jurisdictions and New Zealand. Interviews and focus group discussions were sometimes one-to-one but more commonly run as group discussions. The interviews and focus group discussions provide this research project with a unique, expert, semi-empirical, qualitative source of data for addressing the research objectives of this project (see section 1.3 and Appendix B).

The project's approach incorporates elements from Focused Ethnography and Grounded Theory, which are well established methods for conducting qualitative research (Morse, 2002). Focused Ethnography is used primarily to evaluate or elicit information on a specific topic identified before the research commences. Data may consist only of interviews and Focused Ethnography acknowledges the role the interviewer plays as a participant, with their own experiences, when conducting interviews and focus group discussions (Morse, 2002). The principal investigators/researchers within this project have extensive experience and on-going involvement in cadastral practices.

By contrast, Grounded Theory (Glaser & Strauss, 1967) does not have the researcher start with a theory, but allows the theory to emerge through a systematic process of data collection and analysis (Hammer, 2011). Whilst somewhat contradictory in the application of methods, the semi-structured nature of interviews and focus groups conducted by this project supports direct focus on the research questions (i.e. Focused Ethnography), yet also allows interviewees the freedom to express their views on a broader range of related topics. These can include topics relevant to the research questions but not necessarily anticipated in the project proposal or the original research questions. Where additional relevant issues and questions are still broadly within scope, the Grounded Theory approach provides opportunities for new research questions and insights to emerge.

The issues addressed in section 3.1 on Boundaries and Coordinates emerged from the interviews and are examples of the Grounded Theory approach. These questions are in addition to the problem statement and research questions posed in section 1.3 and identify the need for a deeper understanding of some concepts that are often taken for granted by stakeholders and users.

The Cadastral Triangular Model (section 3.2) and Spatial Cadastral Improvement Levels (section 3.3) were developed to explore relationships within different aspects of the cadastre. The Cadastral Triangular Model was used as the basis for structuring interviews with specific detailed questions for interviewees developed from this framework.

2.2 Data Collection

Based upon the Cadastral Triangular Model and defined Improvement Levels described above, a separate set of questions (refer Appendix A) were developed for the two classes of interviewees:

- **Stakeholders of the Spatial Cadastre**, i.e. the Surveyor-General (SG) or equivalent position in each jurisdiction along with other key advisers and departmental staff involved in management of the cadastral system and the Spatial Cadastre. Stakeholders have responsibility for the development, support and operations of the Spatial Cadastre in their respective jurisdictions.
- **Users of the Spatial Cadastre**, i.e. a representative group of professionals who use the Spatial Cadastre; including representation from private surveyors, utility companies, government agencies and local government authorities/councils. Appropriate users were identified by the Surveyor-General (or equivalent) and invited to be interviewed.

In addition to Stakeholders and Users of the Spatial Cadastre, two international land administration and tenure experts, Professor Stig Enemark of Denmark and Professor Jaap Zevenbergen of the Netherlands, were also interviewed to gain an independent, international perspective.

To assist preparation of interviewees, the questions were generally distributed prior to the interview taking place. Prior to their use, interview questions, Participant Information Consent Forms (PICF), along with other supporting project documentation were submitted to the RMIT University ethics committee. Human research ethics approval SEHAPP 73-17 was granted with the project being deemed low risk.

Interviews were scheduled and conducted between August 2017 and January 2018 through visits to all Australian jurisdictions and New Zealand. All interviews were conducted (usually in the offices of the respective jurisdiction land agency) by the project's principal investigator and research assistant. Except for four single party interviews, all others were group interviews comprising several participants. At the commencement of interviews, PICFs were reviewed with participants, including confirmation from participants to the taking of an audio recording of the meeting to assist documentation and summarisation of the interview. Signed forms were collected and are held in accordance with RMIT University's retention policy along with electronic audio recordings. A list of all participants who consented to the PICF is given in Appendix B. Additionally, artefacts provided by participants during the interview (e.g. summary statistics, academic papers, etc) are held with other project documents. The duration of interviews varied between 1 and 4 hours.

A summary of each meeting was documented and e-mailed to all (and only) interview participants present in the interview. Interview participants were invited to; add, change, delete or correct interview summaries – all amendments received from interviewees were accepted in finalising the interview summaries. Whilst interview summaries may have identified a functional or operational sector to which comments related, no comments are attributed to individuals within the summary. Summaries were not verbatim transcripts but aimed to preserve the meaning and intent of interviewees' words. This was confirmed by the opportunity given to interviewees to review and amend the summaries. Finally, a workshop attended by Australian and New Zealand Surveyors-General was held in Melbourne in February 2018 where draft findings (refer Appendix C) were presented for comment prior to incorporation into this final report.

A total of 21 separate interviews were conducted, representing a total of 50 hours of interview elapsed time, i.e. 9 Stakeholder, 10 User and 2 expert interviews. A total of 80 individual participants were interviewed.

2.3 Data Analysis

In accordance with RMIT University research ethics and documented within the PICFs, only the principal and associate research investigators have access to and have viewed interview summaries. Interview summaries are stored in accordance with RMIT University research ethics policy.

NVivo software by QSR International (http://www.qsrinternational.com/nvivo/nvivo-products) has been used as the principal tool to analyse interview summaries. NVivo is a software tool often used for analysis of quantitative research which includes interviews and summary transcripts. NVivo was principally used to gather material from the interviews about specific topics. This is referred to as topic coding (Morse, 2002; QSR-International, 2011) and topics may be hierarchically structured. Topics are identified that are relevant to addressing the research questions. Specific statements within interview summaries that are related to each topic were allocated (or coded). All statements across interviews within each topic may then be considered and common themes extracted.

3 Discussion and Analysis

This chapter contains three key elements that are prerequisite to discussion of the project's results. It was identified during interviews that cadastral boundaries and the role of boundary coordinates on a dynamic planet needs clear and common terminology and understanding. This chapter draws on an analysis of the literature to define common terminology and clarify important concepts. This provides a necessary context for analysing the interviews and describing the project's results in subsequent chapters. This chapter also explains the evolution of the Cadastral Triangular Model and Spatial Cadastral Improvement Levels which were used as frameworks to formulate interview questions and conduct interviews with stakeholders and users of the Spatial Cadastre and to analyse the results of those interviews.

3.1 Fundamental Concepts of Boundaries and Coordinates

As well as the problem statement and research questions identified in the research proposal, several fundamental issues emerged from the interviews. This process is provided for by the Grounded Theory methodology (Glaser & Strauss, 1967).

When seeking expenditure of tens of millions of dollars of public money (either derived from government funding or regulated property transaction fees) it is appropriate to have a clear understanding of the outputs of that expenditure and how they will benefit society. The area of study for this research relates to the generation of improved coordinates of cadastral property boundaries across a jurisdiction.

To have a clear understanding of what these boundary coordinates can be used for, and the benefits that can be derived from them, we need a fundamental understanding of the nature of boundaries and the nature of coordinates. Given the long-term existence of boundaries, it is particularly important to know how both boundaries and coordinates are maintained over long periods of time.

On reviewing the stakeholder and user group interviews, it became apparent that a deeper understanding is needed about the common expectations of landowners and society in relation to boundaries, as well as an understanding of the technical solutions based on the use of coordinates to meet those expectations.

3.1.1 The nature of boundaries

Ottens and Stubkjær (2007) argue that a cadastral system – and the boundaries within that system – can be categorised as a socio-technical system. The social elements and the technical elements behave differently and need to be treated differently. The cadastral system is based on the social concept of real estate. However, technology plays an important role – particularly in a cadastral surveyor's technical task of locating boundaries on the land.

The success or failure of a socio-technical system depends on both these social and technical elements. A technology-driven proposal for reconfiguration of the cadastral system (more accurate coordinates, the use of spatial databases, capture of cadastral measurements and boundary dimensions into survey databases, positioning within global coordinate reference frames, etc) will not succeed unless the social elements for the good organisation of society and good management of land and environmental resources are also satisfied.

A boundary is created in law by agreement between interested parties (e.g. a subdivider and a purchaser of a subdivided parcel). The creation of the boundary, both in the physical world and in the legal record is usually assisted – either before or after the agreement - by a surveyor. The agreement is the social element of the boundary. For that agreement to be properly realised the land parcel and its boundaries must be identified to a level that is sufficient for the agreeing parties, and their successors, to comprehend and assess it. In the Australian and New Zealand context, the technical task of surveying is required so that the boundaries can be documented in a way that will endure over time and will continue to be agreed by future landowners.

The process in Australia and New Zealand is generally that the surveyor performs measurements, emplaces monuments and documents the proposed boundary, in accordance with the expectations of the subdivider, and for later agreement by the purchaser. This is not the only operational model for subdivision. For example, in The Netherlands, the boundary is created in law first by agreement between the parties and then the surveyor measures, monuments and documents the boundary in relation to the land after the agreement (Zevenbergen, 2002). In that scenario the surveyor is providing guidance and clarification to interested parties for a boundary that already exists in law.

Either way, surveying is the technical aspect of the cadastral boundary – an enduring technical implementation of a social agreement. It should be remembered that it is the social agreement between parties that establishes the boundary in law – not the technical realisation of that agreement in the physical world by the surveyor.

Subsequently, interested parties (future land owners) will rely to some extent on the technical solution provided by the original surveyor to locate that boundary in the real world. This reliance may be direct (relying on boundary marks); indirect (relying on fences or walls supposedly placed correctly in relation to boundary marks); or if there is doubt, by re-establishment of the boundary by another surveyor.

These parties will agree that a right may be exercised in one location, but not another location. If there is disagreement, surveyors – and potentially lawyers and the courts – can be used to resolve the disagreement. Surveyors are experts in identifying locations as well as having expertise in land law (socio-technical expertise). Lawyers are sometimes involved as experts in the application of land law (expertise in the social elements).

The limits in space of a right are the boundaries of that right. To be of any practical use to the landowners or other parties, these rights must be able to be exercised in the real world – and therefore boundaries also need to be identified in the real world. In the real 3-dimensional world, the boundary of a right is a surface that encloses a 3-dimensional volume.

There is a social expectation – seldom explicitly stated but widely understood – that the 3-dimensional volume enclosing rights in land should be attached to the land. This expectation has implicitly been satisfied for centuries by common law and the technical processes of cadastral surveying. More recently, a greater understanding of geodynamics has raised technical questions about how boundaries behave when the land is moving. These questions are vexing for surveyors but not for landowners who generally have little knowledge of, or interest in, geodynamics.

A variation to the concept of boundaries being attached to the land is moveable natural boundaries. In this case the boundary is not attached to the solid Earth but is conditionally attached to a moveable natural feature such as a watercourse. This is discussed further in section 3.1.2 below. A similar exception is part-parcel adverse possession discussed in section 3.1.3 below.

In practice, boundaries are 4 dimensional rather than 3 dimensional because they often endure over very long periods of time. From time to time, they need to have their locations confirmed or re-established. Many boundaries in the central business districts of the main Australian and New Zealand cities have endured since the first surveys of the colonies in the late 18th and early 19th centuries. To the best of their abilities, using the survey technology available to them and the evidence they can accumulate, surveyors re-establish boundaries in their original position on the land – the position of the original social agreement that created the boundary.

In advanced economies with advanced cadastral systems such as Australia and New Zealand, the acceptance of the long-term endurance of boundaries underpins the economy. The parties that invest in land have confidence that their land is, and will remain, well defined and enduring for their use but also for future investment or sale to others. De Soto (2000) describes the role that confidence in property rights plays as being fundamental to the success of capital in countries like Australia and New Zealand.

Over the last few decades, our understanding of the expression “their original position on the land” has become less clear due to improved measurement and understanding of solid earth geophysics and geodynamics. The impact of earth deformation on boundary coordinates is discussed in section 3.1.6 below.

Despite the understanding of earth dynamics by geophysicists and geodesists, most land boundaries are seen by members of the public (those who exercise the rights and those others who respect them) as being “fixed” to the land. The historical and current practices of cadastral surveyors and decisions of the courts, support this societal understanding through an expectation that the boundaries are defined by, or related to, physical features (boundary marks, walls or fences) which are themselves attached firmly to the surface of the land.

Surveyors, in re-establishing a boundary or adjudicating in a boundary dispute will attempt to find physical evidence of the original agreed position at the time the boundary was created in law. The surveying and legal principle in Australia and New Zealand, that (undisturbed) monuments have greater evidential weight than measurements or title dimensions, reflects this expectation of how the locations of boundaries can be maintained over decades or even centuries.

Cadastral surveying therefore combines a technical task (collecting and assessing evidence of survey measurements) with a societal task – satisfying the expectations of society that a fixed boundary has not moved in relation to the land and that a moveable boundary has only moved in accordance with correct legal principles.

One of the biggest challenges of cadastral surveying is therefore not to create and document boundaries, but to facilitate their stable maintenance over time in relation to the land.

3.1.2 Moveable natural boundaries

There are two situations which seem to be exceptions to the concept of boundaries remaining fixed in relation to the land. These are moveable natural boundaries and boundaries that move due to part-parcel adverse occupation (3.1.3 below).

The movement of natural boundaries (e.g. watercourses and coastline) occurs in accordance with the common law principles of accretion and erosion. In general, across Australia and New Zealand, accretion creates a presumptive right to occupy and a right to apply to include the accreted area of land within the title. These rights exist as equitable title even though the accreted land does not lie within the legal title boundaries. Conversely, erosion removes the right to exclusively occupy the eroded land which may acquire the status of a public waterway despite still being within the legal title boundaries.

In practice the title boundaries (and thus the boundaries shown in the spatial cadastre) are generally only changed on acceptance of a new survey depicting the new surveyed position of the moveable boundaries and an application to change the title in accordance with this survey[5]. Therefore, the spatial cadastre is only amended parcel by parcel on application for title by the landowner and acceptance that the common law principles for movement of the boundary have been satisfied. The amendment of the Spatial Cadastre represents a new surveyed boundary rather than a moved boundary.

Therefore, the management of these "moveable boundaries" in the Spatial Cadastre does not depart in practice from the principle in section 3.1.1 that boundaries remain fixed to the land – until such time as they are replaced by a new boundary defined by a new survey.

3.1.3 Adverse Possession

The law relating to adverse possession varies significantly across jurisdictions (Park & Willlamson, 1999). Where adverse possession is provided for in law, a landowner occupying land outside of their title for more than a specified period of time may apply for title to the land.

In some jurisdictions, adverse possession is not provided for at all, in some it can only be claimed in relation to a whole parcel, in others there is a right to claim part of a parcel. This latter case means creating a new boundary on the line of long-standing occupation. The likelihood of succeeding with such an application varies across the jurisdictions that provide for part-parcel adverse possession.

In practice the boundaries in the spatial cadastre are only updated on acceptance of a new survey and an application for a change to the title. Therefore, as with

[5] A notable exception in New Zealand is marginal strips created under the Conservation Act 1987 whereby the legal boundaries (but not the title boundaries) move continuously whenever the natural feature moves. This movement of the legal boundary is in accordance with statute law – not common law. The Surveyor-General is charged with depicting these boundaries in the spatial cadastre although in practice this is very difficult to achieve and creates a disconnect between legal and title boundaries.

"moveable" natural boundaries, boundary changes due to part-parcel adverse possession do not depart in practice from the principle in section 3.1.1 that boundaries remain fixed to the land until they are replaced by a new boundary defined by a new survey.

3.1.4 Surveyor vs Landowner perspectives of boundaries

Different perspectives emerge from the social (landowner) and technical (surveyor) elements of the socio-technical cadastral system as described by Ottens and Stubkjær (2007).

The long-term stability and processes in the cadastral survey system, combined with relatively slow changing legislation and common law precedents, can mean that surveyors tend to focus more on their processes than the societal outcomes that their activities support.

This means that surveyors may naturally think of boundaries in the form that they measure to them, monument them and document them.

- Surveyors take 3-dimensional boundary surfaces and often abstract them to 2-dimensional boundary lines. The 3rd dimension is accommodated by vertical extension of these lines.
- Surveyors then abstract the boundary lines as mathematical straight lines (sometimes circular arcs) between boundary points.
- These boundary points are usually monumented and measurements made to them by surveyors.

The focus for surveyors is therefore on what they can technically measure (boundary marks and fences, etc); then coordinate (abstract mathematical boundary points); and calculate (abstract mathematical straight lines or arcs) between those points.

Similarly, with GIS users or managers of the Spatial Cadastre. Points are the building blocks from which lines and then polygons can be created. Accuracy or uncertainty, where it is expressed as a numeric value rather than a data-source attribute, tends to be defined at the GIS point level as positional uncertainty.

Landowners on the other hand tend to think of boundaries in the form that facilitates their usage of the land and their understanding of what the limits of their usage are.

Historically landowners visualise their boundaries as surfaces such as the face of a fence or wall. The extension of this surface upwards and downwards can be imagined. Therefore, it is the boundary surfaces or lines that mostly constrain their use of the land. Minimum offsets to buildings, encroachments, the length of a commercial frontage – these impact on land value and utility. For landowners, the uncertainty of a boundary point is only of interest to the extent that it governs the uncertainty of the lines that meet at that point.

There are practical limits for a landowner planning to fully utilise their land. These include not only the limits of locating the correct position of their boundary (a surveyor could be engaged for this), there are also practical limits (at least a few millimetres) on the straightness and verticality of any fence or wall constructed on the boundary or at a required offset to the boundary. There will be some physical ambiguity (at least a few millimetres or more) as to the measurement point for the face or centreline of a fence or wall – the structure will generally have some surface roughness, indentations or extensions as part of its construction which contribute to this physical ambiguity. An example of these ambiguities is shown in Figure 3.

Figure 3. Practical issues of ambiguity as to the limits of boundary occupation. At the few cm level, this fence exhibits: (a) an offset from an abutting boundary on the same alignment; (b) non-verticality; (c) lack of horizontal straightness; and (d) a somewhat rough and ambiguous surface. (Melbourne, Victoria)

3.1.5 Functions of boundary coordinates

The function of a coordinate is to provide information about the location of a feature in terms of a coordinate reference frame. A core purpose for this information about location is to enable it to be transferred from one person or agency to another and from one time to another. For features that are maintained over time, a historical coordinate provides information about where that feature used to be.

Cadastral boundaries are maintained over long periods of time, during which time the original boundary marks may have been disturbed or destroyed. Boundary information needs to be transferred from the expert surveyors who determined the boundary location, to many other parties such as land owners and land administration officials. Most of these other parties are only interested in the location itself – not how the surveyors determined it. Coordinates can be reasonably easily used and interpreted using modern widely available spatial technology, without needing much understanding of the process of cadastral surveying.

This makes coordinates very useful as a means of transferring information about boundary location. However, the ease of their interpretation brings with it opportunities for misinterpretation – particularly for users with little understanding of surveying, coordinates or coordinate reference frames, and how they are maintained or changed over time.

For example, the coordinate of a boundary mark, derived from the survey that placed the mark, might be useable later by another surveyor to either:

- confirm that later measurements are to the same physical and undisturbed mark; or
- re-establish the original location of that mark by a later survey if the original mark has been disturbed or destroyed.

However, the use of such a coordinate for boundary re-establishment depends on implicit assumptions about the following factors:

- The uncertainty of the original coordinate determination and whether that was derived from local geodetic control marks (survey uncertainty) or was derived from global positioning (positional uncertainty).
- The accuracy of the new determination of position and whether there are any systematic differences compared with the first determination (different survey technology, different reference marks, different reference frame, etc).
- The stability of the geodetic control marks used to derive the original coordinate and whether these marks were also used for subsequent new positioning or whether different reference marks were used.
- The stability of the land and presence of earth deformation (see section 3.1.6).
- The stability of the coordinate reference frame and the accuracy of any transformations, distortion models, or time-based motion models that were applied to datum changes or the use of a dynamic geodetic datum (section 3.1.6).

Based on typical current cadastral survey standards and methodologies over the last few decades in Australia and New Zealand, and for cadastral surveys that have sound connections to geodetic control, the positional uncertainty of the resulting coordinates can be expected to be within 1 - 2 decimetres. This is generally insufficient in an absolute sense for boundary re-establishment (Outcome A in Figure 1, section 1.1) but it may be sufficient for Outcome B spatial uses.

However, using typical cadastral survey methodologies, it is not positional uncertainty that supports boundary re-establishment. Relative uncertainties between boundary points or to local reference marks is a more important and a relative uncertainty of a few centimetres will usually be achieved. This may be supported by survey uncertainty of 5cm or so in relation to the local geodetic control.

Coordinates that satisfy survey regulation standards for relative uncertainty and survey uncertainty can assist with boundary determination. However, survey expertise will be required to evaluate the assumptions listed above as to how the coordinates were derived, the purposes they can be used for, and to what extent they are likely to be valid.

Where this interpretation is made by an expert surveyor, there is an expectation that these issues will be understood and that the coordinates will be used appropriately. However, where the coordinates are used and interpreted by non-experts the likelihood of misinterpretation is much greater.

Historical cadastral survey positioning techniques were very local in application and this is often still the case. This was partly due to the limitations of the surveying technology of the time. However, it was also fortuitously aligned with the expectations of landowners which are also very localised – focused mainly on their own boundaries and those of their immediate neighbours. Surveyors generally rely on connections to geodetic control marks within a few hundred metres (urban) or a few kilometres (rural) of the boundary.

These techniques, still very common in cadastral surveying, have been and still are sufficient to the purpose of re-establishing the positions of boundaries to meet the expectations of landowners and the requirements of surveying regulations. Cadastral surveyors usually rely on historical survey measurements rather than coordinates. For boundary re-establishment, these historical measurements are immune to the effect of uncertainty in the coordinate reference frame and are mostly immune to the effects of regional or global geodynamics. Cadastral survey regulation requirements for accuracy are still generally expressed in terms of local relative uncertainty, perhaps combined with the survey uncertainty expectations for the connection to geodetic control.

However, the published coordinates used in the Spatial Cadastre, for alignment with other Foundation Spatial Data Framework (FSDF) datasets (ANZLIC, 2014) will be defined in a continental scale reference frame for Australia (ICSM, 2018; Jansen,

2017) or a smaller but tectonically deforming semi-dynamic reference frame as in New Zealand (D.B. Grant, Blick, Pearse, Beavan, & Morgan, 1999).

Emerging survey positioning techniques will allow future coordinates to be generated globally or at least in terms of geodetic control stations hundreds or thousands of kilometres away. If such measurement technology is used for cadastral survey, the distant reference points may have significant differences in earth movement relative to the boundary. In that case, local transformations will be required – derived from measurements to local reference marks and other boundary evidence. Therefore, expertise in measurement and interpretation of coordinates will still be required for the proper use of coordinates that purport to be "survey accurate" or that have a legal status.

3.1.6 Boundary Coordinates and Earth Deformation

This section explores the relationships and dependencies across a broad range – from solid earth geophysics and earth deformation, through geodesy and cadastral surveying, to the potential role of boundary coordinates defining the enduring rights between landowners. Rights in land, and their boundaries, often persist for a century or more. Coordinates tend to be more ephemeral – persisting for years before being changed. Even geodetic datums (on which all coordinates depend) are typically changed every few decades. Earth deformation is a major cause of these geodetic and cadastral changes – even on the relatively stable Australian tectonic plate.

Discussions on the potential legal role of coordinates to define boundaries often leave the issues of earth dynamics and geodetic datum changes unexplored. However, as coordinates in the spatial cadastre become more accurate, and if we also consider increased functions for those coordinates, we cannot ignore the forces that cause them to change – sometimes predictably, but also unpredictably.

The surface of the Earth is affected by tectonic plate movement, seismic events, deep slow-slip (non-seismic) "earthquakes", subsidence resulting from mineral or water extraction, large scale slow landslides, periodic solid earth tides, seasonal effects on the soil resulting from temperature and moisture changes, etc. All points on the Earth's surface (including not only boundaries but also the "fixed" assets of landowners that rest upon the soil or bedrock) are subject to complex motion. This motion is usually insignificant in relative terms at the individual parcel level – but over time can become significant at national or jurisdictional scales in relation to coordinate systems.

The impact of earth deformation on survey marks and boundaries in New Zealand has recently been made clear – most noticeably during and following major earthquakes. Slow continuous deformation also occurs and is reflected in the deformation model which is a part of New Zealand Geodetic Datum 2000 (NZGD2000) and which provides a model for changes to all coordinates throughout New Zealand (D.B. Grant et al., 1999).

The potential impact of earth deformation in Australia is less clear due to the much lower rates of deformation. Except for earthquakes (which are less common in Australia but do occur as in Newcastle in 1989) and large-scale slow landslips, the operation of boundary definition through common law and the usual hierarchy of evidence has always resulted in boundaries moving with slow and imperceptible movements of the land.

The representation of boundaries by coordinates in a Spatial Cadastre raises the question of whether earth deformation could have an impact in Australia as it does in New Zealand – resulting in physical boundary features (boundary marks, fences and walls) moving noticeably or measurably in relation to the coordinates.

Despite the low rates of deformation in Australia, there are three factors which magnify the potential impact of earth deformation on coordinates. These are:

1. The time scales that boundaries are expected to remain in their original position on the land. Original boundaries can endure for centuries.
2. The significantly shorter operational life of geodetic datums that are periodically updated (typically every 1-3 decades) so that they continue to meet the needs of spatial data users.
3. The scale of the Australian continent (approximately 4,000km east – west and 3,700km north – south). A single national geodetic datum extends across the continent to support the coordination of features in FSDF datasets - including cadastral boundaries.

Coordinates that are fixed in a coordinate reference frame (geodetic datum) move in accordance with the axes of that reference frame. If a geodetic datum is defined by the fixed (unchanging) coordinates of geodetic reference marks on a tectonic plate, then the datum moves with the tectonic plate. It may then be referred to as a “plate fixed datum”. The national geodetic datums of Australia (AGD1966, AGD1984, GDA1994 and GDA2020) are all plate fixed datums[6]. New Zealand lies across two tectonic plates and a plate-fixed datum is not a viable option.

[6] The proposed Australian Terrestrial Reference Frame will not be plate fixed. Like the sequence of International Terrestrial Reference Frames, the ATRF will model the motions of geodetic control stations and the datum axes. The role of the ATRF for management of

Stable land moves in relation to coordinate systems due to:

(a) earth deformation relative to the reference frame axes; and
(b) updates to the national geodetic datum to support continued use for personal positioning and FSDF datasets.

Plate fixed datums such as GDA1994 and GDA2020 follow the tectonic plate in an average sense and maintain time dependent 14-parameter conformal transformations with respect to the sequence of International Terrestrial Reference Frames that serve to realize the International Terrestrial Reference System. The use of a plate fixed datum for boundary coordinates removes most of, but not all, the long-term motion in (a) above, between datum coordinates and features (such as boundaries) that are attached to the land. The tectonic shift of boundaries, averaged across the whole plate, is accommodated by the 14-parameter conformal transformation. However, any intra-plate deformation, taking the form of strain rates (non-conformal deformation), will result in movement of land features in relation to the plate fixed datum.

Long term horizontal strain rates within the Australian tectonic plate have been estimated from geophysical and seismic studies. They average about 10^{-17} s^{-1} (0.3 parts per billion per year) (Burbidge, 2004). This is right at the limit of estimation by geodetic measurements although the passage of time and improvements in geodetic measurement precision will make geodetic strain rates more measurable with confidence in the future.

Across the 4000km of the Australian continent this strain rate equates to intra-plate deformation of about 1mm/yr. While this is very low, over the lifetime of a boundary – say 50 to 200 years – it could reach levels (50 – 200mm movements of boundary features in relation to the datum) that would be potentially significant to landowners.

Higher horizontal strain rates of 1 to $5\text{x}10^{-16}$ s^{-1} (3 – 15 parts per billion per year) are reported in some areas including the South Eastern highlands, Flinders Ranges and parts of Western Australia (Braun et al., 2009). This is 10 to 50 times larger than the average continental rate, but these higher values are more localized and therefore apply over shorter distances. The resolution for these estimates of strain is 200km (Braun et al., 2009). The highest of these strain rates equates to more than 3mm/year deformation over 200km or 150mm deformation relative to the rest of the Australian plate in just 50 years. Over distances of 200km, this would still be insignificant for local cadastral surveys. However, over time, it would have a

Spatial Cadastres is still unclear but is the topic of CRCSI Project 3.20 “Implications of a Dynamic Datum on the Cadastre” (van der Vlugt, 2018b).

significant impact on positional uncertainty within a continental scale plate fixed datum such as GDA2020.

In addition to continuous deformation, which accumulates over time, there are other periodic effects which have no significant impact on relative or survey uncertainty of localised cadastral surveys, but which could impact on positional uncertainty depending on how they are managed. Earth tide effects can be as large as 0.4m (Lambeck, 1988) but occur at continental scales, are mostly averaged out by observing for 24 hours, and can be modelled. Ocean loading tidal effects (up to 0.1m – (IERS, 2010) in coastal areas also averaged out over 24 hours but are less easily modelled. Ocean loading tends to be greater in the height direction (potentially affecting 3D cadastres defined by coordinates) but also can have horizontal effects.

Cadastral survey measurements, unlike geodetic measurements, are performed over much less than 24 hours and tidal effects are therefore not averaged out. If performed in relation to local geodetic control as they currently are, the tidal effects have very high spatial correlation and cancel out (even up to a few hundred km). With future advances in positioning such as precise point positioning (PPP), it may be that surveyors are determining instantaneous coordinates which could be centimetres or even decimetres different from an averaged global/national coordinate.

The use of a plate-fixed datum for boundary coordinates offers significant advantages in coordinate stability compared with use of a global or dynamic datum such as ATRF (Jansen, 2017). However, over a few decades (or even a few years as positioning technology advances) continued reliance on a plate-fixed datum limits the usefulness of that datum for most users who will tend to rely on global positioning data and other globally referenced spatial datasets such as up-to-date FSDF datasets. This is the main justification for the periodic national geodetic datum changes over the last few decades – e.g. the change from GDA1994 to GDA2020 (ICSM, 2018).

Datum changes such as the change from GDA94 to GDA2020 will be accompanied by transformation models for users to convert from the old datum to the new datum. This will at least include a conformal (7 or 14 parameter) transformation model. The conformal transformation model may also be accompanied by a distortion model. If earth deformation rates are reasonably well known (as they are in New Zealand – being larger and more measurable) a time-dependent deformation model may also be developed for use to predict coordinate changes over time (D.B. Grant et al., 2014).

The transformation between GDA94 and GDA2020 incorporates a distortion model which identifies distortions as large as 0.5m (ICSM, 2018). This is based on local coordinate variations due to a combination of:

- improvements in the realisation of the national datum over time; and
- intraplate earth deformation over the 26 years between the epochs of datum definition – 1994 to 2020.

In practice, the distortion model cannot separate the influence of these two effects.

The calculation of transformation and distortion models depends on judgements made by geodesists to make the models optimal for all users of the national datum. These judgements are based on the information available at the time. The judgements include the choice of geodetic stations to include or exclude for generating the models[7]; the stochastic model of positional uncertainty for these stations; the mathematical model used for interpolating distortion between stations; and the choice of user interpolation model for users to predict distortion corrections[8].

The information available to geodesists to develop the GDA94 to GDA2020 models was limited. The geodetic control stations used are significantly sparser than the cadastral boundary network. In urban areas the interpolation grid (1.5km x 1.8km) is also significantly sparser than the cadastral boundary network. The process of estimating and applying transformation grids to cadastral boundaries introduces additional uncertainty.

The current default geodetic model for intra-plate deformation between GDA2020 and ATRF is a null model. Plate motion across Australia is considered to be conformal and linear over time (ICSM, 2018). Studies of strain rates in Australia (Braun et al., 2009) indicate that strain (a measure of non-conformal dynamics) while being small, is non-zero and can accumulate over time to levels that could significantly impact on boundaries.

Over the next few decades, as more survey, geospatial and geophysical information becomes available, as the signal of strain rates per year become more easily

[7] For the GDA94 to GDA2020 transformation and distortion grid, 109 geodetic stations were used to calculate the conformal transformation model (average of 1 station per 70,000km^2 across Australia) and approximately 170,000 stations used to estimate the distortion model (average of 1 station per 45 km^2 – although the density varies greatly between urban and remote areas) (ICSM, 2018)

[8] The GDA94 to GDA2020 model interpolates distortion onto a 1' grid – approximately 1.5km by 1.8km) (ICSM, 2018). The user then applies the model by bi-linear interpolation from these estimated grid values (Collier, 2002).

separated from measurement noise, improved and higher resolution distortion and earth deformation models for GDA2020 to ATRF will be generated.

These models will allow up-to-date boundary coordinates to more closely reflect and follow the true legal positions of boundaries (the position on the land where it was originally created by agreement between the affected parties) and then to move the coordinates with the boundaries as the land moves.

Over time these models may also need to reflect the fact that earth deformation is not always linear in time. (The deformation models in New Zealand manage non-linear earthquake deformation (D.B. Grant et al., 2014). Earthquakes also occur in Australia such as in Newcastle in 1989 and the impacts are non-linear and unpredictable[9].

3.1.7 Discussion on Boundaries and Coordinates

The above discussions on the fundamentals of boundaries and coordinates and the differences in understanding of boundaries between landowners (a social perspective) and surveyors (a socio-technical perspective) relate to several fundamental questions and issues which should be addressed before the research questions are approached.

The five questions below emerged from analysis of the interviews and discussions with stakeholders and user groups. The framework of the interview questions, based on the Cadastral Triangular Model described below in section 3.2, allowed these issues and unresolved questions to emerge which might otherwise have been taken to be resolved by common understanding – needing no further examination. The responses which follow each question, are based on the discussions in sections 3.1.1 to 3.1.6 above.

1. To best serve the needs of society (particularly the holders of rights restrictions and responsibilities in land), should boundaries continue to be defined[10] in the <u>physical</u> world where rights are exercised, or should they be defined in a <u>mathematical model</u> of the world using coordinates?

[9] Note also that If a legal coordinate cadastre was extended to legal heights in a 3D cadastre, non-linear and quite localised vertical deformation can result from water or mineral extraction.

[10] Here "defined" is used in the sense of providing strong (definitive) legal evidence for the location in space of the boundary.

In response to this question, it is asserted that landowners are much more likely to consider the physical expression of their boundaries to be relevant to them than a mathematical model of the boundaries. A mathematical model could be accepted but only if it aligns closely and behaves consistently with the physical expression of their boundaries.

2. Over the lifetime of boundaries (typically ranging from decades to centuries) should the boundaries be considered to be fixed to the land (and therefore potentially moving – usually slowly and imperceptibly – in relation to the coordinate system); or fixed in relation to the coordinate system (and therefore potentially moving across the land)?

   In response to this question, it is asserted that if landowners are told that surveyed boundaries (other than moveable natural boundaries) are slowly moving across the surface of the land, this is not likely to meet social acceptance. Even in the case of the Canterbury earthquakes, where the movements were neither slow nor imperceptible, the New Zealand Parliament, through the Canterbury Property Boundaries and Related Matters Act 2016, accepted the social expectation that boundaries move with the land. In cases where earth movement is completely unperceived by the public, boundaries that are tethered to a coordinate system but untethered to the land are most unlikely to gain public acceptance. Without that broad public acceptance, the cadastral system would have failed to meet the End Outcomes.

3. Despite current and expected improvements in survey measurement technology, should there be a lower limit (based on practical, physical, social or economic considerations) for the nominal width or uncertainty sought for or attributed to a boundary line (or in 3 dimensions – the thickness of a boundary plane)?

   In response to this question it is noted that such a limit would be a narrow zone of uncertainty across which neither landowner either side of the boundary could have complete confidence in the assertion of their rights. In survey terms, this would be a lower limit for the accuracy expectation in the cadastral survey standards and regulations or the expression of boundary uncertainty (relative, survey or positional) in cadastral documentation and databases. In legal terms this would be a threshold below which disputes or claims of encroachment would not be entertained by the legal system.

   In practice such thresholds do exist. In Victoria, Sec. 272 of the Property Law Act 1958 specifies a limit of 50mm or 1 part in 500 for longer boundaries. A similar provision applies in Western Australia. In New Zealand the boundary accuracy standards in the Rules for Cadastral Survey are interpreted as a boundary envelope within which the precise location of a boundary point is indeterminate.

Therefore, there are physical and practical limits (at the centimetre or few centimetre level) for surveyors to advise builders and landowners where to confidently occupy the full extent of their land. These limits prevent a boundary line from practically being treated as a line of zero width. Improvements in survey technology or changes to survey regulations may affect these practical limits but ultimately, they cannot be eliminated. These limits are effectively encapsulated in the survey accuracy regulations in each jurisdiction. This study has not addressed the level of these regulations except to note that they set a lower limit for coordinate accuracy. A desired lower limit for the uncertainty of boundary definition will not be proposed in this report except to note that it is not zero uncertainty.

4. What useful functions can coordinates serve while not being definitive as to the boundary location?

   In response to this question it is noted that in some jurisdictions, coordinates can serve a function as evidence of boundary location – useable by surveyors. Even where this is not the case, coordinates which have a positional uncertainty comparable to the width of a fence or wall can still be much more valuable to landowners, than inaccurate coordinates that appear to be divergent from boundary fences or walls. Such "spatially-accurate" coordinates will not provide certainty of boundary location – that remains a task reserved for licensed cadastral surveyors. Nevertheless, combined with other spatial datasets including imagery, coordinates at this level of spatial accuracy can, with a reasonable level of confidence, partly satisfy the vision of Cadastre 2034 (ICSM, 2015) so far as land ownership is concerned – namely: "a cadastral system that enables people to readily and confidently[11] identify the location and extent of all[12] rights restrictions and responsibilities related to land and real property".

5. Where boundary coordinates play a role in the definition of boundaries by cadastral surveyors, will the coordinates need to change over time to reflect changes in the physical world as well as changes to the national geodetic datum?

[11] Confidence is not the same as certainty. However, given that the great majority of boundaries are not in dispute, and that cadastral surveyors provide a mechanism for resolving the few that are in dispute, a reasonable level of confidence is proposed.
[12] The extension to **all** RRRs is beyond the scope of this project. Land ownership is the most important of these RRRs and is covered by this project.

In response to this question, and drawing on responses to the questions above, it is noted that if the boundary coordinates have sufficiently low positional uncertainty, and if they have been derived by a robust, transparent and legally authorised process, then they can and do play a range of roles across jurisdictions in the definition of boundaries by cadastral surveyors.

Regardless of the model for using coordinates, boundaries should be considered to be fixed to the land (question 2 above) and because significant earth movements can occur over time, (section 3.1.6) it follows that boundary coordinates should change over time to reflect these movements. Also as the geodetic datums in use for FSDF datasets (ANZLIC, 2014) are changed from time to time, it follows that the boundary coordinates in operational use will need to be made available in the new datums.

The mechanism for these boundary coordinate changes will depend on the role that the coordinates play and their method of derivation.

3.2 Cadastral Triangular Model

The concept of a cadastral boundary is simple and readily understood by the layperson. However, on closer examination the cadastral system used to record, manage and re-establish those boundaries is highly complex. There are many subsystems with complex interactions and dependencies. Experts describing the complexity of the system often use different terminology for the same concepts or the same terminology for different concepts. This creates the risk that participants in the qualitative research procedure will have a different understanding of the questions and that the researchers will misunderstand their responses.

This research project has therefore developed a model for describing, at a high level, the main information systems relating to cadastral boundaries. This is known as the Cadastral Triangular Model.

3.2.1 Evolution of Model complexity

The Cadastral Triangular model can be described as an extension of earlier conceptual perspectives. Bennett, van der Molen, and Zevenbergen (2012) describe the different perspectives of surveyors and the Courts or legal profession towards cadastral boundaries and identify boundaries as a legal concept. In law this concept of a boundary may be understood as an infinitely thin line where an infinitely thin vertical surface intersects the Earth's surface.

Also noted by Bennett et al. (2012), is the surveyor's perspective of a boundary as being located in space by measurements having some level of stochastic uncertainty. From the surveyor's perspective, the boundary cannot be dimensionless because its location in space has physical and practical limits.

Lawyers and judges may have difficulty with the concept that the true location of a boundary in space is not perfectly known and even not perfectly knowable (Bennett et al., 2012). However, the task of locating a boundary in the world falls to surveyors. The courts can direct a surveyor on how the laws and evidence are to be interpreted. However, the courts have neither the expertise, nor the authority, to conduct a cadastral survey to locate, coordinate or mark that boundary. In the Australian and New Zealand jurisdictions, only a licensed / registered surveyor can perform this task.

Another factor in the surveyor's perspective, as well as the limits in their measurements and the consequent uncertainty in boundary location, is consideration of the intensity of land use and the "need-to-know" of the landowners or right-holders.

Thus, two conceptual views can be identified:

- the view of lawyers and judges that a boundary is a legal concept – perhaps seen as a zero-width line (2D) or surface (3D)
- the view of surveyors that a boundary is a socio-technical concept – having physical and technical limits to its definition as well as the social limits of how accurately the affected parties (landowners) need it to be defined in space.

There is an interaction between these two concepts – in Australia and New Zealand, the surveyor sets out a proposed boundary which is later accepted by agreement as being defined in law. Subsequently, other surveyors charged with the task of locating the boundary will apply legal principles and technical survey procedures when assessing and applying evidence to re-establish the location of the originally surveyed and agreed boundary. Therefore, a simple model of the relationship between surveyed and legal boundaries could be depicted as in Figure 4.

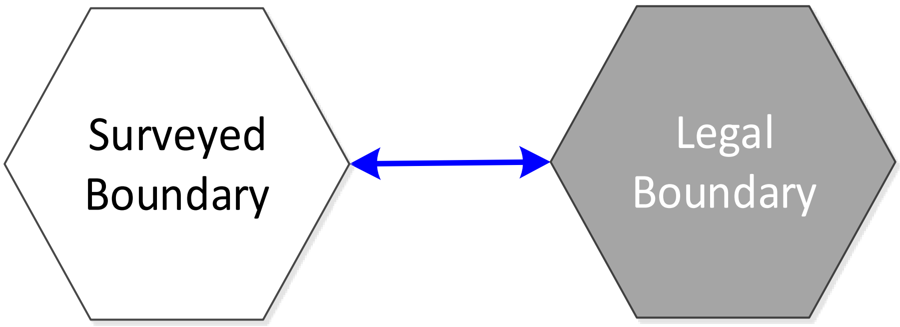


Figure 4. Basic relationship between surveyed and legal boundary

This model in Figure 4, derived from the description in (Bennett et al., 2012), can be extended, as in Figure 5, with the recognition that prior to development of Spatial Cadastres, evidence of surveyed boundaries came in two general forms:

- physical boundaries being the tangible evidence of surveyed boundaries that are the accepted limits of land use in the physical world – e.g. boundary marks, natural boundaries, fences, walls, a visible line between different types of land use or cultivation, etc.
- documentary boundaries being the documented evidence of boundaries that had been accepted and agreed at the time of their creation – e.g. survey plans, titles, field notes, supporting documents, transfers, etc.

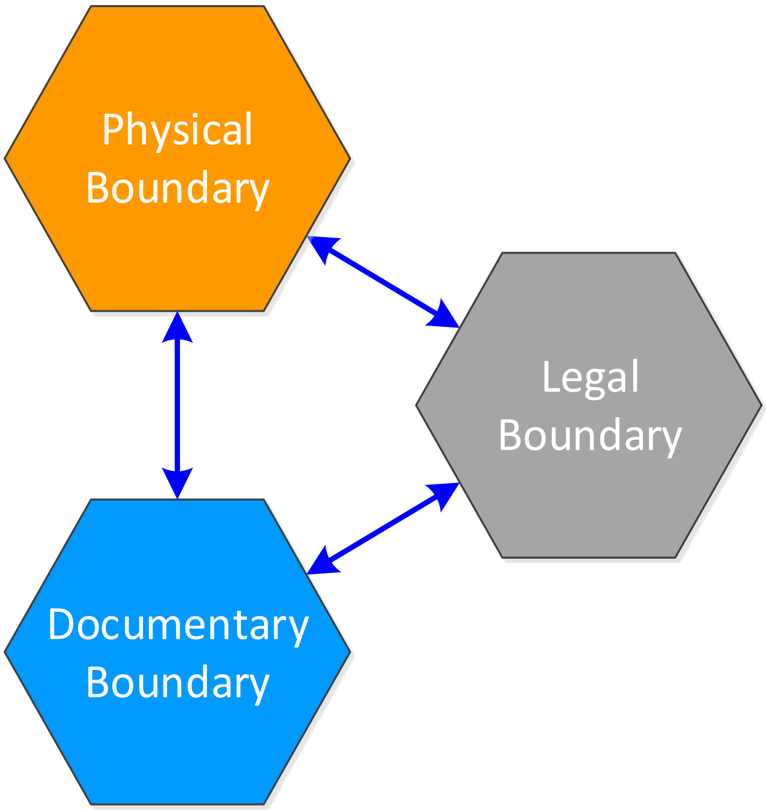


Figure 5. Relationship between Physical, Documentary and Legal Boundary

One form of documentary evidence in Figure 5 was paper cadastral maps covering the jurisdiction or parts thereof. These served as indexes to cadastral information but also showed the spatial relativity and connectedness (topology) of all boundary points, lines and parcels in a jurisdiction in relation to their abutting spatial boundary features.

3.2.2 Spatial Cadastral Triangular Model

From the 1980's, jurisdictions in Australia and New Zealand digitised their paper cadastral maps into Digital Cadastral Databases (DCDB's) using Computer Assisted Drafting/Mapping (CAD/CAM) and Land Information System/Geographic Information System (LIS/GIS) software (Williamson & Enemark, 1996). The primary driver for this change was to allow a reduction in the duplication of management and update of different sets of paper maps amongst different agencies responsible for land administration within government.

Around the same time, the need for a multi-purpose cadastre was identified (McLaughlin, 1975; National Research Council (NRC), 1980). Such a multipurpose system is achieved in practice by sharing the cadastral map as a spatial dataset with other managers of land administration functions (valuation, land use planning, etc). Therefore, while the initial justification for the Spatial Cadastre was to reduce the maintenance cost and duplication of paper cadastral maps (Williamson & Enemark, 1996) its potential value to support a multipurpose cadastre was also recognised – for example in the context of the New Zealand's Spatial Cadastre (Wilson, 1990).

A Spatial Cadastre involves the creation of a spatial representation of the cadastre which can increasingly be used (rightly or wrongly) as a third form of evidence of boundary location. In addition to the physical cadastre encompassing physical boundaries and the documentary cadastre encompassing documentary boundaries (both aiming to represent legal boundaries), we now have the Spatial Cadastre adding an alternative and possibly competing spatial representation of boundaries.

To reflect the development of spatial representations of boundaries and the increasing reliance of government, business and the public on these representations, the above models have been extended to a triangular model of the cadastral boundary system as shown in Figure 6.

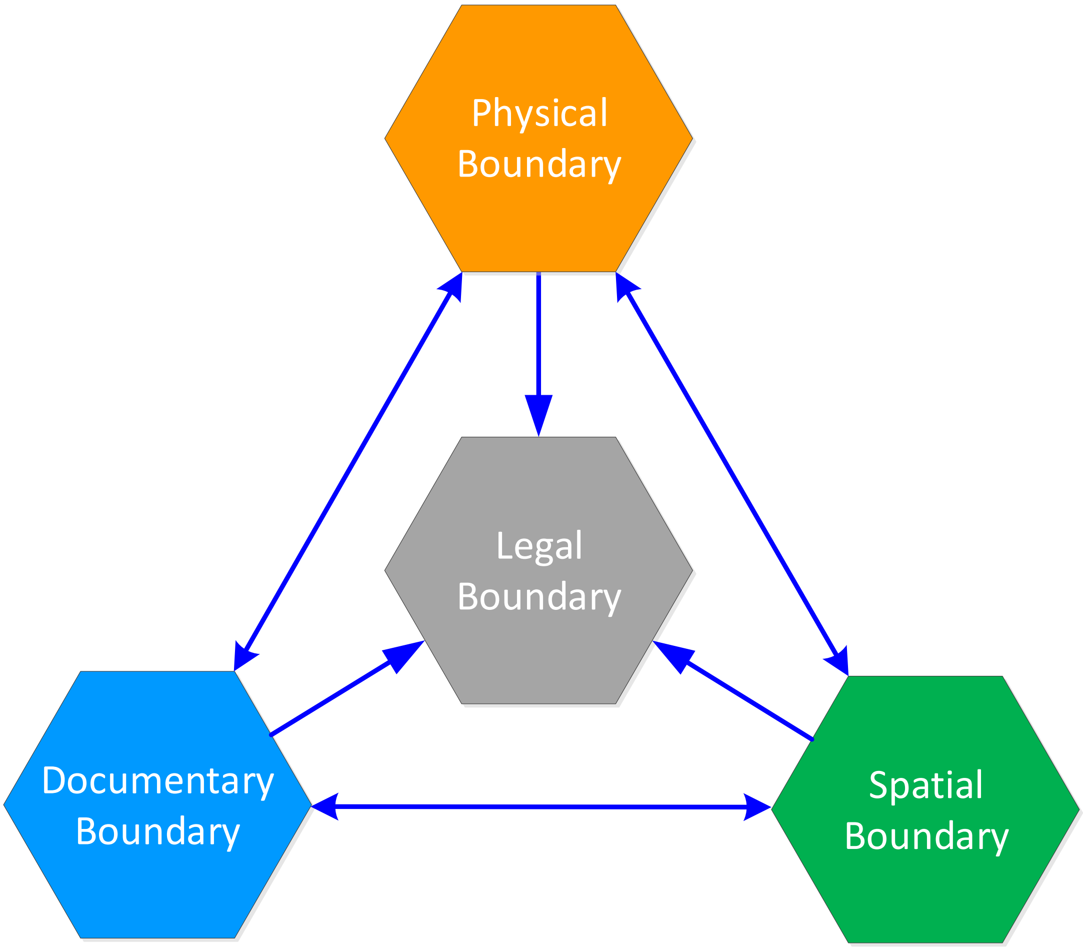


Figure 6. Interrelationship between Physical, Documentary, Spatial and Legal Boundaries

3.2.3 Application to the Research Question

This model has proven valuable in exploring options for upgrading the Spatial Cadastre – in particular, the functions that would be served, and the benefits that would result, from different options for development. The focus of this research is an assessment of the ability of the spatial visualisation of boundaries to accurately represent or define the legal boundaries at different levels of development and improvement. Options for development depend on the relationship between the information provided by the Spatial Cadastre and the information contained within the physical and documentary cadastres which contribute to the maintenance and development of the Spatial Cadastre.

This focus is not complete without an assessment of the competing visualisations of boundaries – physical and documentary. This in turn requires an understanding of the relationship between the physical and documentary cadastres which is the dominant information flow for cadastral surveyors. These relationships – all of which must be explored to understand the operation of the system – are shown as the blue arrows in the Cadastral Triangular model.

The primary focus of this research and the model relationships that impact on it are identified in Figure 7.

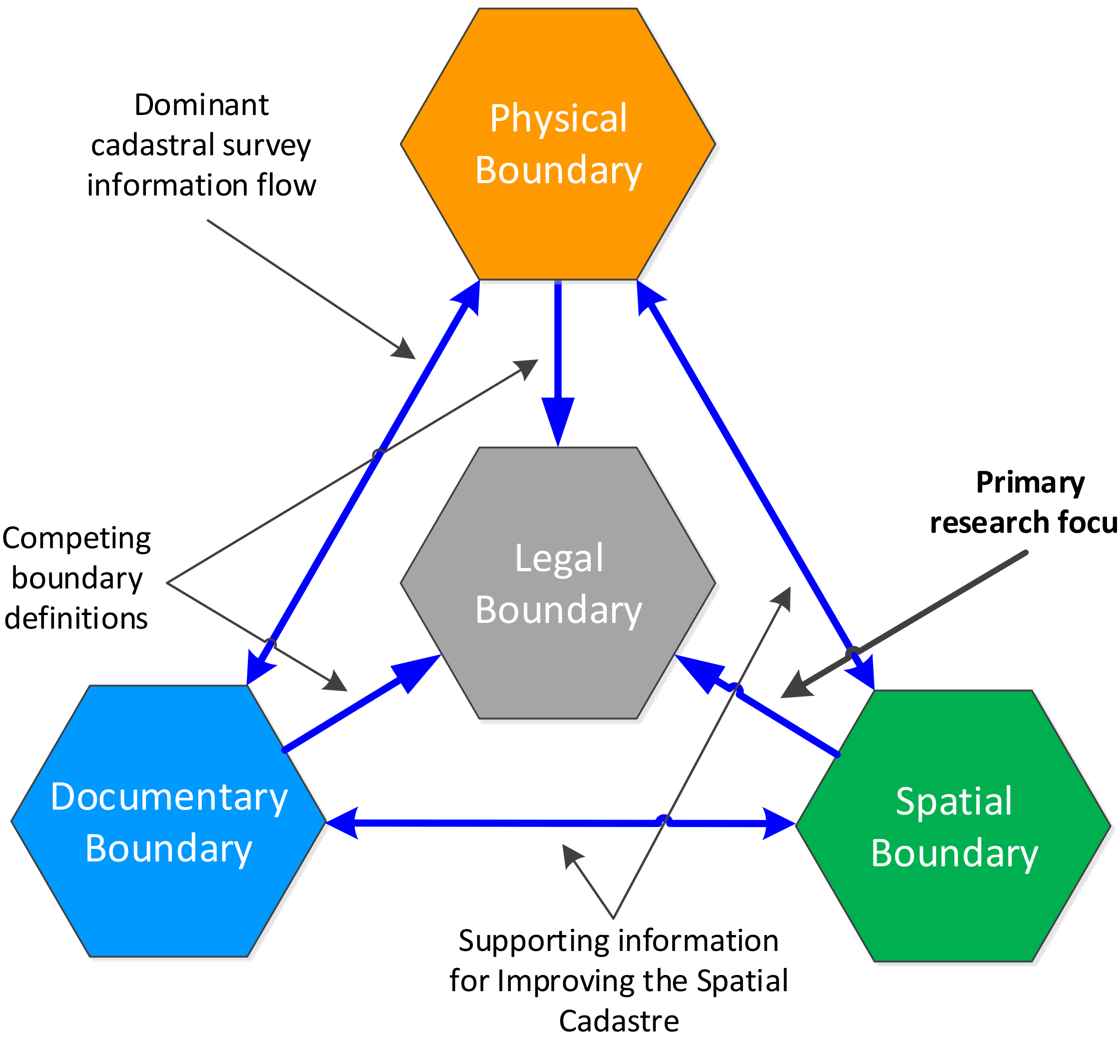


Figure 7. Interrelationships within Cadastral Triangular Model

3.3 Spatial Cadastral Improvement Levels

A proposed framework or hierarchy of Spatial Cadastral Improvement[3] Levels is outlined here and summarised in Table 1. It has been used in partnership with the Cadastral Triangular Model to address the research questions. The Spatial Cadastral Improvement Levels described here have been developed as a modification of the "Levels of Maturity for Survey Infrastructure" (Todd et al., 1998). The earlier cadastral maturity levels described by Todd et al included a mixture of maturity and accuracy considerations at each level, i.e.

- cadastral surveying for boundary definition (which focused on cadastral outcome A); and
- the spatial (digital map) view of cadastral boundaries (which focused on cadastral outcome B).

Because the accuracy requirements may differ for different purposes or outcomes, the Spatial Cadastre Improvement Levels outlined here have been refined and reworded to focus on the improvement levels of the Spatial Cadastre. Nevertheless, there is some overlap in application because in the upper three Spatial Cadastre Improvement Levels: 5 (Survey-compliant Spatial Cadastre); 6 (Survey Coordinate Cadastre); and 7 (Legal Coordinate Cadastre); the coordinates contained within the Spatial Cadastre can also play an informal or formal role in cadastral surveying for boundary definition (Cadastral Outcome A) as well as for land administration and public use (Cadastral Outcome B).

Table 1. Spatial Cadastral Improvement Levels with indicative uncertainties

Level	Name	Description	Uncertainty
0	Graphical Paper Map	Original paper cadastral index maps	High (relative) High (positional)
1	Digitised Spatial Cadastre	Spatial database generated by digitisation of the Graphical Paper Maps. Following lodgement, new cadastral survey boundaries are added to the unchanged digitised boundaries. This replicates the paper map maintenance process.	High (relative) High (positional)
2	2a Survey-maintained Spatial Cadastre - Fitted	Following lodgement, new cadastral surveys are integrated by generating a best fit of the new surveyed boundaries to the parent parcel which is adjusted in-situ to receive the new survey information.	Medium - High (relative) High (positional)
	2b Survey-maintained Spatial Cadastre -Rubber-sheeted	Following lodgement, new cadastral surveys are integrated by fitting the new surveyed boundaries and rubber-sheeting abutting and nearly parcels in the vicinity to reduce distortion and to improve the parcel location within the map grid.	Medium - High (relative) Medium - High (positional)
3	Spatially-aligned Cadastre	Spatial Cadastre systematically upgraded through alignment with other spatial datasets (including a focus on sufficient geodetic survey connections to boundaries) that are indicative of boundary location.	Medium (relative) Medium (positional)
4	Survey-improved Spatial Cadastre	Spatial Cadastre upgraded by systematic back-capture and adjustment of sufficient survey measurements and all boundary dimensions from historical surveys plus new survey connections to geodetic control. At this level survey-compliance is not achieved.	Low – Medium (relative) Low – Medium (positional)
5	Survey-compliant Spatial Cadastre	Cadastral coordinates derived from adjustment of survey measurements and boundary dimensions satisfy relative, survey, and positional uncertainty standards in the survey regulations. Level 5 differs only from level 4 in respect of compliance with survey regulations.	Low (relative) Low (positional)
6	Survey Coordinate Cadastre	Designated coordinates of cadastral boundaries are expressly assigned a status in the hierarchy of evidence for survey definition but are not definitive.	Low (relative) Low (positional)
7	Legal Coordinate Cadastre	Designated coordinates are given primary legal status as conclusive evidence for survey definition (in the absence of a proven error).	Zero in theory (relative) Zero in theory (positional)

3.3.1 Level 0 – Graphical Paper Map

The precursor to the digitised Spatial Cadastre was the set of paper based cadastral index maps. Collectively across a jurisdiction, these maps showed all parcels in a jurisdiction, their boundaries, parcel identifiers (legal appellations) and references to other records including survey plan references, Crown land records, etc. The maps were maintained by inserting new subdivisions within the existing subdivided parcel. These index maps served as an initial point of reference when searching cadastral and land tenure records and provided a graphical record of cadastral parcel topology allowing abutting parcels to be identified. They also were often used to record other rights, responsibilities and restrictions (e.g. licenses) on unregistered land (e.g. roads, river beds, reserves, Crown land); or for recording other rights that are not registered against titles.

Relative uncertainty of boundaries shown on these maps in Australia and New Zealand was quite high (uncertain). The parcel on the map was expected to appear to be the correct size and shape in relation to other parcels. The positional uncertainty in relation to the map grid or geodetic datum was high – particularly in rural areas. This was partly due to the limitations of drafting at the map scale and partly due to historically infrequent connection of cadastral surveys to the geodetic datum. Maintenance was manual, slow and expensive. As rural land on the edge of towns and cities was urbanised, new maps at larger scales were needed to show the denser pattern of land use.

The main disadvantages were that other agencies (government departments, tenure managers, Councils, etc) could not easily access the paper index maps except by copying them. Replicating the maps in other agencies was expensive, error prone and with significant maintenance issues. The manual effort needed to maintain (or replicate) the maps was costly and led to delays in updating the maps when new surveys were approved.

All Australian and New Zealand jurisdictions have improved their Spatial Cadastres beyond Level 0. This level is included here for historical completeness because the spatial cadastral systems still contain some inaccuracies and anomalies derived from the Level 0 cadastral index maps.

3.3.2 Level 1 – Digitised Spatial Cadastre

The original digital cadastral databases were built by digitising the boundary information on the paper maps and geo-referencing the boundary points to the relevant geodetic datum. Following digitisation of the paper maps, new surveys need to be integrated into the database. The simplest form of this integration is where the new intersected boundary points from subdivisions are snapped onto the existing boundary lines external to the subdivision and other new boundary lines are fitted within the subdivided parcel. This results in no positional change to existing digitised boundaries (only a topology change of the new boundary points, lines and polygons). New parcels may be somewhat distorted where they have a mix of new more accurately surveyed boundaries and existing inaccurate digitised boundaries. The Level 1 process is simply a digital form of the graphical process used to maintain paper maps.

Some of the intentions for the conversion from paper to Level 1 Spatial Cadastre were to improve utility and reduce costs by:

- allowing digital databases to be readily shared between government agencies that managed land administration functions – e.g. Councils for land development and planning;
- reducing the maintenance costs for adding new subdivisions to the record;
- avoiding the need for redrawing where increased density of development made the map scale inappropriate; and
- facilitating back up to prevent disastrous loss of records.

The relative and positional uncertainties were initially no better than the Level 0 paper maps and could be somewhat worse due to errors in the digitisation process. There was an introduced risk of creating topology errors when boundary angles were missed, or non-existent boundary angles were added.

All Australian and New Zealand jurisdictions have improved their Spatial Cadastres beyond Level 1. This level is included here for historical completeness because the spatial cadastral systems still contain some inaccuracies and anomalies derived from the digitised cadastral index maps.

3.3.3 Level 2 – Survey-maintained Spatial Cadastre

The Level 2 maintenance process differs from the maintenance processes for new subdivision surveys in Level 1 because the Level 2 processes involve some enhancement of the Spatial Cadastre using the new more accurate data from newly lodged surveys. There are two options for maintaining and improving the Digitised Spatial Cadastre by incorporating new accurate cadastral survey data from subdivisions or redefinition surveys. Both options provide some opportunistic and ad hoc improvement in both relative and positional uncertainty in local areas by relying on new cadastral survey data lodged with the land agency.

The first option called **"Survey-maintained Spatial Cadastre - Fitted" (Level 2a)** involves inserting all the new surveyed parcels into the Spatial Cadastre as a best fit to the existing parent parcel. All newly surveyed boundaries have the correct shape based on the survey definition. This reduces the relative uncertainty of adjacent boundary points within the subdivision or re-establishment survey without any improvement in the positional uncertainty of any boundaries. A disadvantage of this option is that it requires abutting boundary lines to be re-aligned between the newly surveyed exterior boundary points of the survey to the unchanging abutting parcel boundary points. Shifting one end of these boundary lines without shifting the other end will introduce distortion to the abutting parcels. This option causes a relatively low level of disruption to spatial data users who seek minimal changes to boundary coordinates.

The resulting relative uncertainty under this option is variable. It provides low uncertainty and correct topology for recently surveyed parcels – the relative coordinates will have been derived from survey measurements. The relative uncertainty for other parcels will remain as high as it was following digitisation, i.e. the same as Level 1. Parcels abutting recent surveys may have worse relative uncertainty due to the distortion resulting from the fitting process. Positional uncertainties will be no better than for Level 1.

The second option called **"Survey-maintained Spatial Cadastre – Rubber-sheeted" (Level 2b)** reduces distortion in abutting parcels in the vicinity by spreading this distortion across many parcels.

In cases where the new survey is connected to geodetic control it also allows the newly surveyed parcels to be placed more correctly in terms of the geodetic datum. This will improve the positional uncertainty of the boundary points in the survey but creates a risk of severe distortion of abutting parcels – which is avoided by "rubber-sheeting" or spreading the distortion over an area broad enough to smooth it out.

The result is a small group of parcels which now have the good relative uncertainty, correct topology and reasonably good positional uncertainty, surrounded by many parcels with somewhat distorted geometry and positional uncertainty which increases with increasing distance from the new survey.

Over time, the positional uncertainty improves in areas subject to a reasonable number of new surveys. However, the resulting larger scale coordinate changes, with many boundary points being moved whenever a new survey is integrated into the Spatial Cadastre, causes difficulty for some data users who have a spatial database maintenance strategy relying, as much as possible, on the stability of spatial cadastral boundaries.

3.3.4 Level 3 – Spatially-Aligned Cadastre

Level 3 involves a more systematic approach than Level 2 but a significantly less complete back-capture than Levels 4 and 5 below. This is called the Spatially-Aligned Cadastre whereby the Spatial Cadastre is systematically improved over a broad area to provide a general level of alignment with the legal boundaries (which means that they are usually also aligned with the physical boundaries).

Discussion on upgrade of the spatial cadastre is often based on proposals for full back-capture of survey observations for all parcels in an upgrade area. This represents Levels 4 and 5 (discussed below) and has been implemented in New Zealand (Rowe, 2003), Western Australia (Landgate, 2017) and was included in proposals for Victoria (Sinclair Knight Merz, 2011). However, this is expensive, and Level 3 is an option superior to Level 2 in terms of reduced uncertainty but less costly than Level 4.

The Spatial Cadastre could be upgraded to Level 3 described here through alignment with other spatial datasets that broadly include visible features in imagery and which are generally associated with, and usually close to, boundaries – fences, walls, natural features, etc. This has potential to improve the positional uncertainty within the Spatial Cadastre and minimise differences with other datasets that are commonly overlaid on the Spatial Cadastre.

Because the goal for this level is spatial improvement rather than survey accuracy (or survey compliance), the methods employed do not need to be rigorous. The goal is improved positional uncertainty over a wide area while retaining (or not significantly degrading) the relative accuracy.

The process of achieving this change will be somewhat disruptive to spatial data users due to the large boundary coordinate changes involved. However, it is a one-off change during the project and subsequent boundary coordinate changes as new surveys are approved would be expected to be relatively small.

3.3.5 Level 4 – Survey-improved Spatial Cadastre

Level 4 uses systematic and complete back-capture of survey measurements or surveyed boundary dimensions from survey plans over a broad area, together with connections to geodetic control, to significantly reduce the positional uncertainty of boundaries in the Spatial Cadastre over those broad areas. If the survey data is old and inaccurate or if there are unresolved conflicts, the coordinates will not reach the level of positional uncertainty that would allow them to comply with the relative uncertainty (boundary point to boundary point) or survey uncertainty (boundary points in terms of local reference marks) that are specified in the jurisdiction's survey regulations. These coordinates can be called "survey-improved" but do not reach the level of "survey-compliant" which is Level 5.

3.3.6 Level 5 – Survey-compliant Spatial Cadastre

If the coordinates resulting from adjustment of connections of boundaries to geodetic control and boundary dimensions, do comply with the relative and survey uncertainty standards in the survey regulations, then those coordinates can be called "survey compliant". (Another term sometimes used is "survey accurate".) Levels 4 and 5 are likely to co-exist in different parcels (or even different boundary points within the same parcel) following a survey capture program for spatial upgrade. This is because some boundary points will meet the criteria for compliance with the survey regulations while other boundary points may have conflicts or weak geometry. This is the case in New Zealand where the survey conversion project (Rowe, 2003) resulted in many boundary coordinates that were considered to be "survey-accurate" (here called survey-compliant – Level 5) while others did not meet the threshold for survey compliance but are nevertheless derived from cadastral survey measurements and have relatively high uncertainty – Level 4.

Survey-compliant (Level 5) coordinates may sometimes be used informally in relation to the hierarchy of evidence where they are deemed to be a summary of survey observations that have been shown to be consistent with each other and perhaps with other evidence also. Future surveyors may be able to use them to place boundary marks but only if there is no unresolved conflict with other evidence in the field.

3.3.7 Level 6 – Survey Coordinate Cadastre

Level 6 differs from Level 5 in that the Level 6 coordinates have been assigned a status within the hierarchy of evidence. These coordinates can be relied upon if they are not in conflict with other stronger survey evidence. In the case of conflict, the coordinates could be overturned by acceptance of stronger evidence or may prevail against weaker evidence. With the coordinates not being legally definitive (as in Level 7) any conflicts with other evidence could be resolved through changes to the coordinates as required. Coordinates can also be transformed to a new geodetic datum based on an accurate and authoritative datum transformation.

As an example, proclaimed areas in the Northern Territory are at Level 6 where the coordinates do have a legal status in the hierarchy of evidence. South Australia has legislation supporting Level 6 but this has not been applied.

3.3.8 Level 7 – Legal Coordinate Cadastre

A Legal Coordinated Cadastre (Level 7) has boundary coordinates with a pre-eminent legal status. They are taken as evidence of boundary location unless they can be demonstrated to have been created incorrectly. Under this scenario, a boundary coordinate would usually only be refuted as evidence of boundary location where there has been a legal or administrative error in creating it[13].

No Australian jurisdiction or New Zealand has a fully Legal Coordinate Cadastre.

Legal coordinates result in the boundaries becoming almost completely untethered from the original location of that boundary in relation to the land at the time it was first created. In areas with very low and predictable earth deformation, the practical difference may be small but may still grow over long periods of time.

[13] If the coordinate can be changed based on cadastral survey evidence; a change in the geodetic datum; or survey evidence of deformation, then that is an example of Level 6 Survey Coordinate Cadastre above rather than Level 7 Legal Coordinate Cadastre.

4 Results

This chapter contains the project's responses to the principal research questions derived from analysis of the responses to interviews. The chapter is divided into two sub-sections corresponding to the first two principal research questions (section 1.3):

- What functions or purposes does the Spatial Cadastre serve?
- What is the optimal positional uncertainty required of the Spatial Cadastre to best fulfil these functions?

The third principal research question is addressed in Chapter 5.

This chapter also includes several related recommendations for upgrading the Spatial Cadastre.

4.1 Spatial Cadastre Users and Functions

The functions and users of jurisdictional Spatial Cadastres are varied and growing with increased availability and expanded awareness of the datasets. Access may be via replication of the databases, via the land administration agencies' front-end web services, e.g.

- ACTmapi (ACT) – (http://www.actmapi.act.gov.au),
- SLIP (WA) – (https://www0.landgate.wa.gov.au/business-and-government/SLIP),
- Landonline (NZ) – (https://www.linz.govt.nz/),
- theLIST (Tas) – (https://www.thelist.tas.gov.au/app/content/home),

or via 3rd party data services (e.g. https://www.nearmap.com.au) that aggregate cadastral data with other datasets. Along with traditional land administration functions, newer, expanding locational-based service applications also rely on property data in the Spatial Cadastre.

Table 2, derived from the interviews, identifies the main groups of users of the Spatial Cadastres and the functions that the data serves in each case.

Table 2- Users and Function of the Spatial Cadastre

User Group	Functions
Surveyors	Surveyors use the Spatial Cadastre as an index map to identify survey plans and title documents relevant to a street address/parcel. Surveyors use the Spatial Cadastre to locate Permanent Marks or historical boundary marks to connect their surveys to the historical definition of boundaries. Surveyors also use the Spatial Cadastre to assist drafting plans and check surveys for gross errors. However, they generally do not have higher expectations of the Spatial Cadastre than do other users.
Utility Companies	Utility companies (i.e. gas, water, electricity and telecommunication companies) use the Spatial Cadastre for defining the location of their assets and particularly their need to know the status of the land their assets are located in (whether private or public). Utilities companies may use the Spatial Cadastre in a variety of ways for location of assets, e.g. they may be recorded as an off-set to property boundaries, off-set to fencing, or absolute position described by coordinates. Updates to the Spatial Cadastre may be applied to utility company systems to reposition their assets to align to the Spatial Cadastre. Spatial updates can be problematic to utilities depending on how they have recorded their assets. For example, Spatial Cadastre administrators may be able to provide shift vectors with spatial upgrades that utilities can readily apply to their asset location systems. Data may also be aggregated and available via “Dial before You Dig” services.
Local Government Authorities/ Councils	Councils use the Spatial Cadastre to assist with land development application approval processes, e.g. determination of applicability of a planning zone to a parcel. Spatial updates may or may not be problematic to Councils, depending on how planning zones etc. have been defined with respect to the cadastre. Councils may also use the Spatial Cadastre in a similar way to utility companies for asset location and management, e.g. street furniture.

Government Departments/ agencies	Various jurisdictional government agencies use the Spatial Cadastre as a base dataset layer. Such agencies include housing, mining, environmental protection, forestry, main roads, infrastructure, valuation and land taxation etc. Other spatial datasets (including imagery) are frequently overlaid enabling map production, land use areas, granting permits and licenses. Agencies may also use the Spatial Cadastre to define or record secondary interests in land, e.g. forestry licenses. These secondary interests need to be correctly located within the appropriate primary parcel.
Landowners/ General Public	The Spatial Cadastre is generally available online to the public, with restrictions or required payment to selected functions. Whilst the public use the Spatial Cadastre for a variety (and many unknown/non-specific) purposes, the most relevant purpose is to identify the location of their boundary with respect to their neighbours' land. Land administration departments report a small but increasing number of property owners seeking explanation or remediation of a neighbours' apparent but possibly misinterpreted encroachment. There is a growing range of new technology-based applications that acquire Spatial Cadastre data often through 3rd party intermediaries such as real estate agents etc.

Property Developers, Consultants, Architects, Engineers, Construction Companies and Builders	These users may use the Spatial Cadastre for initial concept design of land developments, buildings, public infrastructure, etc, particularly where these are close to or lie across boundaries. Ultimately cadastral re-establishment surveys will often be required to confirm the boundary position in relation to the proposed development. Typical use of the Spatial Cadastre may include subdivision design, identification of planning zones/overlays, restrictions applicable (easements, covenants etc), connection to utilities, building envelopes, set-backs, sight-lines, flood levels, etc. Many of these uses relate to other attribute data not just the accuracy of the Spatial Cadastre. Significant errors in the Spatial Cadastre may cause contractual issues later if a design is found to be non-compliant with offsets to boundary lines, or even where the proposed construction encroaches on another parcel.
Spatial data analysts, aggregators and value-added-resellers	These users serve many of the other users above as well as providing advice or solutions for those with limited expertise in spatial data or cadastral survey. Their needs vary according to the needs of their clients, but a common need is the alignment of the Spatial Cadastre with other spatial datasets. They are impacted by variations in positional uncertainty from place to place – especially if these variations exceed the positional uncertainty of the other spatial datasets and where the uncertainty is unclear or unknown.

4.2 Findings and Recommendations

4.2.1 Optimal Positional Uncertainty of the Spatial Cadastre

Positional uncertainty in the Spatial Cadastre varies widely between jurisdictions and geographic areas within jurisdictions, from a couple of centimetres to kilometres and depends on many factors.

Finding / Recommendation 1

The broad view of stakeholders and users interviewed by this project, was that the optimal[14] positional uncertainty for Spatial Cadastres is 0.1 – 0.2m in urban city and residential areas, 0.3 – 0.5m for rural areas and up to 1m in more remote areas.

Finding / Recommendation 2

The optimal positional uncertainty identified is found to correspond most closely with Spatial Improvement Level 3.

These optimal positional uncertainties are not as small as the accuracy levels achieved by the most accurate Spatial Cadastres (or geographic parts thereof) – for example: Western Australia; Australian Capital Territory (ACT): most parcels in New Zealand; and parts of Northern Territory. However, they are significantly more accurate than has been achieved in many parts of other jurisdictions.

The recommended optimal levels of positional uncertainty enable high economic benefit to be realised by users of the Spatial Cadastre without a requirement for high implementation and on-going maintenance costs. Further assessment of the above optimal positional uncertainty levels for business cases is covered in section 5.1.

4.2.2 Maintenance of the Spatial Cadastre

At Improvement Level 2, on-going maintenance of the Spatial Cadastre results in a significant data management cost for downstream users as boundary coordinates obtained from the land agency move significantly (often metres or more) in relation to other user spatial datasets. These movements are on-going, ad hoc and often unpredictable.

A project-based approach to upgrade the Spatial Cadastre to higher Improvement Levels over a broad area, such as the New Zealand survey conversion project (Rowe, 2003) will initially cause significant disruption. However, this will be predictable for users and will apply for the limited time of the project. Once the upgrade project has been completed, spatial accuracy of at least Improvement Level 3 will have been achieved. Therefore, on-going post-upgrade project changes due

[14] "Optimal means in general terms, that this is the target for positional uncertainty that maximizes the ratio of benefits over costs.

to subdivision or resurvey will be small (a decimetre or so) and therefore will often be able to be ignored by most users.

Finding / Recommendation 3

A clear plan for ongoing maintenance of the Spatial Cadastre should be part of any business case.

Where the positional uncertainty has been improved beyond the optimal level, a greater level of rigour (and thus cost) will be required to maintain it at this improved level. Without this rigour and cost, the improved uncertainty may slowly degrade over time. However, if the investment has already been made to achieve a level of positional uncertainty above that considered to be optimal, this continued maintenance will ensure that the resulting higher benefits, which will be taken for granted by users, continue to be delivered.

Finding / Recommendation 4

Where a jurisdiction has already achieved positional uncertainties better than the level that is found to be optimal here, it is nevertheless recommended that the operational processes needed to maintain these improved levels be continued.

The present value of estimated annual Spatial Cadastral maintenance costs can be calculated, using a suitable finance rate, over an investment period (say 20 years). This present value, combined with the present value of the proposed upgrade costs, can be determined for different upgrade and maintenance options (including a status-quo option). This will allow the total delivered cost of the options to be properly assessed.

Incorporating maintenance options and costs in the business case means that the expenditure of public money to upgrade the Spatial Cadastre should be accompanied by proposals to improve the suitability of new cadastral survey data for maintaining the spatial cadastral database – thus reducing the ongoing maintenance costs. This could be achieved through enhanced cadastral data standards including requirements for digital data.

As well as managing the definition of cadastral boundaries for landowners, the standards should also recognise the role this data plays in maintaining the Spatial Cadastre as a public geospatial dataset and for land administration within government. This will depend, in the long term, on semi-automated or automated processes acting on intelligent structured digital survey data.

Therefore, at least for cadastral surveys of primary parcels, the design of future spatial cadastral maintenance processes should be based on:

- mandatory digital lodgement using an intelligent structured data format (not unintelligent, unstructured pdf files).
- All grid/plane bearings being expressed in terms of the current official geodetic datum[15].
- a connection for cadastral surveys to 3 geodetic control marks.

So far, the use of the LandXML format has been fully successful (with the implementation of mandatory digital lodgement of LandXML data) only in New Zealand. Western Australia has an alternative successful local data format (CSD) and Northern Territory also has its own survey data format. Despite the investment already made by the ICSM ePlan Working Group into adoption of LandXML in some jurisdictions as a supported or mandated format, the suitability of the formats (LandXML, Western Australian CSD, or perhaps other formats) could be reviewed.

4.2.3 Legal Coordinate Cadastre

A topic that is often raised internationally and has been proposed in Australia (Blanchfield & Elfick, 2006) is that of a legal coordinate cadastre. Some users expressed concern that improvement of the accuracy of the spatial cadastre (significant reduction in the positional uncertainty of boundary coordinates) might lead to a de facto but inappropriate legal role for those coordinates. Therefore, the highest level of cadastral "improvement" – Level 7 – it needs some consideration.

Coordinates have a legitimate and very useful role in providing information on the location of cadastral boundaries. Spatial Cadastral Improvement Levels 2 through to 6 provide different levels of utility for this role from Level 2 (indicative only and highly variable) through to Level 6 (authoritative and able to be used by surveyors – but not legally definitive). Each of these levels share a common philosophy – the coordinates attempt (with varying levels of success) to indicate where the true boundary is located on the land. The coordinates are accepted (more or less) but can be improved as new cadastral survey evidence comes to hand and can be transformed as new geodetic datums are defined – or as a dynamic datum changes slowly over time.

[15] An exception is Western Australia where datum independent angles are recorded rather than bearings. The use of angles for traditional cadastral surveys has some merit being unaffected by datum uncertainty and closer to the surveyor's actual measurements. Future use of GNSS will reduce these advantages.

With improvement levels 2 to 6, the coordinate is legally subservient to the position of the legal boundary- although in the case of level 6 the coordinate is often accepted as strong evidence for the location of the legal boundary. The goal in maintaining the Spatial Cadastre is to place the up-to-date coordinate as close as is reasonable to the correct position of the legal boundary. If new survey evidence of physical features indicates that a boundary coordinate does not match the true original boundary position, then the coordinate can be recalculated based on this new evidence.

Spatial Cadastral Improvement Level 7 has an inverted philosophy. The position of the legal boundary becomes subservient to the coordinate – the boundary is wherever the coordinate says it is.

In section 3.1.1 the nature of a boundary as a socio-technical system is outlined. Assigning dominant legal status to boundary coordinates is a purely technical solution to a socio-technical problem. Even as a technical solution, the use of fixed legal coordinates fails to accommodate the technical issue of geodynamics and earth deformation and the ongoing impact these have on geodetic datums and the assets of landowners (section 3.1.6). If boundaries over a wide area are fixed to the reference frame by law, rather than being fixed to the land as most boundaries currently are, then they will appear to the public to be in motion relative to or across the land. Therefore, holding the positions of these boundaries fixed in relation to the coordinate system, is at odds with the response to the second question posed in section 3.1.7.

In New Zealand, the effects of earth deformation are readily apparent – especially in the aftermath of major earthquakes – and the disadvantages of a legal coordinate cadastre are clear. New Zealand has a semi-dynamic reference frame (D.B. Grant et al., 1999) which models changes of coordinates over time. Recent legislation in New Zealand (Canterbury Property Boundaries and Related Matters Act 2016) confirmed the principle that boundaries move with the land following a major seismic event – they do not remain fixed to the reference frame.

Australian strain rates are sufficiently small that earth deformation may be able to be ignored for a few decades. However, eventually intra-plate deformation can accumulate to an extent that impacts on boundaries and that can no longer be ignored. Then the issue of how to manage the legal boundary coordinates will become extremely difficult.

The discussion that follows identifies risks associated with a legal coordinate cadastre for parcels where potential earth deformation is in the range 50 to 150mm in relation to a plate fixed datum over a period of 50 years (see section 3.1.6). Movements of boundaries of this magnitude relative to the land would usually be considered significant by landowners – especially in urban, peri-urban and potentially intensive rural areas.

The allocation of a legal status to coordinates creates legal expectations and obligations. Eventually boundary features over broad areas will be found to have moved in relation to the coordinates. This will be at odds with the expectations of land owners that their boundaries remain in the same relationship to pegs, fences and walls as they always did.

For example, landowners may find that their houses adjacent to boundaries have slowly moved across the invisible line between fixed boundary coordinates and are now legally encroaching on their neighbour's title. Even if this movement does not lead to encroachment, others may find that a house which was clear of the Council's side or rear setback limits is now non-compliant with those limits.

These landowners will find that their enjoyment of "quiet title" has been slowly eroded by a combination of very slow and imperceptible earth deformation, together with the government's decision some decades earlier to allocate a dominant legal status to boundary coordinates. They may demand that coordinates be updated to reflect their reasonable expectations of where their boundaries are. They will discover that if the decision to adopt a legal coordinate cadastre had not been made, their enjoyment of quiet title would have continued indefinitely for them and their successors in ownership. They will have a reasonable grievance.

Conversely other landowners may demand that the legal boundary coordinate **not** be updated to reflect land deformation. These are the landowners who would be disadvantaged by such changes but with a different version of the same problem. In their case a previously compliant house could suddenly become non-compliant with Council's side or rear setback requirements if the boundary coordinates were to be updated. Another possibility would be a house that was previously just clear of the boundary suddenly being found to encroach onto neighbouring land due to boundary coordinates that had been updated.

Landowners, adversely affected by a late change made with the intention of reversing the slow creep of fixed coordinates boundaries across the land, would also have a reasonable grievance against the government. Their expectation of quiet title would be suddenly disrupted with the introduction of a deformation model that moves their legal boundaries from one place to another. They may lose a strip of land that is very valuable to them while gaining a strip of land on the other side of their parcel which is of less use to them.

Over many decades, such a dilemma is almost certain to increase the level of boundary disputes. Those who assert that the boundary should remain in the same position in relation to the land (which is the current situation in most jurisdictions in the world) will be in dispute with those who accepted (as they were entitled to do) that their boundaries were defined by legal coordinates and who acted accordingly.

In this scenario (which would take some decades to become an issue for landowners) a decision not to change legal coordinates to reflect earth deformation would most likely be subject to a class-action judicial review by those landowners adversely affected by it. Conversely a decision to update legal coordinates to reflect earth deformation would similarly be open to a class action judicial review. With this being a problem of the government's own making (albeit a decision made decades earlier) demands across the jurisdiction for financial compensation would be likely.

Increased or widespread boundary disputes between neighbours or between landowners and the government will significantly erode public confidence in the cadastral system. The great majority of landowners who take the integrity of the system for granted are likely to become concerned. Confidence in land as a secure and enduring investment will be diminished.

None of these broad scale problems will occur if coordinates are not given dominant legal status to define boundaries. The great majority of landowners can currently buy, use and sell their land without needing the services of a surveyor and without disputes over boundaries with their neighbours. Where there is a dispute, or where land is being developed, licensed cadastral surveyors gather evidence on boundaries (which can include non-legal but accurate coordinates), weigh up that evidence in accordance with the hierarchy of evidence, and establish to the best of their ability, the original location of that boundary in relation to the land. This satisfies both the social and the technical expectations of land boundaries.

A legal coordinate cadastre might not even require significant earth deformation to cause legal challenges to government. GDA2020 is likely to still contain some residual distortions at the few centimetre or even decimetre level. A routine upgrade of local geodetic control will change the coordinates of the control marks, but legal boundary coordinates will not be able to be changed simply through a geodetic re-adjustment as Survey Coordinate Cadastre coordinate can – they will only be able to be changed by a legal process and that process will need to consider the impact on the landowners potentially affected.

Under current survey processes, where boundary marks are connected by survey observations to geodetic marks, a change to the geodetic mark coordinates does not upset the relationship between the geodetic mark and the boundary mark. That relationship is still maintained through the survey observations which have a strong evidential role for the position of the boundary.

However, if boundary coordinates have a predominant role compared to survey observations, then if geodetic mark coordinates change and boundary coordinates remain unchanged, the spatial alignment between the geodetic system and the cadastral boundary system is disturbed. This could lead to a new and incorrect realisation in the field of the legal boundary coordinates. As above, this could lead to previously compliant buildings appearing to become non-compliant.

The risks identified above apply to urban, peri-urban and potentially intensive rural areas but the risks of widespread litigation would be much lower in extensive rural or remote areas in Australia because movements between boundaries and land assets are likely to be of little consequence to landowners for many centuries. Another lower risk case would be boundaries between different public land parcels (roads, reserves, Crown leaseholds, etc) which are most unlikely to attract litigation. In these circumstances the inherent inconsistency of assigning long-term fixed coordinates to features on the dynamic surface of the Earth, might be outweighed by the low risk and reduced cost of surveys of boundaries which are in very low value land or which are internal to the public estate.

Another problem with legal boundary coordinates in Australia is that they would most likely be defined in terms of a plate fixed datum such as GDA2020. Over time, that dataset of legal coordinates will move away from other spatial datasets that are in terms of either a dynamic International Terrestrial Reference Frame (globally derived spatial datasets) or the dynamic Australian Terrestrial Reference Frame (Jansen, 2017). In time, ATRF may become the preferred datum for FSDF datasets – possibly including the Spatial Cadastre). GDA2020 is likely to eventually fall into general disuse by the spatial community – unless it retains a narrow legacy role as the reference frame for legal coordinates.

If legal boundary coordinates are defined in terms of GDA2020, there will be an enduring requirement for accurate transformations between GDA2020 and ATRF or ITRF. This will have a conformal model for plate tectonic motion. It may or may not include a model for residual distortion in GDA2020. It may or may not include an earth deformation model. There may be a choice of such models with differing levels of complexity and accuracy. These transformation options will create doubt and confusion for ordinary members of the public, landowners, lawyers, etc, who cannot be expected to understand the issues associated with geodetic transformations when they overlay the Spatial Cadastre with other global geospatial or FSDF datasets.

Singapore and Australian Capital Territory (ACT) Cadastres

A legal coordinate cadastre has been implemented in Singapore. Singapore is a jurisdiction of small physical extent (approximately 720 sq. km – less than 1/3 the area of ACT) and is located on a stable part of the Eurasian tectonic plate (approximately 650km from the nearest plate boundary). The following relevant points about the Singapore legal coordinate cadastre are described by Andreasson (2006):

- The legal coordinates are not guaranteed by the government.
- There is a mechanism for changing erroneous legal coordinates – any such change would presumably result in wins or losses of land for adjoining landowners. These might be challenged in the courts.
- The responsibility for any error requiring correction falls on the surveyor. Using this as an avenue for compensation for incorrect or changing coordinates will only be available while the surveyor is alive and solvent.

Andreasson (2006) also reports that the high proportion of residential and commercial properties in multi-story buildings means that once a building is raised, few Singaporeans are interested in the exact positions of legal boundaries – they can see where their walls, floors and ceilings are and have no need for further definition.

By comparison, given the inevitable distortions within a continental scale geodetic framework with magnitudes of centimetres to decimetres (ICSM, 2018) coupled with bedrock-level earth deformation with magnitudes of at least centimetres (see section 3.1.6) in Australia and up to metres as in New Zealand (D.B. Grant et al., 2014); a legal coordinate cadastre poses high long term risks to all jurisdictions – with the possible exception of ACT, which is the closest in nature and size to Singapore.

The ACT situation is analysed below.

As with other Australian jurisdictions, ACT will implement GDA2020 as the reference frame for boundary coordinates. This means that although ACT is much smaller than other jurisdictions, nevertheless its coordinates are consistent with the continental scale national geodetic datum. ACT is within the south-eastern zone identified as having higher than average rates of strain (Braun et al., 2009). This strain is invisible to cadastral surveyors using standard survey procedures. However, over time, deformation between ACT and the rest of Australia will eventually cause the land in ACT to move in relation to GDA2020 coordinates. Therefore, ACT would face the same problems as other parts of Australia if a legal coordinate cadastre was declared.

The ACT is a special case of Spatial Improvement Level 5, bordering on Level 6. The coordinates have no formal status in the hierarchy of evidence but do play a functional role in the definition of boundaries. New boundaries are first defined by coordinates generated from the land development and planning process.

Subsequently marks are placed at these coordinates by a surveyor. Therefore, in practical terms, the coordinate is Level 6 on first placement of the boundary marks but Level 5 subsequently because the hierarchy of evidence gives weight to the mark and no formal weight to the coordinate.

Therefore, cadastral coordinates in ACT are very accurate in terms of the local control network and play a major role in both boundary definition and land administration functions. A change to Spatial Improvement Level 7 (Legal Coordinate Cadastre) in ACT – the only jurisdiction in Australia with some similarities to Singapore – would seem to offer insignificant advantages to counter the potential for disadvantages that could develop over many decades. An option to assign legal coordinates to boundaries in the ACT was proposed (Johnstone & Toms, 1989) but not adopted (Jarman, 2006).

To summarise this analysis, in the interviews there was no interest in implementing a legal coordinated cadastre in any jurisdiction. This perspective of the stakeholders and user groups is supported by the analysis in section 3.1 on boundaries and coordinates, and the assessment above of risks that would slowly but inexorably accumulate.

Finding / Recommendation 5

In urban, peri-urban and intensive rural areas in Australia, and all parts of New Zealand, it is recommended that a fully legal coordinate cadastre (Spatial Cadastral Improvement Level 7) is not appropriate.

4.2.4 Visualisation or Representation of Positional Uncertainty

Currently several jurisdictions have an accuracy attribute allocated to spatial points or lines. Often this is a proxy for the data source attribute rather than the positional uncertainty and this has mixed use. A data source attribute depends on a good understanding of Spatial Cadastral maintenance processes to be interpreted as positional uncertainty. The possibility of having title line widths displayed proportionate to the spatial uncertainty of the boundary line (fuzzy boundaries as they used to be when drawn on paper plans and maps) could assist broader understanding of accuracy and the appropriate use of the data.

More easily interpreted positional uncertainty in the form of thick or fuzzy lines should reduce inappropriate decisions e.g. landowners deciding whether they can build as per planning regulations at the required offset to title. However, the risk of misinterpretation or misuse of the Spatial Cadastre cannot be eliminated. This is a commercial risk decision by a property owner/builder and if in doubt they should engage a surveyor. Nevertheless, the current representation of boundaries as effectively zero width and presumed to be equivalently accurate is misleading and creates risks for the land agency. Improved and easily interpreted clarity of accuracy may reduce this risk by offering a mechanism to assist better decision making at the early planning and design stages.

Finding / Recommendation 6

It is recommended that land agencies implement a system to provide or support clear visualisation of uncertainty for the data they supply to users.

Visualisation of source code data (how the coordinate was derived) is less reliable or understandable to most users. Visualisation could be color-coded or could be line widths that match the uncertainty.

Visualising uncertainty in the form of line widths is more complex to implement but more meaningful. However, visualisation by line width will only be successful if the positional uncertainty is significantly less than the size of the parcel. For example, a 20m wide road with positional uncertainty of 50 metres will not be able to be visualised in the form of line widths. Visualising by line widths depends on the Spatial Cadastre being at Improvement Level 3 or better. For Spatial Cadastres that remain at Improvement Level 2, colour coding (green, yellow, red) may be the best option. The colour code visualisation is deployed in Tasmania.

More detailed positional uncertainty metadata is required by expert spatial users – for example land administrators, asset managers and surveyors. Given the high degree of variability in uncertainty from region to region and even point to point, metadata is needed at the point, line and polygon attribute level rather than general metadata descriptions.

4.2.5 Context and Alignment with Other Relevant Lines

The spatial definition of the title boundary is generally based on the most recent survey of that boundary – which may be many decades old. That is not necessarily the position of the actual legal boundary. Natural boundaries are often moveable, in some jurisdictions the boundary can be moved by adverse occupation, or part of the land may be taken by the government by gazetted action that doesn't immediately result in a change to the title. Another example is statutory boundaries such as marginal strips in New Zealand that are created and change without impacting on title registration or depiction of boundaries.

Finding / Recommendation 7

Most users want the boundary line that is shown to be the title boundary in the case of freehold land and the equivalent for Crown boundaries, roads, etc). This is the boundary line defined by the most recently approved survey.

Other boundary lines with legal status could be shown in addition where the line of the last survey is known not to be the true legal boundary.

Another example of a line that could be shown in relation to title boundaries is the current or recent position of a natural feature boundary (refer to section 3.1.2). Such boundaries are complex from a surveying/legal title perspective, and rules which govern when they move or remain fixed, depend on evidence collected and considered on a case by case basis. Nevertheless, until a claim for accretion has been rejected, the adjoining landowner has a presumptive right to occupy up to the feature. Similarly, with erosion, the public may have presumptive rights of access to sections of public waterways despite the eroded land appearing to still lie within a private title. The Cadastre 2034 strategies (D.B. Grant, 2014; ICSM, 2015) aim to show not only registered rights but also other legal rights in land – such as the presumptive right to occupy accretion and claim it for title. Therefore, the Cadastre 2034 vision aspires to provide public access to information on presumptive rights (and thus areas of accretion and erosion) as well as the last surveyed title boundary.

The way that natural boundaries were initially brought into and recorded in the respective Spatial Cadastres varies between jurisdictions. In most cases the last survey definition is used but in some cases the positions of natural features at the time of digitisation were used instead. In a multi-purpose Spatial Cadastre, a difficulty of interpretation arises for users because the survey definition of a natural boundary may not be updated for decades where the registered boundary has not changed, but the common law boundaries of equitable interests have moved.

An option would be to support the overlay of the current location of natural feature boundaries, obtained from aerial imagery as contextual information which could be interpreted as the ‘presumptive’ boundary but without any declaration to that effect. This effectively occurs where the land agency provides an option to display the Spatial Cadastre over the top of imagery. A spatially aligned cadastre would clarify, with a sufficient level of accuracy, the relationship between title boundaries and the current position of moveable boundaries – allowing significant accretion or erosion to be reliably identified.

Imagery of occupation also could be used to improve gross errors (20 – 1000m) in the Spatial Cadastre. Even though a block shift applied to boundary lines to align them with fences would not result in an accurate representation of boundaries, they would be much more accurate than before the block shift and would be an improvement for most purposes.

Land administration depends on planning zones, overlays and administrative boundaries being aligned with cadastral boundaries to avoid invalid land use or land development decisions. The management of the spatial accuracy of planning overlays and other administrative boundaries is outside the scope of this project. However, a benefit of a spatially aligned cadastre to 10-20cm (urban) or 30-50cm (rural) would be a significant reduction in misalignment of the spatial view of cadastral and administrative boundaries. Some planning overlays are expressed as buffer zones based on physical features that are not well defined (e.g. bush edges). The features are often not defined at the level of 10-20cm so better positional uncertainty in the Spatial Cadastre effectively eliminates any risk of misinterpretation being attributed to the Spatial Cadastre if it has been improved to Level 3 or better.

4.2.6 Completeness of the Spatial Cadastre

In some jurisdictions the Spatial Cadastre is topologically incomplete, e.g. roads and rivers are shown as voids (Northern Territory) or simply represented as a road centre line (Tasmania). Sliver parcels or voids may be present where there is conflicting definition or unclaimed adverse occupation. These topological errors can be confusing to users and can also disrupt spatial queries.

Finding / Recommendation 8

It is recommended that all voids in the Spatial Cadastre be replaced with polygons – to which relevant attributes can be attached where available.

A legal hiatus can occur where a sliver of land between two title parcels is available for application for title but the party eligible to apply for it chooses not to. However, this legal hiatus should not be represented as a topological void in the cadastral fabric. The land exists in the jurisdiction covered by the cadastre, legal and survey actions can be applied to it and spatial queries should include it – even though the legal status and ownership of the land is in hiatus.

Some jurisdictions already have or are considering (in part to facilitate improved land development processes) the creation of a ‘proposed’ parcel/layer category within the Spatial Cadastre. Parcels (e.g. for road acquisitions) could be identified early in the Spatial Cadastre and updated later when titles are amended – which may be years later.

A peripheral finding is that there may also be a need as part of a wider business case to improve the completeness of attribute data (e.g. secondary interests) and improve the spatial uncertainty of other datasets that are expected to align with the Spatial Cadastre (e.g. zoning, planning overlays, imagery, etc).

4.2.7 Mandate Government Usage after Improvement

Finding / Recommendation 9

Jurisdictional Spatial Cadastres should be mandated (if not already) as the single authoritative dataset for land administration purposes across local and jurisdictional government.

An upgrade to at least Level 3 Spatially-aligned Cadastre would assist the suitability of the Spatial Cadastre for most if not all land administration purposes. A decision to mandate use by all government agencies to enforce achievement of these benefits, should be a part of a business case for upgrade. This may require extra funding to convert legacy systems within government.

5 Business Case Framework

This chapter develops a business case framework for upgrading Spatial Cadastres and addresses the third principal research question (section 1.3):

- How should business cases for upgrading Spatial Cadastres be framed to meet the optimal positional uncertainty.

The chapter contains three subsections;

- Analysis of the benefits associated with the recommended optimal positional uncertainty discussed in section 4.2.1.
- The cost/benefit dependencies on positional uncertainty.
- Four business case options (including the recommended preferred option) to progress upgrade of Spatial Cadastres.

Developing business cases for upgrading the Spatial Cadastre is challenging. In 2003 the Intergovernmental Committee for Surveying and Mapping (ICSM) commissioned and published a framework that land administration agencies could use to assist the preparation of business cases (Cadastre Limited, 2003). This document is now 15 years old, the technology has since evolved, and there is minimal awareness or application of this document with stakeholders of the Spatial Cadastre.

Quantifiable fiscal benefits may be in the form of:

- Improved services leading to quantifiable reduced costs for other government agencies involved in land administration.
- Increased revenue to land agencies via cost recovery from other government agencies, charging for premium quality data and for processing survey and title transactions.
- Reduced land agency operating costs, e.g. automated or semi-automated end to end workflows. These workflows may require low positional uncertainty of the Spatial Cadastre to meet relative or survey uncertainty levels specified in survey regulations.
- A reduced number of land-owner queries/complaints which take up the time of experienced staff.
- Reduced costs and better decision making for major government infrastructure projects; etc.

Other harder to quantify economic benefits can include:

- More efficient and effective government services to landowners and the general public.
- Improved decision making on private land investment, land utilisation and development.
- Better environmental and land use outcomes resulting from better access to reliable data.
- Reduced times for land transactions resulting in an increase in productive economic activity and higher GDP.

In preparing a business case, the jurisdictional land administration agencies will need to quantify tangible fiscal benefits and undertake an economic assessment of less tangible economic benefits. Each jurisdiction has differences in its own current Spatial Cadastre, different legacy issues and legislation, and a different economic, policy and social environment. This project has not attempted to create a model business case in the style of the Cadastre Limited report prepared for ICSM (Cadastre Limited, 2003).

5.1 Analysis of Benefits

Determination of parcel boundaries in Australian jurisdictions and New Zealand is principally based on localised surveys of monuments that have a better level of survey or relative uncertainty than the positional uncertainty can reasonably be expected to be.

Unless the legislative framework for determination of boundaries is changed (e.g. a legal coordinate cadastre, Improvement Level 7 which is not recommended) surveyors will still be required to determine boundaries in much the same manner as they do now.

The optimum positional uncertainty proposed for the Spatial Cadastre is approximately that of a fence width or a ‘shovel width’ in the urban context and close to it in the rural or remote context. This will reduce the time that surveyors spend locating reference and boundary marks. Surveyors interviewed did not see any significant benefits in advancing beyond the recommended optimal level of positional uncertainty.

The success of land tenure and cadastre systems may, in part, be measured by a low number of queries and boundary disputes between neighbours. As a percentage of the number of parcels within a jurisdiction, the number of boundary disputes is reportedly very low. If the title boundary as shown (e.g. overlaid on imagery) in the Spatial Cadastre appears to fall within fence posts and fence lines, it is expected to be generally sufficient and optimal for achieving 'quiet title' between neighbours.

Whilst there has been some increase in boundary disputes in recent years, these are believed by interviewees to more often result from secondary disputes between neighbours. Lowering positional uncertainty beyond the proposed optimal level (i.e. down to a few centimetres) in the Spatial Cadastre is not likely to reduce disputes. On the contrary, if landowners believe the positional uncertainty of the Spatial Cadastre is a centimetre or two, or even less, that may prompt more boundary disputes over very small discrepancies between neighbours.

Land developers and surveyors use the Spatial Cadastre in the early stages of planning and engineering design. If the Spatial Cadastre has the recommended optimal positional uncertainty along with links to accurate attribute data, land developers may be able to reduce some of the early cost associated with engaging licensed land surveyors for initial concept plans and options.

A clear visualisation of the uncertainty of boundaries in the Spatial Cadastre will also allow developers to make better informed risk assessments in the early stages of deciding to invest in land, considering building set-backs, etc.

Utility companies use the Spatial Cadastre for location of assets. As with survey marks, a shovel width or the diameter of the asset is sufficient as most assets are 10cm or larger. Positional uncertainty smaller than the optimal level proposed in section 4.2.1 is likely to produce only limited additional benefits for these users – whereas positional uncertainty greater than the proposed optimal level (as it currently is for many jurisdictions) means more time spent searching and digging to locate assets or engaging surveyors to locate them in relation to boundaries. Other issues for utility companies are:

- completeness of the Spatial Cadastre (e.g. inclusion of easements);
- the method they use to record their assets with respect to the Spatial Cadastre (e.g. off-set distance to a boundary or absolute positions); and
- timeliness and awareness of upgrades to the Spatial Cadastre being considered within recommendation 4.2.2.

Local Government Authorities (LGA), government departments and agencies may use the cadastre in a similar manner to utility companies for location of assets where a 0.1 - 0.2m positional uncertainty is sufficient and better positional uncertainty does not provide significant incremental benefits. Other uses of the Spatial Cadastre by this user segment include identification of whole parcels and facilitating planning in the early stages of land development. In addition, they use the Spatial Cadastre in conjunction with other datasets for mapping, planning overlays, analysis for advice to government, land management, issuance of licenses etc.

Sub-centimetre uncertainty or less within the Spatial Cadastre may be considered desirable and achievable by some users to facilitate automated or semi-automated processes for data aggregation and spatial alignment with other datasets. However, there will always be misalignments that require rectification when aggregating data, e.g. noting that the other datasets being integrated with the Spatial Cadastre also contain their own positional uncertainty. The incremental benefits of smaller positional uncertainty beyond recommended levels are considered minimal for the broad group of users including local government, government departments and other land administration agencies using the Spatial Cadastre.

At the positional uncertainty level recommended here, the specific tangible fiscal benefits to land agencies may be relatively small, i.e. automated survey examination of incoming surveys would not be realisable. However, gross errors may be readily identified and integrated in workflow processes.

5.2 Benefit and Cost dependency on Accuracy/Uncertainty

A key focus for this research is a qualitative assessment of how different levels of coordinate accuracy (or positional uncertainty) impact on the costs and benefits.

Under the status quo, there may be recurrent costs incurred for managing processes that result from inaccuracy/uncertainty in the Spatial Cadastre. At different levels of uncertainty, these recurrent processing costs may be lessened, avoided or eliminated (e.g. reduced boundary disputes). These lower costs can be expressed in the form of a benefit of upgrading the Spatial Cadastre.

Conversely, if there are any additional on-going operational maintenance costs incurred from upgrading the Spatial Cadastre (e.g. new processes to maintain the improved levels of uncertainty) then these should also be included in a business case. The inclusion of recurrent/on-going operational costs and benefits should be included as discounted (present) values in determination of the project's total Net Present Value (NPV).

This allows us to consider both costs and benefits in a common indicative form in relation to accuracy/uncertainty. These are presented as multiple graphs in Figures 8(a) through to 12. Because this is a qualitative study, not a quantitative study, these graphs do not depict any numerical assessments of costs or benefits.

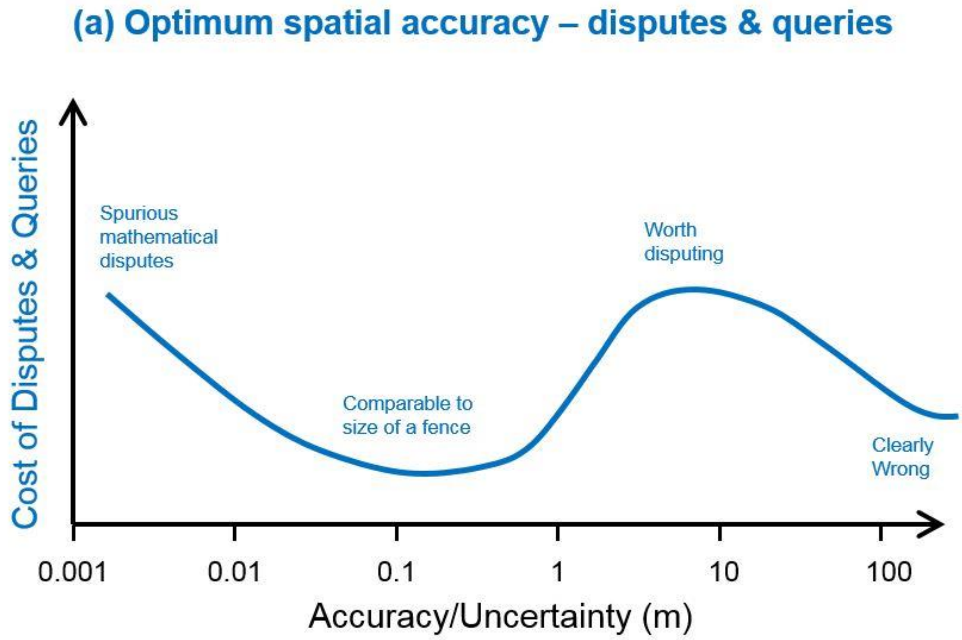


Figure 8 (a). Benefits expressed in the form of on-going operational costs against positional accuracy/uncertainty for three factors in management and use of the Spatial Cadastre: (a) Responding to disputes and queries.

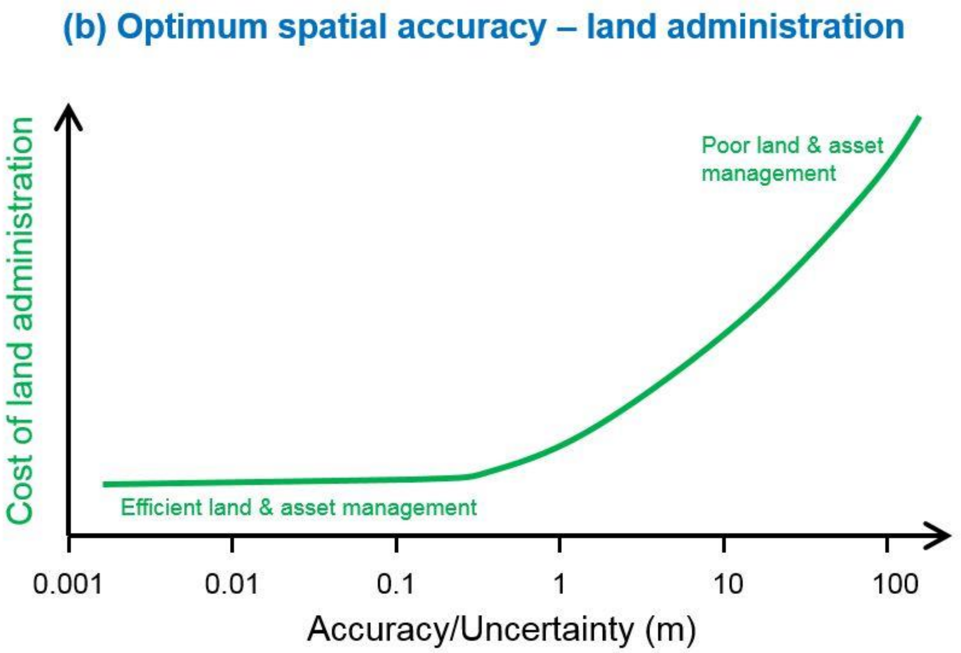


Figure 8 (b). Benefits expressed in the form of on-going operational costs against positional accuracy/uncertainty for three factors in management and use of the Spatial Cadastre: (b) Land Administration functions.

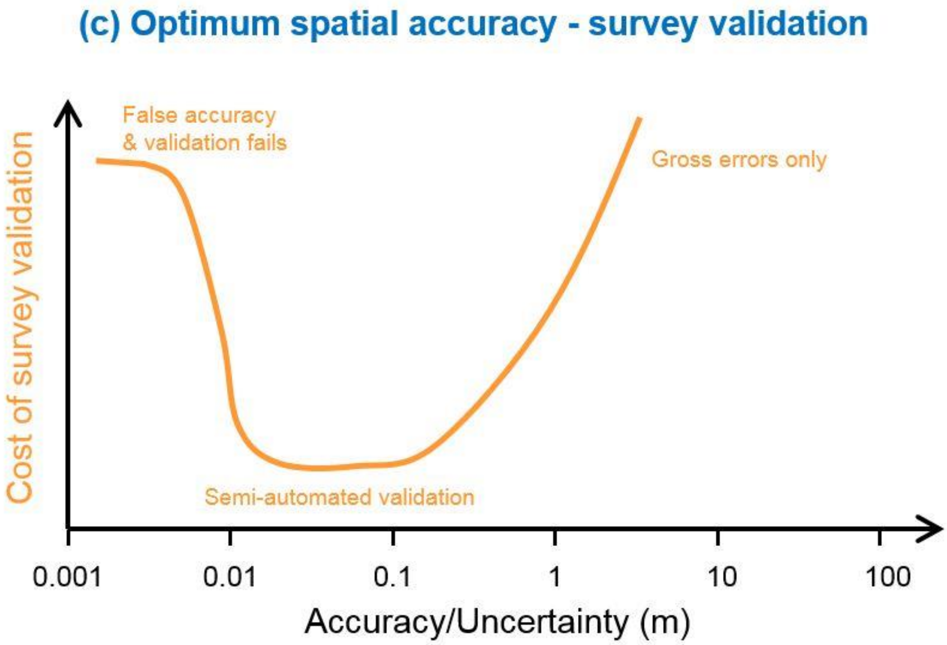


Figure 8 (c). Benefits expressed in the form of on-going operational costs against positional accuracy/uncertainty for three factors in management and use of the Spatial Cadastre: (c) Assistance with survey validation

The cost of upgrading the Spatial Cadastre will increase exponentially if we attempt to achieve smaller levels of positional uncertainty. The costs for low positional uncertainty are asymptotic as it is not possible to remove all uncertainty. Also, positional uncertainty is constrained by uncertainty within the geodetic network as well as the source cadastral survey measurements.

However, the costs associated with smaller positional uncertainty are likely to reduce somewhat in the future due to technology advances. Similarly, the costs associated with ongoing maintenance of the Spatial Cadastre are expected to reduce somewhat over time with increased opportunities for automated maintenance. Even with automation, the physical limits of boundaries and coordinates in the real world – identified in section 3.1 – impose limits to low uncertainty and impose higher costs on attempts to maintain low uncertainty. These considerations are graphically depicted in Figure 9.

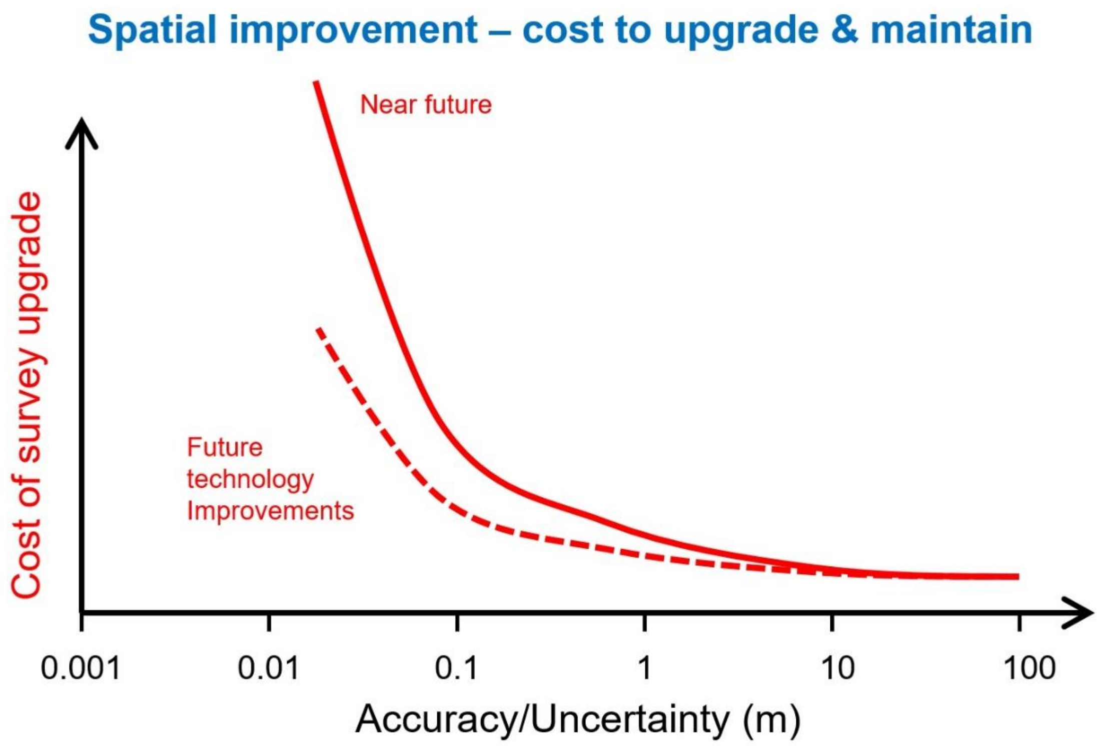


Figure 9. Indicative business case costs vs Positional Accuracy/Uncertainty

The diagrams in Figures 8 and 9 are combined in Figure 10 for an overall qualitative or indicative view that helps to identify the optimal level of positional uncertainty for the Spatial Cadastre. The graphs have been drawn as a way of illustrating the discussions on accuracy needs and the impact of different accuracy levels on benefits. Therefore, the different aspects of costs vs accuracy in graphs 8 and 9 naturally tend to be minimised in the region of 0.2m positional uncertainty – because this is the positional uncertainty level that most interviewees recommended.

Figure 10 also shows the current range of positional uncertainty for those Spatial Cadastres that are still maintained at Cadastral Spatial Improvement Level 2. As expected, and as identified in the interviews, Improvement Level 2 is mostly not optimal or fit-for-purpose.

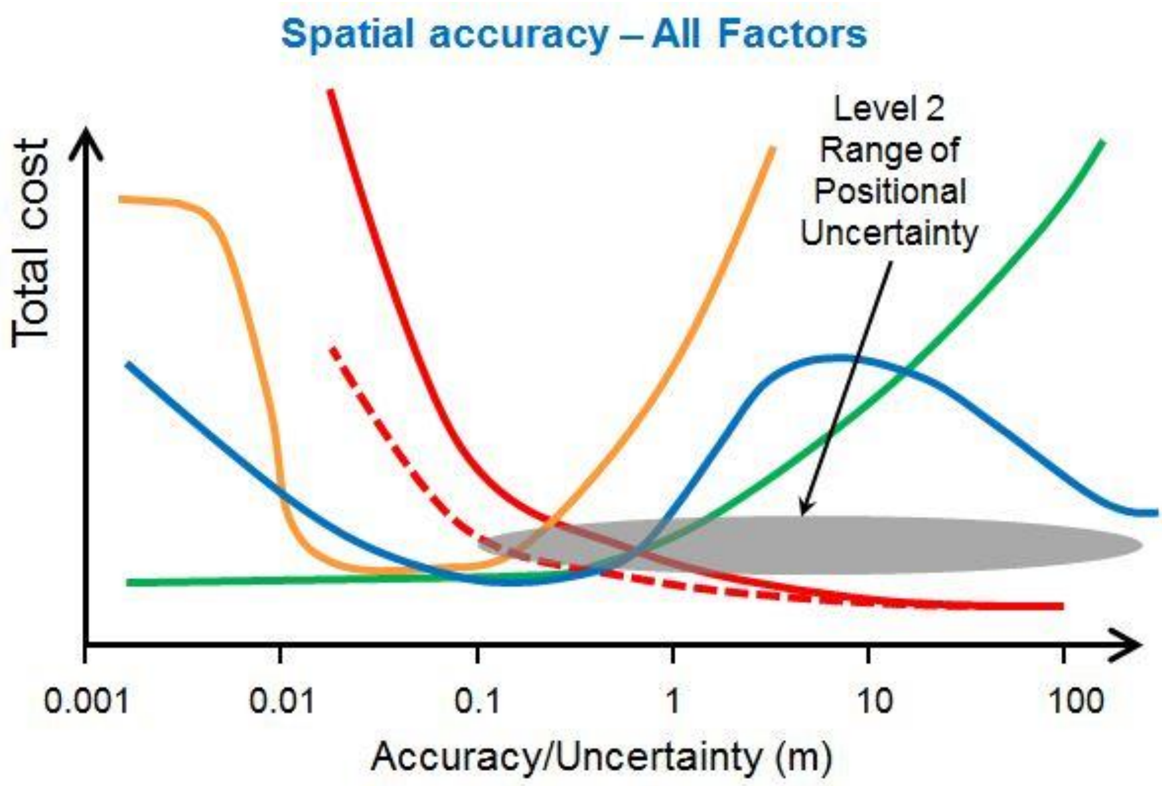


Figure 10. All Costs against Positional Accuracy/Uncertainty for factors shown in Figures 8a, 8b, 8c and Figure 9. The lines represent: Blue – Disputes and enquiries; Green – Land Administration; Orange – Survey validation; Red – Cost to upgrade and maintain.

The recommended optimal level of positional uncertainty was identified in section 4.2.1. This level supports land administration functions (Outcome B) but does not fully support boundary determination functions (Outcome A). Figure 11 shows this range of optimal uncertainties in relation to the four factors for cost vs positional accuracy/uncertainty.

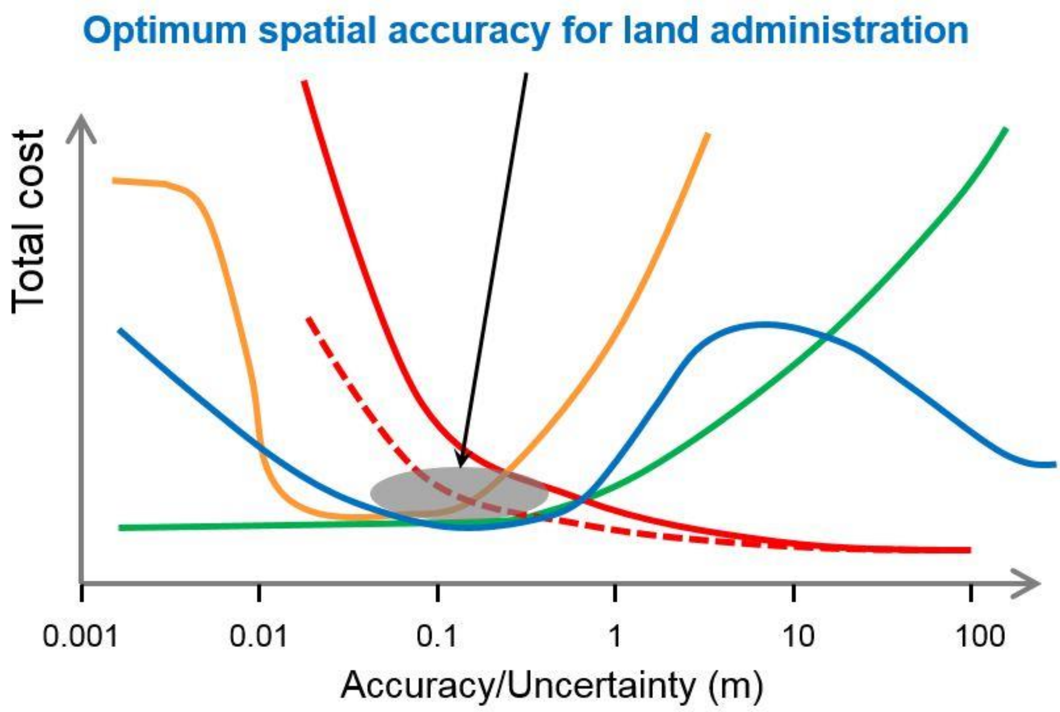


Figure 11. Cost vs Accuracy/Uncertainty for all factors in Figure 8 and 9. The lines represent: Blue – Disputes and enquiries; Green – Land Administration; Orange – Survey validation; Red – Cost to upgrade and maintain. The recommended optimal range of positional uncertainty for the Spatial Cadastral in support of Land Administration and related functions is shown.

Additional fiscal benefits would be delivered to the land agencies by Spatial Improvement Level 5, such as opportunities for automation or semi-automation of departmental processes for validation of new surveys and for ongoing maintenance of the Spatial Cadastre. Figure 12 shows this range of positional uncertainties in support of boundary determination (Outcome A).

A land agency business case might aim for this more rigorous level of spatial cadastral improvement if greater weight is given to the orange line (survey validation) and/or if the business case is deferred for some years to take advantage of improvements in data capture and spatial maintenance technology (the dotted red line). A strategic decision to invest in the conversion of cadastral survey observations and boundary dimensions into a structured digital form as an enduring capital asset could also be a factor.

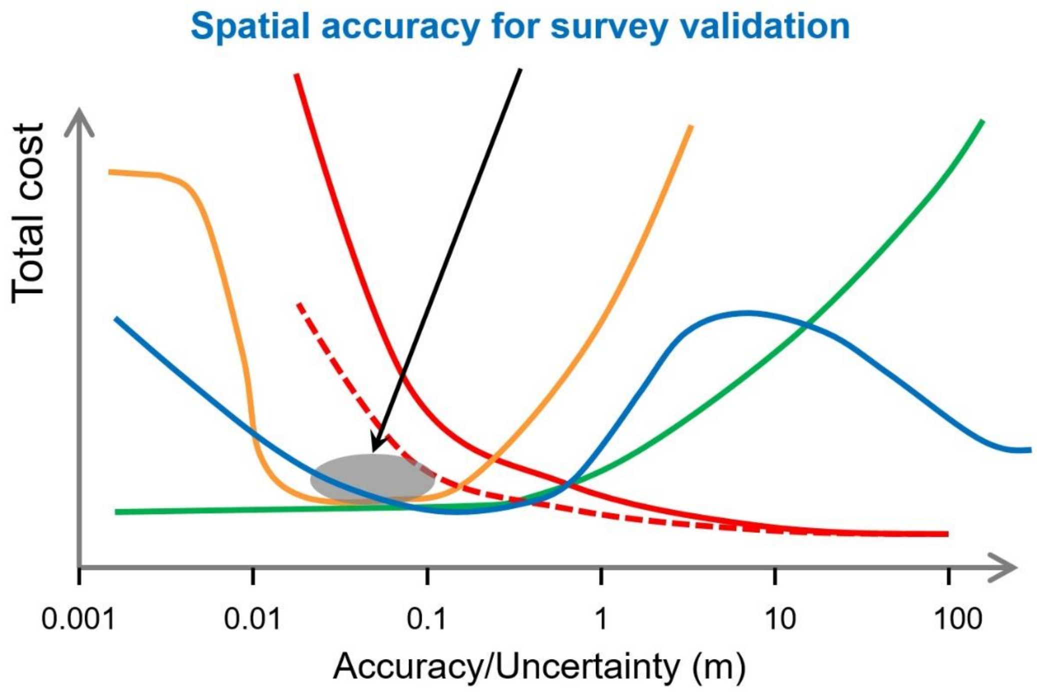


Figure 12. Cost vs Positional Accuracy/Uncertainty for all factors in Figures 8 and 9. The lines represent: Blue – Disputes and enquiries; Green – Land Administration; Orange – Survey validation; Red – Cost to upgrade and maintain. The range of positional uncertainty for the Spatial Cadastral that would be needed in support of (semi) automated survey validation and spatial maintenance is shown.

5.3 Business Case Options

The Spatial Cadastre has multiple purposes and multiple users. However, it is a single entity within each jurisdiction. Thus, the optimum level of positional uncertainty is a compromise between competing purposes and users.

A precursor to business case analysis is an understanding of where the jurisdictions are currently placed – the starting point for their business cases. Some land administration agencies have completed spatial upgrade projects and now believe they have the appropriate level of positional uncertainty within their Spatial Cadastres. Many of these upgrades to the Spatial Cadastre were undertaken in conjunction with other organisational and process improvement initiatives and the fiscal benefits have now been captured with significant staff and related savings, e.g. the Spatial Cadastral Database upgraded by Landgate in Western Australia and

Landonline upgraded by LINZ in New Zealand. The spatial cadastre in the ACT has been of high quality since its inception.

Many jurisdictional land agencies across Australian and New Zealand have plans in place for upgrading their Spatial Cadastres that include, but are not restricted to:

- Northern Territory Government, Land Information Group are in the process of releasing the "survey-accurate" geometry of the cadastre to users and replace the currently available Spatial Cadastre geometry.
- Queensland Land and Spatial Information Group are in the early stages of designing a new cadastral geodetic data management environment. This is a multi-year project which includes electronic lodgement of surveys and consideration of accuracy improvements to their Spatial Cadastre.
- South Australia Government Department of Transport Energy and Infrastructure is investigating the feasibility of using parcel polygons from older surveys which have links to the control network to upgrade the positional uncertainty of their Spatial Cadastre. This is not a complete back-capture of surveys, but utilises existing outputs that have not previously been integrated into the Spatial Cadastre (Department of Transport Energy and Infrastructure South Australia, 2017).
- Victorian Government Department of Sustainability and Environment commissioned development of a business case for upgrading the Spatial Cadastre (Sinclair Knight Merz, 2011). Whilst the upgrade pathway recommended by that report has not been proceeded with, an integrated improvement plan which includes upgrade of the Spatial Cadastre is currently under consideration.
- In New South Wales, cadastral survey data is being captured to LandXML files for the purpose of spatial upgrade. Development of a single Cadastre NSW through a business case to government is proposed (Acil Allen, 2017).

If jurisdictions have already achieved higher Spatial Cadastral Improvement Levels, these should be maintained. Where the Spatial Cadastre has been improved in some areas but not others, any planned extensions, for example into rural or remote areas, should consider the business case options discussed below for these extensions.

Four business case options to improve the Spatial Cadastre (where it is not already at an optimum or better level) are:

A. Business-as-usual Survey-maintained Spatial Cadastre – corresponding to Spatial Improvement Level 2.
B. Spatially-aligned Cadastre – corresponding to Spatial Improvement Level 3.

C. Survey-enhanced, survey-compliant or survey coordinate Spatial Cadastre – corresponding to Spatial Improvement Levels 4, 5 or 6.
D. A staged approach to achieve the result of business case option C – via business case option B followed by an incremental upgrade business case.

These business case options and indicative benefits vs costs are in a qualitative sense based on responses from stakeholders and users depicted in Figure 13.

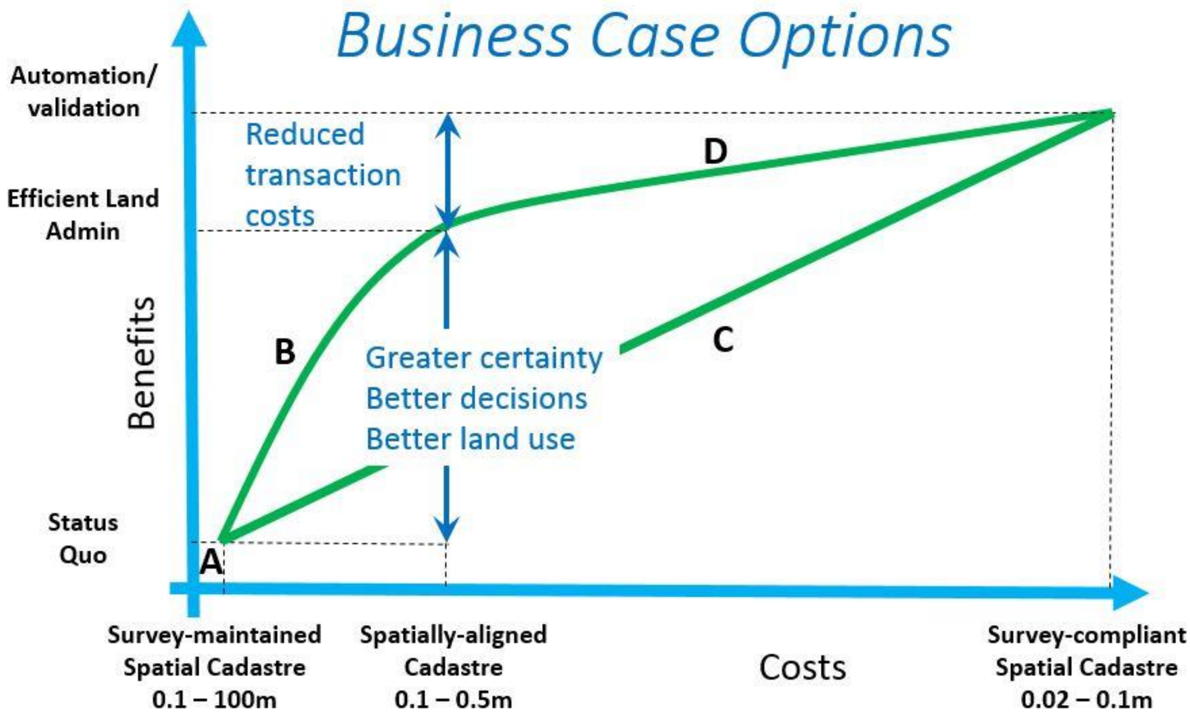


Figure 13. Indicative diagram of Business Case Options and benefits vs costs for Spatial Cadastral Upgrade

The gradient of the line in Figure 13 between business case options is a qualitative indicator of the benefit over cost ratio. A qualitative finding from the user and stakeholder interviews is that the greatest benefit-over-cost ratio would be achieved by business case option B. Business case option C is less urgent from the users' perspective and also the lower benefit cost ratio may make it less urgent from the government's perspective. However, business case options C or the staged approach in D may be cost justified by fiscal benefits to land administration agencies.

5.3.1 Business case option A

Australian and New Zealand land agencies responsible for the respective Spatial Cadastres that are currently at Spatial Improvement Level 2 (section 3.3.3), use incoming survey plans (e.g. subdivision, re-establishment etc.) to integrate the new surveys into their Spatial Cadastre. If they adopt the Level 2b maintenance process (rubber-sheeting) this will slowly improve (reduce) the positional uncertainty within the Spatial Cadastre. Survey regulations often require connection to the geodetic control network – in part to facilitate this form of maintenance and upgrade of the Spatial Cadastre.

Whilst progressive update of the Spatial Cadastre with new digitally lodged plans may occur as business as usual, the time taken for complete upgrade will be a century or more[16]. This *laissez-faire* model for cadastral upgrade (Spatial Cadastral Improvement level 2b in section 3.3.3) is not only very slow, it is also quite unpredictable as to where and when the upgrade takes place, and causes significant ad hoc disruption to spatial data users where rubber-sheeting causes coordinate shifts over a broad area after each new survey is integrated into the spatial cadastre.

This ad hoc, slow, and piecewise improvement in positional uncertainty will not meet the current or near future expectations of users. Business case option A may be considered the “business-as-usual” or “do-nothing” option for upgrading and/or maintaining the Spatial Cadastre.

5.3.2 Business case option B

Finding / Recommendation 10

A finding from the interviews is that the most immediate need and greatest benefit for users of the Spatial Cadastre is the recommended optimal positional uncertainty equivalent to Spatial Cadastral Improvement Level 3 (section 4.2.1).

Option B would also reduce land agency costs for maintenance of the Spatial Cadastre. New cadastral surveys will generally fit reasonably well with the

[16] A broad rule-of-thumb based on analysis of the Parcel-Plan-Index in New Zealand by the principal author is that surveyed parcels have a half-life of approximately 50 years. That is, over a period of 50 years, half of the parcel in a jurisdiction will have been redefined by survey (subdivided, re-established). Over 100 years the figure would be approximately 75% redefined by survey, etc. Abutting parcels will also be partially redefined.

comparable coordinates in the Spatial Cadastre. Opportunities may exist for automation or semi-automation of some maintenance tasks.

The optimal positional uncertainty could be achieved without significant resurvey or back-capture of individual parcels. As an example, upgrade of the Danish Spatial Cadastre is under consideration to achieve the same positional uncertainty recommended as optimal here (section 4.2.1) with the addition of a relatively small number of strategically placed boundary points that are easily identifiable in both aerial imagery and the Spatial Cadastre and which can be captured by GPS. No boundary determinations are proposed before performing spatial adjustments (Enemark, 2017).

The optimal positional uncertainty may also be achieved by upgrading road alignments – perhaps surveyed within 5 - 10cm by GPS – through limited control surveys and back-capture, with all other boundaries spatially (non-rigorously) adjusted within the framework of roads. Several different options could be employed such as rubber-sheeting, distortion modelling, transformation grids, etc.

As indicated by Figure 13, business case option B provides a wide range of public good economic benefits as well as reduced land administration and land management costs within government. The cost of this option would be significantly less than that for full back-capture of cadastral data from survey plans which would be required by business case options C or D. This option is therefore considered to provide the greatest benefit over cost ratio. From a Spatial Cadastre user perspective this upgrade will be the most expeditious option to overcome the limitations of the current Spatial Cadastres that are still at Improvement Level 2.

Opportunities to use aerial imagery/LIDAR (as proposed in Queensland) can also be progressed for this option if they are found to be cost effective as a means of avoiding the need for traditional resurveying and connection to the datum control network. Project initiatives for upgrade of the Spatial Cadastre with this focus are recommended as an upgrade pathway.

5.3.3 Business case option C

Going beyond the optimal positional uncertainty is not likely to realise significant additional benefits to the wider base of users of the Spatial Cadastre. However, it may be justified by fiscal benefit achieved for the jurisdictional land agencies, e.g. automated processing and validation of surveys or maintenance of the Spatial Cadastre.

To achieve these lower levels of positional uncertainty, either re-establishment surveys of boundaries and/or back-capture of previous surveys will be necessary, with field survey work for re-establishments surveys being the most costly option but with back-capture also having very significant costs (Sinclair Knight Merz, 2011).

To achieve and maintain sub-10cm positional uncertainty, land administration agencies should mandate digital lodgement of cadastral surveys within a reasonable time. It would seem hard to justify the Crown expenditure for back-capture of digital survey observations from survey plans, if new analogue surveys are still permitted to be lodged in the traditional plan format requiring further post-lodgement back-capture as an ongoing maintenance task.

An important factor for Spatial Cadastre maintenance resulting from business case option C is that the smaller positional uncertainties (e.g. centimetre level) may result in higher on-going maintenance costs to maintain this more rigorous uncertainty level. For example, additional investigation of all incoming surveys for small variances or assessment of local or regional earth deformation – which now occurs in New Zealand but could potentially be eventually required in parts of Australia also.

Apart from the improved Spatial Cadastre coordinates, the captured survey observation digital database that would result from the implementation of business case C, could be a very valuable capital asset which would depreciate very slowly. The enduring value of cadastral survey observations and boundary dimensions stems from the fact that while coordinates are directly impacted by earth deformation, tectonic plate motion and reference frame changes – making them somewhat ephemeral over periods of many decades – local cadastral survey observations (e.g. parcel dimensions) are generally not adversely affected for much longer time periods (except in the immediate vicinity of an earthquake rupture).

The legal role for title dimensions and the evidential role for cadastral survey observations is a factor in their enduring value. Historical survey and title data have an important place in the hierarchy of evidence for boundaries. While cadastral survey observations and dimensions can be refuted by stronger conflicting evidence, they should always be considered, which means they must be searched for and compared with new survey measurements. Therefore, the long-term value of such a cadastral survey observational database may justify the high cost of back-capture through greater ease of searching and assessing relevant evidence.

Individual jurisdictional land agencies may also be able to progress business case option C if the additional costs can be justified by corresponding internal processing efficiencies through increased automated validation and maintenance of the Spatial Cadastre. However, the benefit to cost ratio for business case option C is likely to be lower than option B.

The Landonline project in New Zealand was an example of business case option C. However, spatial upgrade was not the objective of the Landonline project. The objective of Landonline was to progress to mandatory digital lodgement of all cadastral survey and title transactions with a high level of automated or semi-automated transaction processing (and a consequent significant reduction in land agency staff and offices). The Landonline programme required comprehensive and complex business process engineering of the department which fundamentally changed the nature of the operational (and to some extent regulatory) side of the organisation. The spatial upgrade that resulted in New Zealand was more in the nature of a side benefit to support the automated business rules associated with mandatory digital lodgement and semi-automated processing of cadastral surveys. This focus on business efficiency enabled a positive business case to be developed (a positive Net Present Value for the whole project) but added high complexity and risk to the project.

A lesson from Landonline is that the Survey-compliant Spatial Cadastre, once established, requires rigorous on-going maintenance to retain that level of survey compliance. A group of experienced staff, skilled in the application of least squares adjustment to new cadastral survey datasets, are required to allow timely adjustment and integration of every new approved digital cadastral survey into the existing Spatial Cadastral fabric. Recent earthquakes in New Zealand have significantly complicated this maintenance and integration task.

Note that business case option C requires the largest and most complex single project, carrying additional project risks. That proved to be as true in New Zealand as it has in other countries with large complex projects such as those in Eastern Europe (Adlington, Stanley, Palmissano, Satana, & Baldwin, 2009). The Landonline project was completed but proved much more complex and took longer than initially expected. Also compared with business case options B or D (below) the realisation of broader economic benefits for the majority of users may be delayed until the completion of the whole project.

5.3.4 Business case option D

A staged approach would commence with the same upgrade as in business case option B (i.e. an initial focus on large scale spatial adjustment of the Spatial Cadastre, supported by an improved control network, but without full parcel boundary definitions or back-capture) followed later by an incremental business case providing further upgrade to Spatial Improvement Levels 4, 5 or 6 as appropriate.

Other considerations of the costs and benefits of advancing to Spatial Improvement Level 4, 5 or 6, as described in business case option C above, also apply to the second stage of business case option D. In a staged approach, the second stage of improvement is less urgent for most Spatial Cadastral users.

When considering whether an upgrade to Spatial Improvement Levels 4, 5, or 6 should be undertaken in one stage (business case option C) or in two separate stages (business case option D), the recommended fit-for-purpose approach (albeit in the context of developing countries) is to prefer incremental improvement. Large and complex business cases that attempt to advance from a low level to a high level in one step (the big-bang approach of business case option C) tend to be both financially and politically risky as cost over-runs and project timeframe extensions are more likely. An incremental approach will deliver earlier initial economic benefits for most Spatial Cadastre users on completion of the first stage, as well as providing valuable lessons on how to proceed with later stages, and better information on how to cost the latter stages.

Another consideration is that the cost of the second stage with least squares adjustment of back-captured survey observation, is likely to be cheaper because the starting point for the second stage will be a Spatial Cadastre that has already achieved the optimum level of positional uncertainty (Spatial Improvement Level 3). A pause before commencing the second stage will also allow advantage to be taken of future improvements in capture technology and spatial maintenance.

(Note that a business case option E to progress to a fully legal coordinated cadastre, in which positional uncertainties are effectively eliminated by legal means, is not discussed here because a legal coordinate cadastre – Spatial Improvement Level 7 – is not recommended for Australian or New Zealand jurisdictions.)

5.3.5 Summary of Business Case Options

In summary, business case option B provides the best benefit over cost ratio and will more quickly deliver economic benefits to most Spatial Cadastral users.

Finding / Recommendation 11

If the further upgrade to Spatial Improvement Levels 4, 5 or 6 can be justified, it is recommended that this proceed as a staged approach – i.e. business case option D.

This delivers the initial benefits quickly, has reduced project risk and can take advantage of future technological advances in capture and management of back-captured survey observations and boundary dimensions.

6 Future Research

This concluding chapter identifies recommendations for additional research. These are issues that were identified during interviews that fell outside of the project's scope, and which were therefore not specifically addressed by the project.

The following is not intended to provide a clear scope or indicate priority for the definition of further research but rather seeks to identify possible areas of future research that have a relationship with the Spatial Cadastre.

6.1.1 Three-Dimensional Tenure

Representation of cadastral boundaries in 3D is one of the other projects of interest to the ICSM Permanent Committee on the Cadastre and the CRCSI. Increased prevalence of elevated and tunnelled roadways etc. add to existing interest in the representation of 3D land tenure and rights for traditional high-rise units and office buildings. The frameworks developed by this project such as the Cadastral Triangular Model could be applied to the topic of a 3D Spatial Cadastre. The increased use of 3D Building Information Modelling (BIM) and new technologies in computer point-cloud datasets and visualisation capabilities are likely to have an impact on the requirements of land agencies for development of 3D Spatial Cadastres.

6.1.2 Attribute data and completeness of the Spatial Cadastre

This project has focused on the spatial positional uncertainty of the primary parcel boundaries. Secondary interests in land (i.e. easements, covenants, forestry rights, native title, roads, rights of access, derived land areas etc) are often not included in jurisdictional Spatial Cadastres, are incomplete or not up-to-date. The complete and accurate inclusion of these attributes would potentially have greater benefit in the early stages of a land development project rather than pursuing higher than optimal levels of improvement in the Spatial Cadastre. This aligns with the vision in the Cadastre 2034 strategies (D.B. Grant, 2014; ICSM, 2015).

6.1.3 Legal role of Spatial Cadastre

The legal role of the Spatial Cadastre to assist surveyors with boundary determination and to assist land agencies with survey validation is variable across jurisdictions. As Spatial Cadastres are upgraded, a best practice model for best use of the information warrants further investigation. Also, with increased use of the

Spatial Cadastre by a wide range of non-expert users -the legal status of the Spatial Cadastre may need clarification.

6.1.4 Natural Boundaries

Natural boundaries play an important role in defining many parcels, particularly in rural areas (e.g. access to water) but also increasingly in coastal areas impacted by urban expansion and the effects of rising sea levels. Issues of public access to waterways are also increasingly important. Natural boundaries are not updated within most Spatial Cadastres unless re-surveyed. The common law doctrine of accretion and erosion may not be sustainable for modern societies and may be in need of reform. Investigation into questions of law and spatial data management related to movable natural boundaries may be an area for further research.

6.1.5 Future Technology Advancements

Whilst we cannot know with certainty how future technology will evolve within spatial sciences, recent advancements suggest that the way land management and surveying was conducted in the past will not continue. Technology changes are evident in all related areas, e.g. improvements in satellite positioning systems, aerial imagery/LIDAR, remote sensing/UAVs, laser scanning, 3D visualisation etc. One of the concurrent CRCSI projects is presently investigating the use of aerial imagery/LIDAR. These technologies are likely to have some impact (if not already) in land tenure and land administration. Research opportunities may exist to prepare land administrations systems ahead of these changes (even if only by establishing sound principles) rather than waiting for reactionary responses to eventualities that arise. Technology advancements may also provide opportunities to reduce costs of progressing to lower positional uncertainties for Spatial Cadastres in the future.

7 References

Acil Allen. (2017). *Economic Value of Spatial Information in NSW*. Retrieved from http://www.crcsi.com.au/assets/Consultancy-Reports-and-Case-Studies/Value-of-NSW-Spatial-Information-final.pdf

Adlington, G., Stanley, V., Palmissano, M. B., Satana, S., & Baldwin, R. (2009). *Land Administration and Management Projects (LAMP) in the Europe and Central Asia Region (ECA) Experiences, Lessons Learnt and the Future Agenda.* Paper presented at the FIG / World Bank Conference on Land Governance in Support of the Millenium Development Goals, Washington 9-10 March 2009.

Andreasson, K. (2006). *Legal Coordinated Cadastres – Theoretical Concepts and the Case of Singapore*. Paper presented at the XXIII FIG Congress, Munich, Germany.

ANZLIC. (2014). *The Australian and New Zealand Foundation Spatial Data Framework*. Canberra, ACT: The Commonwealth of Australia.

Bennett, R. M., van der Molen, P., & Zevenbergen, J. A. (2012). Pitter, Green, and Volunteered: Legal and Survey Complexities of Future Boundary Systems. *Geomatica, 66*(3), 181-193.

Blanchfield, F. J., & Elfick, M. (2006). *Legal coordinates as a solution to an irreversible shortage of surveyors.* Paper presented at the 5th Trans Tasman Survey Conference, Cairns, Australia.

Braun, J., Burbidge, D. R., Gesto, F. N., Sandiford, M., Gleadow, A. J. W., Kohn, B. P., & Cummins, P. R. (2009). Constraints on the current rate of deformation and surface uplift of the Australian continent from a new seismic database and low-T thermochronological data. *Australian Journal of Earth Sciences, 56*(2), 99-110. doi:10.1080/08120090802546977

Burbidge, D. R. (2004). Thin plate neotectonic models of the Australian plate. *Journal of Geophysical Research: Solid Earth, 109*(B10). doi:10.1029/2004JB003156

Cadastre Limited. (2003). *Business case framework for improved spatial accuracy in Digital Cadastral Database (DCDB)*. Retrieved from http://www.anzlic.org.au/pubinfo/413.html

Collier, P. (2002). *Development of Australia's National GDA94 Transformation Grids*. Retrieved from https://www.icsm.gov.au/sites/default/files/natgrids_0.pdf

Collier, P. (2018). *3D Cadastre Workshop Outcomes Report*. Paper presented at the ICSM Permanent Committee on the Cadastre Workshop, Melbourne.

CRSBANZ. (2009). Cadastral Survey Outcomes & Objectives. Retrieved from http://www.surveyor.asn.au/for-surveyors/Cadastral_Outcomes_and_Objectives.pdf

De Soto, H. (2000). *The Mystery of Capital*. New York: Basic Books.

Department of Transport Energy and Infrastructure South Australia. (2017). *Spatial Improvement Utilising Controlled Cadastral Surveys. Alternate Spatial Improvement Method Testing Project*. Retrieved from Adelaide:

Enemark, S. (2017). [Interview].

Enemark, S., Bell, K. C., Lemmen, C., & McLaren, R. (2014). *Fit-For-Purpose Land Administration*. Retrieved from Denmark:

Enemark, S., McLaren, R., & Lemmen, C. (2016). *Fit-For-Purpose Land Administration: Guiding Principles for Country Implementation*. In (pp. 120). Retrieved from https://unhabitat.org/books/fit-for-purpose-land-administration-guiding-principles-for-country-implementation/

Glaser, B. G., & Strauss, A. (1967). *The Discovery of Grounded Theory: Strategies for qualitative research*. New York, NY USA: Aldine de Gruyter.

Grant, D. B. (2014). *A New Zealand Strategy for Cadastre 2034*. Paper presented at the FIG Congress 2014, KL Malaysia.

Grant, D. B., Blick, G. H., Pearse, M. B., Beavan, R. J., & Morgan, P. J. (1999). *The development and implementation of New Zealand Geodetic Datum 2000.* Paper presented at the International Union of Geodesy & Geophysics General Assembly, Birmingham, UK.

Grant, D. B., Crook, C., & Donnelly, N. (2014). *Managing the dynamics of New Zealand spatial cadastre*. Paper presented at the Research@Locate'14, Canberra Australia.

Grant, D. B., & Haanen, A. (2006). Cadastral outcomes and the Surveyor-General's rules for cadastral survey. *New Zealand Surveyor, 296*, 24-29.

Hammer, C. S. (2011). Expanding Our Knowledge Base Through Qualitative Research Methods. *American Journal of Speech-Language Pathology, 20*, 161-162.

Hirst, W. (2010). *Cadastre 2014 - Australia and New Zealand; now and the future*. Paper presented at the FIG Congress 2010, Syndey, Australia.

ICSM. (2014a). *Guideline for Adjustment and Evaluation of Survey Control*. Retrieved from

ICSM. (2014b). *Standard for Australian Survey Control Network*. Retrieved from

ICSM. (2015). *Cadastre 2034 Cadastral Reform and Inovation for Australia - A National Strategy*. Retrieved from Canberra, ACT Australia:

ICSM. (2018). *Geocentric Datum of Australia 2020 Technical Manual*. Retrieved from https://www.icsm.gov.au/sites/default/files/GDA2020TechnicalManualV1.1.1.pdf

IERS. (2010). *IERS Conventions (2010)*. In G. Petit, Luzum, B. (Ed.). Retrieved from https://www.iers.org/SharedDocs/Publikationen/EN/IERS/Publications/tn/TechnNote36/tn36.pdf?__blob=publicationFile&v=1

Jansen, V. (2017). *GDA2020, AUSGeoid2020 and ATRF: An Introduction.* Paper presented at the Association of Public Authority Surveyors Conference (APAS2017), Shoal Bay, New South Wales, Australia.

Jarman, R. (2006). [Value of coordinates in the chain of evidence in the ACT].

Johnstone, T. M., & Toms, K. N. (1989). *Review of adoption of Parcel Coordinates in the Australian Capital Territory*. Retrieved from ACT Planning & Land Authority, Canberra, ACT:

Krelle, A., & Rajabifard, A. (2010). *Cadastre 2014: New Challenges and Direction*. Paper presented at the FIG Congress 2010, Sydney, Australia.

Lambeck, K. (1988). *Geophysical Geodesy: The slow deformations of the Earth*. Oxford: Clarendon Press.

Landgate. (2017). *Spatial Cadastral Database (SCDB)*. Retrieved from https://www0.landgate.wa.gov.au/__data/assets/pdf_file/0003/8877/SCDB-Website-20170104.pdf?_ga=2.51057706.20599657.1527735013-1757263909.1484276852.

McLaughlin, J. D. (1975). *The nature, funtion and design concepts of multipurpose cadastres.* (PhD), University of Wisconsin, Morse, J. M., Richards, L. (2002). *Readme First for a User's Guide to Qualitative Methods*. Thousand Oaks, California, USA: SAGE Publications.

National Research Council (NRC). (1980). *Need for a Multipurpose Cadastre*: Washington National Academy Press.

Ottens, M., & Stubkjær, E. (2007). A socio-technical analysis of the cadastral system. *ZEVENBERGEN, J., FRANK, A., STUBKJAER, E.: Real Property Transactions. Procedures, Transaction Costs and Models. IOP Press, Amsterdam*.

Park, M., & Willlamson, I. (1999). Australian cadastres: the role of adverse possession of part parcels. *Australian surveyor, 44*(2), 151-158.

Priebbenow, R., Fraser, C., & Karki, S. (2018). *Pilot - Upgrading the spatial accuracy of the digital cadastre*. Paper presented at the ICSM Permanent Committee on the Cadastre Workshop, Melbourne.

QSR-International. (2011). NVivo 11 Getting Started. In (9.2 ed.).

Rowe, G. (2003). The survey conversion project–making a survey-accurate digital cadastre for New Zealand a reality. *New Zealand Surveyor*(293), 31-38.

Sinclair Knight Merz. (2011). *Business Case for a Spatially Accurate Map Base*. Retrieved from 452 Flinders Street Melbourne:

Steed, J., & Lutton, G. (2014). *WGS84 and the Geocentric Datum of Australia 1994*. Geoscience Australia Retrieved from www.ga.gov.au/__data/assets/pdf_file/0017/18242/GA5036.pdf.

Todd, P., Higgins, M., & Williams, G. (1998). *Levels of Maturity for Survey Infrastructure*. Queensland Surveying and Mapping.

van der Vlugt, M. (2018a). *CRCSI 3.20 Implications of a Dynamic Datum on the Cadastre – Project Update*. Paper presented at the ICSM Permanent Committee on the Cadastre Workshop, Melbourne.

van der Vlugt, M. (2018b). Implications of a Dynamic Datum on the Cadastre: Phase 2 Interim Report: Transition Tasks. Retrieved from http://www.crcsi.com.au/assets/Resources/CRC-3.20-Phase2-Report-1.0.pdf

Williamson, I., & Enemark, S. (1996). Understanding Cadastral Maps. *The Australian Surveyor*, 38 - 52.

Williamson, I., Rajabifard, A., Kalantari, M., & Wallace, J. (2012). *AAA Land Information: Accurate, Assured and Authoritative*. Paper presented at the 8th FIG Regional Conference 2012 Surveying towards Sustainable Development, Montevideo, Uruguay.

Wilson, A. (1990). GIS Technology Used to Establish a Digital Cadastral Database. *New Zealand Geographer, 46*(1), 33-36.

Zevenbergen, J. (2002). *Systems of land registration aspects and effects* (Vol. 51).

8 Appendices

8.1 Appendix A – Interview questions

8.1.1 Spatial Cadastre - Stakeholders

Q1) Do you have any concerns with the project scope excluding boundaries of: (3D) strata parcels, units, easements, covenants, unregistered RRRs including planning overlays?

Q2) Could you please outline the general dataflows and dependencies from a new cadastral survey being lodged through to update of the spatial/digital cadastral database?

Q3) What role do monuments and physical features play in the definition of legal boundaries?

1. In what ways does physical evidence (e.g. (a) to (d) below), most commonly have a definitive or lesser role as evidence when defining legal boundaries? Are there differing circumstances where the status of the underlying or abutting land is not private land – e.g. Crown land, roads, rivers & the sea.
   a. Natural features (river banks, lake edges MHW)
   b. Pegs or other features (fences, walls) that have been fixed by survey as boundaries
   c. Occupation / fencing
   d. Others, e.g. offsets, alignments or angles in relation to physical features
2. What are the accuracy requirements for surveying physical evidence, e.g. for boundary marks, fences, walls, (adverse possession) riverbanks etc?
3. What are the main boundary positioning functions or purposes served by the above groups of physical features? Which user groups most commonly rely on them? What limitations are there on their usefulness for locating boundaries? What proportion of boundary marks can be found or relied upon?

Q4) What role does documentary evidence play in the definition of legal boundaries?

1. In what ways does the documentary evidence (e.g. field notes, measurements, parcel dimensions, plots, coordinates on plans) most commonly have a definitive or lesser role as evidence when defining legal boundaries?

2. How is the documentary evidence interpreted and relied upon by users other than surveyors for the purpose of locating boundaries? Who uses it for this purpose?
3. Is there a hierarchy of forms of documentary evidence (bearings, distances, coordinates, plan plots, boundary descriptions, survey measurements, title dimensions) for defining boundaries?
4. How are discrepancies/errors between different forms of documentary evidence of boundaries handled?
5. What are the main cadastral purposes served by different types of documentary evidence (survey plans, titles)? Which user groups most commonly use or rely on them? What limitations are there on their usefulness for locating boundaries?

Q5) What role does spatial evidence (e.g. coordinates in a digital database) play in the definition of legal boundaries?

1. In what ways does the spatial cadastre most commonly have a definitive or lesser role as evidence when defining legal boundaries?
   a. Is the spatial cadastre ever used as definitive evidence in defining legal boundaries (legal coordinate cadastre)?
   b. Are there any legal requirements for management of changes to spatial cadastral coordinates over time where they play a role in defining legal boundaries, e.g. date stamped coordinates, update history?
2. How do any changes in legal boundaries get updated in the spatial cadastre? How quickly does this update occur?
3. Are any other RRRs (e.g. easements, covenants, planning overlays) maintained in the spatial cadastre? How are they kept accurately aligned?
4. What are the main cadastral purposes served by spatial coordinates in the DCDB? Which user groups most commonly use or rely on them? What limitations are there on their usefulness for locating boundaries.
5. Are there other spatial errors or inaccuracies (missing parcels, topology) that affect the usefulness of the DCDB?

Q6) What is the relationship between the documentary evidence (e.g. survey plans, titles) and physical features (e.g. survey marks)?

1. To what extent is documentary evidence based on survey measurements of physical features including survey marks?
2. Under what circumstances does physical evidence (walls, fences, boundary pegs, natural boundaries) overwhelm or rebut documentary evidence (survey or title dimensions, plan plots)? Are there any circumstances where the reverse applies?

3. To what extent is documentary evidence of boundaries based on planning requirements, rather than the positions of physical features like survey marks, etc?
4. To what extent is new documentary evidence of boundaries required to conform to prior documentary evidence (title dimensions, prior survey measurements)?
5. Some survey plans or datasets include documented boundary coordinates. What role do these <u>documented</u> coordinates (as distinct from spatial database coordinates) play for:
   a. their subsequent use for re-definition of boundaries and placement of marks?
   b. their use to maintain or constrain the spatial cadastre?

Q7) What is the relationship between physical surface features and the spatial (e.g. coordinates in a digital database) evidence of boundaries?

1. To what extent are spatial cadastral coordinates based on the locations of physical features (whether defined by survey or by other means such as photogrammetry or remote sensing)?
2. Under what circumstances does physical evidence (walls, fences, boundary pegs, natural boundaries) overwhelm or rebut spatial evidence (coordinates, cadastral databases)?
3. Does the reverse ever apply (marks placed or moved to match coordinates)?
4. What are the current accuracies or alignment of the spatial cadastre (in urban, peri urban, rural and remote regions) with regard to:
   a. occupation,
   b. natural features,
   c. utility assets,
   d. planning overlays,
   e. other land right/responsibilities/restrictions.

Q8) What is the relationship between the documentary data (e.g. survey plans lodged) and spatial coordinate data for evidence of boundaries?

1. Under what circumstances does documentary evidence (survey plans) overwhelm or rebut documentary spatial cadastral coordinates?
2. Does new documentary evidence (e.g. new survey plans lodged) result in changes to coordinates in the spatial cadastre?
   a. Are there significant delays in the update process?
   b. Are adjoining/nearby boundaries adjusted or rubber sheeted also?
3. To what extent can spatial cadastral coordinates be used to validate or confirm the correctness of documentary evidence (new surveys and titles).

4. Could the spatial cadastre (e.g. boundary coordinates, plots or parcel shape, relationship to imagery) be used to identify errors in the documentary cadastre – resulting in corrections to the documentary records?

Q9) Maintenance of the spatial cadastre after its accuracy has been upgraded?

1. What changes in survey procedures, survey validation and DCDB management do you think will be required to preserve and maintain an accurate spatial cadastre?
2. What legislative & regulatory changes do you think will be required to preserve and maintain an accurate spatial cadastre?
3. What changes to departmental structure do you think will be required to preserve and maintain an accurate spatial cadastre?
4. Are there any processes that do or will lend themselves to automated decision-making?

Q10) ICSM Business Case Framework for improved spatial accuracy in DCDB (2003)?

1. Has it been used in this jurisdiction? How?
2. Is the ICSM Business Case Framework useful or relevant in this jurisdiction? Why?
3. If the ICSM Business Case Framework is not useful or relevant, why not?
4. Do you have a different approach to business case development for DCDB spatial upgrade?
5. The 2003 ICSM Business Case Framework used a questionnaire to DCDB users. Do you think the views of DCDB users today are still broadly consistent with those 2003 results?

Q11) With an upgraded spatial cadastre what are the main opportunities for realizing benefits by surveyors, land registry, landowners & developers, councils & government agencies, the public?

Q12) Are there any other questions you think I should have asked?

8.1.2 Spatial Cadastre - Users

Q1) Does your organisation rely on the land/spatial agency digital cadastral database or do you manage your own DCDB? If you manage your own DCDB:

1. Would you use the land/spatial agency DCDB if it was more accurate?
2. How much more accurate would it need to be to persuade you to switch to it?
3. In general terms are you able to estimate the savings that would result?

Q2 What functions are served by the digital spatial cadastre for you and your clients?

1. In general terms please describe how you use the digital spatial cadastre
2. Do you align it with other spatial datasets? If so, which ones?
3. What problems do you use it to solve? What questions does it help to answer? What positive outcomes does it help to achieve?
4. Are these functions served mainly for you and your organisation or for your clients?
5. Do you operate across Australia? Do you operate mainly in your jurisdiction? Is your interest focused mainly on urban or rural areas?

Q3) What is the impact of spatial inaccuracy?

1. Are you satisfied with the spatial accuracy of boundaries?
2. Do inaccuracies between the location of boundaries in the spatial cadastre and other spatial or positioning datasets impose costs on your use of the data?
3. How accurate are other spatial datasets that you use with the spatial cadastre (absolute coordinate accuracy at 95% confidence – 2 standard deviations)?
4. Are you affected (positively or adversely) by apparent changes in boundary positions when the spatial accuracy of the cadastre is updated?
5. To what extent would it help if the level of accuracy or inaccuracy was made clear, numerically or visually?
6. Do other forms of inaccuracy (e.g. missing road parcels, topology) cause difficulties?

Q4) What coordinate accuracy level would be desirable?

1. What are the accuracy expectations for the cadastre for you and your clients (absolute coordinate accuracy at 95% confidence – 2 standard deviations)?
2. Given that spatial upgrade is expensive, what level of accuracy would be tolerable?
3. Do you anticipate your accuracy needs becoming more rigorous in the future? Why?

Q5) Which "representation" of boundaries is of greatest importance to you?

1. Which are you most interested in?
   a. Boundaries matching the original survey (which may be old and inaccurate)
   b. Boundaries that match the registered title (often the same as (i))
   c. Boundaries that generally align with the owner's occupation of the land (whether it matches the legal boundary or not)
   d. Boundaries that reflect any movement that may have occurred over time to the legal boundaries (natural boundaries, adverse occupation) but which have not yet been updated in survey & title records
2. What type of spatial misalignment causes the greatest difficulty for you?
   a. Misalignment between spatial cadastral boundaries and walls, fences and natural boundaries (e.g. from imagery or GPS positions in the field).
   b. Obvious discrepancies between the shape of a parcel in the spatial cadastre and the shape in survey & title plans and diagrams.
   c. Numerical discrepancies between boundary dimensions in survey & title documents and the dimensions calculated from the spatial cadastre.
   d. Other forms of misalignment or discrepancy (please describe).

Q6) What types of benefit would result from improvement in spatial accuracy?

1. Which of the following benefits would result from improvement in spatial accuracy?
   a. Reduced cost managing the spatial data
   b. Reduced cost for rework or for resolving discrepancies
   c. Improved confidence in solutions or advice provided to clients
   d. New markets and opportunities not currently available
   e. Others (please describe)
2. Are you able to compare the benefits in some areas of the cadastre that are currently accurate – compared with other less accurate areas?
3. If you are a surveyor, could a "survey accurate" spatial cadastre be used to set out boundaries and thus reduce survey costs?

Q7) Do you have any other comments or questions?

8.2 Appendix B – Contributing interviewees

The project gratefully acknowledges the time and contribution all interviewees. Individuals are listed below.

Shanta Vadeveer	Mauri Tringa	Bradley Slape
Tony Gill	Andrew Falkenberg	Bill Watt
Athina Pascoe-Bell	Russell Priebbenow	Michael Burdett
Stig Enemark	Steve Tarbit	Robert Agnew
Jaap Zevenbergen	Sudarshan Karki	William France
Melissa Harris	Tracy Corbett	Eugene Browne
Kieran Perkins	Chris Stephanos	Kevin McMahon
Ken Toleman	Matthew Smart	Allan Campbell
Greg Thompson	David Williams	Dione Bilick
David Hassett	Mark Thomas	Annaliese Walster
Richard Garton	Megan Dillon	Peter Birkett
Nic Donnelly	Stephen Donald	Murray Dolling
Mark Dyer	Alana Easton	Irek Baran
Anselm Haanen	Ashwood Caesar	Michael Bails
Andrew Fenney	Ian Killian	Iain Malcolm
Andrew Clouston	Jeremy Palmer	Michael Nietschke
Kasey Omen	Robert Deakin	Stephen Retallack
Duane Wilkins	Hudson Moody	Barry Donovan
Andrew Murray	Adrian White	Wayne Patterson
Narelle Underwood	Eric Sharpham	Les Gardner

Jeff Brown	Bill Hirst	Ron Jarman
David Sloan	Brian Burbridge	Steven Beljanski
Alex Baklinowicz	Peter William Mayberry	Phillip Rudd
Guenther Reisinger	Robert Sarib	Paul Digney
Peter Taylor	John Vanderniet	Scott Strong
Phillip Page	Michael Giudici	Craig Sandy
David R. Boyle	Roger Fraser	

8.3 Appendix C – Draft Observations Presented to Workshop

The 17 draft observations below were presented to a workshop of ICSM PCC members on 15-16 February 2018. The workshop participants discussed and commented on these initial observations. As a consequence, some of the terminology has been changed and some observations have been modified. These have been grouped into the main findings in section 4.2.

Observation 1 – Coordinated Cadastre

No jurisdictions have a fully legal coordinate cadastre. There seems to be no desire to go that far. All jurisdictions have at least an enhanced graphical coordinate cadastre.

Most jurisdictions have some areas which are still only at the level of digitised (not significantly enhanced) coordinate cadastre. The errors can be in the range of 20 – 1000m. Some jurisdictions have provision in legislation for coordinates to play a role in the hierarchy of evidence.

In Northern Territory the Surveyor-General can "delineate" a boundary with coordinates. "Delineate" provides some authority to the coordinate derived from the SG's legal powers. However, it does not preclude the SG from:

- Changing the coordinate where an error in the original has been identified
- Changing the coordinates to a new datum
- Changing coordinates over time in a dynamic datum

Therefore, the coordinate does not provide full legal definition of the boundary and this is not a legal coordinate cadastre in the sense of the Singaporean cadastre.

Observation 2 – Legal coordinates and boundary monuments

Australia and New Zealand principally have boundary monuments as the highest level of boundary definition evidence. If a legal coordinate cadastre was proposed, a dense and very accurate framework of cadastral reference marks based on the geodetic datum might be required – particularly in areas subject to deformation such as in New Zealand.

In practice the cost may not be justified and would be further complicated in Australia by plate movements and in New Zealand by earthquakes. While there is no desire for a legally coordinated cadastre in Australia and New Zealand, recognition of survey-accurate coordinates as having a place in the hierarchy of evidence – where not in conflict with other physical evidence should be considered, e.g. Northern Territory, ACT and (informally) New Zealand.

Note however that landowners almost always have a physical perception of where a boundary is. A mathematical definition is only likely to be acceptable if the coordinates align with the physical evidence.

This indicates that survey-accurate (or legal) coordinates need to be aligned with where the boundary is in the real world. It is not the case that the real-world boundary must always align with the coordinates. The 2016 post earthquake legislation in New Zealand stating that boundaries move with the land (and the monuments, fences and walls that attach to the land) is a legislative reflection of this principle.

Observation 3 – Users of the spatial cadastre

Surveyors are not the main beneficial users of the spatial cadastre (DCDB). Except where the spatial cadastre has already been upgraded to survey accuracy, surveyors work at accuracies higher than that usually provided by the spatial cadastre. Surveyors do use the spatial cadastre to develop planning proposals, find survey marks, search for cadastral documents in the vicinity, quote for survey work, etc. In most jurisdictions surveyors are required to base cadastral definition on monuments, supported by survey plans/dimensions. Coordinates are usually seen to have little or no role for cadastral survey definition. Therefore, surveyors generally see no benefits in uncertainties better than about 10-20cm for urban areas and greater for rural areas (say 0.5m); greater again for remote areas. These levels of uncertainty are sufficient for the functions they use the spatial cadastre for.

Observation 4 – Survey-accuracy

A survey-accurate spatial cadastre is therefore not necessarily the optimum goal to maximise the benefit/cost ratio. A survey-accurate spatial cadastre has a significantly higher cost compared with enhanced spatial accuracy. Also, the benefits in upgrading from the 10-20cm level to survey-accuracy may not always be justified. (Where the spatial cadastre is already survey-accurate however, this should be maintained as there are benefits.)

Justification for an upgrade step from spatially-accurate to survey-accurate will tend to be based on an anticipated reduction in costs for both surveyors and the land agencies in conducting, validating and integrating new cadastral surveys into the spatial cadastral network.

Observation 5 – Boundary disputes

A goal of the cadastral system is to hold the number of boundary disputes to an acceptable level and to provide a mechanism for resolving those disputes that do occur. The proportion of boundaries in dispute is very small indicating that the system is successful in all jurisdictions.

Moreover, disputes that do occur often have an origin other than the quality of the cadastral survey system. Landowners upset by the behaviour of neighbours may use a boundary dispute as a legally sanctioned opportunity for retaliation or leverage in the underlying dispute. In those cases, no improvement/reduction in boundary uncertainty would avoid the dispute. The complete elimination of boundary disputes (below the current very low level) is not a justification for imposing increased regulatory and database maintenance cost that would result from increasing accuracy beyond the general fit for purpose level.

In fact, very low levels of boundary uncertainty could increase the opportunities for needless dispute over supposed encroachments that have little or no practical impact.

Observation 6 – Misinterpretation of the spatial cadastre

The ready availability of the spatial cadastre as a dataset that can be aligned with other geospatial datasets, such as imagery, creates new opportunities for landowners or other members of the public to:

- Perceive encroachments that are not real or not significant
- Create new encroachments by occupying up to a line that is not the true location of the boundary.

These potential disputes only occur when the misalignment of the spatial cadastre and other datasets has a practical significance in relation to the physical size of fences, walls etc. Any misalignment less than 20cm is unlikely to cause significant problems. It is misalignments greater than 20cm (well above the level of survey-accuracy in regulations) that are likely to cause poor decision-making, anti-social behaviour between neighbours, or poor land management decisions.

Observation 7 – Accuracy requirements for asset management

Utility providers and councils use the spatial cadastre for location of assets in relation to properties and do so with a variety of approaches (e.g. offset to title, offsets to fencing, coordinated positions derived from the spatial cadastre, independent survey of their assets with GNSS, etc). Many reported that survey-accuracy in the spatial cadastre is not required for asset management - usually the assets themselves have a physical size of more than 10cm anyway. A spatially-accurate spatial cadastre would be, or already is, sufficient for many such users.

An issue that was reported, is the need for spatial cadastre managers to improve notification of incremental spatial upgrades and shift vectors in a way that can be used to maintain asset management databases.

Such communication/education for asset managers will also be needed for GDA2020 - and beyond with the ATRF dynamic datum.

Observation 8 – Wide variations in accuracy between and within jurisdictions

Across Australia and New Zealand there are large differences in the accuracy of the spatial cadastre based on geography (CBD vs outback) and jurisdictions, e.g. Western Australia and ACT and much of New Zealand is reported to be already at optimal accuracy. The required accuracy is related to size of land parcel, land value and land use. Spatial Cadastre managers should look at opportunities to obtain and use data from appropriate non-cadastral sources for improvement of their spatial databases, e.g. mining surveys in remote areas, topographic/feature surveys, pre-subdivision boundary surveys in urban areas, imagery, etc.

Observation 9 – Role of spatial cadastre in land development

The spatial cadastre is multi-purpose and a potentially significant benefit lies in having it used earlier in the land development life cycle, i.e. to avoid the necessity to engage surveyors early in the planning process, to be able to perform initial engineering design, to speed up land development planning approvals, etc.

This is perhaps more related to the bigger issue of the completeness of the spatial cadastre and the accuracy of attribute data, (other rights, restrictions and responsibilities, inclusion of all easements, etc) which is outside of this project's scope. However, for spatial accuracy of ownership parcels, which is in this project's scope, land development processes could be improved by inclusion of a 'proposed' layer within the spatial cadastre.

Many users commented on the issue of timeliness of data in the spatial cadastre. An issue is the common delay in issuing title following gazettal for land acquisitions, etc. Process change in conjunction with inclusion of a proposed development layer may address this.

Observation 10 – Visual depiction or dissemination of information on spatial accuracy or source

Currently several jurisdictions have an accuracy attribute allocated to spatial points or lines. Often this is a proxy for the data source attribute rather than the positional uncertainty and this has mixed use. The possibility of having title line widths proportionate to the spatial uncertainty of the boundary line (fuzzy boundaries as they used to be when drawn on paper plans and maps) could assist broader understanding of accuracy and the appropriate use of the data, e.g. being able to build as per planning regulations at the required offset to title. This is always a commercial risk decision by a property owner/builder and if in doubt they should engage a surveyor, but appropriate clarity of accuracy may assist better decision making at the early planning and design stages.

Observation 11 – Locations of natural moveable boundaries

Natural feature boundaries are complex from a surveying/legal title perspective and the way in which they were initially brought into and recorded in the respective spatial cadastres varies between jurisdictions. Most interviewed wanted the spatial cadastre to reflect the legal boundary at the time of the original survey definition, but in a multi-purpose spatial cadastre, recognising that survey data may not be updated for decades after a boundary moves, an option would be to also show the current location of natural feature boundaries, obtained from aerial imagery and included as an additional ‘presumptive’ boundary/layer.

Observation 12 – Showing title and other legal boundaries

Most interviewees indicated that the spatial cadastre should reflect title boundaries. Aerial imagery of occupation/fencing say, may be used by surveyors as another observational data source for boundary consideration within current legislation, but fencing does not define title (except in the case of adverse possession in some jurisdictions) and there may be difficulties with including occupation and potential adverse possession broadly in the spatial cadastre as a means of spatial improvement.

However, imagery of occupation could be used to improve gross errors in the spatial cadastre (20 – 1000m). Even though the shifted boundary lines will not be accurate, they could be much better than before and sufficient for many purposes.

Observation 13 – Mandatory use of spatial cadastre by government agencies

Jurisdictional spatial cadastres should be mandated (if not already) as the single authoritative dataset for land administration purposes across local and jurisdictional government. An upgrade to at least spatial-accurate would assist the suitability of the spatial cadastre for most if not all land administration purposes. The benefits, and a decision to mandate use to enforce achievement of these benefits, should be a part of a business case for upgrade.

Observation 14 – Alignment of administrative boundaries

Planning zones and overlay and administrative boundaries need to be aligned with cadastral boundaries to avoid invalid land use or land development decisions. The management of the spatial accuracy of planning overlays and other administrative boundaries is outside the scope of this project. However, a benefit of a spatially accurate cadastre to 10-20cm would be a significant reduction in misalignment of the spatial view of cadastral and administrative boundaries. Some planning overlays are expressed as buffer zones based on a physical feature and these seldom have an accuracy as good as 10-20cm anyway.

Observation 15 – Business cases to government

A business case to government for upgrade of the spatial/digital cadastral database will involve either the expenditure of public money or the levy of fees through government regulation – or some combination of these.

Therefore, the spatial upgrade should not be an end goal in itself to satisfy the expectations of surveyors or survey officials in the land agency. Upgrade should be a step within a broader strategy to consider what are the services (from government or supported by government) that will be improved by the upgrade, and what are the inputs (cadastral surveys and other data) that will sustain the higher accuracy in the long term.

Therefore, the expenditure of public money to upgrade the spatial cadastre should be accompanied by proposals to:

(a) improve the suitability of new cadastral survey data for maintaining the spatial cadastral database (through enhanced cadastral data standards) and

(b) provide a clarification of the downstream benefits for land administration and public decision making.

Observation 16 – Cadastral Survey Standards

Standards for cadastral survey are set in regulation and vary in each jurisdiction. The scope of this study covers boundary re-instatement, subdivision and consolidation survey standards (not 3D strata).

As well as managing the definition of cadastral boundaries for landowners, the standards should also recognise the role this data plays in maintaining the spatial cadastre as a public geospatial dataset and for land administration within government.

As noted above, the expenditure of public money to upgrade the spatial cadastre should be accompanied by enhanced cadastral survey data standards that support and take advantage of the resulting improved spatial cadastral accuracy.

For cadastral boundary dimensions, the requirement to express distances in terms of the national standard metre is enforced everywhere. But (setting aside Western Australia where boundary angles make this not applicable) the enforcement of a standard for bearings to also be in terms of geodetic grid north is not universally applied.

At least for cadastral surveys of primary parcels:

- There should be a goal to achieve mandatory digital lodgement using an intelligent structured data format (not just pdf).
- All cadastral surveys should have grid/plane bearings expressed in terms of the current official geodetic datum.
- All cadastral surveys should have a survey connection to at least 2 geodetic control marks to support maintenance of the enhanced spatial accuracy.

Observation 17 – ePlan Data Format

So far, LandXML has been fully successful (with mandatory digital lodgement) only in New Zealand with LandXML as the eSurvey format. Western Australia has an alternative successful local data format (CSD).

Despite the investment already made by the ICSM ePlan Working Group into adoption of LandXML in some jurisdictions as a supported or mandated format, the suitability of the formats (LandXML, Western Australia CSD, maybe other formats) could be reviewed.