Metrics Manager for Digital Cadastral Database Management

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Key words: Cadastre, Spatial Upgrade, Metrics, Management

SUMMARY

The recent availability of Cadastral Least Squares Adjustment solutions has increased the pressure on Agencies to improve the spatial accuracy of their Digital Cadastral Databases (DCDB). However, creating a digital cadastre of known high spatial accuracy remains a daunting and challenging undertaking at an agency level. For organisations with jurisdiction over large and diverse cadastres, the process to implement a systematic spatial upgrade of the Cadastre is likely to be lengthy and expensive with many unknowns.

The Land and Property Management Authority (LPMA) (Formerly the NSW Department of Lands) has implemented a multi-pronged upgrade approach that incorporates a Metrics Management System aimed at providing key information to support the management of upgrade initiatives. The System uses standard GIS software to provide:

- objective measures of the current accuracy distribution of the cadastre,
- analysis of past incremental cadastral upgrades and error detection to improve the accuracy of the cadastre fabric,
- data on the extent, distribution, and quality of existing survey control as well as highlighting which control should be improved to efficiently achieve an accurate cadastre,
- data regarding stakeholders, their interests and planned activities, and
- an improved ability to develop a co-ordinated work plan aimed at addressing stakeholder needs and providing a cadastre of know accuracy.

The Metrics Management System provides LPMA, for the first time ever, with an objective measure of the current accuracy of the DCDB. It quickly identifies constraints to improvements and provides an easily accessible view of current and planned initiatives. As a result, LPMA is better able to take advantage of, and to respond pro-actively to, external stakeholder demands and initiatives whilst at the same time providing greater transparency to the wider community. Critically, LPMA over time will be better able to access the efficacy of various upgrade approaches, and be accountable for balancing conflicting demands and optimising the use of limited resources in its pursuit.

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1. INTRODUCTION

This paper introduces the Metrics Manager developed within the Land and Property Information (LPI), a Division of Land and Property Managagement Authority (LPMA). LPMA is the government agency for state owned land and all land and property information in New South Wales.

The Metrics Manager was developed to assist LPI manage upgrade activities aimed at improving the spatial accuracy of the NSW digital cadastre database (DCDB). Cadastral Upgrade requires extensive coordination across a broad range of activities:

- Legislative / regulatory surveying requirements
- Design, distribution and co-ordination of Survey Control Network
- Design and maintenance of a digital Cadastre
- Direct access to digital survey plans
- Capture and management of parcel dimensions
- Field work to augment current adjustment parameters
- Leadership and cooperation between stakeholders

Upgrading digital Cadastres is an expensive and potentially long drawn out process, even with specialised Cadastral Adjustment products. Prior identification of limitations and pre-requisite activities can therefore save LPI significant time, effort and cost. There is a constant need to balance conflicting demands for improved accuracy , optimised the use of limited resources, and to understand what is realistically achievable.

1.1 Land and Property Information

LPI is an internationally recognised 'one stop shop' for all land administration needs. Services within LPI include land title registration, property information, valuation, surveying and mapping.

LPI maintains a secure, efficient and guaranteed system of land ownership for NSW. The land title registry defines the legal ownership and boundaries of land parcels throughout the State, both private and public, and records changes as they occur. The primary register, the Torrens Title register, protects land title by State Government guarantee and has operated since 1863. From property buying and selling to financing, the land title registry underpins billions of dollars of economic activity in NSW each year.

LPI collects, collates and integrates property information in NSW and makes it readily available online via its web site, over the counter and through approved information brokers. The spatial information and property datasets built and maintained by LPI are among the States most important commercial and historical information assets. They include millions of land titles, and land polygons including roads, national parks, forestry, state lands, associated plans and dealings, valuation information, survey control data and mapping and spatial information, including aerial photography.

LPI maintains a single authoritative graphics database of cadastral parcels and records in NSW referred to as the Digital Cadastral Data Base (DCDB). A GIS based system was developed in the 1990's to ensure that new subdivsions and parcels accepted in the State Titling System were added as updates to the DCDB. The cadastral fabric in NSW contains approximately 4 million parcels with a land title, and includes roads and administration boundaries. The DCDB contains in excess of five million polygons.

1.2 DCDB Spatial Upgrade

The community, business and government increasingly demand greater accuracy, completeness and currency of land and property information for a variety of purposes including land management, conveyancing, property development, investment, local planning, state economic and social development and historical research.

LPI has implemented two initiatives aimed at improving the quality and completeness of the DCDB. These are:

- Re-engineering of the Cadastral Maintenance System (2002 - 2004)
- Development of a range of DCDB Spatial Upgrade tools (2008 – present)

These initiatives reflect the vision contained in Cadastre 2014 (Kaufmann & Steudler 1998). Cadastre 2014 Statement 3 emphasizes the migration from maps to modeling, directly paralleling the Cadastral Maintenance redevelopment. Secondly, the adoption of the "Fixed Boundary System" in Cadastre 2014 means that cadastral boundaries are to be located by surveyed coordinates. This will be the direct outcome of a systematic upgrade of the DCDB.

The current Cadastral Maintenance System provides a comprehensive database schema modeling land parcels, interests and administrative boundaries. A key requirement of the system's development was to ensure that the system would be spatially upgradeable in the future, whilst continuing to support its current user base.

The DCDB Spatial Upgrade initiatives are based on commercially available GIS functionality. The "Upgrade Manager" is a solution that uses the rigorous Least Square Adjustment of Cadastral networks to improve the spatial position of the DCDB features.

The Upgrade Manager provides LPI with the tools to upgrade the DCDB, but it does not address such key management questions as "how much will it cost?", "what accuracy is achievable?" or even "what is the current accuracy of the DCDB?"

The Metrics Manager was designed to assist in answering these questions.

The aim of the Metrics Manager is to provide a single source of truth for all factors relating to DCDB accuracy, current and proposed activities that will affect accuracy, and estimates of effort required as well as identifying critical factors for determining what accuracy is achievable.

To appreciate how the Metrics Manager addresses this aim an understanding of the DCDB management, the upgrade adjustment processes, and cadastral practices in NSW are required.

2. UPGRADE METHODOLOGY

The Cadastral Maintenance System is based on ESRI's ArcGIS platform. To upgrade the spatial position of the DCDB LPI uses core adjustment functionality contained within the Cadastral Editor component of the ArcGIS Survey Analyst extension.

2.1 Adjustment Network

Cadastral Editor uses the bearings and distances of cadastral boundaries to form an adjustment network. A least squares adjustment is then performed on the network using observed connections to nominated fixed control marks as the basis of the computed coordinates[1].

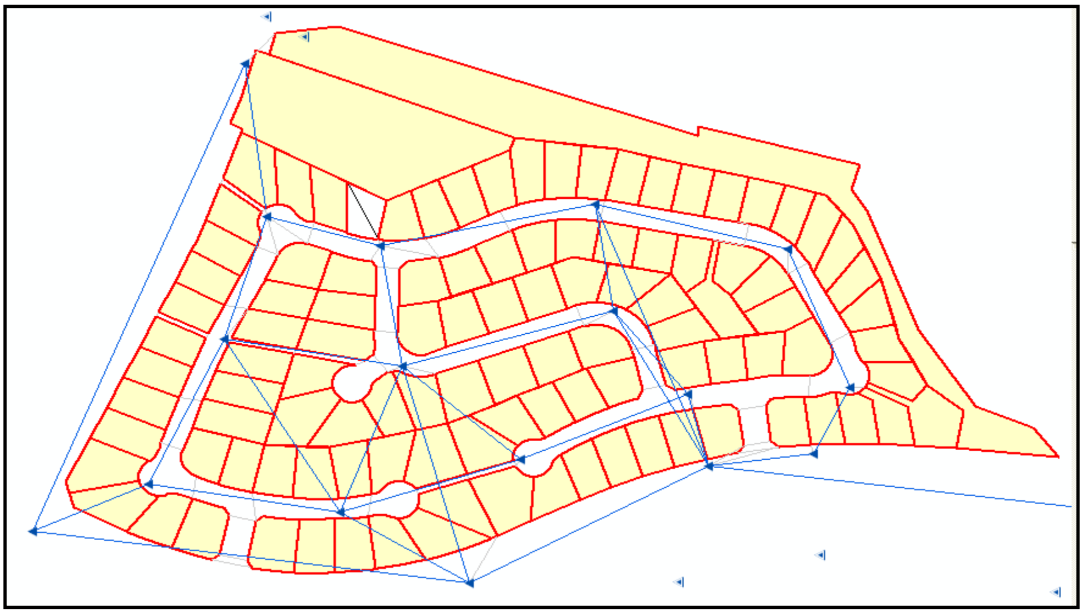

Figure 1 Section of the DCDB and Survey Control Network ready for adjustment

2.2 Accuracy Limitations

Limitations to the potential for accuracy improvements in the DCDB can be broadly described as factors that impact the:

- Accuracy and connectivity of the cadastral boundary dimensions (bearings and distances along boundary lines)
- Availability and Accuracy of the Survey Control Network and
- the density and distribution of connections between Control and the cadastre

The following section provides a brief background on the New South Wales digital Cadastre.

[1] A detailed description of Cadastral Editor is beyond the scope of this paper. Readers are referred to ESRI's website for more information: http://www.esri.com/software/arcgis/extensions/surveyanalyst/index.html

3. THE NSW EXPERIENCE

3.1 Creation of the DCDB

During the period from 1985 to 1994 all cadastral maps and records were consolidated into a single authoritative Graphic Data Base now referred to as the Digital Cadastral Data Base (DCDB). Many different data acquisition techniques were used ranging from digitising and scanning the old cadastral maps to complete coordinate geometry reconstruction of the cadastral boundaries from survey plans.

The accuracy of the cadastral data held within the DCDB varies significantly due to the variety of data acquisition techniques used and the scale of the source documents. Source cadastral maps were based on the best available Central Mapping Authority (CMA) cadastral map sheets. CMA map sheets covered NSW using a rectangular map series for both cadastral and topographic maps and aerial photography. Medium scale (1:25,000) rural cadastral and large scale (1:2,000 & 1:4,000) urban map sheets were produced and maintained until 1988 with the introduction of the DCDB. The remote, sparsely populated Western Region was captured predominantly at 1:100,000.

3.2 Updates to the DCDB

Nearly all freehold land titles in New South Wales are Torrens Title. Torrens parcels are defined by survey plans registered by LPMA.

Since the commissioning of the new Cadastral Maintenance System in December 2004 all cadastral updates (i.e. new surveyed cadastral parcel additions) to the DCDB have been by made using bearing and distance capture to construct the cadastral boundaries. This allows checking of the survey/geometry closure of new parcel boundaries. The plans also show connections from the Survey Control Network to the parcels. This connection allows parcel co-ordination, and defines the correct and accurate location of it's boundaries with respect to the Survey Control Network.

New parcel updates explicitly store the parcel corner co-ordinates in their "as surveyed" locations. The new parcels are made to fit the existing surrounding parcel geometries in the DCDB. This ensures efficiency in the update processes as well as maintaining the integrity of the updated cadastre as a seamless fabric. This approach also eliminates the disruption to customers that would be caused by adjusting the surrounding fabric to fit the surveyed position of the new plan. LPI is therefore able to separate management of Updates from Upgrades. These two processes require differing operator skillsets. Uncoupling the two ensures that Upgrades are only undertaken when a signficant improvement can be achieved consistently across an area rather than just isolated to the extent of a single plan within that area.

Prior to December 2004 DCDB plan dimensions and connections to control were not recorded in the DCDB.

3.3 NSW Survey Control Network

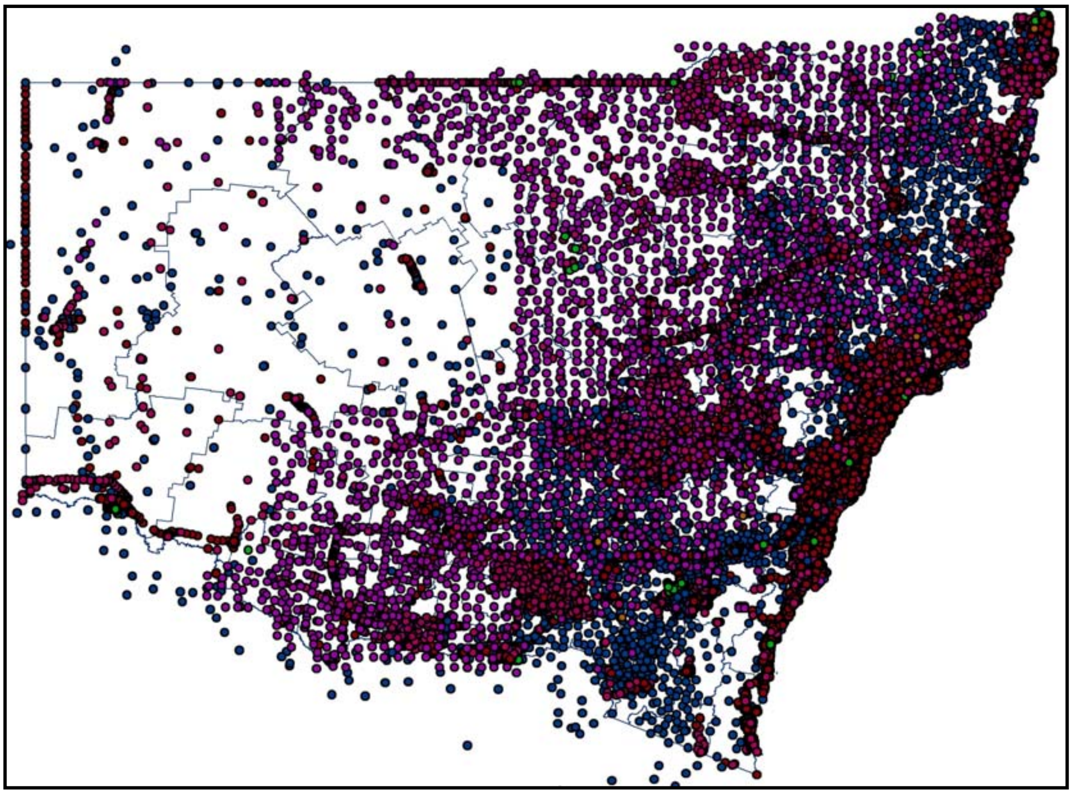

Figure 2 ***Surveyed Permanent Survey Marks within New South Wales***

From 1986 legislative reform to Surveying Regulation required all cadastral surveys to use and connect to the Survey Control Network and to extend and maintain the network with the rollout of development. Today there are over 230,000 permanent survey marks (including trig stations, permanent marks, state survey marks etc) placed within NSW. Most are placed in urban or developing areas. Of these permanent survey marks approximately 150,000 (or 64%) have been accurately surveyed.

Accurate, surveyed permanent marks are paramount to upgrading the accuracy of the DCDB and are a crucial prerequisite for upgrade projects.

3.4 Connecting Cadastral Surveys to the Control Network

Proclaimed Survey Areas were defined under the Survey Coordination Act 1949 after an area was deemed to have sufficient and suitable Survey Control Marks surveyed within the area. If surveys were undertaken within a Proclaimed Survey Areas then connections from the control marks were required to be shown on the survey plan. Hence, connections are recorded on the public survey plans.

3.5 Challenges

Prior to December 2004 DCDB plan dimensions and connections to control were not recorded in the DCDB. Hence the vast majority of the DCDB is undimensioned. This is a major limitation for upgrading the DCDB as Cadastral Editor relies on adjusting a network of boundary line dimensions. Ideally these dimensions are based on survey plan title dimensions. However, in the case of legacy (pre Dec 2004) parcels, the dimensions are derived from the GIS boundary vectors and are significantly less accurate than the corresponding plan dimensions. In areas of predominantly old parcels it is therefore necessary to capture original plan dimensions in the DCDB before an accurate upgrade can be achieved.

Alternatively, LPI would neet to wait until new plans were captured that covered the entire state cadastre. There are approximately 12,000 survey plans creating over 30,000 new titles and 1,500 strata plans creating 15,000 new strata titles registered each year. If the cadastral fabric relied upon the natural replacement of the existing 4 million titles by new surveys, then it would take approximately (4,000,000/13,500 = 296 yrs) 300 years to replace the existing cadastre[2]. That time scale is unacceptable for all users. Whilst the Metrics Manager is not a panacea for this problem, it assists in identifying those areas of the DCDB that need to be additionally dimensioned as part of an Upgrade exercise. And hence assists in estimating the effort required to upgrade prior to work being undertaken.

Significant proportions of rural areas do not undergo any cadastral changes, therefore very few new surveys are undertaken in these areas and consequently very few connections from control marks to the cadastre are recorded on a public plan. In these areas additional fieldwork would need to be undertaken to establish survey connections from the Survey Control Network to the cadastre so that the adjustments would be constrained by the Survey Control Network.

Significant variation in population density, age of the cadastre and establishment and density of the Survey Control Network means that the cost benefit of obtaining an accurate cadastre will vary significantly across the state. A region that contains low population density and a high proportion of parcels defined by old surveys will require significant field work to reach the level of accuracy more readily attainable in well controlled urban areas.

4. IDENTIFYING AND DERIVING KEY METRICS

Upgrade metrics are captured both at the individual unit level and as area based summary statistics.

4.1 Unit Metrics

4.1.1 <u>Control Displacement Vectors</u>

The difference in coordinates of where the corner truly is located (as defined by the survey plan) and where the DCDB displays it’s position will deduce a vector that is an objective measure of the accuracy of the DCDB at that location. This vector is automatically calculated and stored in the Metrics Manager as a “Control Displacement Vector”. These vectors are only stored for plans that have been captured in the new Cadastral Maintenence System (since December 2004) and only where accurate Survey Control Marks are referenced as the datum line for the plan.

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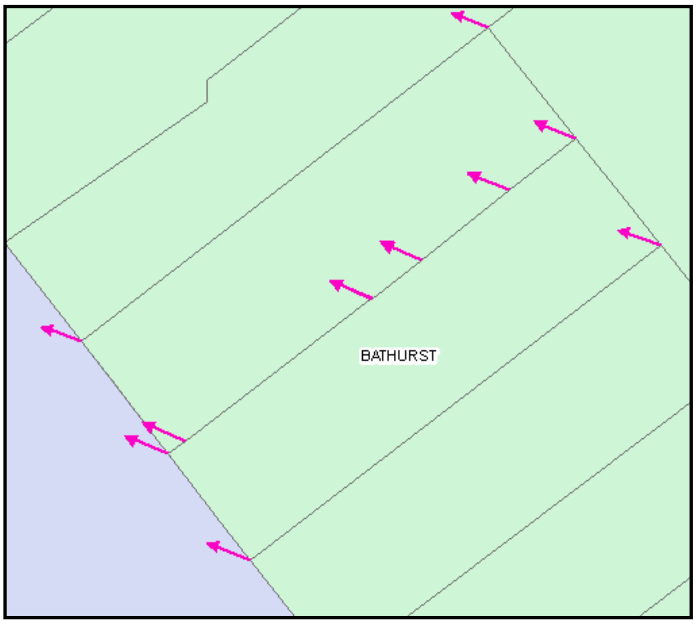
[2] This assumes that each current parcel was only subdivided once, which would not be the case. There would be significant “nesting” of plans at the expense of other areas. This means that the estimated time required for full coverage would be much greater. This only further highlights the point being made.



Vectors showing displacement from DCDB position to the "As Surveyed" position

4.1.2 Control Mark Plan relationships

The relationship between every survey (i.e. Deposited Plan) and permanent mark placed or found in the cadastral surveys since 1990 has been recorded in a Survey database. To date, over 200,000 survey plans (DP's) are recorded with over 540,000 Deposited Plan (DP) to Permanent Survey Mark relationships defined.

The Metrics Manager summarises records from the Survey database displaying control marks attributed with their accuracy class and a count of the number of Deposited Plans that connect directly to that mark. This information is invaluable for assessing which surveyed Control Marks have cadastre connections and which unsurveyed Control Marks should be prioritised for survey prior to upgrading the DCDB.

4.1.3 Existing DCDB Features

The Metrics Manager takes advantage of existing DCDB features for analysis purposes. For instance, current cadastral parcels are attributed and symbolised by their plan registration date. The age of the survey is a good indicator of the accuracy of the measurements used to make the survey. As technology and legislative reform has improved, the accuracy of surveys can also be assumed to improve. It is possible to allocate basic standard deviations or tolerances to each measurement in the survey adjustment to obtain a result of known quality from the Least Squares Solution. The table below provides indicative historical values.

Table 1 Expected Accuracy of Surveys

Code	Date of Survey	Classification / Expected Standard Deviation
1	Survey Control (current)	Accurate Survey Control Standards (Class 2A – C) (2mm + 2ppm)
2	Present – 1990	Survey Integration & GNSS (5mm +5ppm)
3	1990 – 1975	EDM introduced (10mm + 5ppm)
4	1975 – 1933	Uniform Survey Practice - Surveyors Act 1929 (10mm + 20ppm)
5	1933 – 1870	Theodolite & Steel Wire Chain 20mm + 50ppm)
6	pre 1870	Circumferenter & Gunters Chain (50mm + 100ppm)
7	Exclude from Adjustment	RAG Measurements/Surveys

These accuracy values can be directly loaded into the cadastral adjustment. This ensures that old plan dimensions, as well as undimensionsed boundaries, are given significantly less weight in the adjustment compared to modern plan dimensions.

4.2 Area Based Summary Statistics

Metrics are derived on an area basis for analysis purposes. Regional comparisons are undertaken by symbolizing areas on one or more of the summary metric attributes. In the initial release metrics have been summarized at two levels of resolution, the suburb level (large scale) and the Local Government Area (small scale).

Metrics support analysis in three key areas:

- Current status
- Upgrade Potential
- Stakeholder Interests & Actions

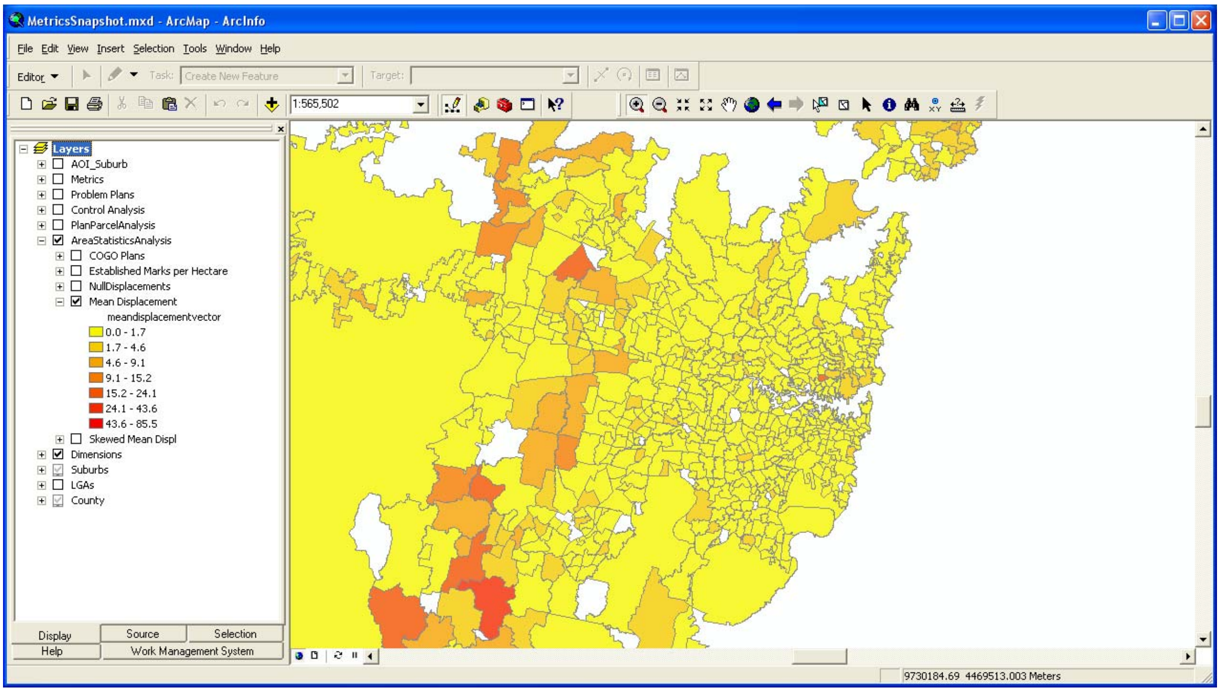


Figure 3 Mean Displacement Vectors for the Greater Sydney area based on Suburbs

4.2.1 Current Status

Understanding the current status of the DCDB enables potential users to access if it meets their requirements. It also allows LPI to priorities areas for upgrade based on business specific criteria. For example, prioritise those areas that are the most inaccurate, or that have high current levels of subdivision activity, or the best potential for accurate results. Metrics include:

- Number of Plans
- Number of COGO captured plans
- Parcel Count
- The number of Control Vectors in the area
- Mean of the Control Displacement Vector distances within the area
- Standard Deviation of the Control Displacement Vectors
- Number of Control Marks within the area
- Density of Control Marks (number / area)
- Density of accurate Control Marks
- Number of Boundary Points within the area
- Percentage of Boundary Points that are directly connected to accurate control marks

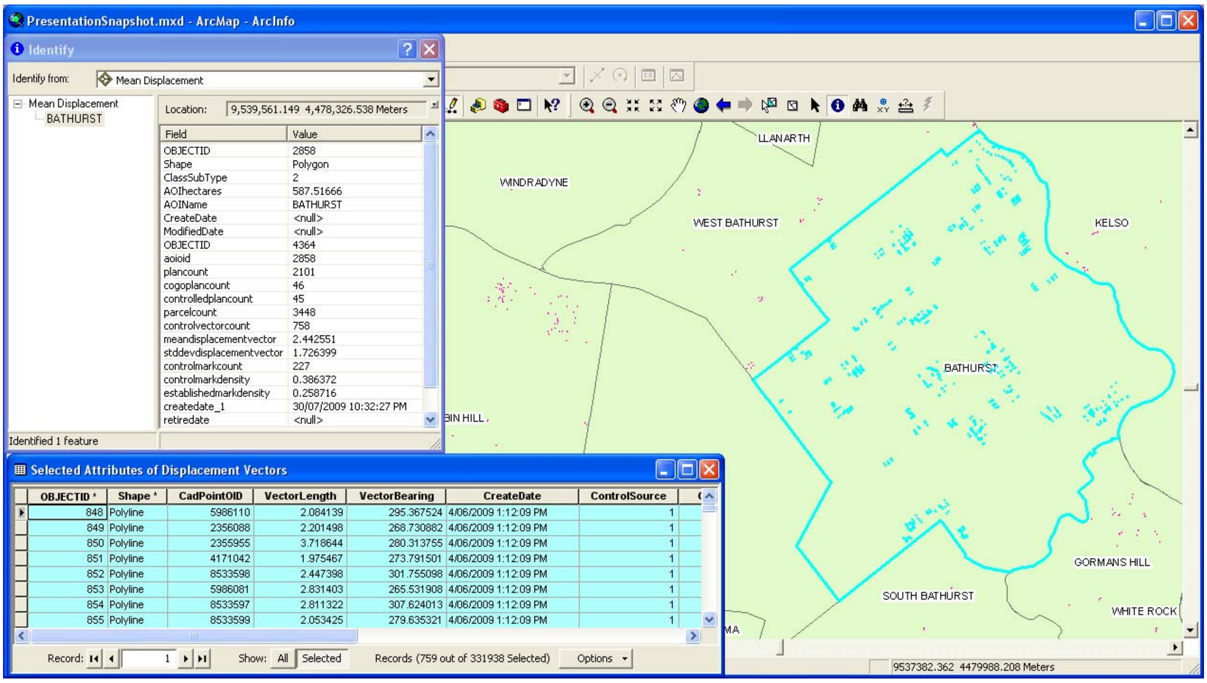


Figure 4 Displacement Vector data for the town of Bathurst

Figure 4 shows both the individual Displacement Vectors and the area based summary statistics for Bathurst. The bottom left table displays the attributes for the Displacement Vectors selected from Bathurst (there are 759 selected). This table includes a "VectorLength" field that can be queried or sorted. This allows the operator to identify and focus on problem areas. The top left "Identify" form displays the summary statistics for Bathurst, including the Mean Displacement Vector (2.4 m) as well as parcel, plan, and Control Mark summary statistics. The summary statistics allow for regional comparison with other surrounding suburbs.

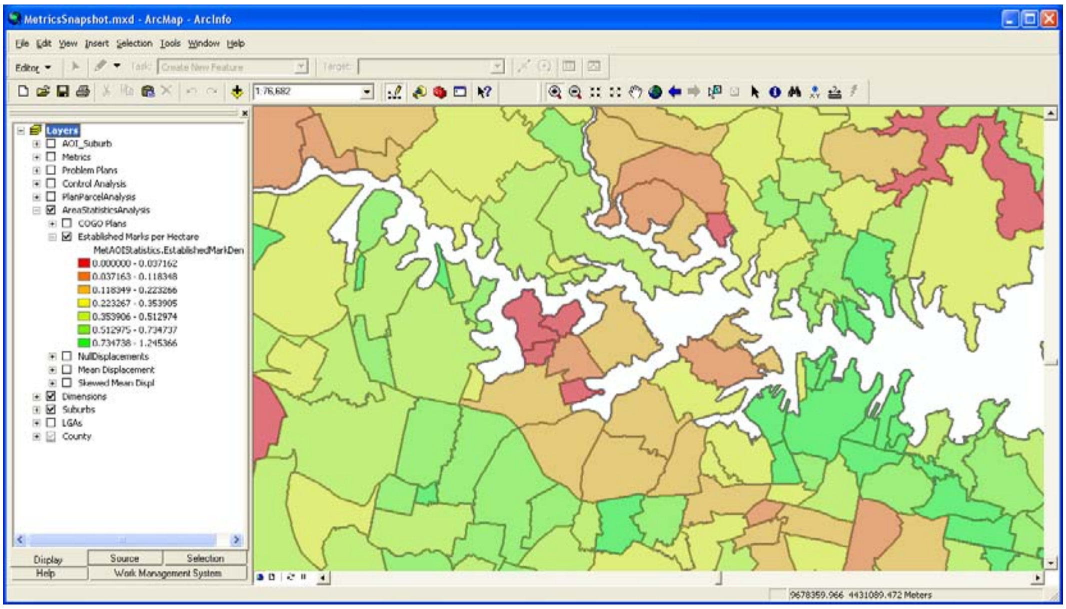


Figure 5 Variation in Control Mark density in Sydney Suburbs

4.2.2 Upgrade Potential

Metrics can be used to assess an area's suitability for upgrade including the need to undertake additional field work for either surveying control marks or connecting marks to boundary points, and the need to COGO capture of parcel dimensions. Metrics include:

- Age of plans (refer to previous accuracy table)
- Control mark quality and density and connections to plans
- Spatial relationships between plans and across roads

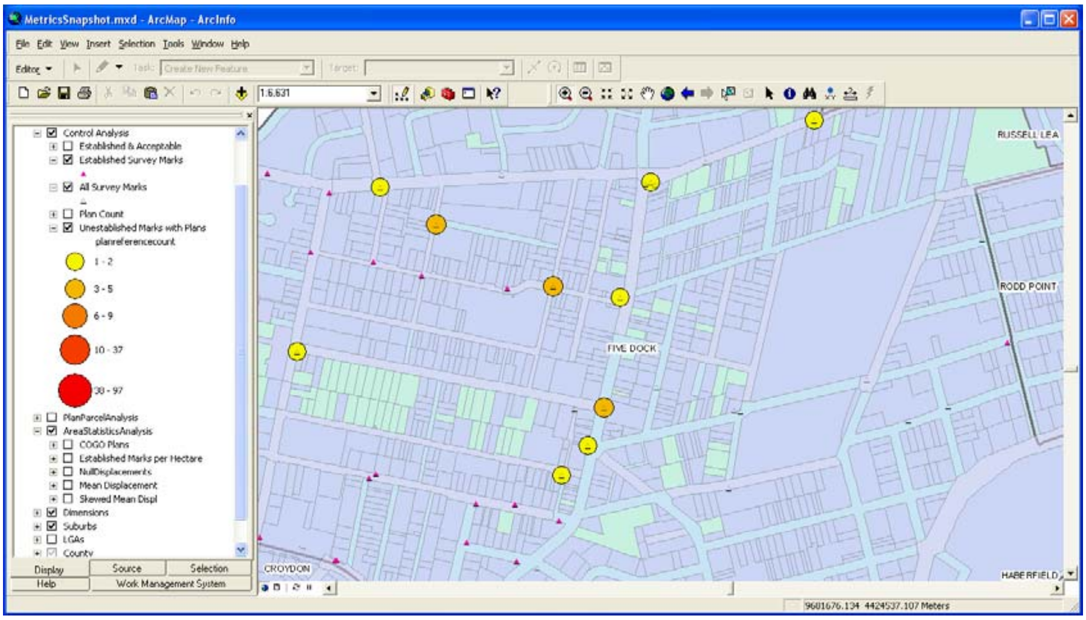


Figure 6 Unsurveyed Control Marks symbolized by the number of connections to Cadastral Plans

Figure 6 illustrates a lack of surveyed Control Marks. The surveyed Control Marks are shown as solid magenta triangles, whilst unsurveyed marks are hollow triangles. The colour and size of the circular symbol indicates the number of Cadastral Plans that connect to that mark. This is extremely useful for isolating those marks that will improve DCDB upgrade potential if surveyed.

4.2.3 Stakeholders, Interests and Actions

The Metrics Manager includes modeling of stakeholders, areas of interest and any agreed/planned actions that will have an impact on the potential for upgrade of the DCDB. Stakeholders can be both internal and external to LPMA. For instance the LPI Upgrade Team are able to chart out their planned activities in the Metrics Manager and provide visibility to interested parties. This encourages activities to be better coordinated between teams. For instance, the data supply team can notify customers within an area of a planned upgrade that may impact the next supply of the DCDB.

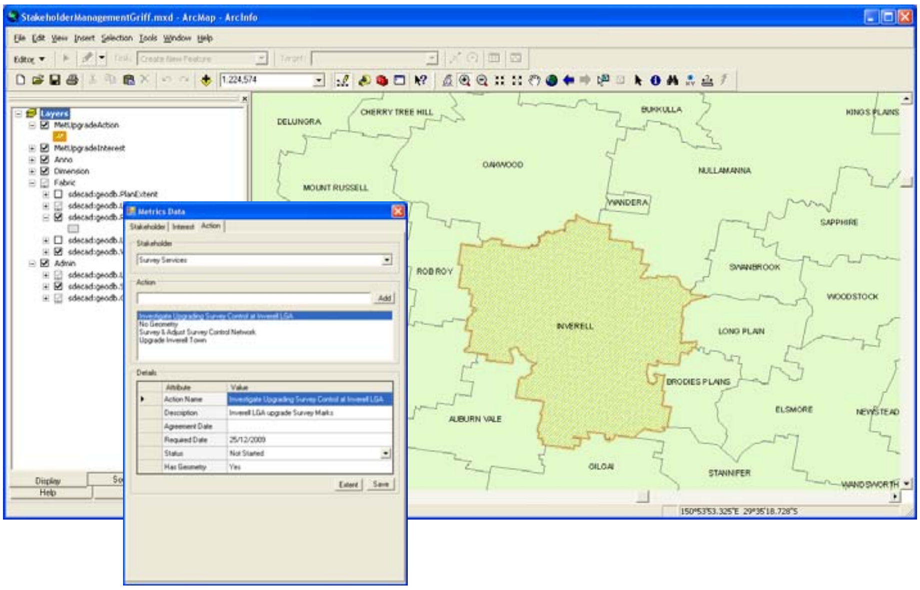


Figure 7 Interface for recording planned Stakeholder Actions

4.3 Managing Metrics

4.3.1 Refreshing Metrics

Statistics can be refreshed on both an event basis, for example following completion of an Upgrade of the DCDB, and on a scheduled frequency.

4.3.2 Non-Decaying Metrics

Summary statistics are maintained as a "non-decaying" dataset. When new statistic records are generated the superseded record has its "end date" attribute set to the current date. This modelling supports temporal analysis of the changing quality of the DCDB and allows the efficacy of differing upgrade approaches to be objectively assessed.

5. FINDINGS

The Metrics Manager provides LPMA, for the first time, with an objective measures of the accuracy of the DCDB. It quickly identifies constraints to improvements and provides an easily accessible view of current and planned initiatives. It is proving extremely useful for planning, managing expectations and coordinating activities. The Metrics Manager acts as a noticeboard that stakeholders can reference concerning the scheduling and progress of planned upgrade activities.

The Metrics Manager promotes a dialogue on the relative quality of different regions and presents constraints and limitations through a series of easy to understand views. Prior to attempting any upgrade activity, an experienced operator can view and query the Metrics Manager and determine: what field work (if any) needs to be undertaken; what additional dimensions need to be captured; and provide an initial assessment of the accuracy achievable. The operator can also review key criteria to determine which areas should be prioritised for upgrade.

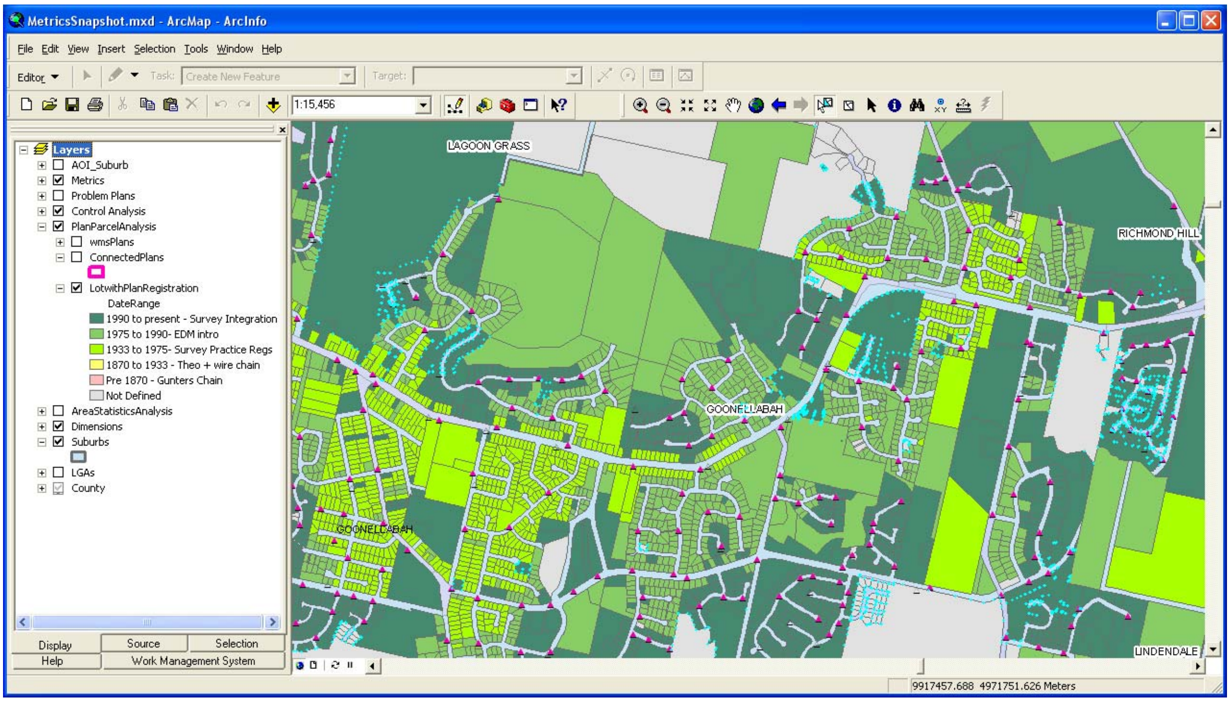


Figure 8 Goonellabah a peri-urban area on the NSW North Coast

Figures 8 and 9 show two areas with contrasting upgrade potential. Parcels are shaded according to the age of the plan registration. Dark green is most recent through to grey being not defined. Figure 8 shows an excellent coverage of accurate Survey Control Marks (displayed as solid magenta triangles) with a good distribution of modern parcels. Contrast this with Figure 9 where Control is largely unsurveyed (except for along the highway on the Southern extent of the town). There are a large number of old and unidentified plans. To be worthwhile, an upgrade of Gunning would require substantial fieldwork to establish control and would potentially require some parcel re-definition.

An Upgrade is only as strong as its weakest link. An area that is covered predominantly by recent plans, showing accurate dimensions and frequent connections to control may have limited Upgrade Potential if the referenced control is not accurately co ordinated in the Survey Control Network. In that case it would be essential to undertake field work to observe and adjust the Control Network prior to attempting a Cadastral Upgrade. The limiting factor is easily identified using standard GIS functionality to view and interrogate the Metrics data.

It is anticipated that Cadastral metrics will evolve and grow as new indicators are identified and maintained within the system.

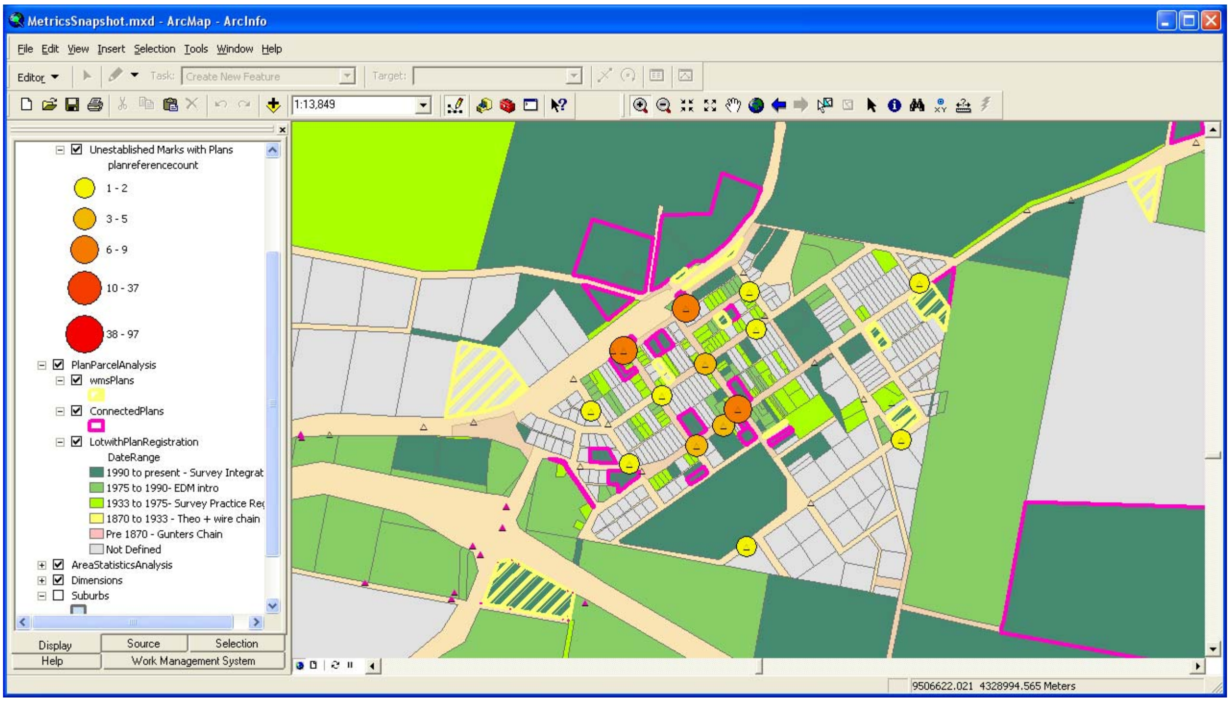


Figure 9 Gunning a small rural town North of Canberra

6. CONCLUSIONS

The Metrics Manager's introduction enables LPI to be pro-active in its upgrade efforts and to provide a focussed program of works as well as providing greater transparency amongst stakeholders. It helps to identify those factors that will limit the accuracy achieveable with upgrade in an area prior to work commencing.

Both the DCDB and associated Survey databases provide invaluable data that feed the Metrics Manager. The capture of most metrics is automated within the Cadastral Maintenance System. The success of the Metrics Manager is directly attributable to the vision shown in designing the re-engineered Cadastral Maintenance System to be "upgradeable". Without this vision the Metrics Manager would be considerably less useful and more expensive to maintain.

Whilst the Metrics Manager is developed specifically for NSW, the concepts may have application for other Australian and International Cadastral Authorities. The potential efficiencies it provides for planning and monitoring a systematic upgrade regime would be particularly beneficial for organisations with similarly large and diverse jurisdictions.

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BIOGRAPHICAL NOTES

Les Gardner attained a Bachelor of Surveying from Newcastle University in 1983 and became a Registered Land Surveyor in 1985. A Bachelor of Science (Earth Sciences) added to Les’s Surveying knowledge in 1993. Les has worked in private practice, Department of Public Works and the Department of Lands as a registered surveyor. Les has implemented many of the reforms to surveying practice and standards for the coordination of cadastral surveys since 1992.

Marc Strong began his professional career as a Registered Surveyor before developing a keen interest in GIS. He holds a Bachelor Degree in Surveying and a Masters degree in GIS from the University of NSW. Marc has 20 years experience managing GIS projects in the public and commercial sectors. Previously he managed Professional Services within ESRI Australia’s Sydney Office. Marc has had extensive involvement with the redevelopment of LPI’s Cadastral Maintenance System and has been responsible for the development of a suite of applications to support the systematic upgrade of the NSW DCDB.

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