Realigning the Christchurch Digital Cadastre after the Canterbury Earthquake Sequence

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Key words: Cadastre, Canterbury Earthquake, Christchurch

SUMMARY

The Digital Cadastre Parcel Dataset is produced and maintained by Land Information New Zealand (LINZ), the New Zealand Government agency that has responsibility for the cadastre and land title systems. This dataset is a fundamental base layer used extensively by surveyors and the wider geospatial community through both Landonline and the LINZ Data Service (LDS), which provides free online access to LINZ's digital land and seabed data. This data is now made more readily available and users such as landowners and other spatial professionals expect the digital cadastre to accurately reflect the legal location of their boundaries.

As part of the maintenance of the digital cadastre, LINZ periodically carries out Wide Area Cadastral Adjustments (WACAs) to realign data covering large geographical areas. The standard WACA process is used where new or improved geodetic control or a large amount of new cadastral data has been added to an area which can be used to generate a more consistent set of coordinates.

The 2010-2016 Canterbury Earthquake Sequence (five earthquakes including the 14 February 2016 earthquake) had a significant impact on the digital cadastre and meant LINZ could not use the standard WACA process to realign the cadastre in areas affected by shallow land movement. As a result of the earthquakes, pre and post-earthquake data does not fit very well together in these areas of shallow ground movement.

To realign the digital cadastre in Christchurch, LINZ developed an alternative WACA process with the aim of ensuring that the digital cadastre is as consistent as practicable with post-earthquake boundary locations.

This paper provides an overview of the problem and the process used to realign the digital cadastre and presents findings from a series of pilot adjustments that LINZ carried out.

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1. INTRODUCTION

From 2010 through to 2016 the Canterbury region of New Zealand experienced an earthquake sequence that caused significant damage to buildings and properties as well as infrastructure.

A large part of the Canterbury rebuild programme has involved trying to understand where property boundaries are currently located on the ground, as well as updating the spatial representation of New Zealand's digital cadastre to reflect the post-earthquake situation. This work is led by Land Information New Zealand (LINZ), the New Zealand Government agency responsible for the cadastre and land titling systems.

Landonline is New Zealand's digital Survey and Titles system. It holds the spatial representation of the digital cadastre, which is propagated into the geospatial community through the LDS, which provides free online access to LINZ's digital land and seabed data. It is frequently combined with other datasets, such as aerial imagery, made available to the general public.

While the digital cadastre has no legal status it is used by surveyors to plan and execute cadastral surveys and pre-validate their datasets. For example, coordinates of survey marks in the vicinity may be loaded into Global Navigation Satellite System (GNSS) equipment to help find marks. Pre-validation is the process where Landonline runs several business rule tests to check that the Cadastral Survey Dataset (CSD) is compliant with the Surveyor General's (SG's) Rules concerning survey accuracy before the surveyor submits the CSD.

It is also used by LINZ during the validation process, where comparisons are made between survey-accurate data in Landonline and data submitted through the surveyor's CSD. If the underlying data in Landonline is not in the correct location there is an increased chance of false failures being identified by Landonline validation rules, as well as for surveyors at pre-validation. It is also more time consuming for LINZ staff to integrate new surveys into the existing digital cadastre if it is not accurate.

In December 2013 LINZ updated the coordinates in Landonline to account for deep-seated movement, using a deformation model. However, the update to the coordinates did not reflect any shallow ground movement due to the earthquakes as there was not sufficient information to do so and the random nature of the movement made it difficult to model; hence the need to update the coordinates in Landonline to ensure they reflect the deep-seated earthquake movement. The LINZ process will need to account for the total earthquake movement, i.e. both deep-seated and shallow movement.

This paper provides an overview of the process LINZ developed for re-aligning the digital cadastre in areas of Christchurch affected by shallow ground movements due to the 2010-2016 earthquakes and presents findings from a series of pilot adjustments that LINZ undertook.

2. THE STANDARD WIDE AREA CADASTRAL ADJUSTMENT PROCESS

LINZ has a standard process for realigning the cadastre, known as the Wide Area Cadastral Adjustment (WACA) process. The standard WACA process is used where new or improved geodetic control or a large amount of new cadastral data has been added to an area which can be used to generate a more consistent set of coordinates. This involves grouping cadastral data into geographical areas known as "parcel blocks".

Figure 1 shows a typical parcel block and the parcel boundaries (properties and roads) within it.

Figure 1: The blue color represents the extent of the parcel block. All cadastral data within and going down the roads that bound the parcel block are bought into the adjustment.

Each parcel block consists of about 800-1300 marks, covering 1-3 city blocks. Both boundary and non-boundary marks and observations are included, as well as connections to geodetic control. A least squares estimation is carried out using cadastral observations to calculate coordinates for all the marks in the parcel block, with the geodetic control providing the source of the coordinates. In some cases (rare in urban areas) there is no cadastral data for a boundary point so "pseudo" observations derived from digitised coordinates can be used to provide connections.

2.1 Accuracy of the digital cadastre

The least squares process also produces an estimate of uncertainty associated with each set of coordinates, which is used to assign coordinate orders and Survey-Accurate Digital Cadastre (SDC) status to these coordinates.

For example, a boundary coordinate which is accurately positioned (derived from survey accurate data which is connected directly or indirectly to high order geodetic control of Order 0 to 6)[1] would be assigned an Order of 7. A boundary coordinate with a less accurate position (for example, because there is no reliable cadastral data) might be assigned Order 8.

Table 1 provides an indication of the expected boundary point accuracy in a survey-accurate area.

Accuracy Status	Land Use	95% Accuracy[1]	Landonline Accuracy Order[2]
Survey Accurate (bearing and distance from Survey Plans)	Urban	0.20	7

Table 1: This table shows the expected boundary point accuracy with regards to the order of the mark and the area they are in.

[1] 95% of boundary marks are more accurate than this value.
[2] A number between 7 (most accurate) and 12 (least accurate) indicates the accuracy of boundary
coordinates in Landonline.

2.2 Overview of the standard WACA process

The purpose of conducting a WACA is to maintain the alignment of the geodetic and cadastral nodes in Landonline where the overall aim is to generate Order 7 boundary nodes and Order 6 non-boundary nodes which provide the origin of coordinates for CSDs.

These adjustments differ from the usual cadastral adjustments carried out, because they incorporate all cadastral data within a geographic area, rather than just data pertaining to a particular survey dataset.

[1] **For more information on coordinate orders see http://www.linz.govt.nz/data/geodetic-system/datums-projections-and-heights/coordinate-and-height-accuracy/coordinate-orders**

Figure 2 shows a high-level diagram that outlines the stages of the standard WACA process.

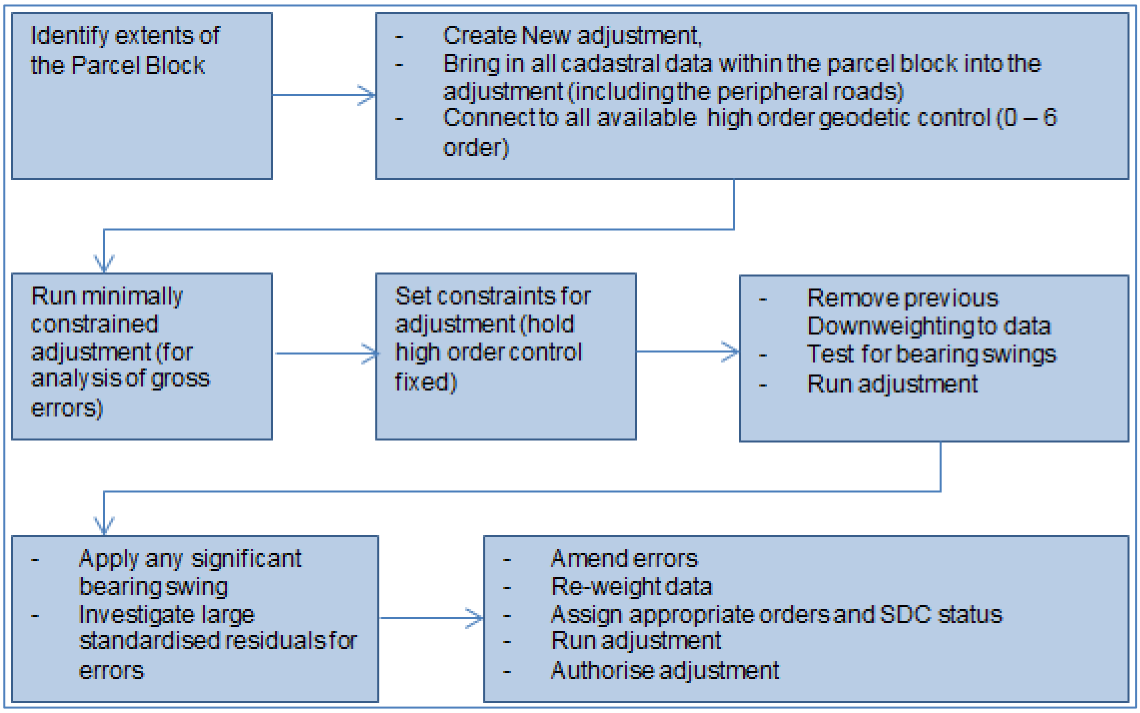


Figure 2: This chart shows a high level overview of the WACA process that is currently used to realign the digital cadastre.

2.3 Regulatory requirements to realign the digital cadastre

The regulatory requirement to realign the cadastre after an earthquake is covered by section 6.1(b)(ii) of LINZ10003 – Standard for integration and provision of cadastral survey data dated 15 September 2009 which states (additional explanation/interpretation in square brackets):

Where practicable, the requirements in section 6 of this standard [which include requirements for accurate coordinates] must be met before a user relies on the data for cadastral purposes after any subsequent event [such as an earthquake] causes the data to become obsolete or incorrect.

Section 6.2 of the same standard identifies regulatory requirements for WACAs, which includes section 6.2.1 (d):

Orders…must be the best that can be practically achieved, compatible with:

(i) *The related observation data,*
(ii) *The accuracy of the existing nodes, and*
(iii) *The ability of the mark to maintain the coordinate accuracy*

3. THE 2013 LANDONLINE COORDINATE UPDATE

The deformation caused by the 2010-2016 CES had degraded the relative accuracy of the NZGD2000 coordinates. As described in Grant et al (2015), this was addressed in 2013 when LINZ updated the coordinates in Landonline using a new version of the deformation model. This update included patches for four of the CES earthquakes, as well as four other significant earthquakes in southwest New Zealand since 2000 (Crook et al, in press).

The local shallow ground movement caused by the earthquakes could not be reliably modelled by the patches meant that the geodetic and cadastral coordinates (Order 0 to 6) were no longer accurate, so their orders were downgraded. For example, some Order 7 boundary marks got downgraded to Order 8 or 9 and some Order 5 coordinates downgraded to Order 6 to reflect uncertainties in the deformation model. Most of these downgrades occurred in areas that had been impacted by liquefaction and other localised land damage (Geotechnical information on horizontal land movement due to the CES) or areas close to the earthquake faults.

Immediately after the deformation model was applied the coordinates of marks which had been accurately surveyed using GNSS since the earthquakes were updated to provide a reference framework of higher order marks (Order 6 or better).

Once the overall update was completed the high order control fell into two categories; surveyed coordinates (updated using post-earthquake GNSS data) and modelled coordinates (updated by using the deformation model).

However, the modelled update to the coordinates accounted only for the deep-seated movement caused by the earthquakes and not for the shallow ground movement, so modelled coordinates were not used for higher order control in areas of known land damage.

4. REALIGNING THE DIGITAL CADASTRE IN AREAS NOT IMPACTED BY SHALLOW LAND MOVEMENT

In 2014 LINZ carried out work that selected high priority areas, which were not impacted by shallow ground movement, for realignment using the standard WACA process. The high priority areas selected for the pilot included Amberley, Kaiapoi, Lyttelton, Mount Pleasant, New Brighton, Oxford, Rangiora, Rolleston, Sumner and Woodland and consisted of 140 parcel blocks.

Figure 3 shows the high priority areas (yellow) that were selected for realignment and shows that, not many areas (other than some in New Brighton) were selected in the city of Christchurch because much of the city was affected by shallow ground movement.

Note that Figure 3 also shows areas that have been designated ‘Red Zone’ areas. A Red Zone area is land that has been identified by the New Zealand Government as not being suitable for continued residential occupation for a prolonged period of time. These areas have significant and extensive area-wide land damage (CERA 2016).

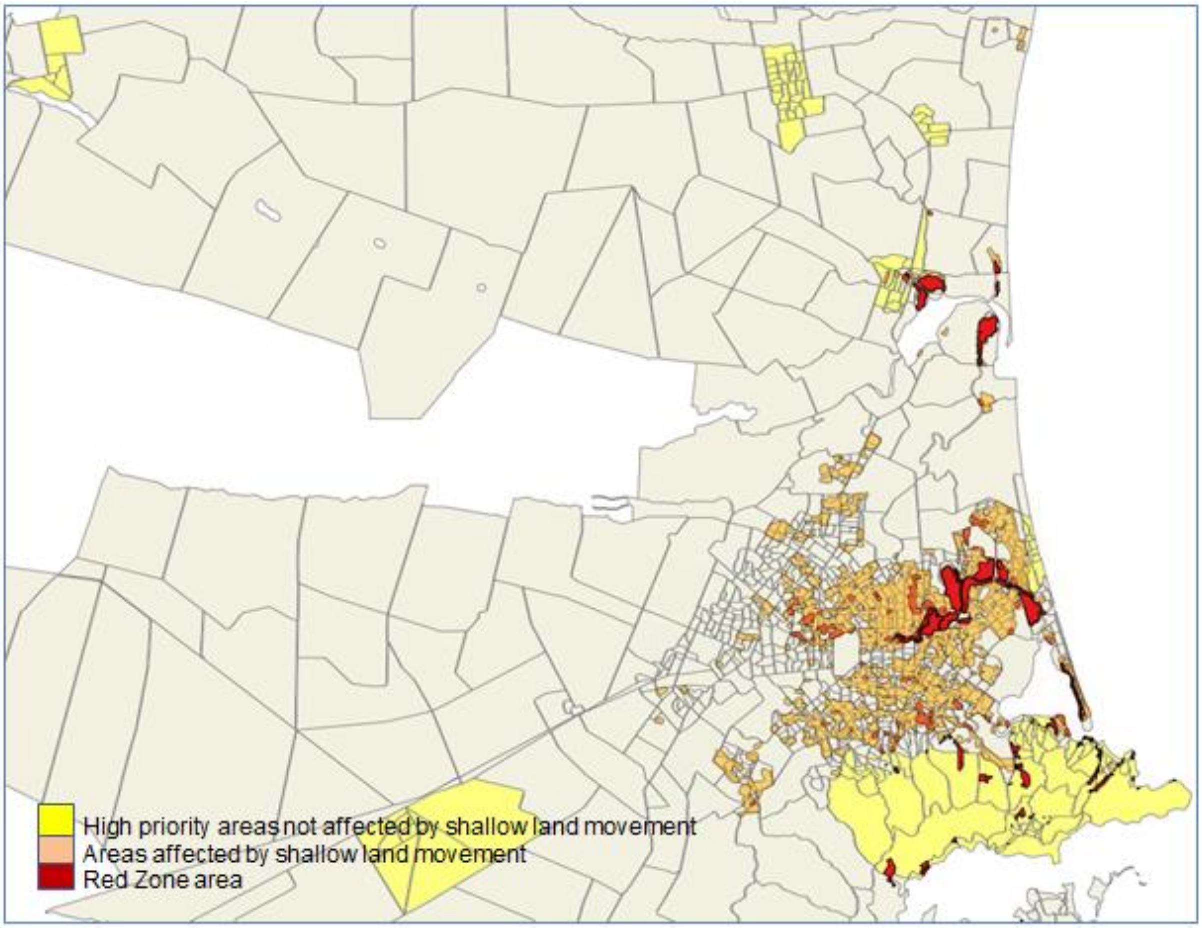


Figure 3: This image shows the high priority areas, in yellow, that were realigned in the 2014 work carried out by LINZ.

The result of the 2014 realignment work showed that the standard WACA process worked very well for areas that were not affected by shallow ground movement and that the coordinates generated from the least squares estimate adjustments met the required accuracy standard.

However, it was found that the process did not work well where parcel blocks abutted or contained areas of shallow ground movement or fell in 'Red Zone' areas due to a lack of post-earthquake data, and in some cases the parcel block could not be adjusted because the process did not deal effectively with the pre and post-earthquake data conflicts.

For example, applying bearing swings[2] and re-weighting of the data in an appropriate way was very difficult to achieve, hence the need to develop a new process which updates the coordinates in

[2] **A bearing swing is a value that is added or subtracted from a bearing in one coordinate system, to bring it into terms with another coordinate system.**

Landonline that best reflects the total earthquake movement (deep-seated and shallow ground movement) in a more efficient way.

5. HE PURPOSE OF REALIGNING THE DIGITAL CADASTRE IN CHRISTCHURCH

The overall purpose of realigning the cadastre in Christchurch is to ensure that the digital cadastre is as consistent as practicable with the post-earthquake location of property boundaries.

More specifically, the aims of realignment in Christchurch are:

1) Calculate coordinates that best reflect where survey marks and boundary positions are located after the earthquakes, therefore any distortions currently in the digital cadastre will be corrected.
2) Ensure that the coordinate order is reliable for each mark and reflects the actual uncertainty in position.
3) Enable post-earthquake data conflicts to be identified (which may relate to disturbed or unproven marks; this is not discussed in this paper as this is a separate piece of work that will be done after the realignment of Christchurch City).

6. THE CHRISTCHUCRH WIDE AREA CADASTRAL ADUSTMENT PILOT

This standard WACA process was refined to realign the digital cadastre in Christchurch. Post-earthquake geodetic control and post-earthquake cadastral observations provided the basis for realigning the digital cadastre.

Even where property boundaries have not been resurveyed since the earthquakes, the nature of the WACA process for Christchurch means that these boundaries will be pulled into approximately their correct position. This is because the pre and post-earthquake observations are connected through sharing common marks.

6.1 Developing the Christchurch WACA process– Refining the standard process

As previously stated the standard WACA process did not work well in areas that were affected by shallow ground movement (e.g. lateral spreading due to liquefaction).

There are a number of issues that relate specifically to wide area adjustments in parts of Christchurch affected by shallow ground movement. In particular, pre and post earthquake data does not fit very well together. Most nodes do not have post-earthquake data, in which case it is not possible to generate coordinates with the usual degree of accuracy or reliability. One of the key aims of the Christchurch WACA process is to ensure that node orders are appropriate given the nature of the data that is available.

The two main areas of the standard process that required refining were around the application of bearing swings and the re-weighting of the data. The error analysis part of the process (described as 'Investigate large standardised residuals for errors' as shown in Figure 3) was removed from the refined process. This is because any gross errors should have been identified and corrected as part of the validation process for the CSD that captured the observations or nodes. Validation is the process where Landonline runs several business rule tests to check that the CSD is compliant with the SG's Rules concerning survey accuracy.

6.1.1 Bearing Swings – the Standard WACA process

In some cases bearing swings would be applied in a wide area adjustment, if they proved to be significant, to bring different coordinate systems in terms of the coordinate system that the adjustment is in terms of (e.g. Old Cadastral Datum data (OCD)[3] to be in terms of the official datum, New Zealand Geodetic Datum 2000 (NZGD2000)). There are also likely bearing swings between pre and post-earthquake data but it was not practical to deal with these by calculating and applying these bearing swings. These are dealt with by re-weighting the data.

Analysis of Landonline data was carried out to determine whether bearing swings between datums were significant in the Canterbury region. The results of the analysis confirmed that non-zero bearing swings for OCD data are rare and therefore may not be genuine bearing swings (they may be related to errors in old data). So, for WACAs in Christchurch no bearing swing is applied to OCD data.

6.1.2 Re-weighting data – the standard WACA process

Re-weighting the data in the standard WACA process occurs after all gross errors are corrected. The parcel block adjustment is then run through a program called Survey Network Adjustment Package (SNAP) and is used to calculate the Root Mean Squares (RMS) value for all CSD's in the adjustment. The RMS, similar to the Standard Error of Unit Weight (SEUW), provides an indication of the overall accuracy of the observations on a given CSD. On average the standardised residuals are expected to be equal to 1, if the observations are weighted correctly in the absence of gross and systematic errors.

If the RMS is significantly greater than 1, assuming all gross errors have been removed, then it is most likely that the observation weightings are incorrect. When the data is re-weighted using the RMS value it is assumed that the observation weightings are incorrect, by the amount indicated by the RMS.

There are two approaches for re-weighting the data:
Approach one – Re-weighting by Survey Plan: This approach is used where the number of observations flagged as an outlier (observations with standardised residuals greater than 5.0) exceeds 10. The RMS value, calculated by SNAP, is used as the error multiplier that is applied to each observation for that CSD.

[3] **Old Cadastral data is an earlier Datum used in New Zealand for cadastral surveys.**

Approach two – Re-weighting individual observations: This approach is used when the number of observations in the adjustment flagged as an 'outlier' is five or less. These observations are downweighted individually by using the smallest error multiplier such that they no longer flag as an 'outlier'. The RMS value calculated from SNAP is not used in this approach.

The results of the work outlined in section 4 of this paper showed that the standard process did not work well in areas where shallow ground movement had occurred. This made it very difficult to re-weight the pre and post-earthquake data using the method and approach outlined above.

6.1.3 Re-weighting data – the Christchurch WACA process

One of the key outcomes of realigning the digital cadastre in Christchurch is to ensure that appropriate orders are assigned to the nodes. Analysis carried out on Landonline data determined that an error multiplier of 125 would be sufficient to ensure boundary nodes that are connected to pre-earthquake data would achieve an accuracy no better than 0.2m (Order 7), which is the accuracy level for reliable cadastral boundary data (pre-earthquake data may not now be reliable).

Once the pre-earthquake data has been downweighted then in theory there should not be any remaining observations flagged as outliers as the only observations not downweighted that remain are post-earthquake measured observations. These observations should be of high quality as they have already been checked and corrected at the validation and Cadastral Maintain Network (CMN) stage. The CMN stage is the process that integrates the CSD data into the existing digital cadastre via the least squares estimate method. Therefore, any large standardised residuals in post-earthquake data are likely due to factors such as the presence of calculated vectors that are based on pre-earthquake data.

Usually there are fewer than five observations flagged as an 'outlier', therefore in this case the single observation downweighting approach is used to ensure that nodes associated with these observations are not given inappropriately high orders.

6.2 Overview of the Christchurch WACA process.

Figure 4 shows the WACA process that has been developed for realigning the digital cadastre in Christchurch in accordance with the discussion above.

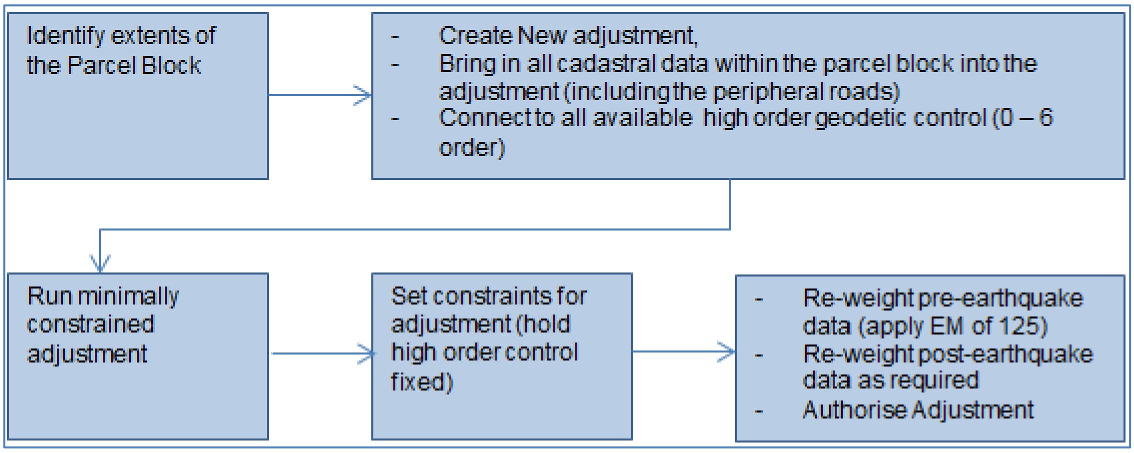
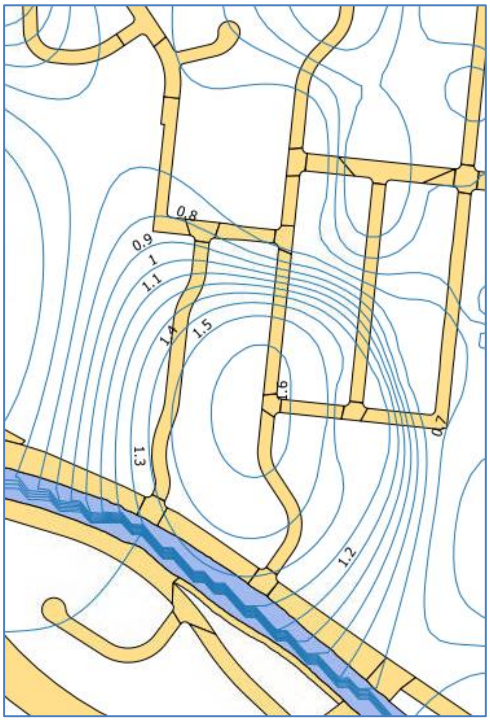


Figure 4: This chart shows a high level overview of the WACA process used to realign the digital cadastre in Christchurch.

6.3 Selecting high priority areas in Christchurch for the realignment pilot

The aim of the pilot was to focus on areas of greatest shallow ground movement, as this is where the existing digital parcel boundaries are least likely to reflect the post-earthquake positions.



To identify the areas of greatest movement, a model of shallow ground movements was calculated using cadastral and geodetic survey data held in Landonline. The model is calculated as the difference between the **total** movement and the **deep-seated** movement due to the earthquakes and is represented as contours as shown in Figure 5.

Figure 5 shows an example of an area of Christchurch where the shallow ground movement (horizontal movement) ranges between 0.70 metres to 1.6 metres.

The model was used to identify areas of shallow movement of greater than 0.20 metres for realignment of the digital cadastre. This threshold of 0.20 metres was chosen as it is also the network accuracy standard (refer Standard for tiers, classes and orders of LINZ data – LINS25006) for boundary marks in urban areas (see Table 1 in Section 2.1 of this paper). Movements less than this are not necessarily significant. All parcel blocks which

Figure 5: Shallow ground movement model represented as contours.

include ground movement greater than 0.20 metres as identified by the shallow ground movement model are shown in Figure 6.

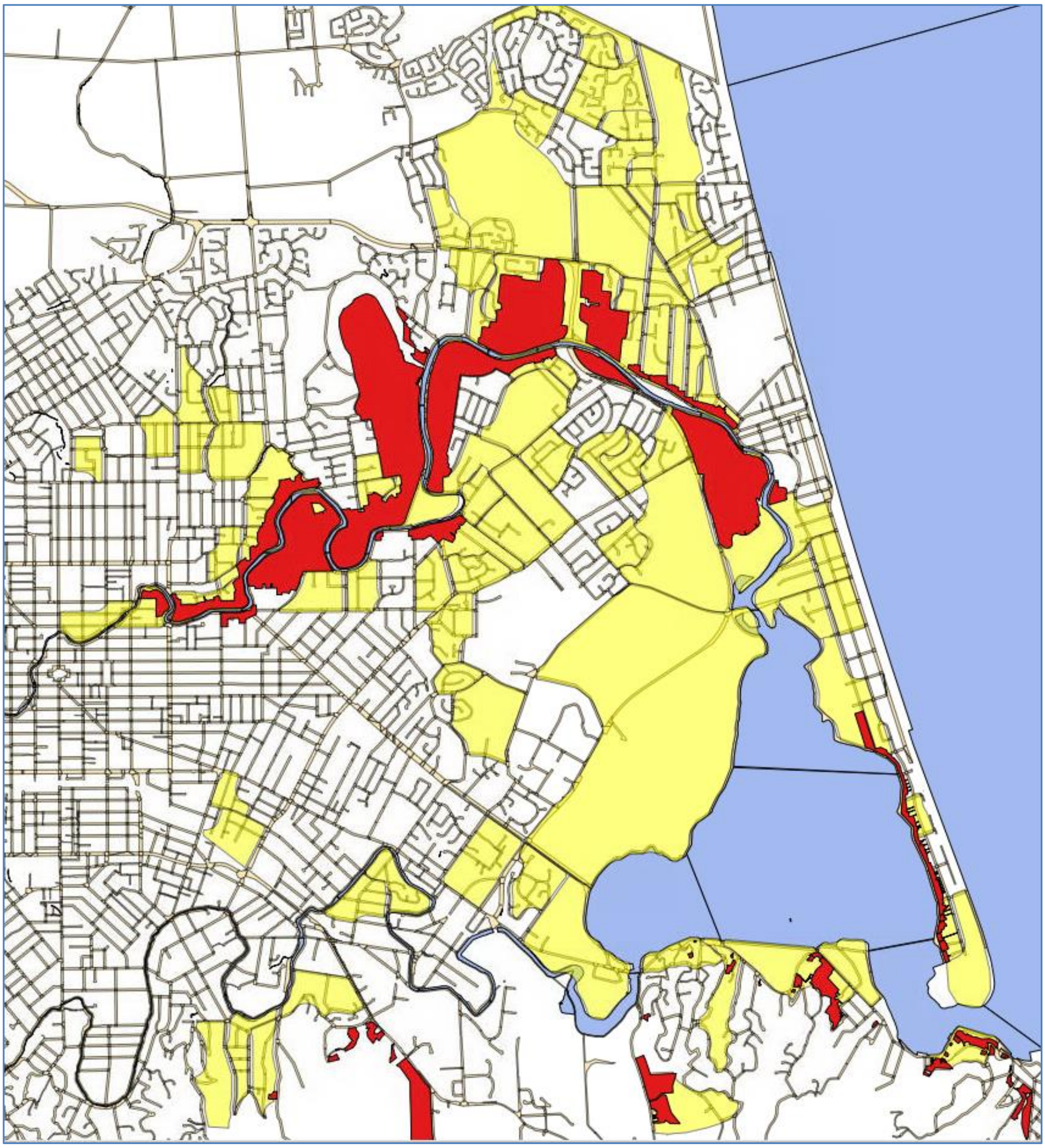


Figure 6: High priority areas (parcel blocks) impacted by shallow ground movement, shown as yellow, selected for the Digital Cadastre Realignment pilot. The 'Red Zone' areas are shown in red.

A total of 105 high priority parcel blocks were identified with the majority of them located on the eastern side of Christchurch where most of the land damage occurred. 24 parcel blocks were selected for the pilot. Using the model parcel blocks were selected based on the percentage of the parcel block that exceeds 0.20 metres of the shallow ground movement model. For example, three groups of eight parcel blocks were selected for which 80-100%, 50-79% and 30-49% of the area had shallow ground movement greater than 0.20 metres.

7. PILOT RESULTS AND DISCUSSION

To determine whether the Christchurch WACA process was effective for a parcel block it is important to be confident that this process was actually improving the position of the parcel boundaries given that most of the data in each of the least squares adjustments was pre-earthquake data.

Direct comparisons using post-earthquake surveys proved to be difficult as it was not certain, without investigation, whether the boundaries were defined as moving with the land or not. Therefore, the coordinates generated in the WACA were compared with those calculated by adding shallow and deep-seated movement to pre-earthquake coordinates.

A 0.30 metre discrepancy was chosen as the threshold[4] with which we based analysis on to determine the effectiveness of the WACA process for a parcel block.
Only marks with 'good' pre-earthquake coordinates had the comparison done and analysis was carried out of the coordinate differences. For example, the median coordinate difference, the 95% confidence interval and the maximum difference.

Table 2 shows three groups, each with eight parcel blocks that fall within the stated percentage of the 0.20 metre contour o the shallow ground movement model.

[4] **The 0.30 metre threshold was chosen because other key datasets, such as aerial imagery, that are used the accuracy is generally good to around 0.30 metres.**

% of PB in 20cm contour - 80-100%	Parcel Blocks							
	1	2	3	4	5	6	7	8
% of Parcel Block in 20cm contour	100	100	100	100	97	94	100	91
Median	0.09	0.18	0.22	0.07	0.45	0.10	0.61	0.13
95% Confidence Interval	0.39	0.54	0.40	0.27	0.99	0.33	1.61	0.50
Maximum	0.98	0.68	0.5	0.44	1.24	0.70	2.02	0.64
% of PB in 20cm contour - 50-79%	Parcel Blocks							
	9	10	11	12	13	14	15	16
% of Parcel Block in 20cm contour	50	51	54	63	63	63	78	69
Median	0.07	0.08	0.00	0.12	0.06	0.14	0.04	0.06
95% Confidence Interval	0.24	0.25	0.25	0.59	0.16	0.56	0.25	0.29
Maximum	0.36	0.41	0.29	0.69	0.21	1.05	1.20	0.53
% of PB in 20cm contour - 30-49%	Parcel Blocks							
	17	18	19	20	21	22	23	24
% of Parcel Block in 20cm contour	34	34	34	33	45	42	39	44
Median	0.05	0.09	0.05	0.05	0.06	0.05	0.11	0.04
95% Confidence Interval	0.19	0.22	0.26	0.15	0.18	0.14	0.53	0.13
Maximum	0.24	0.30	0.52	0.15	0.21	0.33	0.93	0.18

Table 2: This table shows s the results of the parcel blocks selected for the pilot based on the percentage each parcel block is within the 0.20 metre shallow ground movement model (represented as contours as shown in Figure 5). The median, 95% confidence interval and maximum refer to coordinate discrepancies between the shallow ground movement and the WACA coordinates.

The first group looks at parcel blocks where 80-100% of their area is greater than the 0.20 metres of the shallow ground movement model. As can be seen from the table the median coordinate discrepancy is less than the 0.30 metre threshold. However, at the 95% confidence interval, only one of the parcel blocks meets the desired threshold. It is noted that many of these parcels blocks were partially within the residential red zone, where there is a lack of geodetic control and post-earthquake cadastral data.

As the parcel block area percentage that exceeded the 0.20 metres of the shallow ground movement model decreases, the results become more consistent with the shallow ground movement model. Most of the discrepancies were less than 0.30 metres at the 95% confidence interval. Where there were distortions in the digital cadastre, the adjustments did straighten out boundaries that were distorted as a result of the pre and post earthquake data not fitting well together.

Figure 7 shows an example of an adjustment correcting the distortion in a parcel boundary.

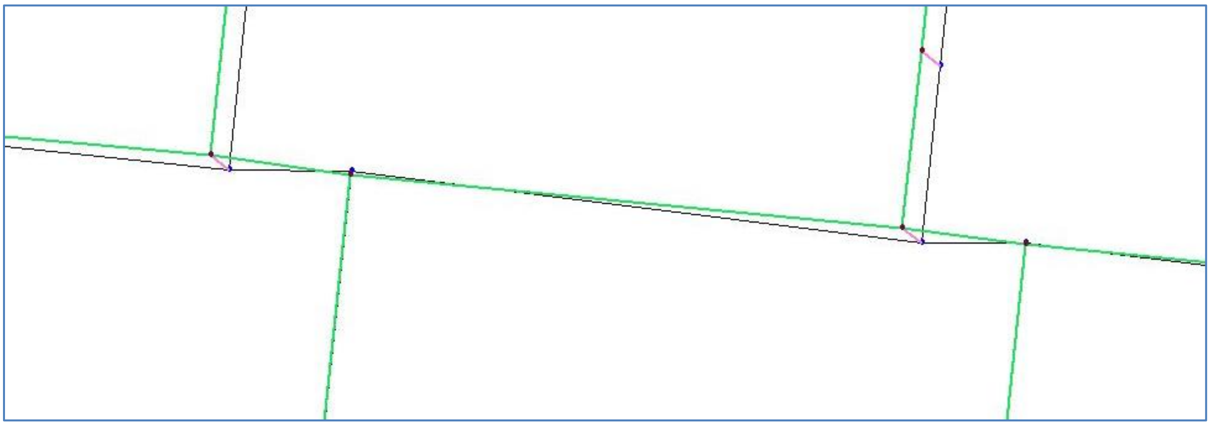


Figure 7: Image showing a distorted parcel boundary (black line) and how the boundary has been corrected by the least squares adjustment (green line).

Overall, we can conclude that the Christchurch WACA process works well through most parts of Christchurch affected by shallow ground movement. Even in areas of significant ground movement, where the red zone classification means there is a lack of new data to support readjustment, there are still significant improvements to be made by carrying out the readjustment process, as indicated by the median discrepancy values.

Legislation is currently before Parliament to clarify the effect the CES has had on property boundaries. If passed in its proposed form, the legislation will state that property boundaries moved with the land during the earthquakes, irrespective of whether the land movement was deep or shallow. There are some exceptions to the proposed registration where the land has lost its integrity (for example, where a retaining wall has collapsed).

Now that the pilot is complete, further work will be undertaken to develop and implement an operational process to undertake these adjustments. This will be subject to the legislation being passed in its proposed form and analysis of the potential impact from the most recent earthquake that occurred on 14 February 2016.

In addition to this there is still value in doing a WACA in those areas where the process did not work so well as the adjustments did correct distortions within the digital cadastre such as the one as shown in Figure 7.

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BIOGRAPHICAL NOTE

Scott King currently works in the National Geodetic Office at LINZ. He has been with the department for 25 years and has had a number of roles through out that time including being a Property Rights analyst in the Wellington Office. He has also been part of projects such as improving the accuracy of the digital cadastre and is now currently involved with a project to Realign the digital cadastre in Christchurch City after the Canterbury Earthquake Sequence as part of the Canterbury rebuild programme. Scott also has a variety of roles within the geodetic team that goes towards improving the Geodetic system.

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