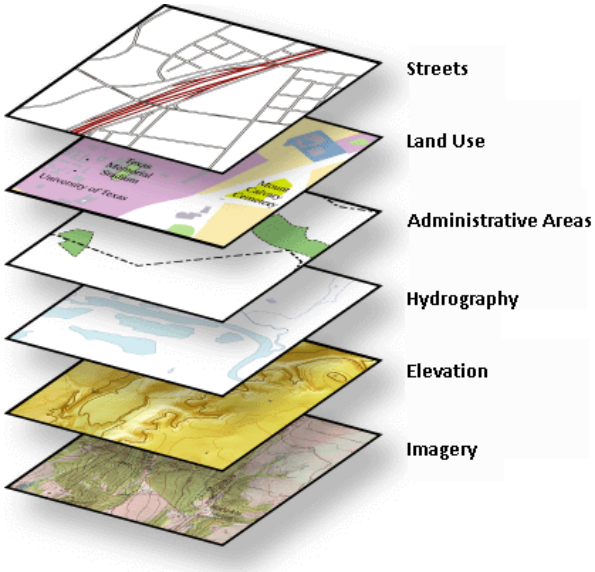


GEOM 20013

The Use of GIS and Spatial Analysis in Legal Proceedings

Dr Gary Hunter
GIS Expert Witness

(E-mail: garyhntr@gmail.com)

About your Presenter

Dr Gary Hunter's professional career began in 1971 at age 17 when he enlisted in the Australian Regular Army for 6 years as a trainee topographic surveyor. For the next 17 years he continued to work directly in the surveying and mapping industry. His experience in that period includes surveying for engineering, topographic mapping and cadastral (land boundary) projects in Australia, Indonesia and Papua New Guinea. During that period he worked for the Royal Australian Survey Corps; the Shire of Lilydale (Victoria); the Victorian Department of Crown Lands & Surveys (Surveyor-General's Office); G.V. Valentine Ltd (a private survey firm in Oakleigh); the Victorian Land Titles Office and the Victorian State Rivers & Water Supply Commission. His Bachelor, Master's and PhD degrees in surveying and GIS are all from the University of Melbourne and he became a licensed land surveyor in Victoria in 1984. He then served for 21 years in the Department of Surveying (later named Geomatics) and was Deputy Head/Acting Head of the Department for 10 years before leaving in 2009 as an Associate Professor and Reader in GIS and Cadastral Studies. He also served for 7 years on the Surveyors Board of Victoria and is an Honorary Fellow of the Surveying & Spatial Sciences Institute (SSSI).

At the university he taught cadastral surveying, land law, land development, residential subdivision design, spatial analysis and introductory and advanced GIS. In 2006 he became the first (and only) Australian to be inducted into the international GIS Hall of Fame (https://www.urisa.org/awards/gary-hunter/). He has worked as a visiting research professor in GIS at universities in USA, the Netherlands and Denmark, served on the editorial boards of the world's top GIS research journals and written more than 170 research papers.

In 2009 he retired from the university and now works as an international technical advisor in the areas of cadastral systems, land administration and GIS. Since 2009 he has worked for the World Bank, Australian AID, USAID, UNDP, UN FAO, UKAID, U.S. State Department and the German Development Agency (GIZ) in Afghanistan (5 projects), Zimbabwe (5 projects), Nigeria (2 projects), Philippines (1 project), Saudi Arabia (1 project), Nepal (1 project), Myanmar (1 project), Vietnam (1 project).

1974, surveying with the Australian Army on mapping operations along the border between Indonesia and Papua New Guinea.

PART 1

Australian Capital Territory (ACT) Supreme Court Case No. 326 of 2007

Farmwide Pty Ltd v Commonwealth of Australia

In 2000, the Federal Government wanted to provide internet facilities to selected rural areas of Australia not being served by the only two internet providers at that time – Telstra and Optus – who served only the major urban population centers.

The government proposed to enter into an agreement with a private company where the government would construct the 81 major Wi-Fi towers and associated IT facilities needed to service the rural population, and in return the private company selected would create a new rural customer base and connect them to the internet.

Tenders were called and a company was chosen, *Farmwide* – part of the National Farmers Federation. It then took about two years to hire new staff, set up new offices and develop business and rollout plans.

Meanwhile, the Federal Government was working to sign contracts with Wi-Fi equipment providers to commence constructing and connecting the 81 towers.

In this way, the government would be able to provide internet to selected rural areas, while *Farmwide* would become a new Internet Service Provider specializing in rural customers – which could be very lucrative – without having to pay for any of the internet infrastructure.

Unfortunately… the Federal Government suddenly decided in 2002 not to proceed with the rural internet project and immediately froze all funding for it. No internet towers were ever built and *Farmwide's* business plans and organizational structure that had been created had to be shut down.

No reasons were ever given by the Government for cancelling the project.

Compensation claims by *Farmwide* against the Government were then made and negotiated for 5 years, without ever reaching agreement. So *Farmwide* commenced legal action in 2007 against the Commonwealth of Australia in the ACT Supreme Court.

My Role in the Legal Proceedings

- I was approached in 2014 by Minter Ellison Lawyers to act as a GIS Expert Witness for the Commonwealth.
- In its claim against the Commonwealth, *Farmwide* had engaged a GIS Expert Witness (an unknown research fellow from ANU) to use GIS and spatial analysis to estimate the number of potential rural internet customers who would have been served by the 81 Wi-Fi towers that were to be installed. These customer numbers formed the compensation claim.
- My task was to act as the opposing GIS expert witness, and either confirm or disprove the customer numbers that had been estimated by the other consultant.

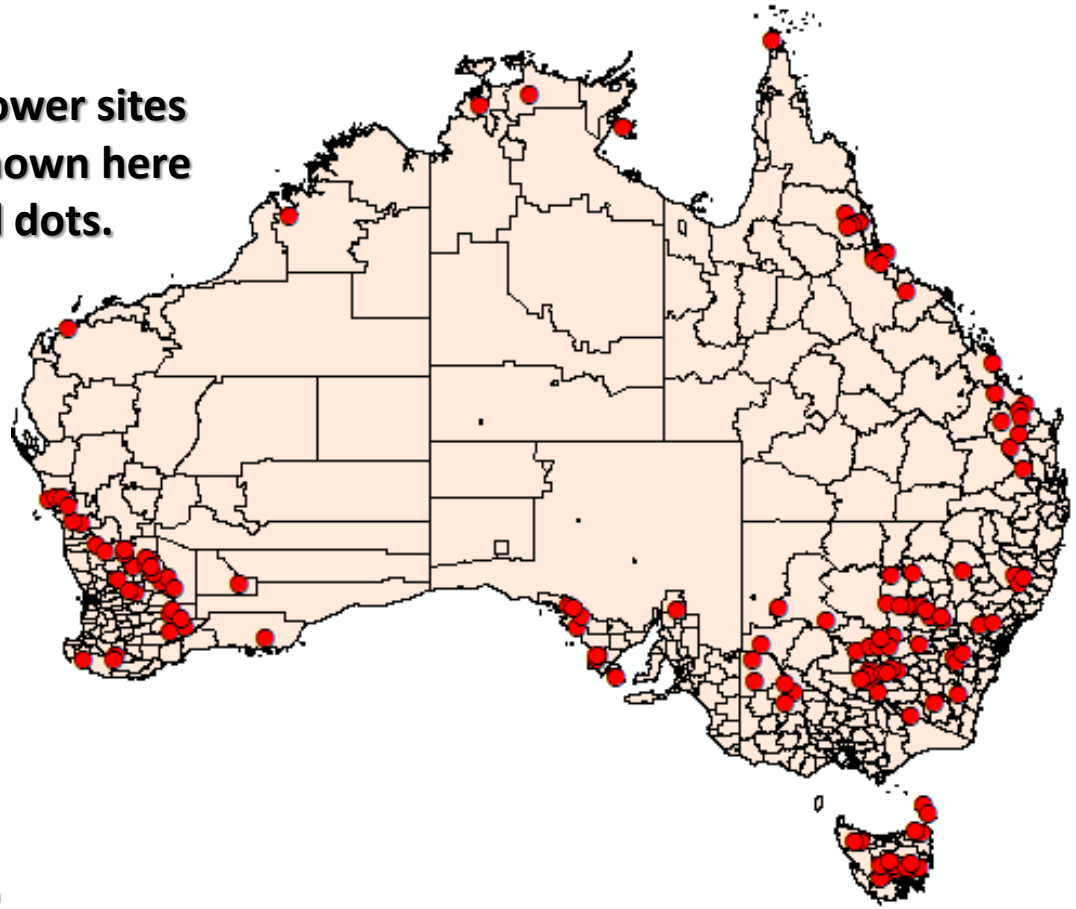
My Specific Tasks were to Answer the Following Questions

- Are the geospatial analytical techniques used (by the other expert witness) appropriate?
- Are there any opinions or conclusions expressed (by the other expert witness) which you consider to lie outside of geospatial expertise?
- Provide an estimate, applying geospatial analysis techniques, of the number of: residential dwellings and total population within a 15 km, 45 km and 50 km radius of the 81 originally intended Wi-Fi tower locations.
- Provide your estimates having regard to: data from the Australian Bureau of Statistics (ABS) 2006 national household census and also the 2011 national household census.
- What is the size of each of the 81 (alternative) WiMAX coverage areas identified in the mapping files in square kilometres? ? (More about WiMAX in Part 2)
- Provide an estimate, applying geospatial analysis techniques, of the number of: residential dwellings and total population within the total of the 81 WiMAX coverage areas.

Data Used: Positions of the 81 Wi-Fi Towers

- These were contained in a simple Excel spreadsheet of latitude and longitude values (with the tower names) that were then imported into ArcGIS. In addition, 52 additional tower sites were added to the analysis, making a total of 133.

The tower sites are shown here as red dots.



- **Next, simple circular 15 km, 45 km and 50 km buffers were created and merged around each tower**

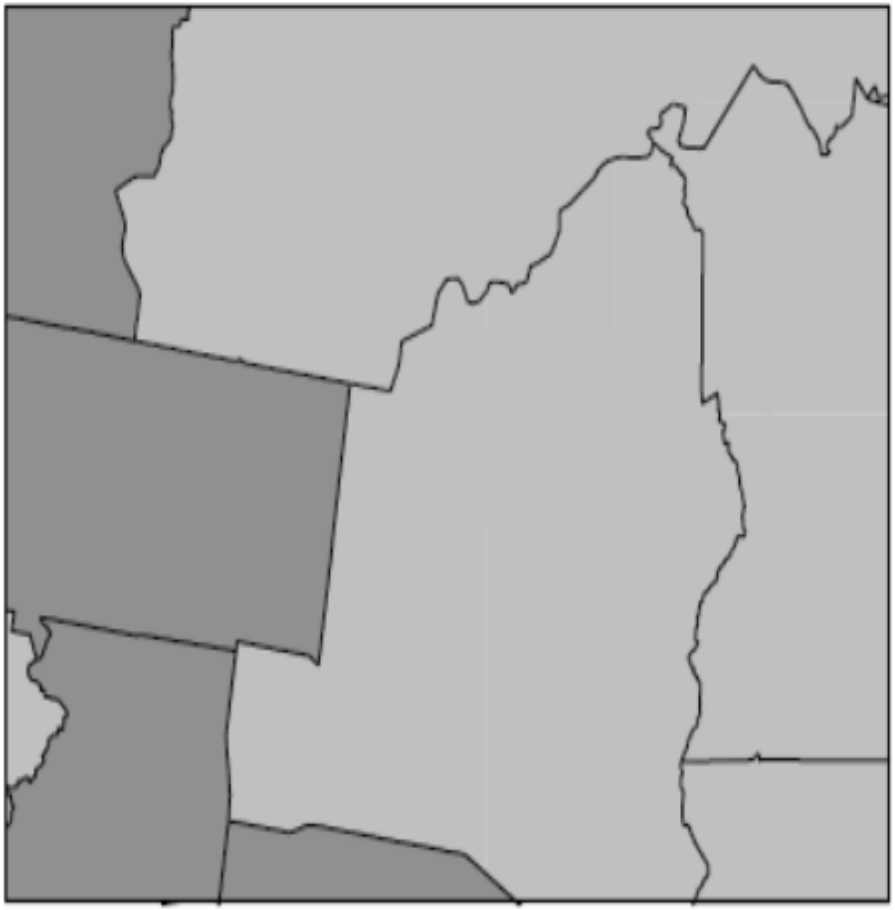
(Note: The reason they appear to be elliptical and not circular, is <u>not</u> because I have stretched the image. It is because I am working with latitude and longitude coordinates on a global curved projection that covers all of Australia, not a flat map projection, and this causes the elliptical shape).

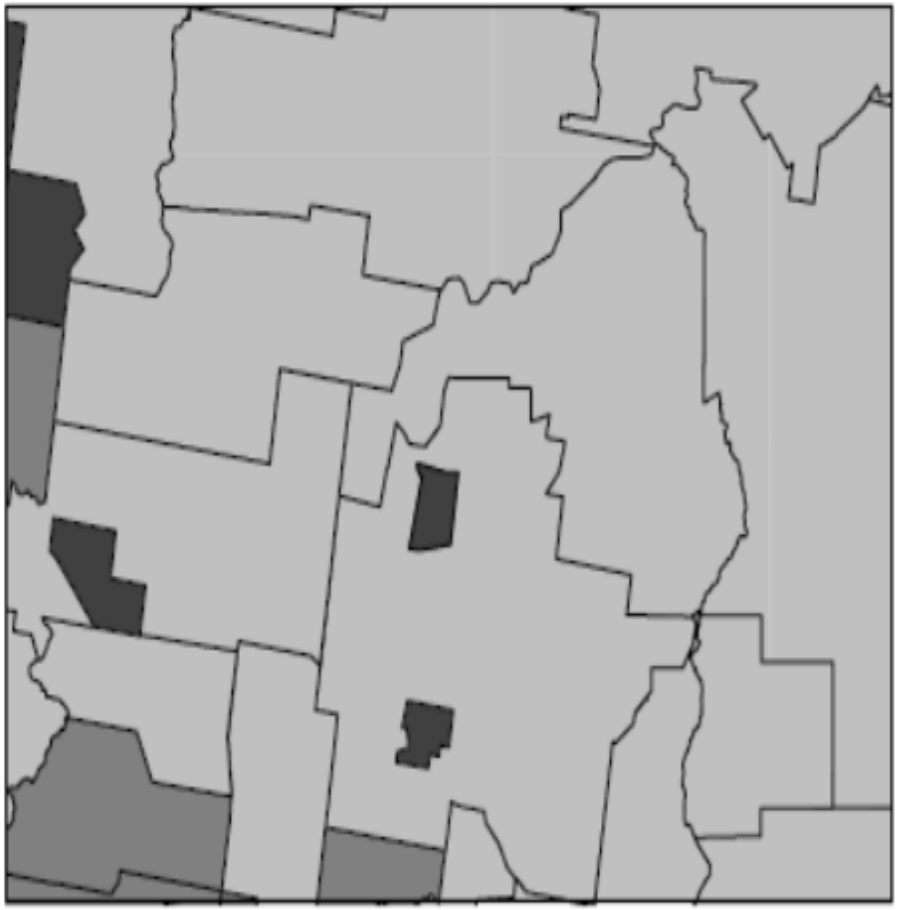
Data Used: Census Collection Polygons

- Collection Districts (CDs) were historically the smallest statistical area for which census data would be collected. They contained on average 225 dwellings, but this number was smaller in rural areas. However, they were designed for data collection management purposes (the expected workload of one census collector), and not for spatial analysis. They were not compatible with other administrative boundaries such as electoral and postcode boundaries. Plus they would contain a wide mixture of land use types – such as residential, agriculture, industrial, schools, parklands, water bodies etc. CDs were not used after the 2001 census.

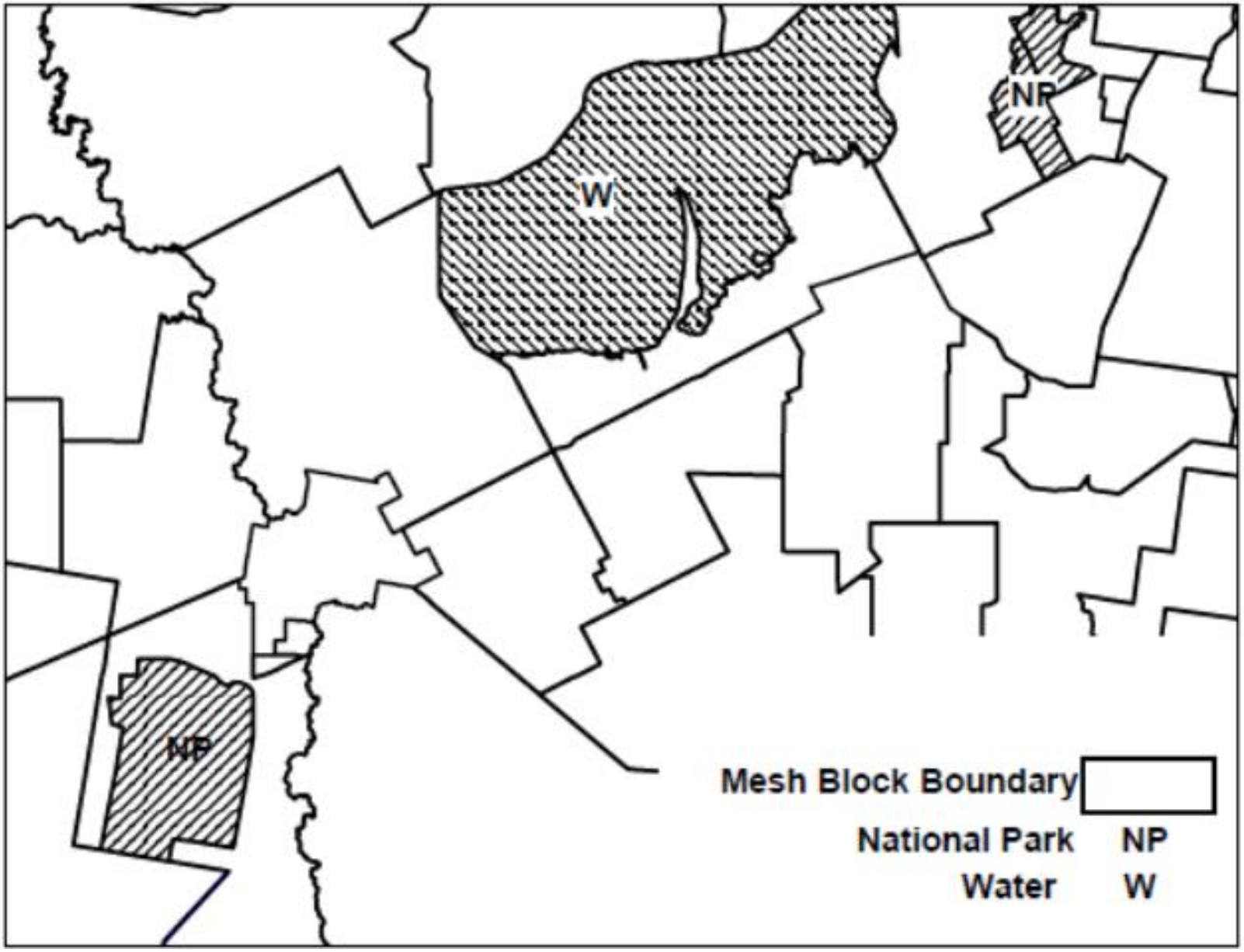
- Mesh Blocks were a new concept used in each census from 2006 onwards and were designed by Dr Serryn Eagleson, of Geomatics at this university in the early 2000s. They are much smaller than CDs and contain 30-60 dwellings in residential areas. Importantly, each different land use is allocated its own pre-dominant mesh block. That is, agricultural, commercial, education, hospital/medical, industrial, other, parkland, residential, transport, water. Mesh blocks are also aligned with other boundaries (election, local government, postal, police, catchments etc.)

Comparison of CDs (left) and Mesh Blocks (right) for the same area.

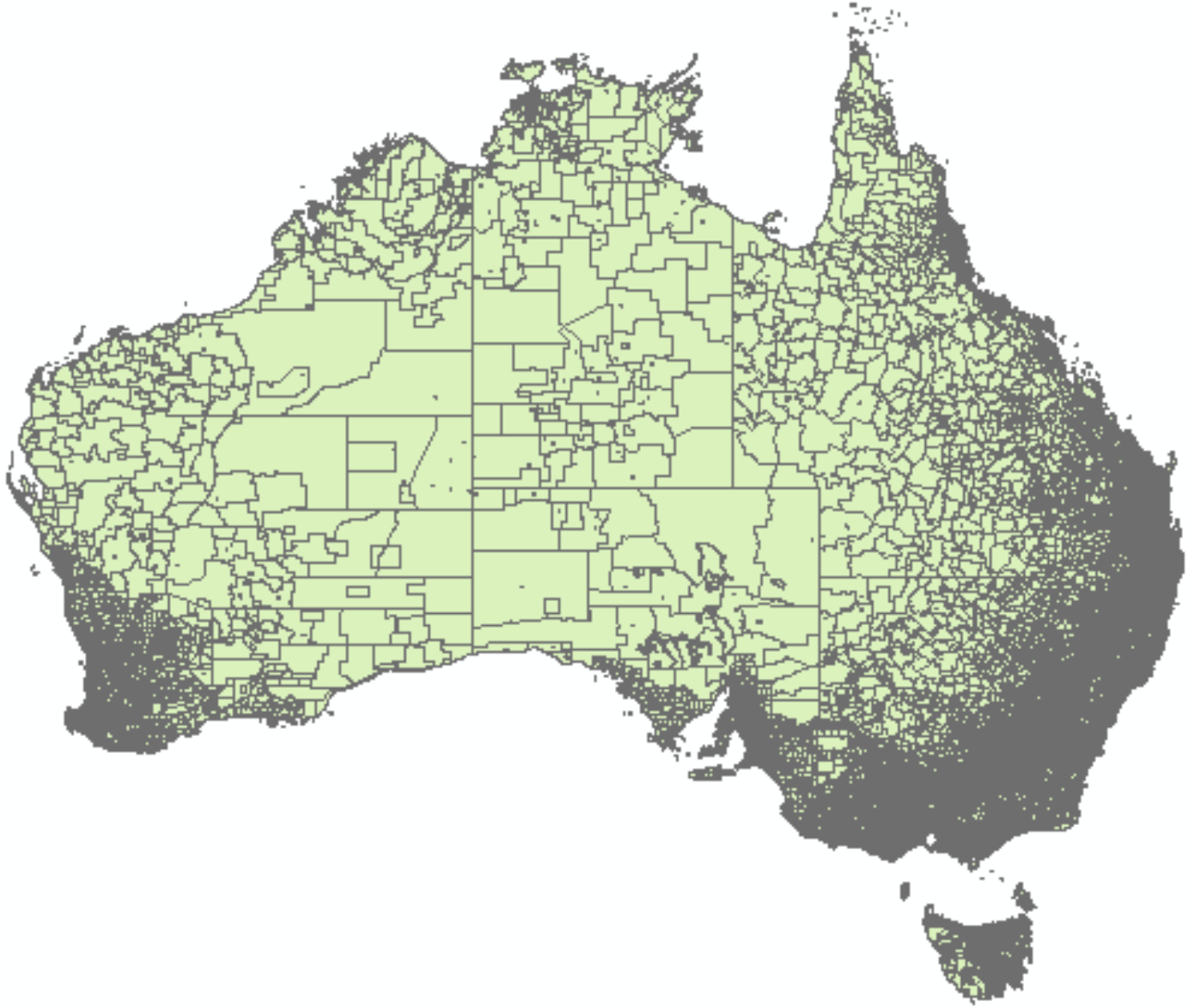




Examples of zero population mesh blocks (Water and National Parks).



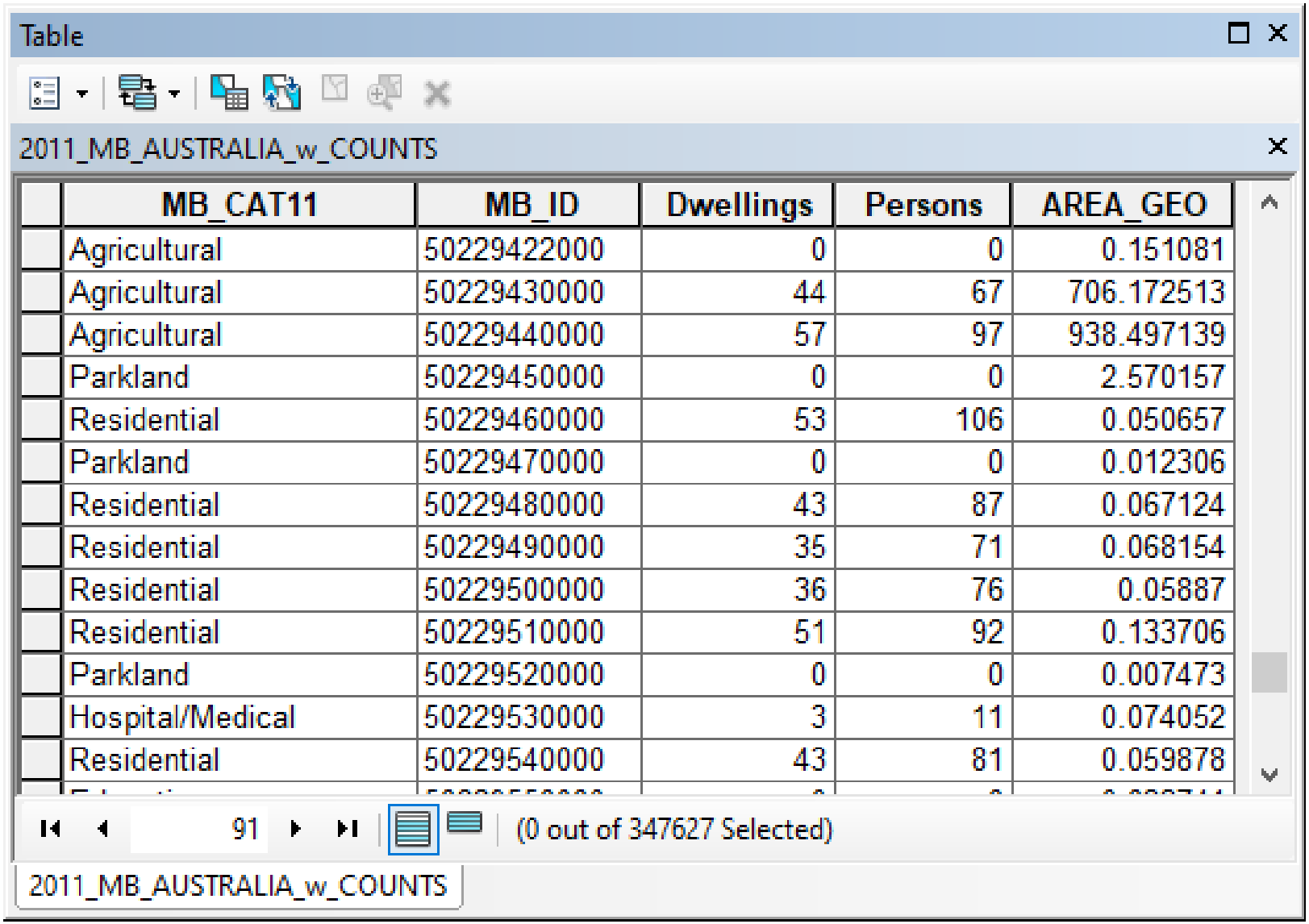
This is what 347,000 mesh block polygons from the 2011 census look like in a GIS (display time 2 = seconds)



Data Used: ABS Census Attributes

- We were required to first apply our analysis to the 2006 ABS National Household Census data, and then repeat the process for the 2011 National Household Census data. This would help determine the potential customer growth over the intervening 5 years.
- For the attribute data in both cases, the census data tables held population and dwelling summary statistics for each census mesh block – so that's great. It comes as an Excel spreadsheet which you simply join in ArcGIS to the shapefile containing the mesh block polygon boundaries.
- The common identifier that allows you to join the spreadsheet data to the polygons is the unique number allocated to each mesh block stored in both datasets.

2011 Mesh Block Attribute Table showing Dwelling & Population



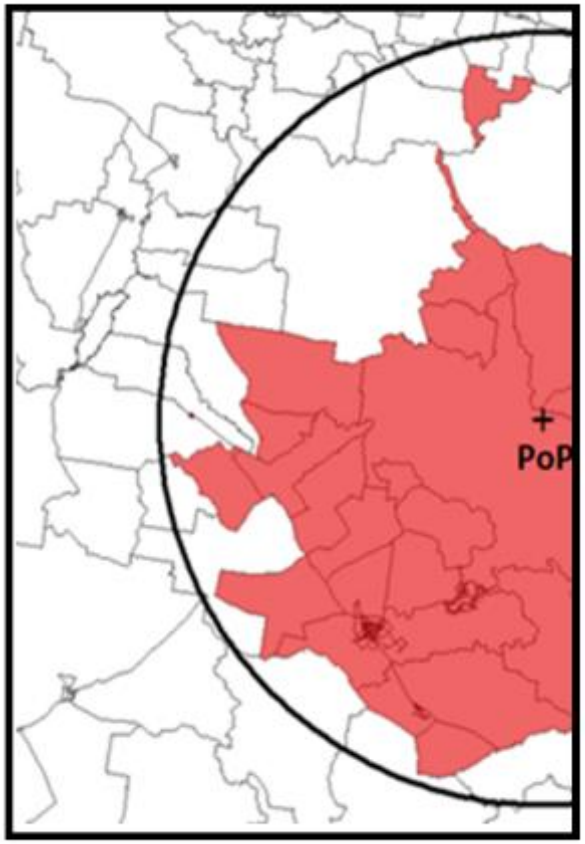
MB_CAT11	MB_ID	Dwellings	Persons	AREA_GEO
Agricultural	50229422000	0	0	0.151081
Agricultural	50229430000	44	67	706.172513
Agricultural	50229440000	57	97	938.497139
Parkland	50229450000	0	0	2.570157
Residential	50229460000	53	106	0.050657
Parkland	50229470000	0	0	0.012306
Residential	50229480000	43	87	0.067124
Residential	50229490000	35	71	0.068154
Residential	50229500000	36	76	0.05887
Residential	50229510000	51	92	0.133706
Parkland	50229520000	0	0	0.007473
Hospital/Medical	50229530000	3	11	0.074052
Residential	50229540000	43	81	0.059878

Data Used: Problem with Dwelling Locations

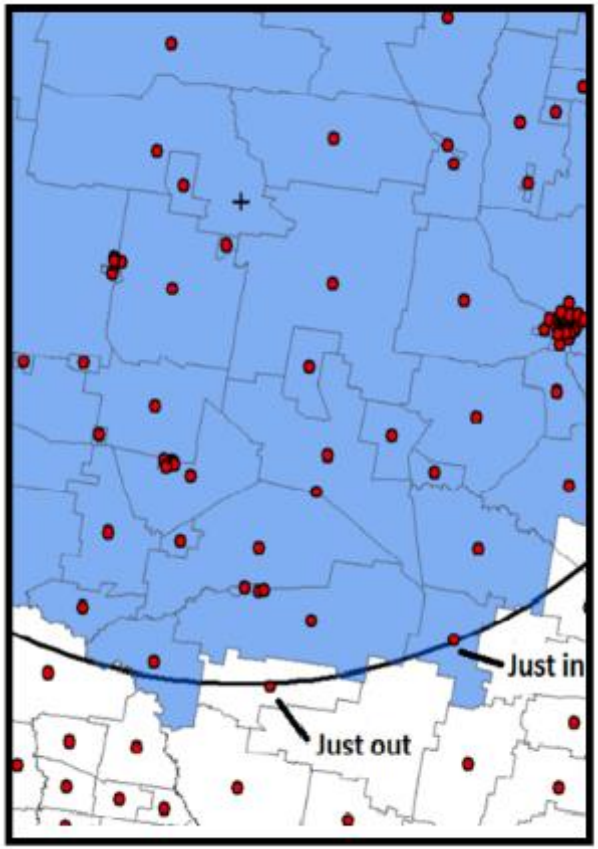
- There is a problem with the positions of the dwellings in the census mesh blocks – we don't know where they are located.
- There is a very good reason for this, as the privacy of census respondents has to be protected at all times and giving away dwelling positions can allow very smart researchers to determine what the census statistics are for each individual dwelling. This is called disaggregation.
- So the only thing we can do is to assume that all dwellings are randomly positioned in the mesh blocks, and not clustered in one location or uniformly spaced throughout the mesh block.
- The importance of this assumption will be shown later.

We have to determine which census mesh blocks fall within each circular tower buffer. We can choose one of the three options below:

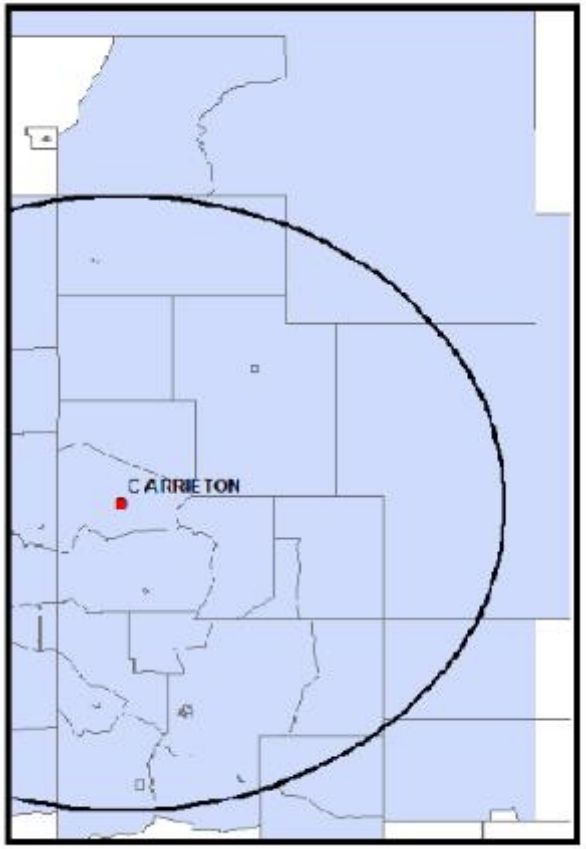
Option #1: Mesh Blocks are to be completely inside the buffer



Option #2: Mesh Block centroids are to be inside the buffer



Option #3: Mesh Blocks are to be partially inside the buffer



Discussion of the Choice of Method on the Previous Slide

- The problem with Option #1 is that if the whole of a mesh block is not inside the buffer, then its dwelling and population counts will not be included. So this option always underestimates the true dwelling a population count for the buffer.

- The problem with Option #3 is that if any part of a mesh block (no matter how small) is inside the buffer, then its full dwelling and population counts will be included. So this option always overestimates the true dwelling and population count for the buffer.

- Finally, Option #2 requires that if the centroid ('central' point) for the mesh block is inside the buffer, then its dwelling and population counts will be included. So some boundary mesh block will be included while others will be excluded. This balance seems to be the most practical of the three options.

Task #1: Check the GIS Analysis of the other Expert Witness

- Use the two different Census dates – 2006 and 2011 – and the counts for the number of residential dwellings and the resident population for every mesh block in Australia.
- Use the two sets of PoP coordinates – the Initial 81 PoPs and the Additional 52 PoPs (for a total of 133 PoPs).
- Note: PoP stands for Point of Presence (that is, a tower)
- Place two different zones around the PoPs – the 45 km and 50 km circular zones (however my lawyers also wanted me to add a 15 km buffer zone to the analysis).
- Conduct three different tests relating to the 15 km, 45 km and 50 km zones.

Steps to Check the other Expert Witness' Analysis

STEP 1: Construct a point map of PoP locations from the revised coordinates and assign a code to them according to whether they are in the Initial 81 PoPs or the Additional 52 PoPs. This results in a single GIS data set for the PoPs from which either the Initial 81 PoPs or the 133 Total PoPs may be selected.

STEP 2: Construct circular zones at distances of 45 km and 50 km around each PoP, ensuring the common boundaries between any overlapping zones are removed to avoid possible double counting of dwellings and populations. This results in the following four GIS data sets:

- a set of 45 km zones for the Initial 81 PoPs;
- a set of 45 km zones for the Total 133 PoPs;
- a set of 50 km zones for the Initial 81 PoPs;
- a set of 50 km zones for the Total 133 PoPs.

STEP 3: Select mesh blocks by location on the basis of the following eight scenarios:

- Using the 2006 census mesh blocks and the Initial 81 PoPs, find all mesh blocks that have their centroids within the 45 km zone;
- Using the 2006 census mesh blocks and the Total 133 PoPs, find all mesh blocks that have their centroids within the 45 km zone;
- Using the 2006 census mesh blocks and the Initial 81 PoPs, find all mesh blocks that are completely within the 50 km zone;
- Using the 2006 census mesh blocks and the Total 133 PoPs, find all mesh blocks that are completely within the 50 km zone;
- Using the 2011 census mesh blocks and the Initial 81 PoPs, find all mesh blocks that have their centroids within the 45 km zone;
- Using the 2011 census mesh blocks and the Total 133 PoPs, find all mesh blocks that have their centroids within the 45 km zone;
- Using the 2011 census mesh blocks and the Initial 81 PoPs, find all mesh blocks that are completely within the 50 km zone;
- Using the 2011 census mesh blocks and the Total 133 PoPs, find all mesh blocks that are completely within the 50 km zone.

STEP 4: For each of the eight scenarios listed in Step 3, calculate the total dwelling count and the total population count for the selected mesh blocks.

STEP 5: For each of the eight scenarios listed in Step 3, calculate the number of mesh blocks with the land use categories of commercial, education, hospital/medical, industrial and other that are likely to contain non-residential subscriber addresses.

Comparing my Results with the Other Expert Witness

Zone Size	Test Applied	2006 Census Dwelling Counts		2011 Census Dwelling Counts	
		Initial 81 PoPs	All 133 PoPs	Initial 81 PoPs	All 133 PoPs
50 km	Mesh block completely within zone	390,296	473,017	416,867	511,391
45 km	Mesh block centroid within zone	260,385	307,782	275,653	331,250
15 km	Mesh block centroid within zone	14,242	24,539	14,996	26,112

Dwelling counts

Notes:

- **There is exact agreement between (the other expert witness) and Hunter for the 45 km and 50 km zone dwelling counts.**

Zone Size	Test Applied	2006 Census Population Counts		2011 Census Population Counts	
		Initial 81 PoPs	All 133 PoPs	Initial 81 PoPs	All 133 PoPs
50 km	Mesh block completely within zone	878,660	1,078,836	913,661	1,135,552
45 km	Mesh block centroid within zone	587,265	692,762	602,569	725,362
15 km	Mesh block centroid within zone	28,575	49,712	28,232	49,281

Population counts

Notes:

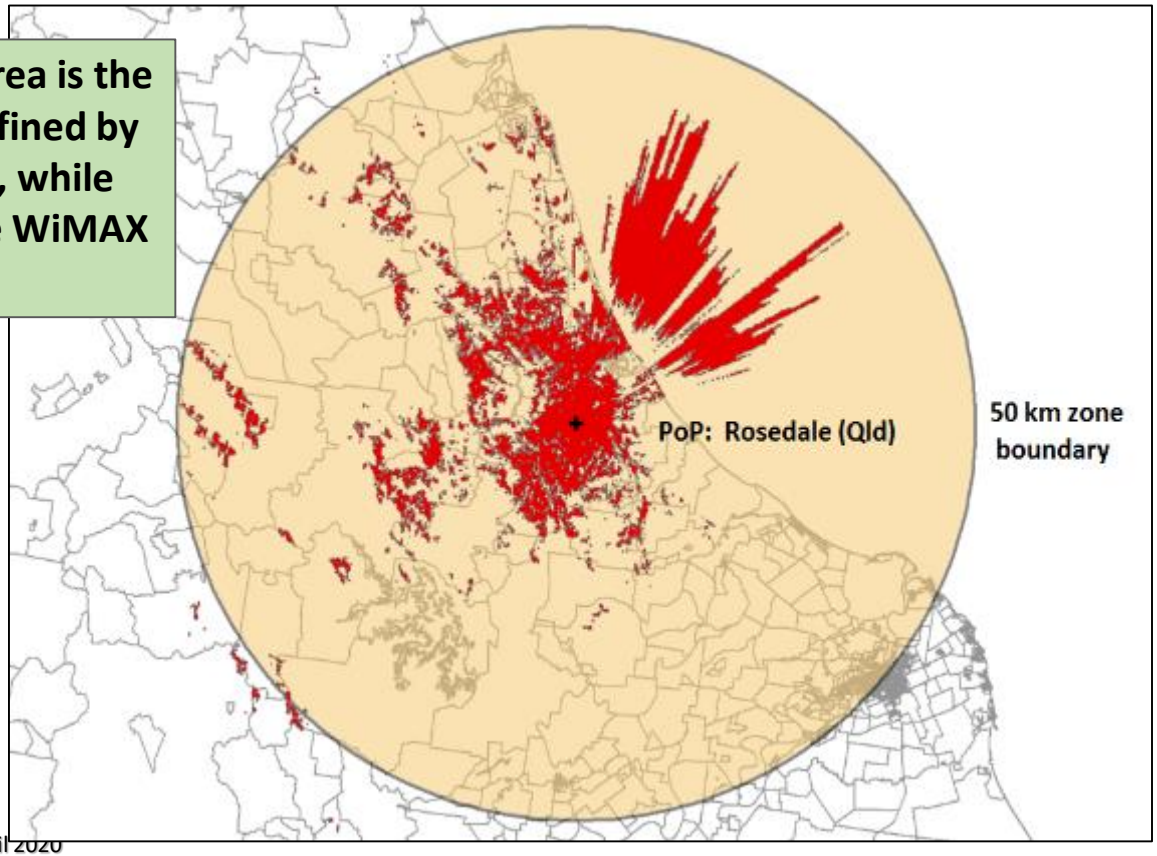
- **There is exact agreement between (the other expert witness) and Hunter for the 45 km and 50 km zone population counts.**

PART 2

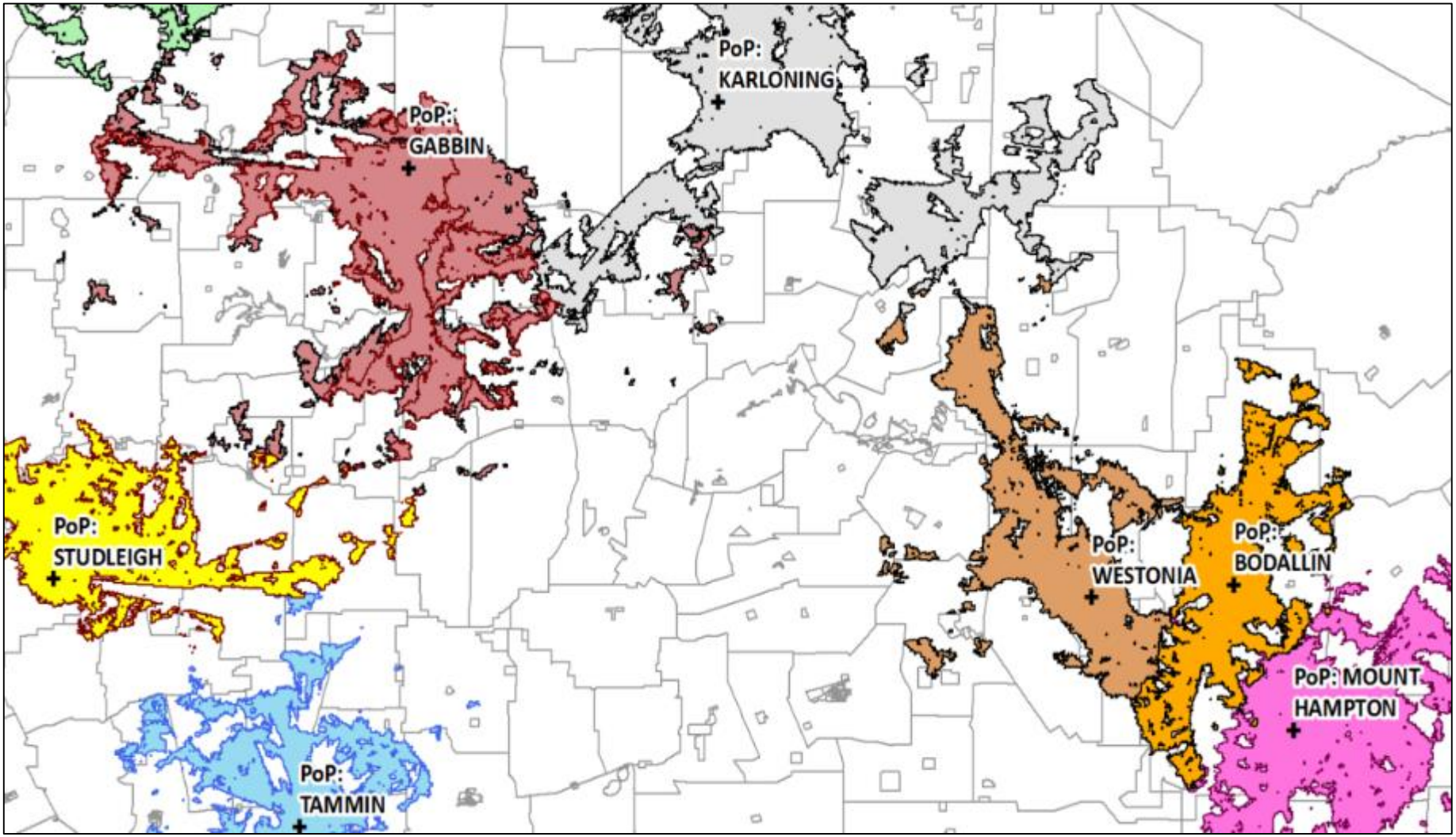
Introducing WiMAX Radio Coverage Modelling

- My lawyers informed me they had tasked another consultant with providing shapefiles for the modelled Wi-Fi coverage from each of the 81 towers, using an alternative method (called WiMAX) that takes terrain height into account. The results are very different to those of the method the other consultant used by drawing circular buffers.

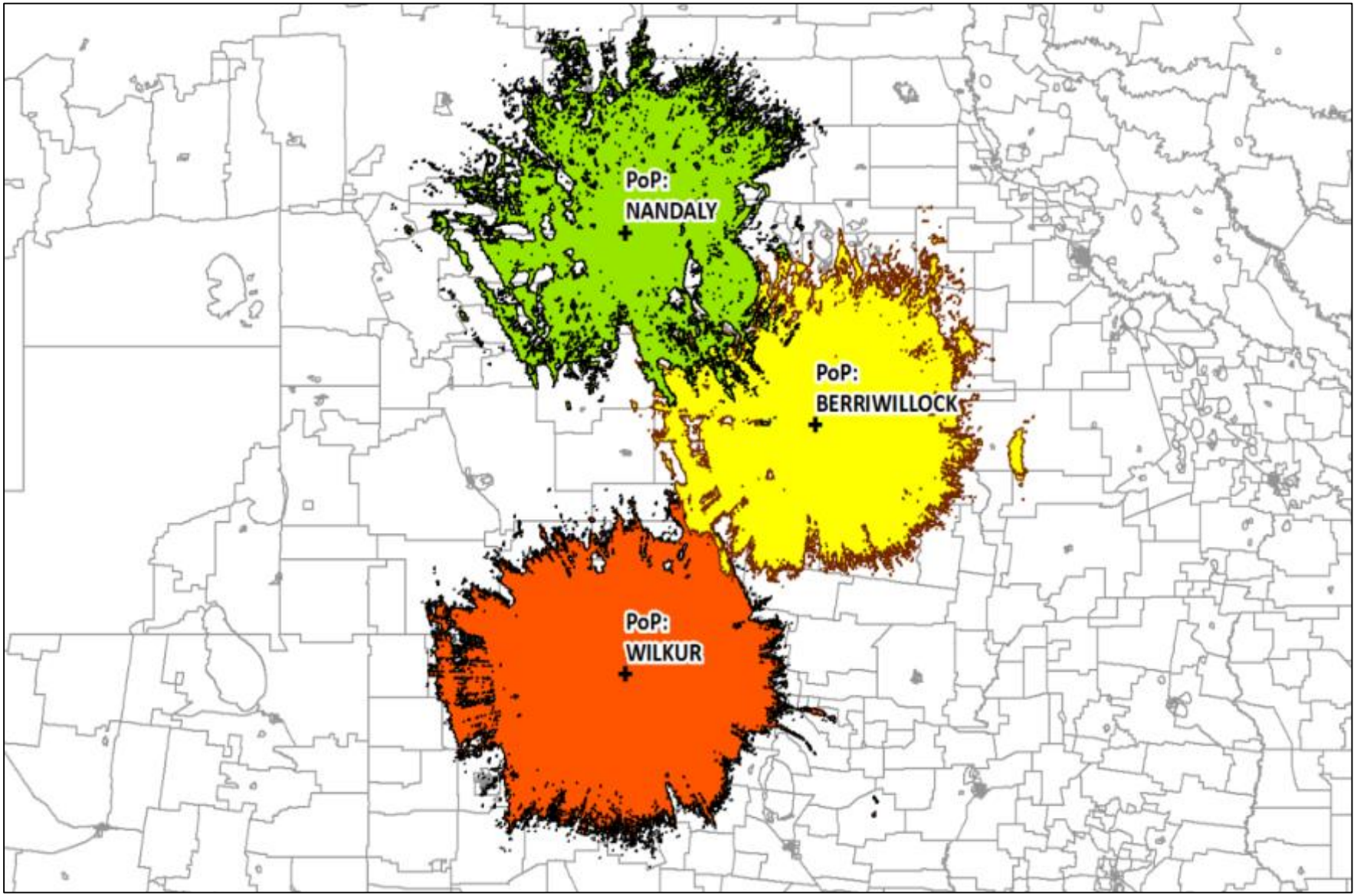
The light brown area is the Wi-Fi coverage defined by the circular buffer, while the red area is the WiMAX coverage.



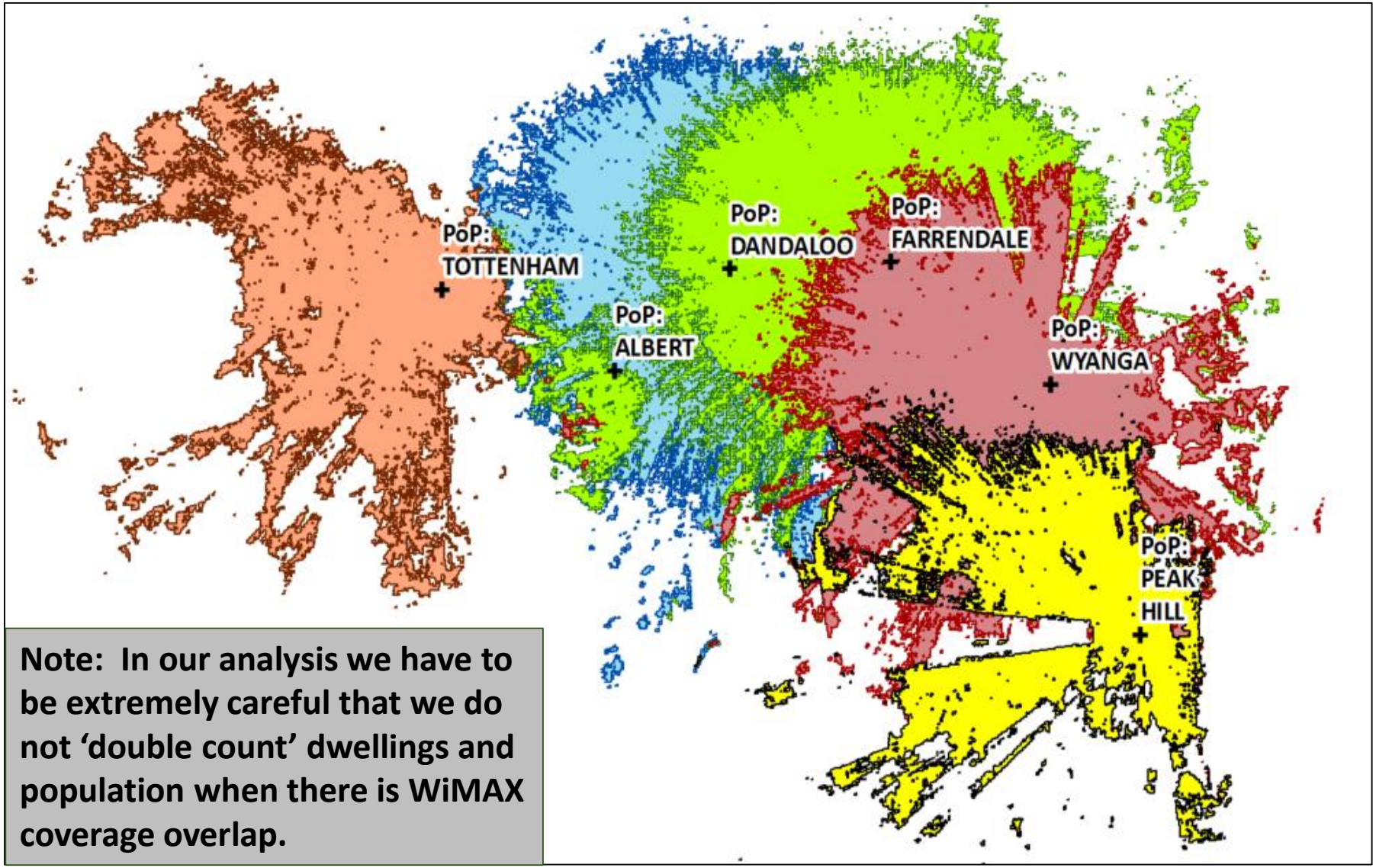
WiMAX coverages can be very fragmented (showing 7 PoPs in WA).



But the flat terrain of North-West Victoria gives an almost circular WiMAX coverage in some cases.

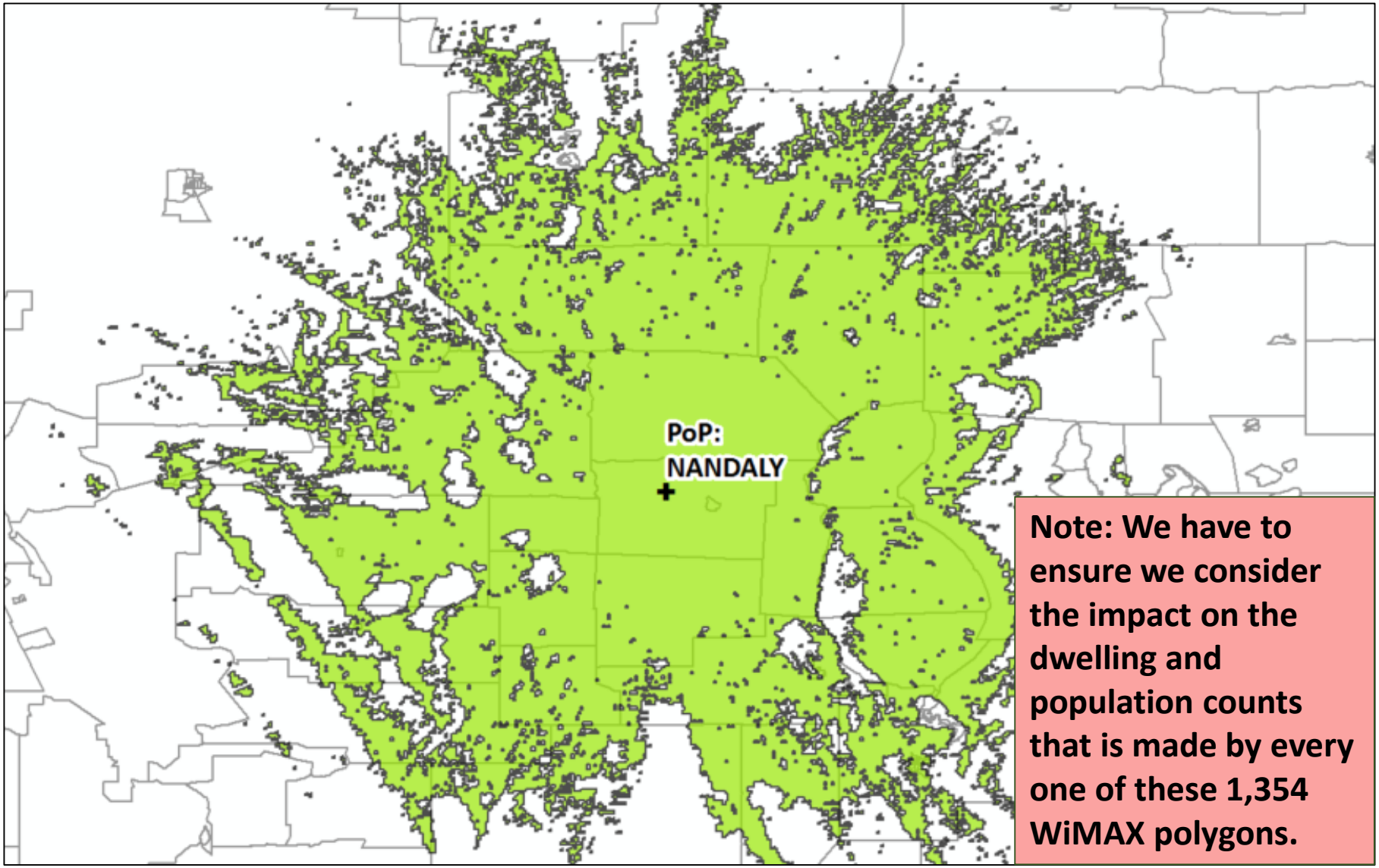


The WiMAX coverages from these six adjacent PoPs in NSW are all overlapping.



Note: In our analysis we have to be extremely careful that we do not 'double count' dwellings and population when there is WiMAX coverage overlap.

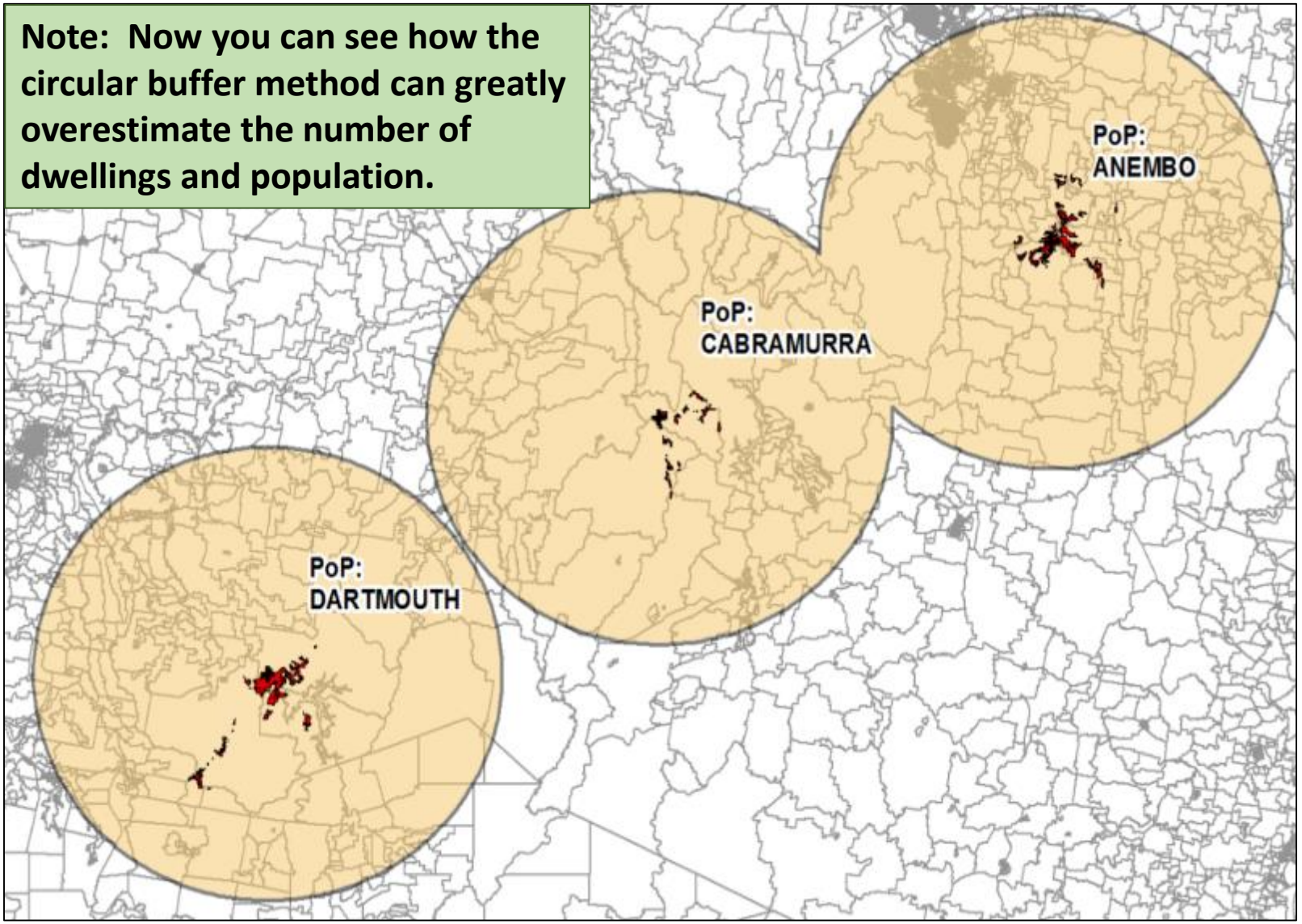
This WiMAX coverage for this PoP consists of 1,354 polygons and more than 23,000 boundary lines.



Note: We have to ensure we consider the impact on the dwelling and population counts that is made by every one of these 1,354 WiMAX polygons.

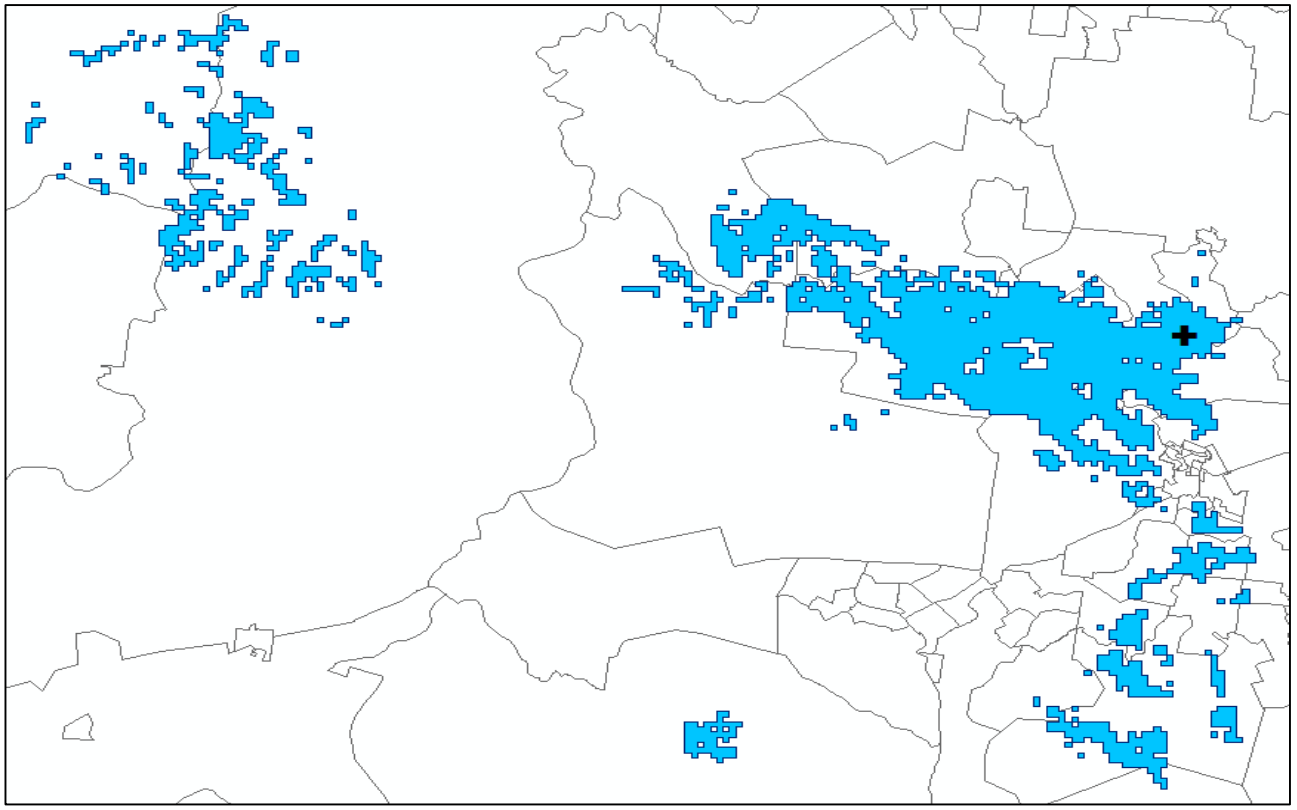
WiMAX coverages (in red) can be extremely small compared to the circular 50 km Wi-Fi zones.

Note: Now you can see how the circular buffer method can greatly overestimate the number of dwellings and population.

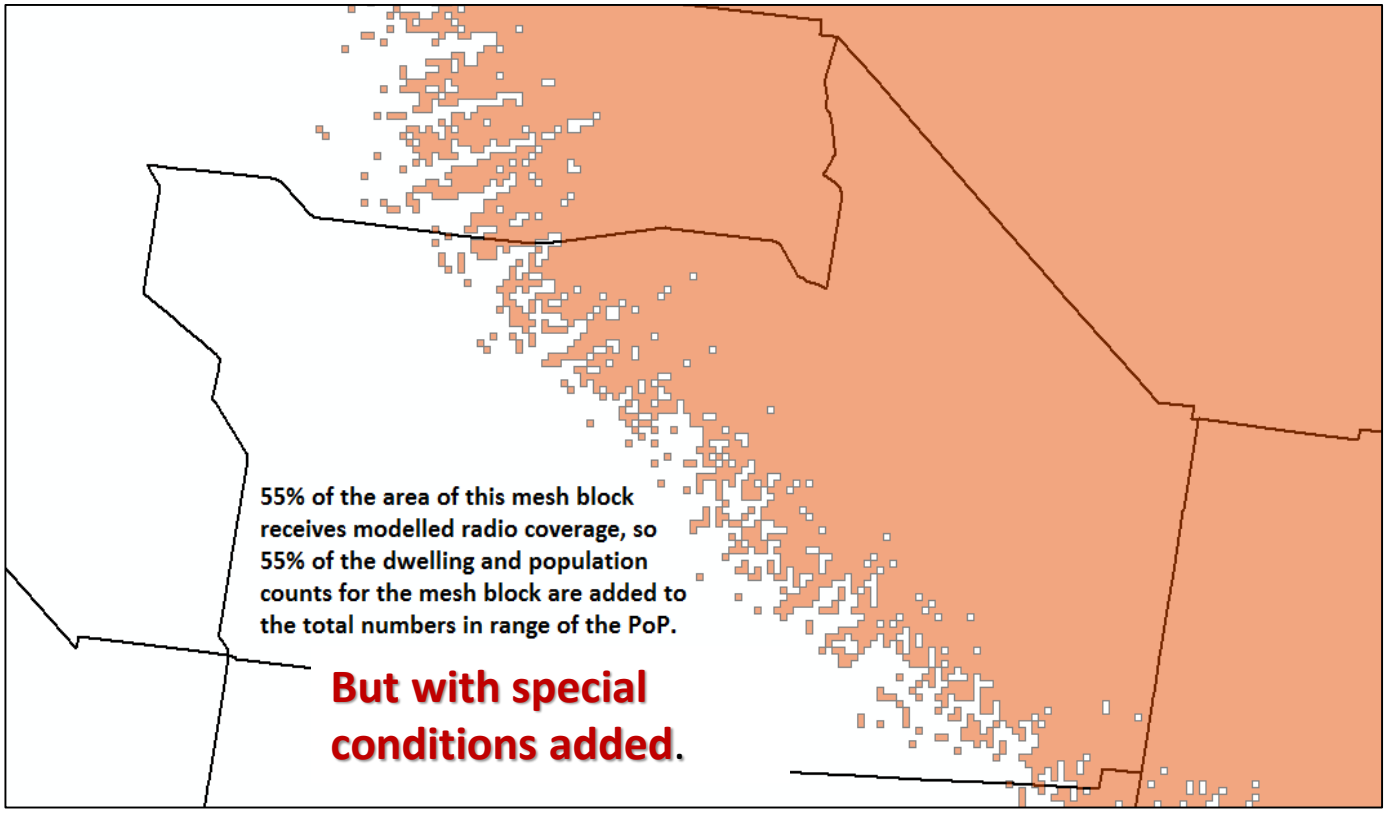


Method for Analysing the WiMAX Data

- You can understand now that creating the circular buffers around each tower and determining which mesh blocks intersected with them was a very simple, but inaccurate, solution.
- So how can we analyse the fragmented WiMAX data when it often rarely completely covers a whole mesh block, as below?

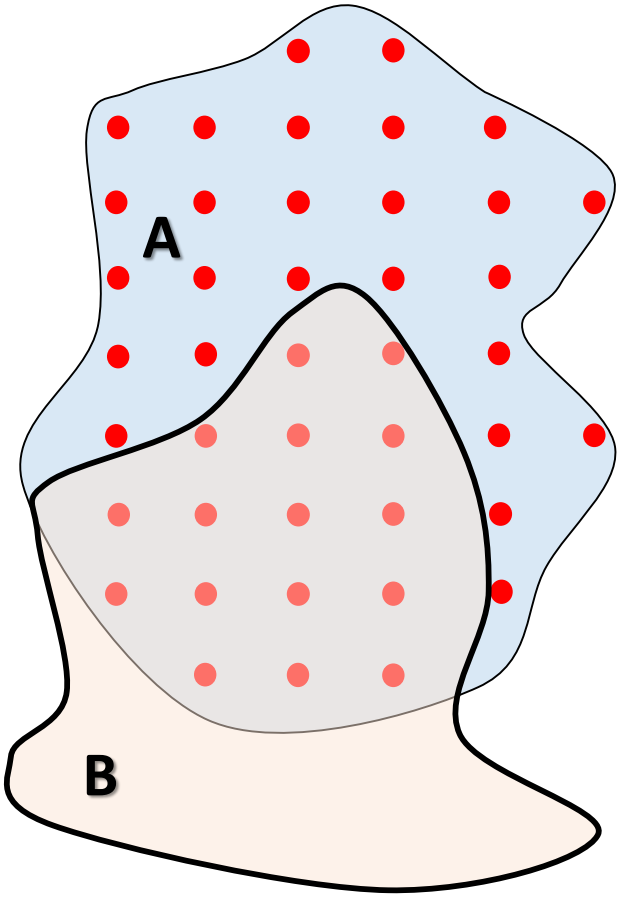


- **The approach I adopted is known as the 'Areal Interpolation Method' and it enables the estimation of statistics for one set of geographical areas to be calculated from aggregated statistics for a second set of geographic areas – but with some very important differences.**



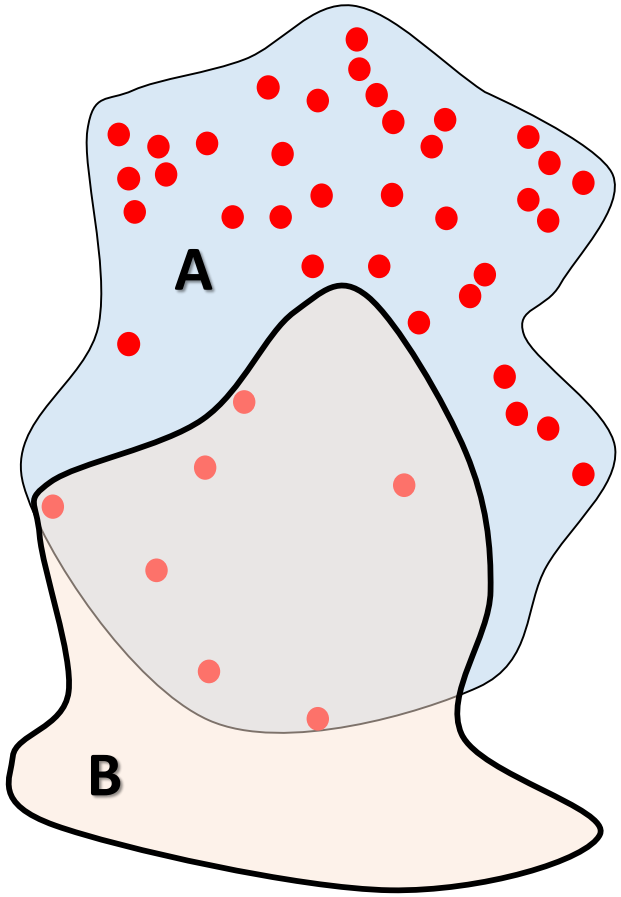
- **Usually, this approach would be extremely inadvisable, as under normal circumstances you simply cannot say that because a polygon A overlaps another polygon B (which contains dwellings and population) by 55%, then polygon A must contain 55% of the dwellings and population.**
- **That could only ever be true when we know for certain that the dwellings and population are uniformly (homogeneously) distributed throughout polygon B.**
- **But we don't know if that is true, and therefore we must assume that the dwellings are randomly distributed in the mesh blocks.**
- **The next slide demonstrates the areal interpolation problem.**

Polygon A (below) contains 42 uniformly distributed dwellings (the red dots)



Polygon B overlaps Polygon A and contains 40% of the area of A. In this case we can state with some confidence that B contains 40% of the dwellings in A.

Polygon A (below) contains 42 randomly distributed dwellings (the red dots)



Polygon B overlaps Polygon A and contains 40% of the area of A. But in this case we cannot state with confidence that B contains 40% of the dwellings in A.

What Changes were made to the Areal Interpolation Method?

1. <u>Fractional values were rounded down:</u> If a residential mesh block contains 20 dwellings and there is 25% WiMAX coverage over the mesh block, then it is calculated that 5 dwellings are could possibly lie within the WiMAX coverage area for that mesh block.

   - **However, where there is a fractional part of a dwelling (and/or person) in the estimate, the number will always be rounded down to avoid illogical values. Thus, 6.337 dwellings becomes 6 and 0.782 dwellings becomes zero. And similarly for population values.**

   - **So I always took the conservative (lower) and logical estimate.**

2. **Small WiMAX Polygons will have no effect: The Areal Interpolation Method as modified by me also prevents small WiMAX coverage fragments from being allocated dwelling and population values unless they are sufficiently large enough to justify the allocation.**

- **For example, if a mesh block contains a total of five dwellings then any one portion of the WiMAX coverage will have to occupy at least 20% of the total mesh block area before it can be assigned a dwelling. We can monitor this by calculating the percentage of the mesh block area that each and every WiMAX polygon covers, and then compute their respective dwelling and population counts.**
- **Therefore, the many tiny WiMAX fragments (such as those shown previously) will be calculated to have correspondingly small fractional dwelling counts, which will be rounded down to zero if they have dwelling/population values less than one. So my method only takes into consideration the larger, whole portions of the WiMAX coverage areas for dwelling (and population) allocations.**

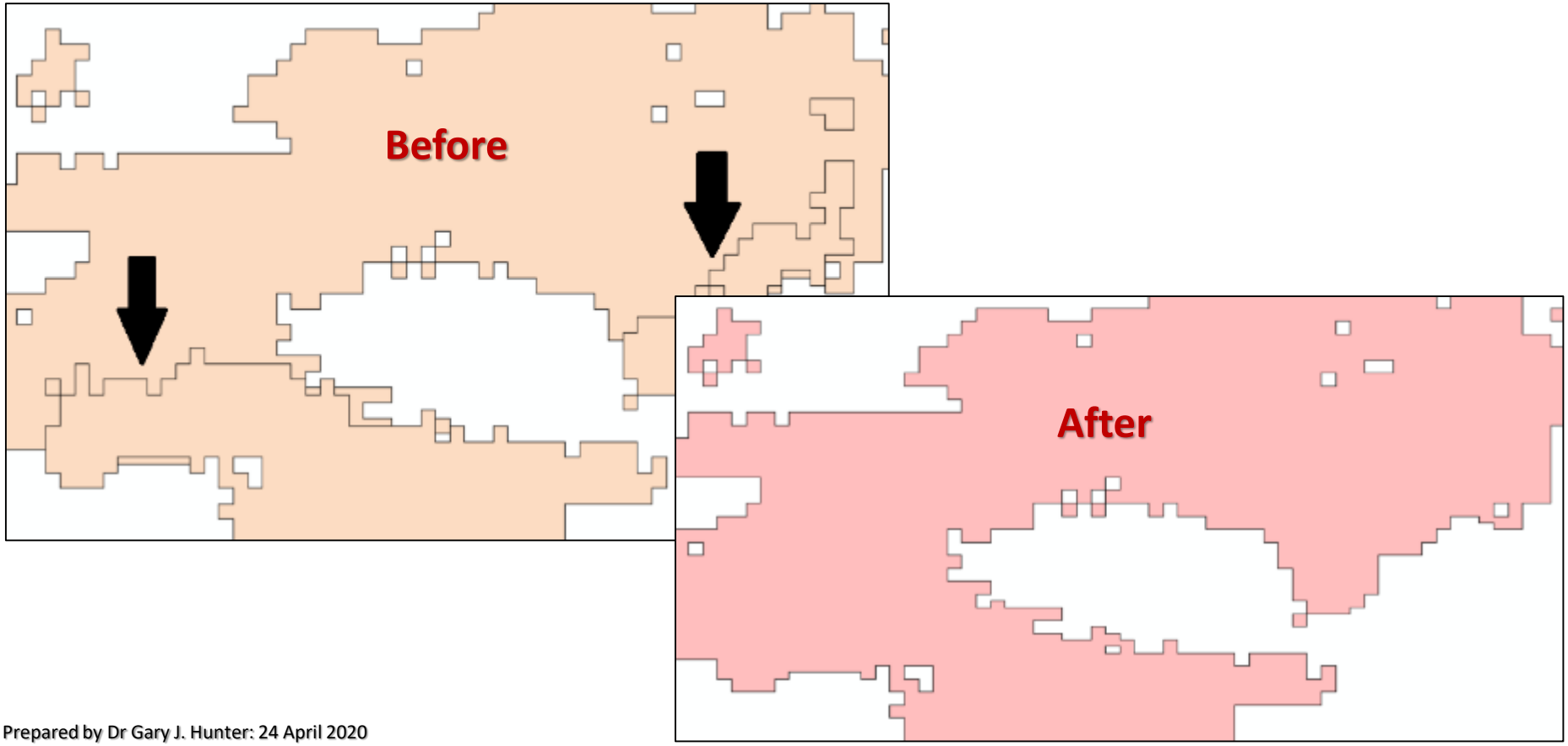
The GIS Procedure for Analysing the WiMAX Coverage Data

STEP 1: Merge the individual WiMAX coverage files for each of the 81 Initial PoPs into a single file for ease of processing. This still leaves us with 360,000 individual WiMAX polygons.

STEP 2: Change the coordinate projection of the merged WiMAX coverage file to be the same as the 2006 and 2011 mesh block files. The re-projection of map coordinates is a function of GIS software and follows rigorous and long-established advanced mathematical principles.

STEP 3: Dissolve the internal polygon boundaries in the re-projected merged WiMAX coverage file. This removes any overlapping polygons that could later result in double counting of dwellings in the radio coverage area. The figure on the next page shows examples of overlapping polygons in the WiMAX coverage that remain after the merger of the 81 individual coverage files.

The overlapping polygon boundaries have resulted from different WiMAX coverages being present in the same rural areas. If the overlapping boundaries are not removed, then dwelling counts from different mesh blocks will be applied to the same area, leading to double-counting. The figures below show the same area before/after removal of the overlapping polygons.



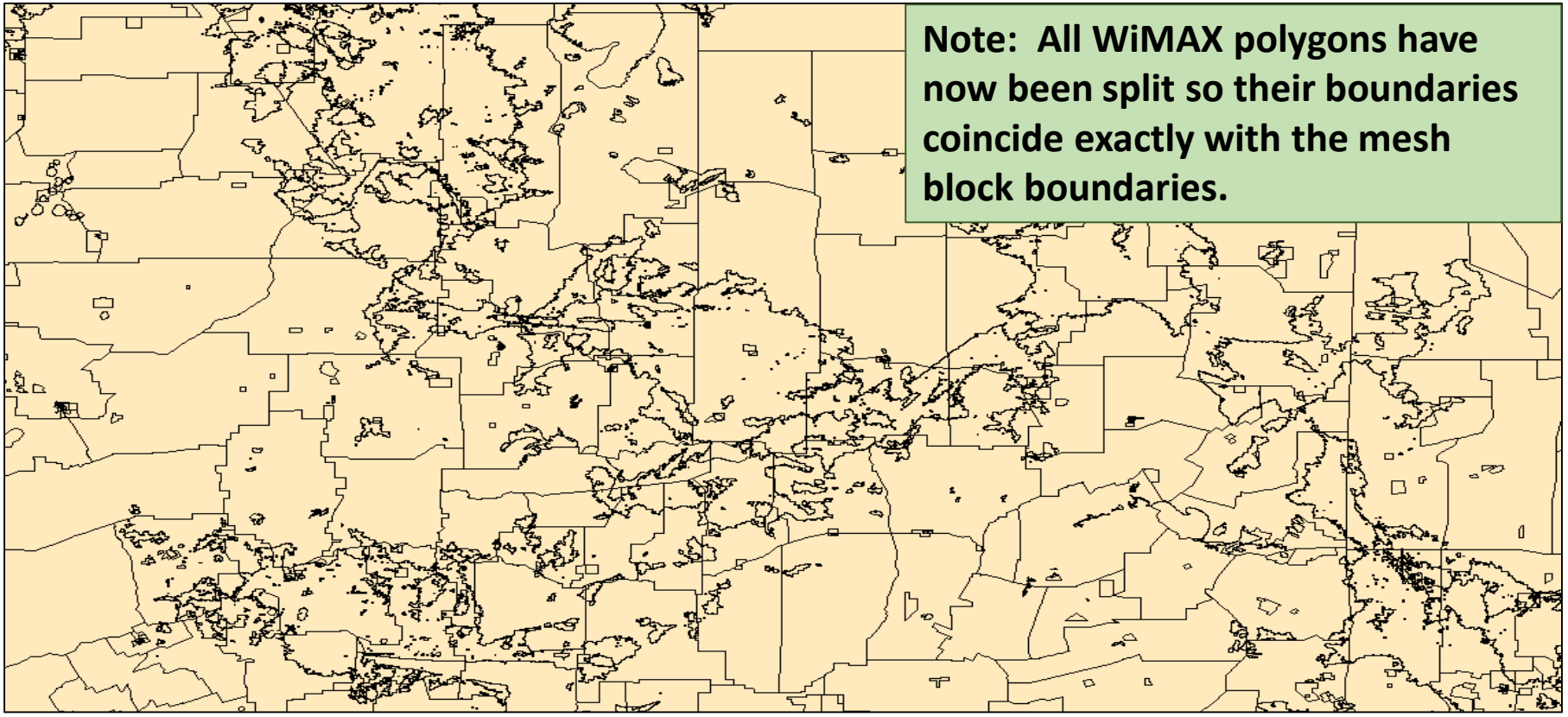
Prepared by Dr Gary J. Hunter: 24 April 2020

STEP 4: Calculate the area for each mesh block in the 2006 and 2011 census files. There are 314,369 mesh blocks in the 2006 Census and 347,627 mesh blocks in the 2011 Census.

STEP 5: Compute the geometric intersection of the merged WiMAX coverage area with the Census mesh block files from 2006 and 2011. This will result in WiMAX coverage polygons being split exactly along the lines of the mesh blocks that they overlap. This allows the percentage of WiMAX coverage in each mesh block to be calculated in Step 6. It will also ensure that any part of the WiMAX coverage file that extends out to sea will be excluded.

STEP 6: Calculate the area of each of the polygons in the intersected files from Step 5.

STEP 7: Calculate the number of residential dwellings and population in the WiMAX areas. This involves determining the percentage of the area covered in each mesh block by the radio coverage and multiplying it by the mesh block number of dwellings and resident population, and then rounding down. Then get the total for all mesh blocks.



Note: All WiMAX polygons have now been split so their boundaries coincide exactly with the mesh block boundaries.

My Final WiMAX Coverage Statistics (for the 81 PoPs)

COUNT TYPE	2006 CENSUS WiMAX counts	2011 CENSUS WiMAX counts
Dwellings	26,374	27,482
Population	57,938	57,589

Other Expert Witness' Total Dwelling & Population Counts

Zone Size	Test Applied	2006 Census Dwelling Counts	2011 Census Dwelling Counts
		81 PoPs	*81 PoPs*
50 km	Mesh block completely within zone	390,296	416,867
45 km	Mesh block centroid within zone	260,385	275,653

Zone Size	Test Applied	2006 Census Population Counts	2011 Census Population Counts
		81 PoPs	*81 PoPs*
50 km	Mesh block completely within zone	878,660	913,661
45 km	Mesh block centroid within zone	587,265	602,569

Other Comments

- **As an expert witness in the legal proceedings I was required to read and sign the Australian Capital Territory (ACT) Supreme Court's "Expert Witness Code of Conduct".**

  "This code of conduct applies to any expert witness engaged or appointed:

  (a) to provide an expert's report for use as evidence in a proceeding or proposed proceeding; or

  (b) to give opinion evidence in a proceeding or proposed proceeding."

- **The main features of the code are:**

  (1) "An expert witness has a paramount duty to assist the court impartially on matters relevant to the expert's area of expertise.

  (2) This paramount duty to the court, overrides any duty to a party to the proceeding or other person retaining the expert.

  (3) An expert witness is not an advocate for a party."

Other Comments (continued)

- Lawyers like to deal only in black and white issues, not grey uncertainties. So expert witnesses must be clear in reporting what they believe to be correct and what they do not believe to be correct.
- In this case, the accuracy of the estimates of dwellings and population numbers likely to receive the new Wi-Fi coverage was critical – as this would affect the compensation paid to *Farmwide* for its lost business opportunities after the project was cancelled.
- It was only possible to tell the lawyers that the census statistics for dwellings and population in mesh blocks are the best available data in the country – and we simply have to assume they are true.
- However, we had to be clear to the lawyers that because the dwelling positions are not known, then our actual estimates of dwellings and population inside the Wi-Fi areas are just that – best available estimates of the true values which can never be known.

How did the Legal Proceedings Finish?

- After I submitted my 100-page report to my lawyers, they would have studied how my WiMAX dwelling and population statistics compared to the other consultant's data. They would have then passed the report to the *Farmwide* lawyers, who would have immediately asked their consultant to comment on my findings.
- It was made quite clear in my report that the circular buffer approach used by the other consultant overestimated dwelling and population statistics, and the assumption that Wi-Fi radio coverage was circular was also technically wrong (except in extremely flat country).
- That would have given my lawyers the opportunity to say, *"OK, we understand there should be some compensation for Farmwide's loss of potential business, but we will only negotiate on the much smaller and more realistic WiMAX statistics."*
- Case closed – it never went to trial and was settled out of court.

Thank you.

Any questions?