# LOCATING PEOPLE SPATIALLY: 2006, 2010, 2100 AND 2:36PM ON FRIDAY

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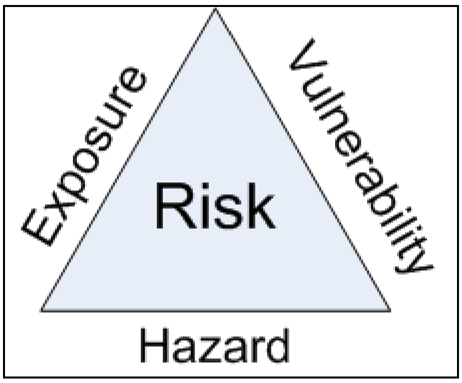
**ABSTRACT:** The National Exposure Information System (NEXIS) is a major national project being under-taken by Geoscience Australia (GA). NEXIS collects, collates, manages and provides the information required to assess multi-hazard impacts. Exposure information is defined as a suite of elements at risk from a hazard and includes populations, buildings, businesses and infrastructure. Understanding population exposure is essential for emergency planning and management. However exposure information can also be used for understanding climate change risk, assessing energy efficiency policy, urban planning and other spatial research. This paper focuses on the population aspects of NEXIS and recent work on estimation methods for the present day over any geographic extent. Plans for work on small area population estimates to the year 2100 will also be presented. Finally future work on activity modelling, the prediction of population movement throughout the day, will also be highlighted.

## 1. INTRODUCTION

Knowing the location of people is crucial to understanding disaster risk. Risk in disasters, according to Crichton (as discussed in detail in Middelmann, 2007, p. 33), is described as the probability of loss. Risk has three main factors which are normally portrayed as a triangle: Hazard, Exposure and Vulnerability (Figure 1). Hazard is the event, for example a cyclone or bushfire, which is usually measured by magnitude and likelihood of occurrence. Exposure refers to the elements that are likely to be impacted by the hazard and includes populations, buildings, businesses and infrastructure. Vulnerability is the degree to which exposed elements will be impacted by the hazard. By changing any one of the three factors, you change the level of risk.

**Figure 1.** The Risk Triangle



The 'Sea change' and 'Tree change' phenomena have seen in-migration increasing in coastal and rural areas. These population increases mean increased population exposure to hazards such as cyclones, storm surge and bushfires. With many climate change scenarios predicting an increased number of hazard events with greater severity, and with increased exposure, the expected community risk is also potentially much higher.

In 2004 the Council of Australian Governments (COAG) accepted a report reviewing disaster arrangements in Australia (COAG, 2004). The report made 12 natural disaster reform commitments. Geoscience Australia (GA) established the National Exposure Information System (NEXIS) in response to the commitment to establish a 'nationally consistent system of data collection, research and analysis to ensure a sound knowledge base on natural disasters and disaster mitigation'.

NEXIS is a nationally consistent database of exposure information at the building level. NEXIS aids risk assessments and scenarios for a number of hazards and feeds into hazard and vulnerability models. NEXIS was designed for regional impact analysis, and is not intended for precinct analysis involving only one or two buildings. However future data collection may allow this kind of micro analysis (Nadimpalli, 2009).

This paper presents the *people* aspects of NEXIS to highlight the usefulness of this dataset and to allow scrutiny of the method. The population estimation method is presented and the social indicators that are currently being added are discussed. This development work is largely complete and GA is seeking feedback on the technical aspects as well as the usefulness of the data. Initial work on the spatial disaggregation of population projections, activity modelling and service populations are also presented to highlight the forward work program and to gain initial feedback on methods.

## 2. 2006: A DATA ODYSSEY

Hazards are not known for conforming to administrative boundaries. The Australian Bureau of Statistics (ABS) uses features in the landscape to determine the boundaries of their smallest unit, the collection district. As such many boundaries in the Australian Standard Geographic Classification are along rivers or along the edges of vegetation (ABS, 2007), areas prone to disasters. To accommodate the variability of hazard footprints it is important to have a method of estimating exposure that is as flexible as possible. This generally requires that all data, including population estimates and socio-economic indicators, need to be allocated to the building level. An example of the problem is illustrated in Figure 2.

Figure 2(a) illustrates a typical city built on a river. The collection district boundaries (indicated by the dotted lines) are determined by features in the landscape, in this case the roads and river. In our example the river floods, resulting in the damage footprint illustrated in Figure 2(b).

One way of easily determining the population, and dwellings, contained within the flood footprint is by capturing the data for all CDs within the footprint. However this approach results in all CDs having equal influence on the total regardless of whether the population represents 1 per cent or 100 per cent of the actual population. Taking a proportion of the CD based on the area flooded may improve the accuracy of the total. Although this assumes that the distribution of the population within the CD is homogenous. When the population data is allocated to the building, the situation is improved by a population-weighted total for the flood footprint.

**Figure 2.** Example of How Hazard Footprints and Data Boundaries Interact

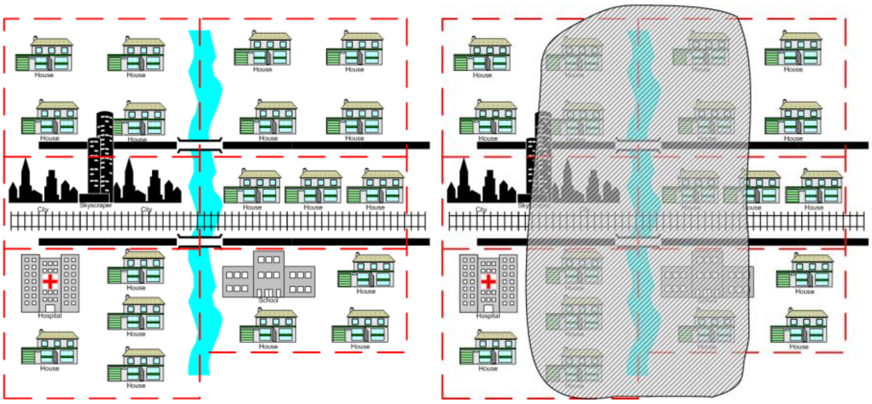


**Figure 2a** **Figure 2b**

NEXIS data is managed at the building level but only released at an aggregated level. Standard outputs of NEXIS are aggregated to Local Government Areas (LGAs), Statistical Local Areas (SLAs) or to specific footprints. With any social data there are concerns about identifying individuals. There are also concerns about users misinterpreting the accuracy of the data when Census data is allocated to a building. These concerns are addressed when the outputs are aggregated.

It is not intended to discuss the architecture of the full NEXIS system here as this has been published elsewhere (Nadimpalli, Edwards and Mullaly, 2007; Nadimpalli, 2009). However, this paper gives a brief overview of the identification of dwellings, as they are key to the NEXIS estimation of populations. The accuracy of the population estimates is dependent on the quality of the dwelling input data, or the accuracy of the statistical method applied. NEXIS initially determined building use and type using a purely statistical method. However NEXIS is now moving toward using real data, largely through Valuer General’s data but also using survey data, data purchased from commercial providers and local council data. The NEXIS team is currently actively engaging authorities to provide this data for a wider area.

The main input data sets for the statistical method of identifying buildings and their dwellings are the Geocoded National Address File (G-NAF), ABS Meshblock land use classification, and the Property Cadastre, with the location drawn from G-NAF. In rural areas GA's National Geographic Information Group provides 1:25,000 map data of homestead locations.

G-NAF is a national geocoded index of all known addresses in Australia. The data is maintained by PSMA Australia Limited (PSMA, 2010). The Property Cadastre is the register of individual land parcel boundaries. The Cadastre is maintained by state/territory authorities. The ABS Meshblock geography contains a category for basic land use. The land use categories are derived from state and territory planning/zoning information so may reflect planned land use as opposed to actual use (ABS, 2008).

While NEXIS uses ABS Meshblocks to determine land use, the size of the Meshblocks are too large to discern fine details. For example all dwellings in commercial or industrial areas are classed as commercial or industrial. Similarly, businesses within residential areas are classed as dwellings. Institutions such as schools, hospices or hospitals that do not have their own Meshblock are also misclassified in this way. The population and dwelling counts within the Meshblock attributes can help this situation, but without supplementary data it is difficult to definitively locate the dwelling. To mitigate this problem NEXIS is currently replacing the statistical method with data derived from direct surveys or development plans.

The NEXIS statistical method defines a residential building as those G-NAF addresses that fall within Residential or Agricultural Meshblock classifications. The residential dwelling type (as per ABS dwelling structure type) is then determined by the number of G-NAF addresses and the size of the Cadastral parcel in which it falls. This process is derived using a lookup table. For example, a single G-NAF address on a Cadastral parcel 351- 4000 $m^2$ is a single house but 31 addresses on the same Cadastral parcel would be an apartment of four storeys or above. Dwellings refer to the individual residences or addresses. Each building is attributed with one or more dwellings depending on the structure type. Separate houses contain only one dwelling for each building, but the other structure types, semi-detached houses, flats and units, contain two or more dwellings for each building according to the number of G-NAF addresses.

To calculate the population at the building level an average population per dwelling structure type (*DWSTR*) is calculated using the 2006 Census $(People_{DWSTR})/DWSTR$. The dwelling structure types are drawn from the ABS Dwelling Classification and include separate house; semi-detached, row or terrace houses; flats and units; and other dwellings including caravans and houseboats. The average population per dwelling type is multiplied by the number of G-NAF addresses at the building level to derive a population per building (Equation 1).

$$Pop_{Building} = \sum \left( \frac{People_{DWSTR}}{DWSTR} \times NEXIS_{DWSTR} \right) \tag{1}$$

where $Pop_{Building}$ denotes the population of each building, $(People_{DWSTR}/DWSTR)$ is the number of people per dwelling structure type in each CD, *DWSTR* is the number of dwellings by structure type in each CD, and $NEXIS_{DWSTR}$ is the NEXIS count of dwellings for each building.

## 3. 2010: ODYSSEY TWO

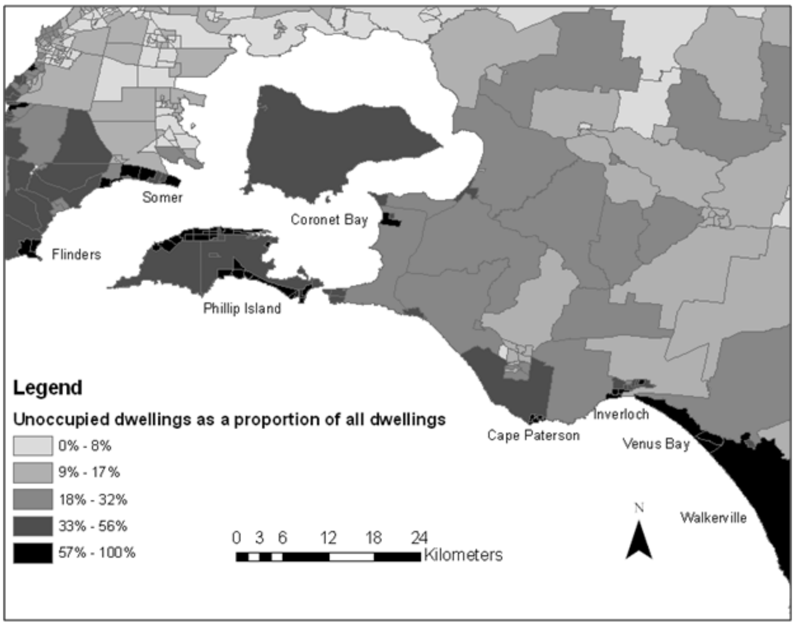
Since the initial development of NEXIS, validation of population estimates has led to a number of improvements. Some of these changes have been focussed on improving the input data for determining building type. However, over the last year changes to the way the population is estimated have also occurred. The NEXIS team are also in the final stages of adding social characteristics to the database.

### *3.1 Not Every House is a Home*

Calculating populations on the basis of the number of dwellings is problematic. The underlying assumption of the basic method of population estimation is that every dwelling is a primary residence. This is not always the case, particularly in coastal or lifestyle regions where many dwellings are holiday or second homes. The population estimate in NEXIS is a residential population estimate, so dwellings that are not primary residences need to be excluded.

The number of holiday homes in a region can be determined through data collected as part of the Census. The time and date of the Census is such that people are more likely to be "at home", that is in their place of primary residence. This means that a second home is likely to be unoccupied on Census night. Census collectors record when a dwelling is unoccupied and the structure type of the dwelling. This data is available by request through the ABS.

**Figure 3.** Unoccupied Dwellings for Coastal Victoria Covering the LGAs of Mornington, Casey, Cardinia, Bass Coast and South Gippsland



An analysis of the unoccupied dwellings data presents no surprises in terms of spatial distribution, but some surprises in the numbers of dwellings. In locations like Phillip Island, the number of dwellings unoccupied on census night can be up to two-thirds of the dwelling stock. Figure 3 maps the proportion of unoccupied dwellings on Census night for part of coastal Victoria to illustrate the scale of the phenomenon.

The unoccupied dwellings data can be used to estimate the proportion of the dwelling stock that is a primary residence. The new population estimate could be calculated by dividing the average number of people per structure type by the total dwelling stock, that is the occupied and the unoccupied homes. However due to the way NEXIS is structured, it calculates a ratio and applies it to the population (Equation 2).

$$Unocc_{ratio} = \left( \frac{People_{DWSTR}}{DWSTR + Unocc_{DWSTR}} \right) \Leftrightarrow \left( \frac{People_{DWSTR}}{DWSTR} \times \frac{DWSTR}{DWSTR + Unocc_{DWSTR}} \right) \quad (2)$$

where $Unocc_{Ratio}$ denotes the unoccupied homes ratio and $Unocc_{DWSTR}$ is the number of unoccupied dwellings by structure type for each CD. This is called the Unoccupied Homes Ratio, but in reality it is a ratio for estimating the proportion of occupied homes or primary residences.

### *3.2 Estimated Resident Population*

Some people are not counted in the Census if they do not complete Census forms, because they were overseas at the time of the Census or for other reasons. The official population estimate for Australia, Estimated Resident Population (*ERP*), accounts for these differences. The number of people who do not complete Census forms is estimated by the Post Enumeration Survey. The number of Australian residents travelling overseas is estimated using passenger cards. Other, smaller, demographic adjustments are made to the population estimate. Finally the estimate is backdated to June 30 (approximately 5-6 weeks before the Census is taken) by adding or subtracting deaths, births and migration. No other adjustments are made to the estimates for a Census year (ABS, 2009). Table 1 shows the adjustments made in 2006 to calculate *ERP*.

The NEXIS population accounts for the difference between *ERP* and the Census through a simple ratio of the Census year (in the current case 2006) *ERP* over the Census population total for each CD (Equation 3).

$$ERP_{ratio} = \frac{ERP}{People_{total}} \quad (3)$$

where $ERP_{ratio}$ denotes the ratio to adjust for *ERP* and $People_{Total}$ is the total population of the CD. *ERP* for the inter-censal years is not used in the NEXIS application. *ERP* following the Census is estimated using data such as Medicare records, birth and death records, postal redirections and building approvals. For each year after the Census, more errors can be introduced, with areas of high population growth or decline showing the highest errors (Howe 2008). Once a Census has been completed, the ERP for the inter-census years is recalculated by the ABS to the new benchmark.

**Table 1.** Adjustment components of Estimated Resident Population, Final – 30 June 2006

| **Components** | **Australia (persons)** |
|---|---|
| Census count place of usual residence | 20,061,600 |
| Plus allowance for under-enumeration | 549,000 |
| Plus demographic adjustment | -14,300 |
| Plus residents temporarily overseas | 346,000 |
| **Equals ERP as at 8 August 2006** | **20,736,600** |
| Backdating components to 30 June 2006: | |
| Less births | 29,300 |
| Plus deaths | 15,600 |
| Less net overseas migration | 25,000 |
| **Equals final ERP as at 30 June 2006** | **20,697,900** |

**Source:** Source: Reproduced from table 2.1, ABS (2009).

NEXIS allows for the spatial distribution of population change through changes in dwellings. The statistical method of NEXIS using addresses, cadastral boundaries and detailed land use accounts for many population changes. One change not accounted for is declining household size. An analysis of the average household size using the Census Time Series Profile between the last two Censuses shows no change nationally, however some regional areas can greatly differ. Between 2006 and 2001 three quarters of SLAs with a population of 50 or more showed household size declining by less than 0.2 people. One in seven SLAs of population 50 or more showed an increasing population size.

The size of the NEXIS error caused by declining household size increases each year following the Census, with the maximum error occurring in the new Census year (before the data is released). We can calculate the error but only for the inter-censal period before the latest Census. To understand the maximum size of the NEXIS error for 2006 we sum the change in household size multiplied by the number of households for each SLA. Nationally there is an overestimate of 310,000 people, less than two per cent of the population. It may be possible to adjust for the error by using the trends exhibited between the previous two Censuses, in this case between 2001 and 2006, however this assumes that the trends do not change between repeated Censuses. Nationally the average household size declined from 2.7 to 2.6 persons per household between 1996 and 2001 but remained stable between 2001 and 2006, so the assumption of a continuing trend does not hold. Without a regular estimate of the number of households, it is difficult to see a way of accurately correcting the error.

### *3.3 Total Population Estimate*

The total population estimate at the building level is calculated by combining equations 1, 2 and 3 (Equation 4). The aggregation of building numbers provides a total population estimate of an area, based on the current building stock.

$$Pop_{building} = \sum \left( \frac{People_{DWSTR}}{DWSTR} \times Unocc_{ratio} \times ERP_{ratio} \times NEXIS_{DWSTR} \right) \quad (4)$$

NEXIS captures changes in the dwelling stock that occur after the Census due to new construction or redevelopments. To account for areas where changes mean that the appropriate structure type is not available from Census data, or even areas that previously had no dwellings of any kind, average values are applied in the following order:

- Average population and Unoccupied ratio for the CD
- Average population and Unoccupied ratio for the SLA

### *3.4 Remote and Indigenous Communities*

G-NAF does not represent remote areas well. This is particularly the case for Indigenous Communities where the community may have one address and one Cadastral parcel for the whole community. Many of these areas have been identified through the Indigenous Profile from the Census. In these cases data from the Census is used as a count for the number of dwellings and population estimates. However, since the exact location of the dwellings is not known and it is unknown where the community resides at different times, it is recognised that this method is not ideal for dispersed or mobile communities.

### *3.5 Validation*

The development of the population aspects of NEXIS is considered largely complete. The NEXIS team have been conducting validation of the 2010 population estimates against *ERP* for 2009 at the CD level. We cannot compare *ERP* with the 2009 NEXIS estimates because of improvements made to the estimation technique in the last year. While the population estimate compares well in total, some CDs can have large differences. Some differences are not due to errors in the NEXIS estimations. Rather they highlight that the strength of NEXIS, areas of new or high growth, can address a known weakness of *ERP* (Howe, 2008). However, NEXIS can be inaccurate in some areas, largely related to the statistical approach for identifying dwellings. As real data is obtained and accurate land use data replaces the statistical approach, NEXIS population estimates will increase in accuracy. GA is in discussions with the ABS to help improve the population estimates further, but it is expected future improvements will come from improved land use and address data only.

### *3.6 Social Characteristics*

Increasingly requests for data include a need to understand the characteristics of the population. Social characteristics need to be applied to the building level for the same reason that population estimates are applied to this scale. GA is in the process of incorporating a number of social indicators drawn from Census data. The indicators have been identified in the literature as having an impact on social vulnerability to disasters. The indicators, their measurement and a selection of the relevant literature are listed in this paper's appendix.

The social indicators are allocated to dwellings by assigning the proportion of dwellings that exhibit that characteristic to each dwelling. For example, the proportion of dwellings in the CD that do not have a motor vehicle is allocated to every dwelling in the CD. This requires many of the indicators to be transformed to a dwelling format. Households were considered equivalent to dwellings for this purpose. Some indicators are already measured in this way; no access to a motor vehicle and household income are two examples. However person based variables are available on a dwelling basis from the ABS on request. The table in the appendix details how the indicators are measured. In some cases the interest is in dwellings where any one person is at risk, such as dwellings that contain any one aged under 5. In others we are more interested if all residents are at risk, such as dwellings where all residents are aged over 65.

Allocating proportions to dwellings results in extremely small numbers for each building. This is especially so for the smaller sub-populations such as the indicator of those with insufficient English. However, as the buildings are aggregated to larger areas the results become meaningful. Aggregating to ASGC boundaries produces the results that GA started with, Census data. However the power of NEXIS is that aggregations to disaster footprints lead to more accurate results that could not otherwise be obtained.

## 4. 2100: FINAL ODYSSEY

Population estimation for the seemingly distant future is not often conducted for small areas. However, expected climate change has pushed the planning horizon out to 100 years and more. Increasingly, planners and policy analysts want to know where the population is going to be when the real effects of climate change are expected to be felt. While it can't be known for certain the trends that determine where people prefer to live in a 100 years, causing 100 year population projections at any level to be inaccurate, having some projections provides better information than none.

Previous worked conducted by GA for the Garnaut Climate Change Review (Waters, Cechet and Arthur, 2010, provides a summary of the method and results) projected the regional population in proportion to the Australian Bureau of Statistics' Series B (middle) population projections. There are two main problems with this method. The first is that all sub-regions within the projection regions are assumed to grow at the same rate. The second is that the urban boundary was assumed to remain the same, and population density increased to accommodate growth rather than spatially expand the settlement.

In partnership with the Australian Government Department of Climate Change and Energy Efficiency, GA is embarking on a project to develop a method for assessing population growth that takes into account the spatial growth of settlements. The method will then be trialled on a case study basis. Local development plans will be fundamental to assessing growth areas, as are state government and ABS population projections. However, even within these areas, growth is likely to occur unevenly. It will be necessary to use spatial disaggregation techniques to accurately distribute the population growth.

One approach which shows potential is the use of dasymetric techniques. This method was shown by Li and Corcoran (2010) to be a useful tool to disaggregate Statistical Division level population projections for South-East Queensland (SEQ). Dasymetric techniques map data into homogenous zones, often using additional data to disaggregate spatial data into finer areas. The advantage of dasymetric techniques is that multiple classes of population densities can be used for disaggregation.

Li and Corcoran note that improved data on current population densities may lead to improved disaggregation. The intention is to use NEXIS data as the source to calculate population density. Planning documents will be obtained for a case study region identifying urban growth boundaries. These will be combined with appropriate population projections to estimate the future location of the population.

## 5. 2.36PM ON FRIDAY AFTERNOON

Using Census and housing data as a basis for locating populations during a hazardous event is very useful for events that occur in the early hours of the morning when most of the population is at home. While it is true that some events do occur at this time, obviously hazards are just as likely to occur at other times. For this reason it is necessary to gain an understanding of the movement of people across the day, week and year. This movement is referred to as activity modelling.

An excellent demonstration of the practicality of activity modelling was conducted in Finland (Ahola *et al*, 2007). This demonstration combined static data, such as the Census and building catalogues, with a spatio-temporal population model. The spatio-temporal population model was attached to each building in the catalogue and detailed the proportion of sub-populations occupying the building by time of day and week. The population at any one time of the day is then able to be calculated by multiplying the total building population by the proportion.

GA will be starting work on activity modelling soon. GA, in partnership with the Bushfire CRC and University of South Australia, is looking for a suitable PhD candidate to undertake activity modelling of peri-urban areas to understand bushfire risk. This work will be conducted in conjunction with a number of other bushfire modelling projects being undertaken at GA.

Until detailed activity modelling can be completed, there are a number of activities either underway or planned to estimate populations at specific points of time. The NEXIS team are currently investigating the construction of a “capacity” population. This population estimate would reflect the expected maximum overnight population if every residence and accommodation was occupied. This estimate is particularly useful in areas dominated by tourism and holiday homes.

The method being explored as a “first cut” capacity population estimate was used to calculate the capacity population for a study of Phillip Island and

Torquay. The study commissioned by the Victorian Department of Sustainability and Environment (Urban Enterprise, 2007), supplemented Census data with the Tourist Accommodation Survey (produced by ABS), the National Visitor Survey and International Visitor Survey (produced by Tourism Research Australia) and local tourist surveys and data.

For other areas education and employment may be the main driver of daily population movements. City populations are driven by a weekday daytime population as people commute from suburban areas into the cities to work. Universities and schools are also common commuting destinations. Through the Census Working Population Profile, building data already contained in NEXIS, and data on schools it is possible to estimate a “regular working” daytime population. This data could be supplemented with extra information on service populations.

The concept of service populations ties together many of these concepts. Service populations are the group of people who access services and facilities within a location. The ABS has conducted a pilot study into estimating the service populations for five LGAs in Western Australia. While they were able to derive estimates, the ABS concluded that further work was out of the expertise of the Bureau, mainly because of the amount of industry liaison with infrastructure providers, and the program was discontinued (ABS, 1999). A similar method was used for a second study of Phillip Island, where water and waste consumption was assessed as indicators of population (SGS Economics and Planning, 2007).

GA has established relationships with a number of infrastructure providers and is in a position to obtain data to make estimates of service populations. Static data as a base can be supplemented with data from infrastructure providers, such as water or telecommunications providers, to estimate the movement of populations throughout the day, week and year.

## 6. CONCLUSION

Since its inception the NEXIS system has improved its social methods to become a useful tool for estimating the location of populations and their characteristics. Starting with simple population averages, major improvements include adjustments for holiday homes and the bringing of estimates into line with ERP. The inclusion of social characteristics is a major advance which opens the scope of use to new areas. Intended for disaster research, planning and evaluation, NEXIS has already been used for policy evaluation, assessment of climate change risk and urban planning.

Early work on spatial population projections, service populations and activity modelling has already commenced. Over the next one to two years these will significantly enhance NEXIS and will provide further scope for research and planning. GA is seeking feedback on the technical aspects of NEXIS and on the usefulness of the data included already. In particular GA is looking for collaborations and partnerships with agencies to help build the NEXIS capability. If you feel you have a need that NEXIS can meet, or can help expand the usefulness of NEXIS, please contact the author.

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**Appendix 1.** Initial Social Indicators to be Included in NEXIS

| **Indicator** | **Measurement and References** |
|---|---|
| Single parent families | Dwellings that contain single parent families with children under 15<br>Buckle, Marsh and Smale (2001) |
| Young at risk | Dwellings that contain residents aged under 5<br>Buckle (2001); Buckle, Marsh and Smale (2001); Yelataysi *et al.* (2009) |
| Elderly at risk | Dwellings where all residents are aged over 65<br>Buckle (2001); Buckle, Marsh and Smale (2001); Yelataysi *et al.* (2009) |
| Volunteering rate | Dwellings that contain a resident who volunteers<br>Maguire and Hagan (2007) |
| Income (three classes) | Weekly household income: low = less than $500 (OECD measure of half national median for 2006); medium = between $500 and $1699; high = $1700 or more (ABS measure of Decile 8 and 9)<br>Buckle (2001); Buckle, Marsh and Smale (2001); Insurance Council of Australia (2008); Yelataysi *et al.* (2009) |
| New to region (1 and 5 year indicators) | Dwellings where all residents lived at a different address 1 or 5 years ago<br>Bushnell and Cottrell (2007); Li (2009) |
| Tenure type (four classes) | Tenure of the dwelling: Owned or mortgaged; Rented private; Rented public; Other<br>Collins (2005); Cutter, Boruff and Shirley (2003) |
| Not completed year 12 | Dwellings where all residents have not finished year 12<br>Tobin (1999); Cutter, Boruff and Shirley (2003); Insurance Council of Australia (2008) |
| Need for assistance | Dwellings that contain a resident with a core activity need for assistance<br>Buckle (2001); Buckle, Marsh and Smale (2001); Handmer (2006); Yelataysi *et al.* (2009) |
| Motor vehicle access | Dwellings with no motor vehicle<br>Handmer (2006) |
| Insufficient English | Dwellings where one resident and dwellings where all residents speak English not well or not at all (two indicators)<br>Buckle, Marsh and Smale (2001); Yelataysi *et al.* (2009) |