

Visualizing the Urban Development of Sydney (1971-1996) in GIS

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Abstract



This paper investigates ways of recording and visualizing the spatio-temporal trends of urban development in the Sydney metropolitan area from 1971 to 1996, which is an important component in modelling the urban development of metropolitan Sydney. Using GIS as a visualization tool, the paper first analyses the problems and quality of spatial data from different data providers. ABS census data are therefore selected to be used in this research. A fuzzy boundary criterion is defined to illustrate the physical urban extent of Sydney. Animations in both 2-D and 3-D are created for the visualization of Sydney's urban development. Visualization shows that the urban area of Sydney had been developing largely in accordance with what was planned in the Sydney Region Outline Plan. West, southwest and south parts were major directions for this development. It also shows that this development had been supported by the transportation network and the relief. It is concluded that GIS is an important and useful technique both for the visualization of spatial data quality and consistency and for the visualization of urban development in space and over time.


Keywords and phrases: visualization; urban development; Sydney; GIS.

1 Introduction

Urban development and the migration of population from rural to urban areas are significant global phenomena. More and more small isolated population

centres are changing into large metropolitan cities, and the conversion of natural land to urban use is quite obvious. In the last 200 years, the Earth's urban population has increased over 100 times while the total global population has increased only six times (Hauser, et al. 1982). According to the report of the United Nation's Population Division, in 1975, about 38 percent of the earth's people lived in urban areas; by 2025, this proportion will have risen to 61 percent, which means that about 5 billion people out of a total world population of 8 billion will be living in urban areas (UNPD 1995, quoted in WRI 1996). The majority of this growth will happen in the developing countries. In the developed countries, the most rapid urban growth took place over a century ago, but their urban growth continues, although at a much slower rate on average than in previous decades. Much of the population shift now in the developed countries involves movement from concentrated urban centres to vast, sprawling metropolitan regions or to small- and intermediate-size cities (WRI 1996), resulting in the physical expansion of the urban land and the conglomeration of multiple cities known as megalopolis.

The expansion of urban areas to the surrounding land has an increasing impact on global environmental change, which has now been fully recognized as a significant global problem (Vitousek 1994). Understanding the processes and patterns of urban development in space and over time is an important compo-





ment of the human dimensions of global environmental change research, which has been a long and continuing preoccupation of urban geographers, planners and environmentalists.

Sydney is a global metropolitan city. The urban areas of this city have been growing very rapidly since World War II, and there is no sign that this growth will slow down. Therefore, visualizing and modelling the spatio-temporal processes of the urban development of Sydney are of practical significance, especially for urban planners, government and institutional decision makers and environmentalists.

This paper investigates ways of recording and visualizing the spatio-temporal trends of urban development in the Sydney metropolitan area from 1971 to 1996, which is an important component in modelling the urban development of metropolitan Sydney. The paper is organized as follows: section 2 describes the study area and the data sources. Problems about data quality from different sources are visualized in GIS and discussed. In section 3, criteria on defining a fuzzy boundary to illustrate the physical urban extent of Sydney with census data are presented. Section 4 introduces methods of visualizing urban development in GIS. The spatial patterns and temporal rates of the urban development of Sydney will therefore be analysed. Finally, conclusions on both the urban development of Sydney and the visualization technique of GIS are presented in section 5.

2 Study Area and Data

2.1 The Study Area

This research is based on an area bounded by the Nepean-Hawkesbury River and its tributary, which is within the County of Cumberland region. It covers an area of 4100 square kilometres. Geographically, this area consists of three parts, the Hornsby Plateau to the north, the Woronora Plateau to the south, and the Cumberland Plain in between (Figure 1). The Hornsby and Woronora sandstone plateaus are quite similar in topography. They rise to elevations of 270

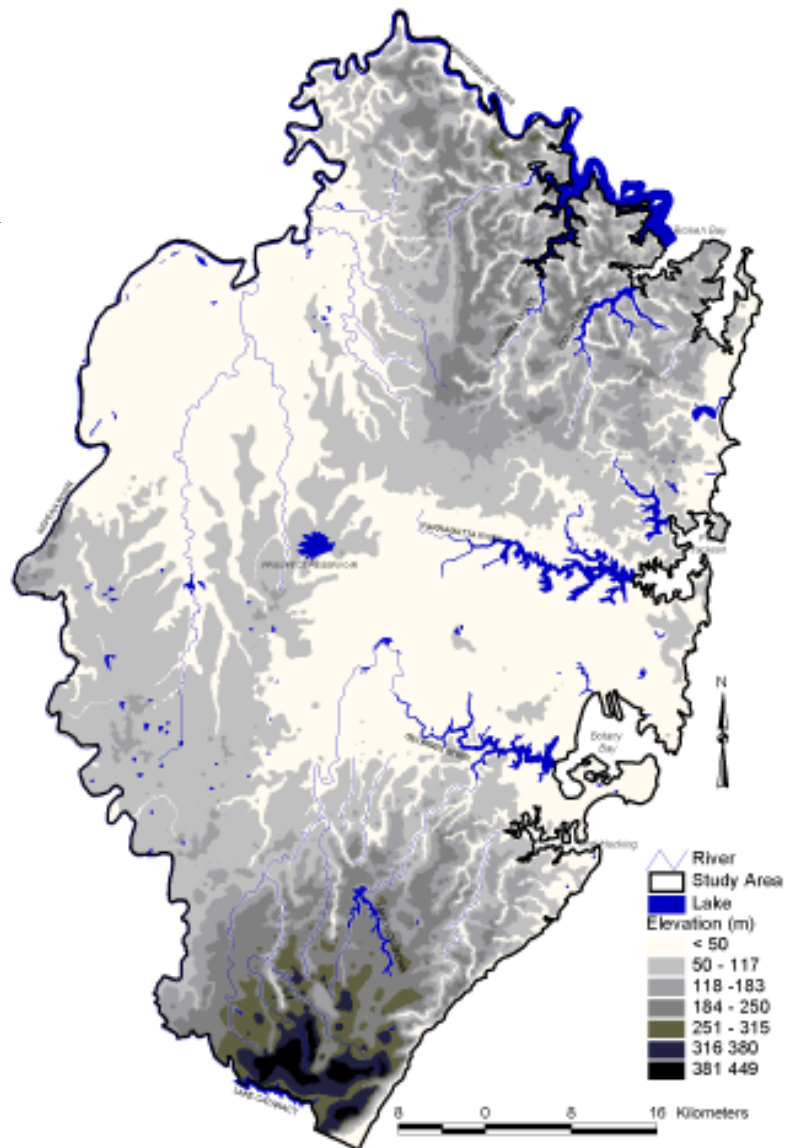


Figure 1 The study area and its topography (Data source: AUSLIG's TOPO-250K relief)





and 440 metres respectively and are divided into a series of ridges and gorges with smaller branching ridges and steep gullies. Some of these areas are defined as national parks, national recreation areas or nature reserves. The Cumberland Plain lies between the two sandstone plateaus and it pushes through to the sea at Botany Bay. For the most part this plain is flat or gently undulating, and through which wind the Parramatta and Gorges rivers and a number of creeks flowing north and west into the Nepean (Winston

1957). The topographical characteristics of this region have a great influence on the spatial expansion of the urban areas of Sydney.

Urban development in Sydney began at 1788 when the first fleet under Captain Arthur Phillip arrived at Sydney Cove, but the early growth of Sydney was very slow and painful because of the despotism of its early governors, the unwilling labour of its convict population and its utter dependence on the outside world (Spearritt & DeMarco 1988). The real urban

growth of Sydney started from the gold rush of 1850 and the growth rate accelerated significantly since the use of motor vehicles in the 1910s. By 1925, Sydney became a metropolis with a population of one million. By 1947, about 1.7 million people lived in the County of Cumberland area, 1.2 million of which lived in the main urban area between Port Jackson and the Georges River (refer to figure 2). Most of the remainder lived in the Parramatta-Hornsby-Mosman triangle and in Manly-Warringah. The more remote coastal areas of Pittwater and Sutherland were sparsely settled, and the outer western and south-western suburbs were fringed by a wide belt of scattered development. Beyond the city, all the large towns such as Penrith, St. Mary's, Blacktown, Richmond and Windsor had populations of less than 5,000 (CCC

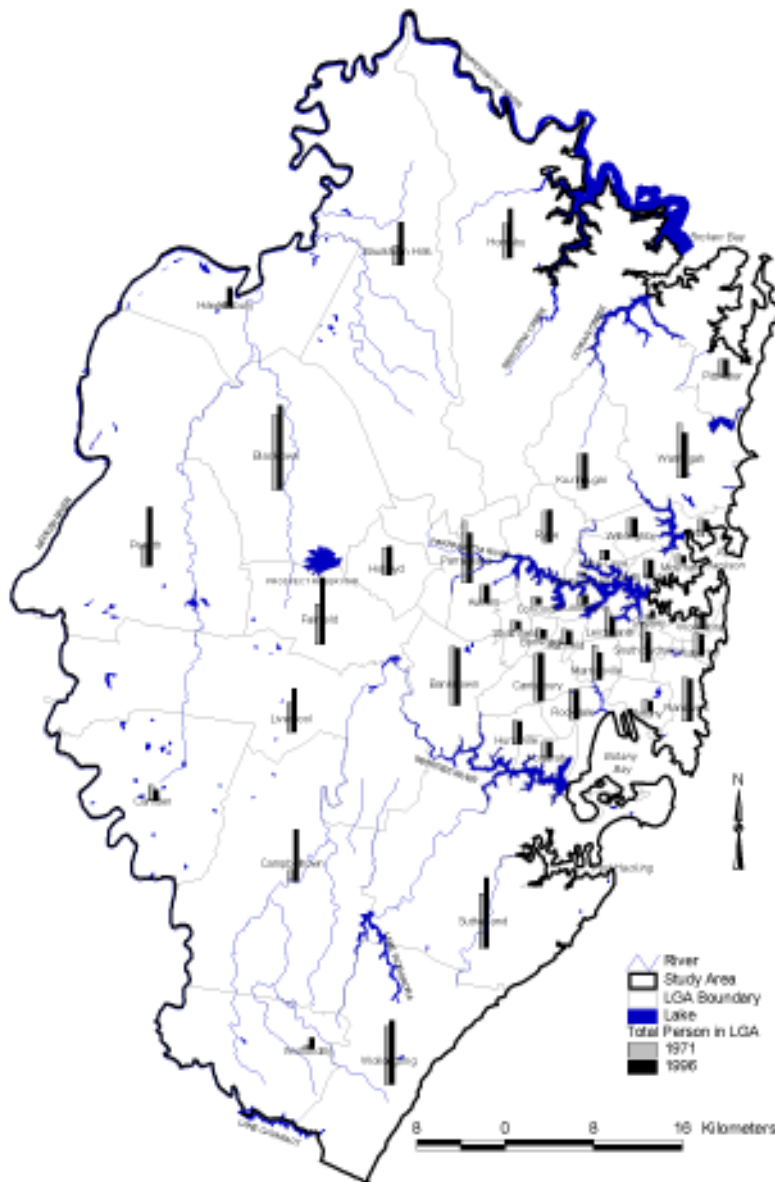


Figure 2 Population distribution by LGA in Sydney (1971-1996) (Data source: ABS Census 1971, 1996)



1948). The population of Sydney almost doubled in the following 50 years. According to the 1996 census data, total population in this area was 3.36 million, which was 55.6% of the total population in NSW and 18.8% of Australia. Population increased more rapidly in the outer part of the metropolitan Sydney than in the inner part. Figure 2 shows population distribution and changes by Local Government Area (LGA) from 1971 to 1996.

2.2 Data Sources and Data Quality Problems

Geographical data are needed to generate an information system to illustrate the spatio-temporal change of

the urban extent of Sydney. These data are available from different agencies, including the Australian Surveying and Land Information Group (AUSLIG), the Australian Bureau of Statistics (ABS) and some other government departments.

As one of the major spatial data providers in Australia, AUSLIG produced a TOPO-250K vector data package in 1992. There are several data themes in that data package, including hydrography, infrastructure and relief data. The relief and transportation network data for this study were extracted from that data package. However, problems were experienced using

that data package to illustrate the physical urban extent of Sydney.

First of all, it was discovered that the dates of data for the urban built-up area in the study area are not consistent. Three different dates for the survey of the built-up areas exist within the study area (Figure 3).

These range from 1972 to 1992. Data in the inner part of Sydney were revised to 1992, but in the northeast coast and the west part, these data have not been revised since 1972; data in some of the southwest part were revised to 1984. Within the built-up area, some portions are defined as built-up void areas, but the dates of these data also range from 1972 to 1992.

Another problem for AUSLIG's built-up area data concerns its reliability and consistency. While

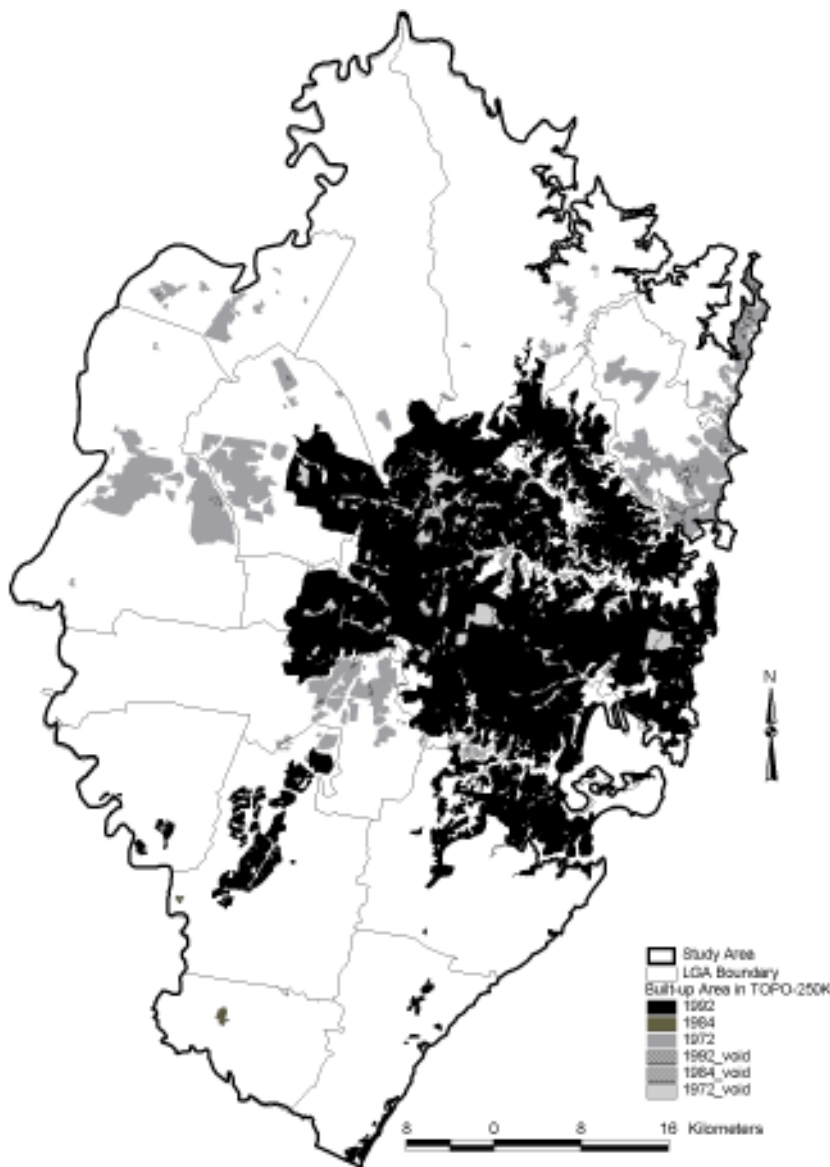


Figure 3 AUSLIG's TOPO-250K built-up area data problem (1)

comparing data from different sources in ArcView GIS, it was found that some built-up areas mapped in AUSLIG's TOPO-250K data package were suspect. A good example is in Terrey Hills, in the northeast part of Sydney (Figure 4). From the TOPO-250K data source, Terrey Hills was mapped as an urban built-up area in 1972. Another data source, the Raster-250K, which was also produced by AUSLIG and revised in 1993, shows that this area was not mapped as an urban area even in 1993. To decide which data were more reliable, the population density in this area was examined. The census data produced by the ABS show that before 1991, population density in this area was less than 193 persons per square kilometre, which approximately equals the minimum standard of

500 persons per square mile in Godfrey Linge's urban delimitation (Linge 1965) and should not be considered as an urban built-up area. Even the 1996 census data show that only a small area in the northeast of Terrey Hills met Linge's urban delimitation and could be mapped as urban; the population density in the rest part of this area was still too low to be considered as an urban built-up area. The same problems could also be seen in other areas near Liverpool and Penrith.

Due to the data inconsistency and low reliability, this research does not use AUSLIG's TOPO-250K data to define the urban extent of Sydney. It is used only to help establishing and checking thresholds to delimitate practical urban boundaries from the census data.

2.3 Using the Census Data

The Australian Bureau of Statistics (ABS) is another major data provider in Australia. As the ABS publishes census data for population and housing every five years since 1961, the census data are therefore able to be used to set up temporally consistent standards in defining the urban extent. In addition, instead of defining a sharp boundary between urban and non-urban areas, the census data could be used to define fuzzy or buffer zones between urban and non-urban areas, which would help to accurately visualize the process of non-urban to urban conversion.

Though the census data has been published at collection district (CD) level since 1966, the 1966 Census data are difficult to use in this research. One reason is that the area for each CD was not published in the 1966 Census therefore it is impossible to calculate its population density. In addition, the digital CD boundaries were not available either from ABS or by tracing back from the most recently published census. The 1971 Census shows that about half the CDs had boundary changes, but no specific information on how these boundaries had changed. It is with this concern that the starting date for this research is set to 1971, which is the earliest date with our available and consistent data source.

The 1981 to 1996 CD boundaries were converted into a GIS directly from ABS raw data in digital format. The 1976 and 1971 CD boundaries were created

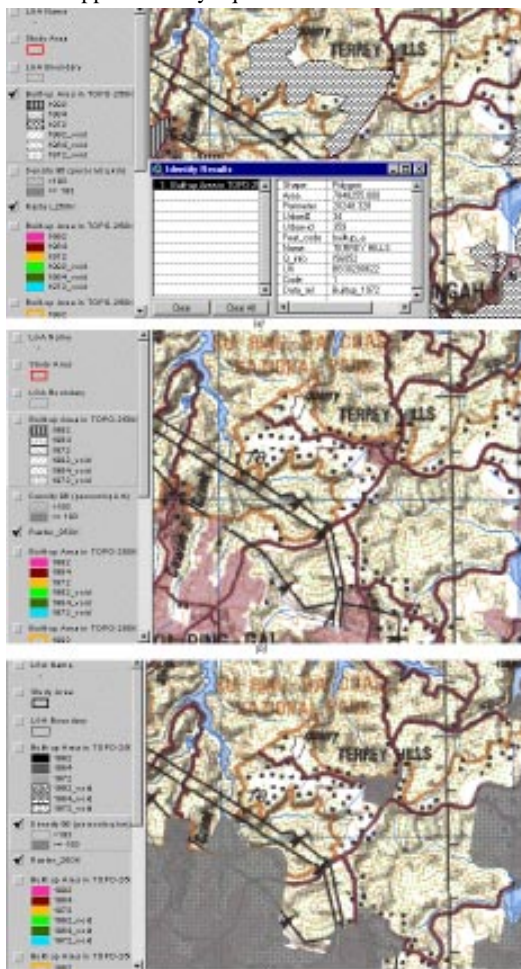


Figure 4 AGULIG's TOPO-250K built-up area data problem(2) (a - Built-up area in AUSLIG's TOPO-250K data; b - AUSLIG's Raster-250K data; c - Population density in 1996 from ABS census)



mostly from 1981 CD boundary file, according to the comparability indicator on CD boundary change between 1971 or 1976 and 1981 census; for the incomparable CDs, the printed CD boundary maps for 1971 and 1976 were consulted thereafter.

3 Defining the Urban Extent with Census Data

3.1 ABS Criteria

In the 1960s, at the request of ABS for statistical purposes, Godfrey Linge (1965) developed a set of principles and criteria to delimitate urban centres in Australia. It was delimited that a boundary be defined for all settlements with a population of 1,000 or more. For urban centres with a population of 30,000 and over and for a few smaller centres, the metropolitan area or urban centre was delimited 'by including all contiguous census collection districts with a population density of 500 or more persons per square mile', and 'certain collection districts, although not reaching the required population density, were also included by virtue of a) land use; b) being completely surrounded by urban CDs; c) forming a 'bridge' between two urban centres less than two miles apart so that they could be regarded as one single urban centre'. In areas with large numbers of holiday homes, dwelling rather than population criteria were used. These criteria were 250 dwellings (in lieu of the 1,000 population) and 125 dwellings per square mile (in lieu of the 500 persons per square mile). For urban centres of less than 30,000 population, local government area boundaries were adopted, unless they contained a large rural component or urban development was known to extend beyond the local government boundary. In these cases they were delimited by inspection of aerial photographs, by field inspection, or by consideration of any other information available, and the boundaries were set as closely as possible to the periphery of the built-up area without regard to local government boundaries.

Around each metropolitan area and urban centre with a population of at least 75,000 and a regional population of at least 100,000, a further boundary was defined, designed to circumscribe an area which would contain the urban development of that centre

for at least twenty years and which would generally be socially and economically oriented to the centre (SSDA 1998a).

These criteria were accepted by ABS and used in the 1966 Census. In the 1971 and the following census, concepts and methods used in defining urban centres were similar to those used at the 1966 Census, the main changes being the elimination of the 'indentation' provision in the 1966 Census and the re-interpretation of the 'enclosure' rule, i.e., if a CD with a density of less than 193 persons per square kilometre was surrounded partly by the sea or by a wide unbridged river, although the other surround areas were urban CDs, it would not be included within the urban centre. In addition, the threshold of 30,000 population of an urban centre to use the rules to determine its urban boundaries was reduced to 25,000 since the 1971 Census (SSDA 1998b). Concerns were also given to the impact of changing average household occupancy rate while using the dwellings criteria.

3.2 Defining a Fuzzy Boundary for Urban Extent

As Linge's criteria were not intended to 'draw a boundary around the built-up area of a town, but around the areas in which people are living an urban way of life' (Linge 1965, p. 67), the 193 persons per square kilometre criterion is very low in delimiting an urban extent. For the purpose of visualizing the urban development of Sydney in space and over time, it is necessary to define another criterion to illustrate the fully urbanized area in terms of the real world situation.

From Linge's delimitation, it is accepted that a CD area with a population density of less than 193 persons per square kilometre could be regarded as a non-urban area unless it meets one of the other sub-criteria in that delimitation. To define the fully urbanized area, both practical experience and spatial survey in GIS were used. Pragmatically, it is borne in mind that 'a fully built-up housing area in a large Australian town would have a density of at least 3,000 persons per square mile (approximately 1158 persons per square kilometre)' (Linge 1965, p. 67).



The census data show that the overall gross population density of Sydney changed from 770 persons per square kilometre in 1971 to 870 persons per square kilometre in 1996. Some areas at the urban-rural fringe were further consulted in GIS, these areas include Penrith, Campbelltown and Baulkham Hills Shire. From a 1981 Landsat Thematic Mapper (TM) image, it is not difficult to find out the non-urban or rural areas of these three local government areas. For these non-urban areas, the population densities at CD level were all under 1000 persons per square kilometre from 1971 to 1981.

In addition to the survey of population density, investigation was also made from the census data on household densities at CD level. The household densities were converted to gross population density with the concern of the household occupancy rate as well.

Both practical experience and spatial survey in GIS show that the 1000 persons per square kilometre density at CD level is good to be accepted as a minimum standard to define a fully urbanized area in Sydney metropolitan area. This figure, therefore, is used in this research. Areas between non-urban and fully urban areas, which have population density between 193 and 1000 persons per square kilometre, are urban-rural fringes. They are therefore regarded as partly urban areas.

4 Visualizing Sydney's Urban Development in GIS

4.1 GIS for Visualization

A better knowledge of the spatial data is considered important for further analyses and modelling; the more one knows about the data, the better one can deal with the data. Therefore it is important to have some techniques to help understand the data before any further analyses or modelling. GIS provides a powerful technique both for the management of spatial data and for a visual insight into these data. As for its spatial functions for visualization, GIS has been used to visualize spatio-temporal process of some physical change in several cases (e.g., Batty 1994; Batty & Howes 1995; Clarke & Gaydos, in press; MUS 1998).

In this research, GIS is used not only to identify errors in data and to check consistency of data from different sources, as have been shown in section 2, it has also been used to explore visually the development of urban areas of Sydney in a certain period of time. By overlaying the urban extent data layers created from census data series on the physical topography, a temporal process of the urban expansion of Sydney in relation to the relief could be visualized, and the rates of change at different time periods could be detected as well. The urban expansion could also be visualized in relation to the transportation network or other infrastructure or to the urban planning schemes. The influences of infrastructure or urban planning on the urban growth, or vice versa, could therefore be evaluated. Based on a GIS's functions for visualization, movie programs are created and visualized in the next section.

4.2 Movies on Sydney's Urban Development

First of all, a digital elevation model (DEM) was generated using data from AUSLIG's TOPO-250K relief data. Roads, railways and ferry routes were extracted from the same data source. To illustrate the urban development of Sydney from 1971 to 1996, images were generated in and exported from ArcView layouts to show the urban and partly urban areas in relation to the relief. To keep the images neat and clear, the transportation network was not overlaid on top of the images. These images were then used to create a time series animation with Jasc's Animation Shop program. Jasc's Animation Shop was selected for this purpose due to its advantages in controlling the frame rate of animation, which is important for a better visualization. The spatial expansion of the urban area of Sydney could be visualized clearly in this time series animation, which is available on the website <http://www.une.edu.au/geoplan/yliu/research.html>.

In addition to the two-dimensional time-series animation, a spatial flyby animation over the changed areas of Sydney from 1971 to 1996 was generated in IMAGINE VirtualGIS (ERDAS 1997). The digital elevation model was used as a surface in this 3-D animation. On top of the DEM were draped the 1981

1971 \ 1996	Non-urban	Partly urban	Urban
Non-urban	2622.03	179.74	154.60
Partly urban	3.52	268.96	138.80
Urban	0	2.35	753.00

Table 1 Urban Area Change in Sydney (1971-1996) Unit: square km

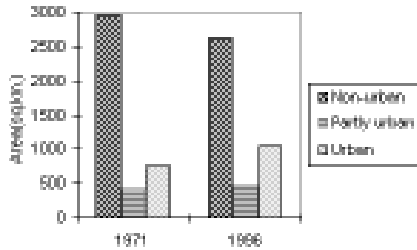


Figure 5 Urban area change in Sydney (1971-1996)

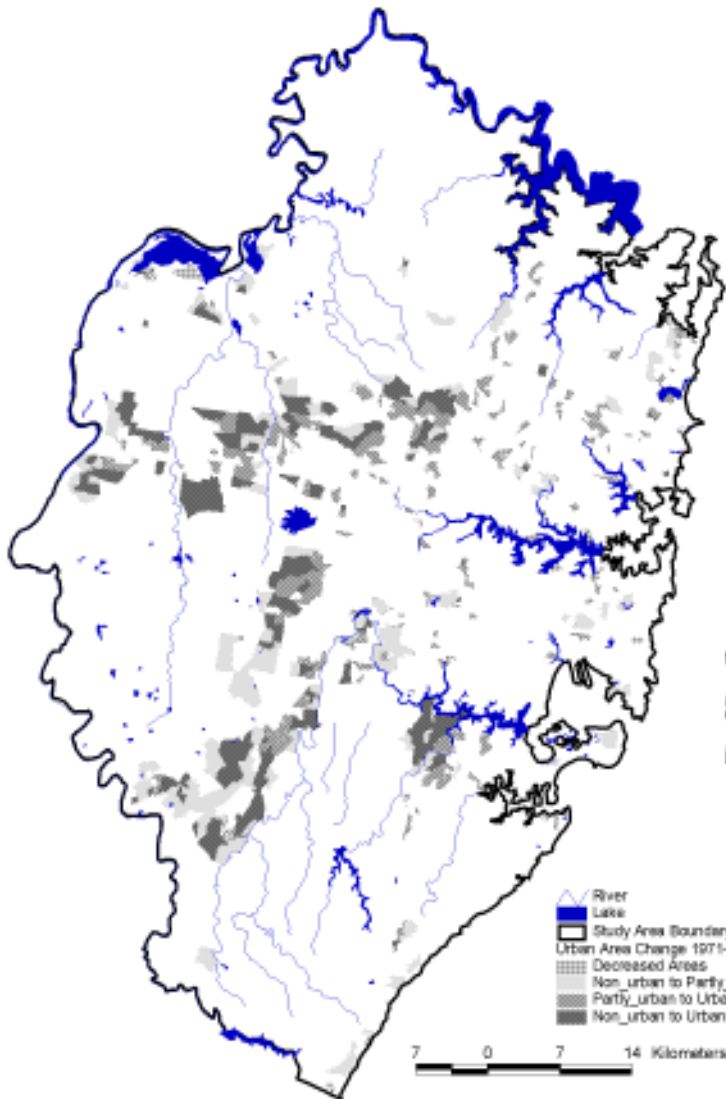


Figure 6 Expanded urban areas in Sydney (1971- 1996) (Data source: ABS census 1971, 1996)

Landsat TM IMAGE and a polygon coverage showing areas developed from non-urban to partly urban or urban, or from partly urban to urban areas from 1971 to 1996. This polygon coverage was created by overlaying the 1971 and 1996 urban extent data from the ABS census. In IMAGINE VirtualGIS, a flight path over the areas with physical urban expansion was created and a fly-by animation was generated thereafter. As a fly-by animation over all areas with physical urban expansion would be very large, only a sample of this animation from Parramatta to Campbelltown is available on the website <http://www.une.edu.au/geoplan/yliu/research.html>. In this sample animation, areas

circulated by red lines are the expanded urban areas.

4.3 Sydney's Urban Development in Space and Time

From the visualization of census data in GIS, it is understood that fully urbanized area of Sydney had increased from 18.26% in 1971 to 25.38% in 1996. In addition, 4.36% of the area had been partly urbanized (Table 1 and Figure 5). In total, an area of 473.1 square kilometres had been developed from non-urban to partly urban or urban, or from partly urban to urban; an area of 5.87 square kilometres had decreased from partly urban to non-urban or from urban to partly urban. The decreased areas were most likely near inundated lands. Whether these areas were actually depopulated or they were just artificially changed because of the CD boundary change during the census years is not certain at this stage, which need to be checked through field work. The average urban expansion rate of Sydney was 1.52%. Compared with its average annual popula-



tion growth rate of 0.43% at the same period, the urban expansion of Sydney was much greater than that of its population growth.

While visualizing this change spatially (Figure 6 at next page), it is understood that the urban expansion of Sydney from 1971 to 1996 had been largely in accordance with what was planned at the Sydney Region Outline Plan in 1968 (SPA 1968) (Figure 7). The south west sector covering Campbelltown, Camden and Appin, the west sector covering Penrith and Blacktown, the Fairfield-Hoxton Park and the south sector at Liverpool and Sutherland had been major directions for urban development during this period of time. Development also happened in areas at the north west part along the roads and railway lines and at the north east part in Warringah-Pittwater. Whether the Sydney Region Outline Plan had successfully controlled the urban development of Sydney over the past 25 years, or it had just identified the obvious directions of urban growth in that area is worth of further consideration.

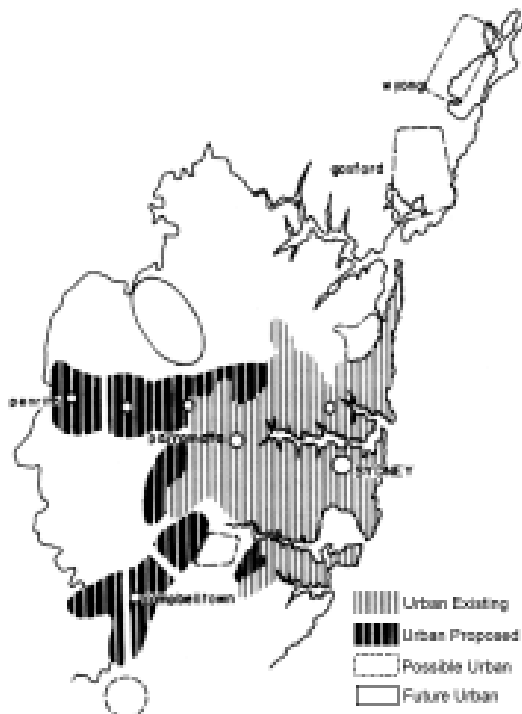


Figure 7 Sydney Region Outline Plan (1970 - 2000 A.D.)
(Source: Sydney Region Outline Plan published by SPA in 1968)

5 Conclusion

This paper has discussed the way GIS could be used for the visualization of the urban development of Sydney from 1971 to 1996. GIS was used first to manage the spatial data from different data providers and to check the reliability and consistency of these data. Both AUSLIG's TOPO-250K data for urban built-up area and the ABS census data in 1966 and 1971 were found to have problems. In delimiting the urban extent with census data, while Linge's rules were accepted to define the non-urban or rural areas of Sydney, GIS was used to set up criteria to define a fuzzy area between non-urban and the full urban areas, therefore a new state of partly urban area was added.

In addition to the careful visualization of data quality and consistency, GIS was used to visualize the urban development of Sydney during that period of time. Animations show that the urban development of Sydney had been supported by the transportation network and the smooth relief, and it was largely in accordance with what had been planned in the Sydney Region Outline Plan.

The paper shows that GIS is an important and useful technique both for the visualization of spatial data quality and consistency and for the visualization of urban development in space and over time. Visualization in GIS has provided a virtual background knowledge for modelling Sydney's urban development, which is an ongoing research on this project.

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