The Costs of Infill versus Greenfield Development – A Review of Recent Literature

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1 Introduction

Sydney's rapid growth provides urban planners and government infrastructure departments with perplexing difficulties which necessitate long term strategies. Complicating the issue are changes in Government or even changes of policies during a Government's stay in office, which results in what appears to be unplanned development. Often the planning has been at a local government level, as is evidenced by the variety of building types, particularly high rise, or infill, that are observed across Sydney, and by the American-style sprawl, or greenfield development, that has occurred along Sydney's outer arterial roads. One of the likely reasons growth has occurred in this seemingly unplanned manner is that the lack of available information about the real costs of infill and greenfield development may lead to sub-optimal and inconsistent government planning decisions over time.

This paper reviews recent literature related to assessments of the total community costs of developing infill versus greenfield areas. These cost comparisons include: essential infrastructure such as roads, transport, water and sewerage; other infrastructure such as new schools versus under-utilised schools; community services, such as police and health; public transport; and social costs such as comparisons of environmental conditions and air quality. Given the unique mix of infill and greenfield development in Sydney, we undertake this literature review with specific reference to Sydney as an Australian case study.

We found that while there are many comparisons of specific costs such as transport infrastructure, there are few studies that have attempted to quantify all the costs in a structured and comparable manner. The selection of reviewed studies offered different approaches to quantifying the comparative costs in part, and, in one case, in total.

The trend to sprawl is not generally seen in the older developed nations, such as those in Europe, to the extent that it occurs in rapidly growing wealthy western countries such as the United States, Canada, and Australia. Overall, the literature tends to favour infill redevelopment over greenfield development, because of lower costs, demand for housing close to the CBD, and reduced contribution to greenhouse gas emissions. On the other hand, there is some literature that recognises the need for urban growth, or at least fringe development, because it recognises other market forces, provides low cost housing, economic development, and areas of clean air for families to live in, rather than in polluted, congested, and crowded inner suburbs where apartment living may provide the only low cost choice for many.

2 Definitions

One of the key barriers in this literature review process was the existence of many terms that are used to describe urban development and redevelopment in different parts of the world, and in different literature. For this terminology to be understood and used to describe similar properties of land areas, the following definitions were obtained from the various sources used in this paper.

2.1 Brownfield

According to the US Environmental Protection Agency (1997), a brownfield is *"an abandoned, idled, or underused industrial or commercial facility where expansion or redevelopment is complicated by real or perceived environmental contamination."* More recently, the following definition of 'brownfield' can be found on the US EPA website: *"With certain legal exclusions and additions, the term 'brownfield site' means real property, the expansion, redevelopment, or reuse of which may be complicated by the presence or potential presence of a hazardous substance, pollutant, or contaminant."* (EPA, 1997). This definition was codified into US Federal law in 2002 in "Public Law 107-118 (H.R. 2869) - "Small Business Liability Relief and Brownfields Revitalization Act".

The definition adopted by the National Round Table on the Environment and the Economy is as follows: "*brownfields are abandoned, vacant, derelict or under-utilised commercial and industrial properties where past actions have resulted in actual or perceived contamination; brownfields differ from other contaminated sites in that they hold active potential for redevelopment*" (NRTEE, 2003).

The complicating issue in the empirical definition of brownfield is the *potential* (but not necessarily actual) contamination by some pollutant or substance. In the Sydney context, this issue is important in determining whether to classify a redevelopment of, for example, a section of the potentially mine-scarred military base in Holsworthy, as a brownfield. A good deal of waterfront land on Sydney Harbour, quite close to the CBD, may also be defined as a brownfield, with the resultant high real estate value making decontamination and infill development financially feasible, while lower value sites may be less attractive to developers.

Another issue is the geographical location of brownfields. While Amekudzi *et al*. (2003) utilise the US EPA's (EPA, 1997) definition of brownfields, they also state that *"while some brownfields are rural, the majority are in urban areas."* (p.28).

2.2 Greyfield

The term "greyfield" was recently defined in a study by PricewaterhouseCoopers and the Congress for the New Urbanism as *"old, obsolete, and unprofitable retail and commercial sites"* (PricewaterhouseCoopers, 2001). Clearly, one major difference between a greyfield and a brownfield is the lack of perceived contamination of the site. In the Sydney context, the term 'greyfield' may refer to a declining retail strip of land, for example Parramatta Road.

2.3 Infill

Infill is also described as 'urban consolidation', 'medium density housing', 'redevelopment' or 'high rise development'. Infill has been defined as: *"the more intensive use of land for residential development in urban areas. Such development can be in the form of medium to high density residential flats, town houses (row housing) and villa units. Urban consolidation is generally deemed to refer to redevelopment of existing urban areas and infill development of vacant or under-utilised urban areas. However, by inference it is also taken to mean the more intensive use of land in fringe areas by the development of residential land of higher densities."* (TM & AE, 1991, p.5).

Infill was the term we adopted for this paper to describe redevelopment of used land. In addition to the redevelopment of land within the confines of, or surrounding, existing urban areas, the definition of infill development appears to encompass the definition of "brownfields" and "greyfields", described above.

2.4 Sprawl

The concept of sprawl has been difficult to define empirically, as noted by the authors of TCRP Report 74 (2000), who defined sprawl as: "*low-density, leapfrog development that is characterized by unlimited outward extension. In other words, sprawl is significant residential or non-residential development in a relatively pristine setting. In nearly every instance, this development is low density, it has leapt over other development to become established in an outlying area, and its very location indicates that it is unbounded."* (Burchell *et al.*, 2002, p.2). Sprawl is a pejorative term denoting "un-aesthetic, lazy and undisciplined" development. (Gordon and Richardson, 1997), and it has even been referred to as promiscuous urbanisation (Bunker and Houston, 2003).

The TCRP Report 74 (2000) further complicated the definition of sprawl by distinguishing between 'uncontrolled growth' and 'controlled sprawl', the latter defined as *"limiting a significant share of development to already developed counties or to areas as close to already developed locations as possible.",* which is a combination of urban consolidation (20 percent increase in dwelling density in urban areas) and planned fringe development at a greater density than uncontrolled sprawl. (Burchell *et al.*, 2002, p.4).

2.5 Greenfield

Greenfield is also described as "suburbanisation", "urban growth" or "suburban fringe development". A universal definition of "greenfield" was difficult to find in the literature. This was probably due to simplistic associations with the terms "green" and "field", which signify farmland and/or forests. The majority of articles define "greenfield" as, for example, *"unused land parcels or farmlands outside urban borders"* (Amekudzi *et al*., 2003, p.28). De Sousa (2000) defines greenfield more specifically as *"a **clean** agricultural or open land site located in the periphery"* (p.833, emphasis added). The definition of 'greenfield' thus appears to encompass wildlife habitats and productive farmland on the urban periphery. Because this is the nature of fringe land in Sydney, this was the definition we adopted for this paper.

The definitions given for greenfields raise concerns about whether to define greenfields as occurring solely on the urban periphery (as is normally expected) and whether to define brownfields as former urban industrial (or other) sites. In other words, the two complicating issues are the geographical proximity of the to-be-developed land to existing urban areas and whether the to-be-developed land was previously a farmland or an industrial or military site. Given the greater scope of the term 'infill', particularly in encompassing the development of brownfield sites, we have chosen to use the term 'infill' for the purposes of this paper.

Taking the above definitions together, we argue that, in the specific example of Sydney, the north western and south western growth areas can be classified as 'greenfield' development. The development of industrial and harbour side land, as well as the development of existing suburban areas into high density housing can be referred to as 'infill' development.

3 The Sydney Context

In 1951 the incumbent government of NSW declared a strip of land to the west of Sydney to be the "green belt" which was designed to restrict urban sprawl and provide "lungs" for the city. Beyond this was a rural zone, extending to the edge of the plain, beyond which there lay "rough land", generally unsuitable for urban development. This plan was known as the "County of Cumberland Plan". Since then, successive governments have either reversed or revised this decision. Planning responsibilities have been shared by state and council government, and little focus has been put on planning policy regarding the entire fringe.

(Bunker and Houston, 2003, p.308). As a result, parcels of land have been gradually handed over to developers, and the green belt has diminished accordingly. Thousands of hectares of previous farmland in the north-west, west, and south-west of Sydney have been urbanised, prompting infrastructure development such as roads, public transport, town centres, and schools. West of Parramatta, where sprawl has occurred along the major arterial roads, there are inadequate public transport services and the car is the main form of household transport. There is frequent traffic congestion on these arterial roads, connecting the outer suburbs to regional centres, and on main roads from them to Sydney's major work centres. These growth activities have not only reduced the size of the "green belt", but have resulted in increasing levels of emissions into the Sydney airshed. The Sydney region is "a basin-like structure bound by elevated terrain to the north, west and south" and the ocean to the east. This topography combined with wind patterns, sunlight and air temperature creates the Sydney airshed in which pollutants may become concentrated for a time. As much as 80% of oxides of nitrogen and 90% of carbon monoxide, as well as high levels of particulate matter, are emitted from private and commercial motor vehicles, principally during the morning and evening peak traffic periods (NSW EPA, 2001).

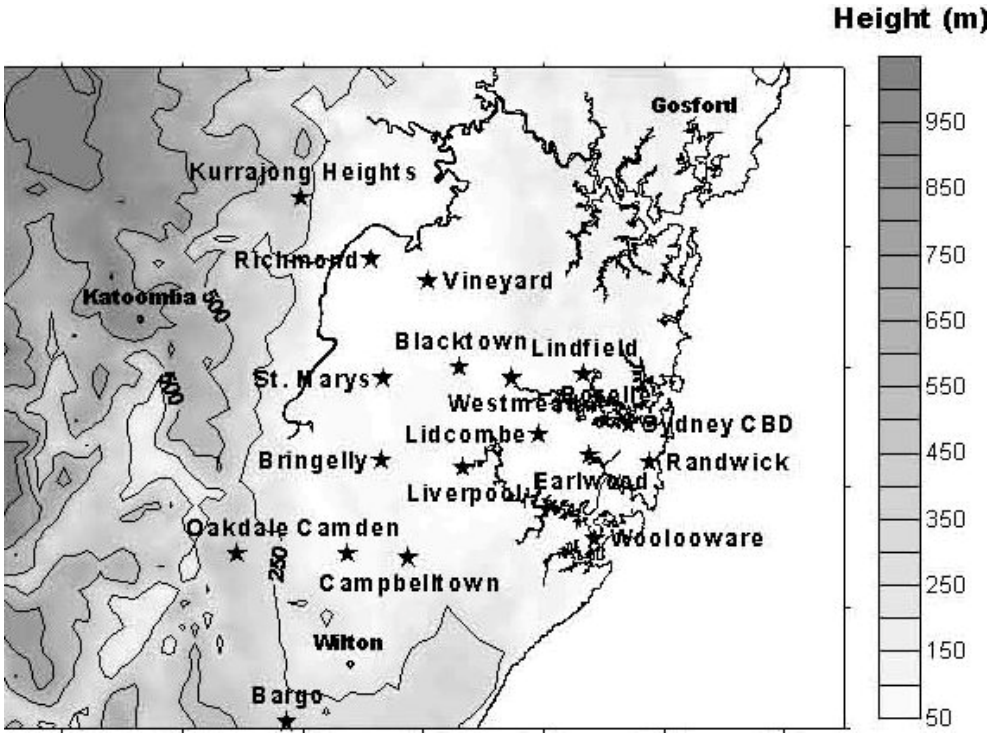

Figure 1: The Sydney airshed showing air monitoring stations and altitude above sea level. Air monitoring stations are indicated by a star. Shading indicates height above sea level in metres. Source: (NSW EPA, 2001).

Population growth in Sydney, and indeed throughout Australia, is an additional consideration. Australia's population doubled between 1901 (3.8 million) and 1947 (7.5 million). Since then growth has moved at a faster rate, now exceeding 20 million, and expected to reach 30 million by 2051. Sydney has grown from a population of 1.5 million in 1947 (Wilson, 1947) to 4.1 million in 2005 (ABS, 2002). This has been principally from overseas immigration and migration from rural areas. Additionally, the average size of households in Sydney is falling, creating demand for extra housing. The Australian Bureau of Statistics (ABS) projects that the population of Sydney will grow from its current (2005) population of 4.1 million (including overseas visitors) to over 5 million by 2021 and close to 6 million by 2051, given projected overseas (positive) and internal (negative) migration levels (ABS 2000). The growth rate is expected to slow to zero by 2063. The ABS projects that

between 1996 and 2021 Sydney will require an additional 560,000 households (cited by Smith, 2003).

In its 2003 Managing Sydney's Urban Growth forecast, Planning NSW has higher population growth estimates, projecting that the Sydney – Central Coast – Illawarra region will require 27,800 new dwellings a year in the period 2001 and 2016, with 139,395 in total between 2003 and 2008. Of these dwellings, over 23 percent or 32,505 are forecast to be detached housing built in greenfield areas. An estimated 48 percent, or 67,293 new dwellings are forecast to be multi-unit dwellings in older urban regions, or infill. The remaining 28 percent, or 39,202 dwellings, are to be multi-unit dwellings in existing outer suburbs (18 percent), detached houses in existing suburbs (8 percent), and 2 percent other dwellings (cited by Smith, 2003).

The City of Cities strategy released by Planning NSW (2005) forecasts population growth in the Sydney Greater Metropolitan Region, including the Lower Hunter, Central Coast, and the Illawarra, of 40,000 people per year, reaching 5.3 million by 2031. The strategy provides for 220,000 new dwellings in fringe areas and 420,000 new dwellings in existing suburbs, an estimate that produces an annual average of 25,600 new homes to be built. This new strategy apparently anticipates a lower dwelling growth rate than previously, accompanied by an increased number of greenfield dwellings including a far higher level of multi-unit dwellings in fringe areas. These forecasts are summarised in Table 1.

Table 1: Planning NSW forecasts for Sydney Greater Metropolitan Region

New Dwellings	**2002 Managing Sydney's Urban Growth forecast for 2003-2008**	**2005 City of Cities forecast for 2006-2031**
New dwellings required annually	27,800	25,600
Comprising		
- Greenfield detached	6,533	8,800
- Multiunit in greenfield suburbs	5,004	
- High-rise in infill areas	13,483	16,800
- Detached houses in infill areas	2,224	
- Other	556	0
Total new dwellings for the period 2003-2008	**139,000**	**128,000**
Total new dwellings for the period 2006-2031	**695,000**	**640,000**

The strategy envisages a rapid growth of new industry in the west, in an area directly between proposed and existing greenfield housing developments. The result of these changes has been that Sydney is growing out, particularly in the north-west, west, and south-west, along the highways that traverse these areas, and low density housing and commercial development has proliferated, while closer to the CBD, developers have moved in on old industrial sites, and even disused wharves, and built high value, relatively expensive high density housing. In addition to this, older low to medium density housing areas surrounding transport hubs between the CBD and the outer western suburbs, such as Hurstville, Chatswood, Ashfield, and Parramatta, to name a few, have undergone development through demolition of older low rise buildings and the building of higher density relatively inexpensive housing as infill development.

Greenfield development requires substantial infrastructure costs for local councils to build suburban roads; government owned utility authorities to lay water and sewer lines, power supply and telephone cables; and government to provide basic community services such as town centres, schools, emergency services, police, public transport and efficient road systems. By contrast, these services and infrastructure generally already exist and may have spare capacity in infill areas. Therefore, there are possibilities that they can be provided at comparatively little infrastructure expense in infill areas, compared to greenfield developments, although infill areas are at times subject to decontamination and landscaping

costs. Additionally, because the infrastructure and community support systems are in existence, they are quite frequently the *reason* for infill development, for example in suburbs such as Hurstville, Chatswood and Bondi, which are located close to Sydney's public transport hubs, shopping centres and main roads.

4 Objectives and scope

This paper reviews and summarises selected literature that is applicable to, but not necessarily restricted to, the Sydney growth scenario. The component issues researched herein are as follows:

- The capital costs of greenfield development and related infrastructure;
- The capital costs of infill redevelopment;
- The development of a good model for this comparison; and
- The social costs and implications of either course of development.

5 Australian evidence

In this section, we provide a brief summary of the most significant pieces of literature found on costs of infill and greenfield development in Australia.

5.1 Housing costs study number 2 - *Evaluation of fringe development and urban consolidation*

According to Travers Morgan and Applied Economics (TM & AE, 1991), demographic and family structures in Australia since 1970 show an ageing population, an increase in household incomes, and a rise in single person households. Since 1950, Sydney has experienced an increasingly rapidly rising population through intrastate, interstate, and overseas migration. Alongside this, housing prices have increased in Sydney more than in other Australian cities. Overall housing cost surges led the Commonwealth Department of Industry and Commerce, and Departments of Housing in New South Wales, Victoria, and South Australia to commission the Housing Costs Study of 1991. Part of this study was to compare the costs and benefits of urban consolidation (infill) to fringe development (greenfield) in Sydney, Melbourne, and Adelaide.

The reason for the study was the collective concerns of these governments about the debt funding of infrastructure, whereby governments borrowed the funds required to build the infrastructure related to greenfield developments. The cost of servicing each block (of land) was estimated to be between $20,000 and $60,000. These costs include physical and social infrastructure, including 'piped' services such as water, sewerage, drainage, gas, electricity, and telephone; suburban roads and a share of the arterial roads; and health, education, and community service costs. There have been increasing calls for these costs to be passed on to developers and ultimately to the purchasers of building blocks, in an attempt to retard urban development and excess land consumption. However, there is debate regarding the equity of the impacts of such housing policies. Encouragement of medium density housing in older suburbs, through reductions of controls, has been recommended by prior studies and these policies have been adopted by some State governments with limited success. These measures have met with strong opposition from some councils who impose strict controls to limit increases in urban densities.

The housing costs study achieved three main aims. The resulting report:

1. Discussed current policies and legislation in place to encourage urban consolidation;

2. Developed a social welfare methodology for calculating social costs and benefits; and
3. Applied a methodology to measure four strategies for housing a given population in each of the three cities, namely:
    a. A 'dispersed fringe' scenario with eight dwellings per hectare housing the base population;
    b. A 'concentrated fringe' scenario with ten dwellings per hectare housing a proportionately higher population than the base population;
    c. Two thirds of the base population located at the fringe with eight dwellings per hectare, and one third of the base population located in middle ring suburbs, by erecting four units on existing blocks; and
    d. The base population located at the fringe with eight dwellings per hectare, plus an additional population equal to one third of the base population located in middle ring suburbs, by erecting four units on existing blocks.

The results of this methodology are shown in Table 2. The results given in Table 2 were principally determined by the underlying house prices in each of the cities. In Sydney, housing costs on the fringe were close in cash terms to the 'resource cost' of providing the housing and the entire associated infrastructure. There were, however, holding costs of developing the infrastructure, especially roads, water, sewerage, and stormwater, in advance. In Melbourne, the dwelling price was well short of the resource cost. In Adelaide, a consumer surplus may arise from fringe development because consumers are willing to pay more for such dwellings than the full resource cost. This is a result of medium density housing being considered less desirable and infrastructure and land prices being much lower on the fringes of Adelaide.

Table 2: Net Social Benefit ($M) from Urban Strategies in Sydney, Melbourne, and Adelaide

Scenario	**Sydney**	**Melbourne**	**Adelaide**
	Urban Consolidation Middle Ring Suburbs		
	Hornsby, Parramatta and Ryde LGAs	**Brunswick, Melbourne, Northcote and Preston LGAs**	**Enfield, Port Adelaide and Woodville LGAs**
Dispersed fringe (8 dwellings/ha)	-26.88	-240.61	47.5
Concentrated fringe (10 dwellings/ha)	-40.6	-197.76	59.36
A ⅔ dispersed fringe @ 8 dwellings per hectare and ⅓ infill @ four units per existing block.	126.73	-61.16	46.44
Dispersed fringe @8 dwellings per hectare plus an additional population equal to ⅓ infill @ four units per existing block.	143.72	-133.61	62.2

The housing costs study report concluded that areas with excess infrastructure capacity should be identified, that developers should not pay the capital contributions for the use of this infrastructure, and that there be greater scrutiny of fringe development and full charging of costs, including all infrastructure costs, to the developer or purchaser.

5.2 Sydney – the urban sustainability challenge

In 2003, the Total Environment Centre (TEC) published a literature review addressing the challenges facing urban planners in Sydney (TEC, 2003). This review included an appendix by Gillespie Economics titled "Economic Analysis of Urban Forms", which continued the theme used in TM & AE (1991), and brought in additional literature to consolidate the theme of social welfare economic cost and benefit analysis beyond a mere infrastructure cost comparison. Included in the analysis were:

- Economic infrastructure, including water, sewerage, power and communications;
- Social infrastructure, such as education, recreation, health and welfare;
- Developers' net benefit (producer surplus);
- Transport costs and benefits, both public and private;
- Amenity/congestion effects; and
- Environmental effects.

The literature reported in the TEC review (TEC, 2003) suggested that while there may be excess capacity in Sydney's older suburbs of services such as water and sewerage, capacity constraints on infrastructure, such as roads, may result in high costs of infill development in developed areas. Due to the complexity of the relationship between infill and transport costs and benefits, few studies have been undertaken on the subject. The majority of studies have focused on more easily identifiable infrastructure costs such as water, communications, schools, hospitals, etc. Exceptions to this cited by TEC (TEC, 2003) included:

1. The Road and Traffic Authority's (RTA) study of 1991 (Travers Morgan, 1991), which compared three broad development scenarios for Sydney based on decentralisation rather than infill versus greenfield. This study assumed scenarios in which half a million, and a million, people were decentralised (moved to non metropolitan cities) and worked in those locations, thus reducing transport and road infrastructure costs as well as environmental effects as the level of decentralisation increased.
2. A 1992 ACT Government case study of infill versus greenfield development in the suburb of Gungahlin. It estimated that the savings of infill rather than greenfield development over 5 years amounted to $58 million in infrastructure costs including a $21 million saving in arterial and access roads, and savings of $6 million in recurrent costs. These savings were based on an expansion of 3,000 dwellings per year in two contrasting scenarios.
3. The 1991 "SEQ 2001: A Plan For An Under-Developed Economy" (SE Queensland) review which identified capital savings on the order of $3 billion over 20 years in the cost of roads by adopting a concentrated development pattern rather than the existing trend. However, the Regional Planning and Advisory Group (RPAG), which developed the review, received considerable criticism for the methodology used (CPSD 1994).

6 International evidence

In this section, we provide a brief summary of the most important overseas studies of the costs of infill and greenfield development.

6.1 The costs of sprawl

This publication by Burchell *et al*. (2002) was a study of the future infrastructure needs of the USA for the period 2000 to 2025. It was based on an estimated population growth of 60 million people housed in an additional 26.5 million dwellings. Of this 60 million population increase, 49.5 million people will be employed in 26.5 million units, leading to a total of 53 million units (households and workplaces) to be built and serviced by new or existing infrastructure. The study compared an uncontrolled growth scenario, or "sprawl", to a controlled scenario, which is a combination of urban consolidation (twenty percent increase in dwelling density in urban areas) and planned fringe development at a greater density than uncontrolled sprawl.

The scenarios studied identified the possibility of the following savings over twenty five years from using a controlled versus uncontrolled growth policy:

- One million six hundred thousand hectares of land including six hundred thousand hectares of farmland, six hundred thousand hectares of environmentally fragile land and four hundred thousand hectares of other land;
- A local road infrastructure cost saving of 303,000 lane kilometres and US$109.7 billion or 11.8 percent;
- Water savings of 564 million litres/day;
- Water infrastructure cost savings of US$13 billion;
- A fiscal impact of US$4.205 billion through lower service provision expense; and
- Property development savings of US$420.3 billion, or 6.6 percent.

This important report is highly applicable to the Sydney context, where water shortages and finite land resources present a sustainability question to the city's projected growth. Extrapolating the calculations used in Burchell *et al.* (2002), for a projected population growth of 2 million in Sydney, Sydney might expect the savings shown in Table 3. This is indicative only, because the cost and availability of raw materials may vary between the US and Sydney, and different economies of scale may be present. Water savings are achieved through the limitation in water supply laterals, which must be filled, and through limiting the land that homeowners need to irrigate, by limiting the size of building blocks. These savings demonstrate the possible reason for new housing developments being on small blocks, with large homes built in very close proximity.

Table 3: Savings achievable through controlled growth in the Sydney region for a population increase of 2,000,000 between the years 2006 and 2051

Projected Savings	**Amount**	**Units**
- Land use	53,333	Hectares
- Road kms built	10,100	Kilometres
- Road building cost	$5,500,000,000	
- Water quantity	18,800,000	Litres/Day
- Water infrastructure costs	$650,000,000	
- Fiscal impacts of lower service provision	$210,250,000	
- Property development savings	$21,000,000,000	

6.2 The impact of residential density on vehicle usage and energy consumption

Golob and Brownstone (2005) examined and modelled the relationship between urban density and vehicle usage, and fuel consumption in particular. The model is created to test the opposing hypotheses, on the one hand, that unplanned growth causes, *inter alia*, an automobile-dependent transportation system accompanied by traffic congestion and increases in energy consumption an air pollution (Ewing, 1997), and the alternate view that sprawl is the inevitable outcome of market preference for low density housing and private automobile use (Gordon and Richardson, 1997). While Ewing argues that higher densities result in fewer and shorter trips, and a lower mode share for automobiles, Gordon and Richardson (1997) contend that low density housing and private rather than public vehicle use is an inevitable outcome of market preference, and that industry will follow the population to the suburbs, resulting in a reduction in VKT[1]. The Golob and Brownstone (2005) model employed California data drawn from the National Household Travel Survey (NHTS) 2001, focused on residential density, and drew the following conclusions.

Urban density was directly correlated with:

- The type of vehicle used;

[1] Given current predictions that oil demand will outpace supply in the near future, this seems an irrelevant argument.

- The number of vehicles in each household; and
- The number of drivers in each household.

Compared to households in higher density areas, households in lower density areas:

- Drove larger and less fuel efficient vehicles, often sports utility vehicles (SUVs);
- Owned more vehicles per household;
- Had more drivers per household;
- Drove the larger vehicles more often than smaller vehicles in the household; and
- Drove more kilometres.

Additionally, there was a direct correlation between average household income and each of vehicle usage, energy consumption, and low housing density. Hence, higher levels of low density greenfield development create higher per capita levels of energy consumption, particularly fossil fuels, and consequently greater levels of greenhouse gas emissions and air pollution per capita for a given the metropolitan airshed, such as Sydney's. This has a continuing effect on the costs of low density (greenfield) development and must be measured in any analysis of comparative costs in addition to infrastructure costs. Such societal costs are not readily apparent to the residents of greenfield suburbs, because the ambient air pollution levels therein are generally lower than in high density suburbs, although they all exist within a single airshed. This is supported by evidence showing that air pollution levels in Sydney Central are consistently higher than those recorded in the outer suburbs (NSW EPA, 2001).

6.3 Measuring the public costs and benefits of brownfield versus greenfield development in the Greater Toronto area

As has happened in Sydney, brownfields present a problem to virtually every industrialised nation due to the migration of industries from cities, leaving them with innumerable under-utilised or vacant sites. In this paper, De Sousa (2002) attempted to analyse and model the economic, social, and environmental costs and benefits of redeveloping brownfields vis-à-vis greenfields for both industrial and residential use. This in-depth level of analysis differentiates the De Sousa (2002) study from those that compare compact development with sprawl.

De Sousa (2002) cited the Persky and Wiewel (1996) Chicago study which assessed the impacts of locating an industrial facility in the urban core brownfield site rather than a greenfield. A net social and public annual benefit of between US$467 and US$3,250 per employee in a 1,000 employee scenario, including infrastructure savings of between US$250 and US$1,350, was identified. Utilising brownfield redevelopment case studies in the Greater Toronto Area (GTA), De Sousa calculated the following results:

- In terms of travel related costs including external costs, the annual net benefit per hectare of brownfield versus greenfield development was CAN$19,170 for industrial use and CAN$66,619 for residential;
- From a municipal point of view, brownfield development for industrial use created an annual net benefit of CAN$288,616 and for residential use a cost of CAN$135,535 per hectare; and
- The total annual net public benefit per hectare developed for the GTA region amounted to CAN$100,703 for industrial use and CAN$74,124 for residential use.

The significant net benefits of residential brownfield development to the citizens of Toronto were deemed to be related to the avoidance of high transport costs, but came with externality costs from living with higher levels of air pollution. In the case of industrial

brownfield redevelopment scenarios there are substantial benefits over and above transport benefits (p.271).

6.4 A preliminary investigation into the economic impact of brownfield redevelopment activities in Canada

While costing the land development portion of brownfields versus greenfields, this study by Regional Analytics (2002) established that brownfield development was of greater cost, but that the economic, social, and environmental benefits of brownfield development far outweighed the cost difference. These benefits included a reduction in urban sprawl and associated cost, such as traffic congestion and pollution. Of particular relevance to Sydney, this study quantified the societal savings of rehabilitating contaminated land, which is in plentiful supply close to Sydney Harbour, due to its historical "working harbour" nature.

The study by Regional Analytics (2002) investigated numerous case studies in Canada and the USA to identify land usage savings and economic advantages derived from brownfield redevelopment. In all cases, there was a remediation cost for decontamination, and this was generally provided by US or Canadian Government financial incentives. A number of case studies, both complete and incomplete, were reviewed. In the case of the Canadian study, the paper concluded that for every CAN$1 spent on brownfield redevelopment, between CAN$3.50 and CAN$3.80 additional output would be generated by the Canadian economy.

7 Discussion

As noted earlier, this paper summarises literature addressing the component issues regarding infill vis-à-vis greenfield development costs, namely:

- The capital costs of greenfield development and related infrastructure;
- The capital costs of infill redevelopment;
- The development of a good model for this comparison; and
- The social costs and implications of either course of development.

These issues are addressed below with specific reference to the Sydney context.

7.1 The capital costs of greenfield development and related infrastructure

While greenfield development requires the provision of all those facilities available in existing urban areas, the trend is for many of these, such as schools, hospitals, municipal services, fire service, police, shops and recreation, to be provided in centres reached by motor car rather than available throughout the suburbs. Infrastructure, including utilities (such as electricity, gas, water, sewerage, and stormwater) and suburban roads, must be provided in all planned greenfield developments. Several studies identified high car usage in fringe areas, due to the lack of adequate public transport and the centralisation of services around town centres. This tendency of households in outer suburbs to use a private motor vehicle rather than public transport creates a requirement for more main road capacity. This requirement includes not only motorways from the fringe, but also upgrading the capacity of roads in inner Sydney due to the trend towards the Sydney central business district becoming a centre for "new economy" jobs such as financial services, information technology and global trading, and workers from outer suburbs travelling there by car. Related to this is the requirement for additional parking within the CBD and its environs.

While 42 percent of people living in Sydney's inner suburbs use public transport to travel to work, the overall Sydney average is 22.9 percent (Smith, 2003). Car use for travel to work is

most prevalent in the outer suburbs where public transport services are fewer. The provision of additional public transport infrastructure in these areas, such as rail, may defer the need for additional road infrastructure. Additionally infrastructure costs of greenfield development are minimised by restricting its density or its tendency to sprawl.

7.2 The capital costs of infill redevelopment

Few, if any, capital costs for development in infill or brownfield areas were identified other than actual land and building costs. In many cases these established areas have identifiable spare capacity in the provision of all the services and infrastructure described above as requirements of greenfield development. While there may be congestion on roads and public transport in infill areas, there is considerable traffic congestion in traffic coming from greenfield areas because alternative forms of transport do not exist to the extent that they are provided in Sydney's older established suburbs.

Relatively inexpensive infill development in Sydney has tended to be situated close to existing infrastructure and services, in particular rail infrastructure. Where the relatively expensive infill development has been on brownfield land, such as in a number of harbour side locations, the capital costs are higher due to the need to build new suburban roads and provide utilities. Because these capital items are merely laterals, their costs are lower than the costs that might occur in greenfield locations. However, decontamination costs of infill developments have been cited by a number of reports as being the most significant cost holding back development.

Searle (2003) questioned the sustainability of infill development, highlighting the existence of limitations to the use of existing infrastructure, especially roads and public transport. Any increase in population will simultaneously increase public transport and car use in proportion to the resulting modal split. Targeting infill development to increase public transport ridership is limited by public transport supply, as evidenced by middle ring developments, where public transport service levels are often insufficient during peak times. Road capacity increases are limited by the existence of buildings preventing road widening. Searle (2003) cited the water, sewerage, and stormwater systems as an example, much of which is breaking down as evidenced by harbour and sea water pollution levels following rainfall. Despite the existence of water infrastructure with excess capacity to supply substantial growth in infill areas, the water storage capacity for the entire needs of the Sydney population and industry has been seen to be reaching its limits during periods of drought, requiring a full appraisal of infrastructure alternatives to meet those needs. On the other hand, government schools in infill areas are identified by a number of studies as social services with excess capacity. Searle's (2003) study was one of a few that discuss the costs of infill qualitatively. Further research in this area is required to quantify these costs.

7.3 The development of a good model for this comparison

All the papers reviewed offer a methodology for measuring the difference in cost and benefits of various scenarios. Generally, these papers were based on case studies. Burchell *et al.* (2002) actually measured a number of costs across the USA , excluding Alaska, county by county, but neglected a number of important items, such as main road costs and other infrastructure items. The Australian housing costs study (TM & AE, 1991) provided a good framework for measuring social welfare benefits and costs, but was limited in its scope. Golob and Brownstone (2005) discussed only the costs of vehicle usage in differing urban densities, and the Canadian study by Regional Analytics (2002) concentrated on brownfields and the need for government intervention.

De Sousa's (2002) model, whilst related to the redevelopment of industrial brownfields rather than greyfields, appears to provide a comprehensive inclusion of all costs and benefits, including the value of the agricultural and environmentally sensitive land being preserved. By removing decontamination costs from the model where appropriate, the De Sousa model provides an excellent starting point for model development.

7.4 The social costs and implications of either infill or greenfield development

The social costs and implications of infill versus greenfield development include all those externalities that are the subject of so much scrutiny and yet are difficult to quantify. These are the costs of:

- Congestion and the economic value lost as a result;
- Greenhouse gas emissions, which are greater overall in the greenfield scenario (Golob and Brownstone, 2005), but of a higher density in the infill scenario (NSW EPA, 2001);
- Mental health costs, related in some cases to inner city living and also to outer areas that are lacking in social services and amenities;
- Parking needs related to the lack of public transport service and subsequent high car usage; and
- The cost of not rehabilitating contaminated and abandoned potential infill locations.

Population growth and urban development may cause environmental damage in a fragile environment such as Sydney's. Strong connections to environmental costs and implications due to population growth were identified (AATSE, 2000, iii) as:

- Pollution of land (and groundwater basins) due to waste disposal and landfill;
- Pollution of coastal waters, rivers and lakes due to urban development and higher stormwater runoff;
- The depletion of freshwater stocks near major urban areas due to higher demand; and
- Pollution of urban airsheds due to fossil fuel emissions, particularly from vehicles.

8 Conclusion

The evidence reviewed points to a conclusion that the costs of infill are less than the cost of greenfield development in terms of infrastructure costs and externalities such as air pollution and water supply, and the rehabilitation of contaminated industrial sites. It also suggests that market forces command that both forms of development exist and that each provides for housing at a lower cost than most existing housing. Beyond this conclusion, it is clear that densities and development control in both scenarios are important. With infill development, there are societal costs, particularly in terms of health issues, both mental and related to pollution levels. The studies reviewed in this paper did not identify large savings in costs to society from high densities of infill over medium density infill. Savings over greenfield development were similar for all densities of infill studied. On the other hand, low density, uncontrolled greenfield development had far greater societal costs than medium density greenfield development. Those living in low density situations may experience the benefits of cleaner air themselves. Their doing so, however, may cause higher levels of overall greenhouse gas emissions and increased levels of airshed pollution and global greenhouse gas emissions overall, in addition to being more costly for society as a whole in terms of energy consumption, infrastructure and human services. Greenfield development is expected in a rapidly growing city like Sydney. As identified in different ways in a number of studies reviewed, greenfield development should be controlled and lot sizes restricted if costs overall are to be minimised.

The literature pointed to some potentially fruitful avenues of research in this domain. One of the key areas of interest is an investigation of economic and social costs of people's preferences for single family dwellings on a block of land, rather than high density units with minimal access to private outdoor space. Another important area is the health impacts of residing in high density rather than low density developments. Also, an often neglected area in cost analyses is the effect of the loss of productive farmland which has been redeveloped into suburbs. Finally, there needs to be a greater understanding of whether people actually want to live in high density infill areas, as opposed to moving out into suburban fringes. In other words, what are the existing market forces that can potentially influence the cost of infill development? These are areas that need further investigation, and that may contribute to a greater understanding of the true costs, economic and otherwise, of infill versus greenfield development.

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