# Chapter 1. Introduction

The indifferent rivers
Will keep flowing to the sea
Or ruinously overflowing dikes,
Ancient handiwork of determined men.
The glaciers will continue to grate,
Smoothing what lies beneath them,
Or suddenly fall headlong,
Cutting short fir trees' lives.
The sea, captive between
Two continents, will go on struggling,
Always miserly with its riches.
- First stanza, 'Almanac', *Primo Levi*

## 1.1 Setting the scene

The diverse Australian landscape has inspired poetry, song and stirring fiction. It seems almost disrespectful to both the enormity and overwhelming beauty of the largest island in the world to subject it to the dizzying array of dispassionate taxonomic classifications favoured by scientists. Yet, to even begin an analysis of the water resources of Australia, we must do so.

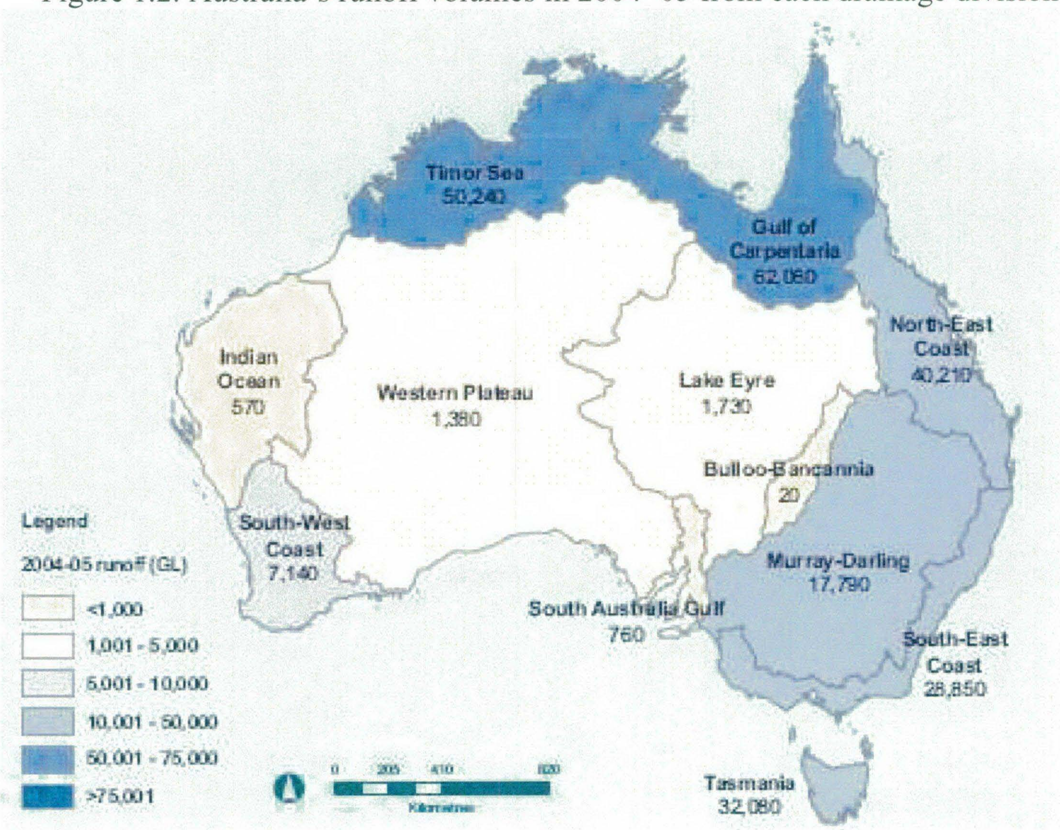
Scientists and bureaucrats have divided the Australian landscape into eleven separate drainage basins during the 1960s, as illustrated in Figure 1.1. The largest is the Western Plateau, covering much of Western Australia, yet draining very little of the rain that falls across Australia. The smallest is the state of Tasmania, receptacle of around 3 per cent, on average, of the nation's rainfall each year. The division of arguably most interest – over the last century, at least – is the Murray–Darling, home to Australia's food bowl and irrigated agriculture industry. Yet for all the interest, in terms of population and economic value added, the neighbouring South-East Coast basin is far more significant. Home to two capital cities (Sydney and Melbourne) and the majority of the nation's population, this long, narrow and steep tract of land has only recently received the attention of policy makers.

Figure 1.1: Australia's drainage divisions


Source: DEH (2001)

The focus of this thesis is on water and wastewater utilities located in both the Murray–Darling and South-East Coast drainage divisions. The two have similarities and stark contrasts. For example, the Murray–Darling is around one million square kilometres in area, representing 14 per cent of the Australian land mass (MDBC, 2007). The South-East Coast, in contrast, covers 264,000 square kilometres, or around one-fifth of the area of the Murray–Darling. Average annual rainfall across the Murray–Darling is approximately 480 millimetres (mm) (NLWRA, 2002). The South-East Coast receives between 533 and 1,879 mm per year. Likewise the run-off volume in the Murray–Darling Division was around 61 per cent of that recorded in the South-East Coast during 2004–05 (NWC, 2006), as illustrated by Figure 1.2.

Figure 1.2: Australia's runoff volumes in 2004–05 from each drainage division




NWC (2006)

The defining geographic feature between the two divisions is the Great Dividing Range. This collection of mountain ranges and tablelands forms the watershed for most of the eastern seaboard of Australia. Rain falling to the west of the range is destined for the Murray–Darling River Basin, eventually making its way to the Southern Ocean via either the Murray or Darling River systems. Combined, this river system is about half the length of the longest river in the world, the Nile (Geoscience Australia, 2007).

Rain falling to the east takes a much shorter and turbulent path to the South Pacific Ocean, more often than not travelling through deeply dissected gorge country characterised by spectacular waterfalls and sheer rock faces. A more mundane path is travelled in the Murray–Darling Basin. Not only would one be hard pressed to find a waterfall along the rivers that make up the Murray–Darling, but rainfall is far more likely to spend time in a large storage dam before being diverted to an irrigation enterprise. Furthermore, the initially pure raindrops are likely to finally exit the Murray–Darling accompanied by salt, pesticides and other forms of pollution.

## 1.2 Status of the resources

While most of the attention of policy makers over the past two decades has been trained on finding ways to manage the competing interests in the Murray–Darling, the last two to three years have seen greater focus on the South-East Coast Division. At least two factors explain this. First, rainfall patterns across the southern half of Australian appear to have deviated from long-term trends (NWC, 2006; WGCS, 2006). In particular, annual rainfall has been significantly lower in the south-eastern and south-western corners of Australia than in previous periods (NWC, 2006). While Australia has a long and celebrated history of drought followed by flooding rain, some scientists claim that the current 'drought' is better described as a 'step change in [Australia's] weather patterns' (WGCS, 2006).

Second, a combination of population growth and declining rainfall has brought the 'drought' to the cities (Young et al., 2006). In January 2007 almost every capital city in Australia was subject to water restrictions, the favoured policy tool of urban water resource managers for rationing dwindling urban water supplies.

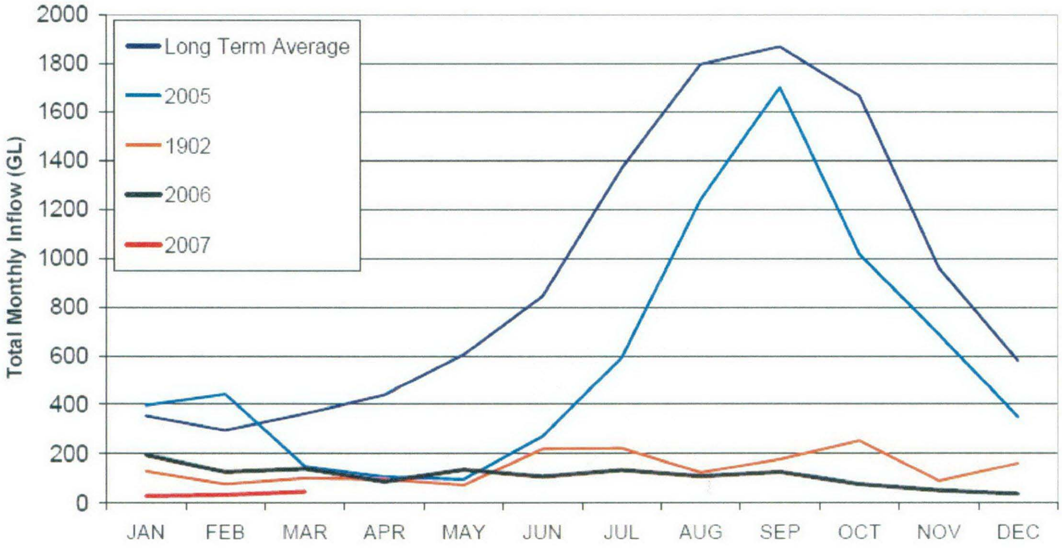
In 2006 the National Water Commission (2006) undertook a stocktake of sorts of Australia's water resources. The results represented a snapshot as at 2005. While the study was not intended to chronicle the drought that had gripped the south-east and south-west of the continent, the report confirmed in stark detail the growing stress being placed on the nation's water resources by repeated years of lower than average rainfall. In fact, rainfall for each of the five years preceding 2004–05 was below average (NWC, 2006).

The audit established the diverse nature of rainfall across Australia, noting that the deserts received around 200mm of rain a year on average, while some coastal regions in the far north regularly recorded 10 times that quantity. The Commission found that around 75 per cent of water 'used' in Australia was returned to the environment following in-stream use, such as hydro-electric power generation. The agricultural sector was responsible for around 65 per cent of the water that was consumed, 91 per cent of which was used in the pursuit of irrigated agriculture. On the other hand, households were responsible for only 11 per cent of water consumption, and that had declined by eight per cent over the previous four years. Agricultural consumption had also declined over the same period, primarily as a result of the drought.

While rainfall across the Murray–Darling Basin had been below average for a number of years, intermittent rainfall events tended to mask the growing problem that the drought was to become during 2006. It became clear in July of that year that this was a drought that had lasted at least six years, and was characteristically different to previous events in a number of respects (MDBC, 2006).

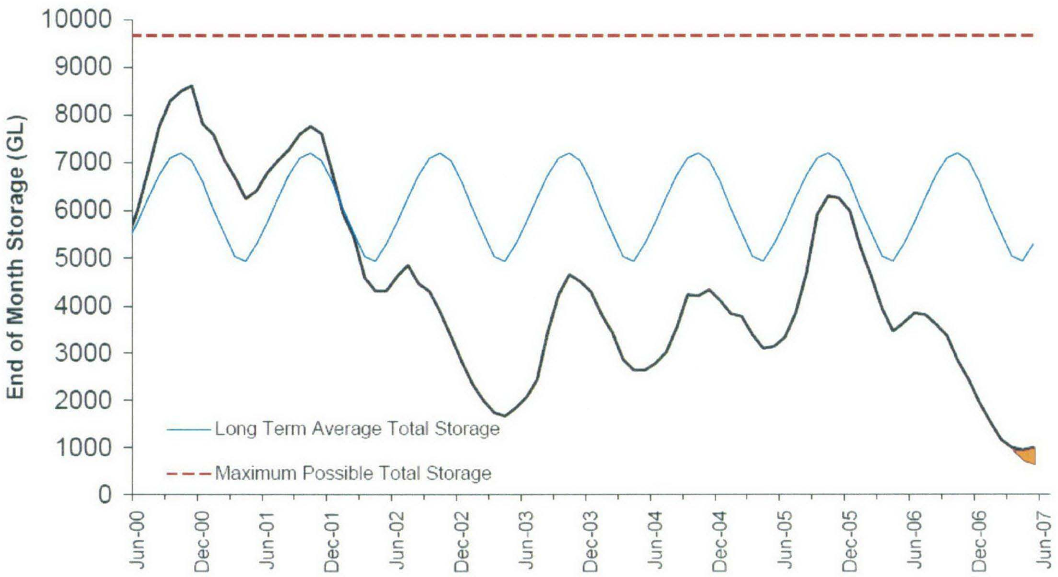
First, repeated years of below average inflow to the system had resulted in periodic rainfall events yielding little to no run-off into the catchments storages, as illustrated to dramatic effect by figures 1.3 and 1.4. The implication of this was that restoring the Basin to normal 'operating' conditions would require repeated episodes of an unlikely triumvirate: substantial, widespread and reasonably lengthy rainfall (MDBC, 2007). In other words, breaking the drought would prove less likely the longer it continued.

Figure 1.3: River Murray inflows – long term average and selected years[1]




Source: MDBC (2007)

Figure 1.4: Murray–Darling Basin Commission total storage: June 2000 to July 2007




Source: MDBC (2007)

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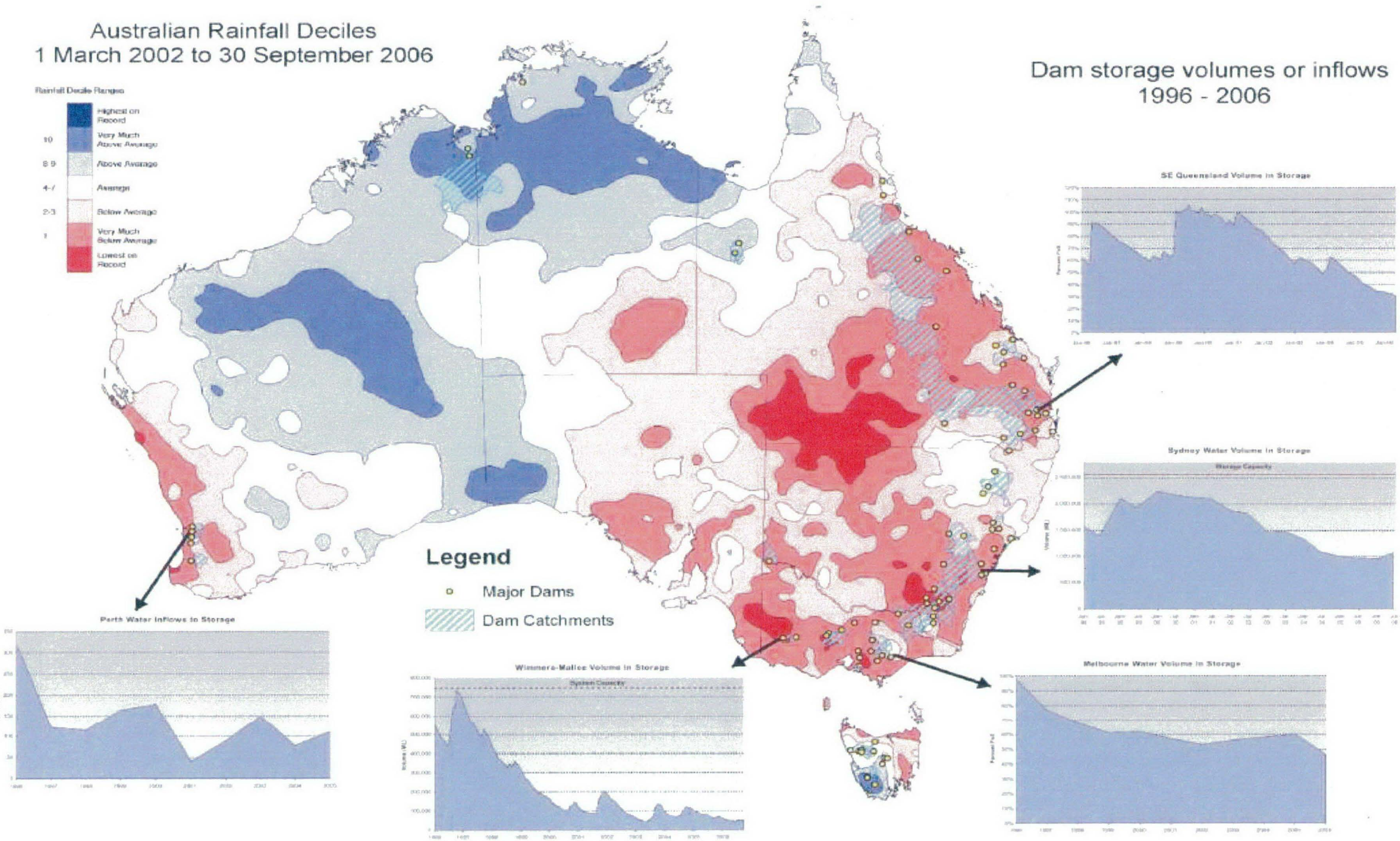
[1] Excludes Snowy Scheme releases and Menindee Lakes inflows

Second, the drought came to the city. In May 2007, five capital cities around Australia had resorted to water restrictions to manage dwindling supplies (NWC, 2007a). Figure 1.5 illustrates the situation as at September 2006. Leaving aside the debate as to whether the policy response of the majority of state governments has been an efficient solution to the problem (see, for instance, Byrnes et al., 2006), almost universal water shortages in the capital cities have provoked unprecedented interest in water resource management policies in Australia (Crase and Dollery, 2006). Drought was once of only marginal interest in the capital cities of Australia; during 2006 it became front page news.

Figure 1.5: Rainfall with major dams and catchments




Source: NWC (2006)

Outside of the capital cities, the state of urban water supplies is mixed. In the south of NSW, and in particular those towns reliant on supplies from the Murray River, the situation is dire (Smith, 2007). In fact, a collection of government ministers declared in January 2007 (Vaile et al., 2007) that should drought-breaking rain not fall in the autumn and winter of 2007, irrigation along the Murray River was to temporarily cease in order to safeguard urban water supplies for towns along the Murray, and the capital city of Adelaide (MDBC, 2007)[2]. In northern inland NSW, some towns face water shortages since they are reliant on dams that are perilously low (for example, Tamworth), while others that source water from groundwater aquifers (for instance, Gilgandra) have bountiful supplies relative to population. In contrast, a number of communities located on the coastal fringe on NSW have endured stringent water restrictions as a result of low water storage levels and inexorable population growth (for example, Gosford). In Victoria, a more uniform set of circumstances prevail. Most water authorities in regional Victoria have faced water supply pressures during the drought (VicWater, 2007).

State governments have responded to the crisis in a variety of ways. Most began by implementing progressively more stringent conditions on household water use, while simultaneously mounting arguments against augmentation of water storage infrastructure such as dams and weirs (Byrnes et al., 2006). As the crisis deepened, the West Australian Government committed to the construction of a desalination plant to provide potable water to Perth. This was followed by a similar commitment by the NSW Government, and investigation of the technology by the Queensland and

[2] Adelaide, the capital of South Australia, relies upon the Murray River for potable water. The city has diversified raw water sources, and as a result the reliance is not total, however the prospect of a low running Murray River, with relatively high salt concentrations is one the State government of South Australia is likely to face in 2007/2008.

Victorian governments. By September 2007, NSW, Victoria, Queensland and South Australia had all committed to constructing desalination plants. The Victorian Government has taken the extraordinary step of augmenting this new source of supply with a pipeline that will divert water from the Goulburn Valley (part of the Murray River system) to augment potable water supplies for the city of Melbourne (Bracks, 2007). Watson (2007:8) has observed that "it would be a notable fluke if both the pipeline and desalination plant were justified for Melbourne, in parallel".

The Queensland Government has taken a two-pronged approach. While imposing the most draconian regime of water restrictions in the nation as a means of managing the short-term prospect of a major capital city running out of potable water supplies, the government has used the crisis to push through a proposal that will substantially alter the institutional regime by which the urban water resources of that state are managed. In essence, the state government will assume ownership of much of the infrastructure and link the various supply networks in a grid, ostensibly enabling transportation of water from one basin to another depending on need. Along with this, two new sources of urban water are to be developed: a desalination plant and a sewage recycling plant that will treat urban wastewater to a standard suitable for re-use as potable water (QWC, 2007).

The state of the water resources in both urban and rural Australia has resulted in some bizarre policy outcomes. As we have seen, state governments have switched from a negative bias toward urban water infrastructure expansion to a distinctly positive stance in the space of just two years. In the rural water arena, a long-term plan to substantially re-shape rural water infrastructure has been proposed in response to a particularly short-term crisis[3]. The forceful intervention of the Commonwealth into the traditionally state government arena of water resource management is likely to have long-term ramifications that will be felt well after the current drought has broken. In sum, some of the hard fought-for economic principles that underpinned much of the reform of the sector in the 1990s are at risk of being abandoned in the long-term in attempts to address the short-term problems arising from widespread water shortages in both the urban and rural sectors (Watson, 2007).

## 1.3 Historical considerations

The history of water in Australia touches many disciplines. Engineering feats, social experiments, attempts at 'nation building' and quests to hold back the inexorable drive of nature are but a few of the landmarks along the continuum. A unifying theme, however, is irrigation (Powell, 1989). Since at least the 1860s, the development of inland Australia has largely rested on the great hope of irrigated agriculture. Prior to World War I, the colonies saw population growth and spread as a means of addressing many of the threats on the horizon, from invasion to economic demise. Although mining was a lucrative drawcard, agriculture was also significant. Yet much of the arable land in south-east Australia had already been settled. Irrigation provided the potential for communities to farm arid land in areas of extremely low and inconsistent rainfall (Connell, 2007). The development paradigm continued to shape policy

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[3] The 'National Plan for Water Security' announced by the Prime Minister of Australia on 26 January, 2007, committed the federal government to a fiscal expenditure program slightly in excess of $10 billion in order to pipe and seal irrigation infrastructure (approx. $6 billion) and buy back irrigation licences (approx. $3 billion). The balance was to be spent on an investigation of the potential for the relocation of Australian irrigated agriculture to a vast tract of land in northern Australia and a major increase in resources for the recording of water related data.

following each of the world wars, with returning soldiers settled in irrigation districts to work small plots of land (IRF, 2002).

Since the aim was to engineer inland towns and communities, average plot sizes were deliberately kept to a minimum and water allocations were tied to the land. The planners of the Australian settlement deeply feared a repeat of what they had observed in the United States: massive blocks of irrigated land, owned by the rich but worked tirelessly by the poor (Connell, 2007). One hundred and fifty years later the results have been devastating. According to Watson (2007:5), "all states have irrigation skeletons in their water closets".

The historic allocation of water according to land ownership, the subsidisation of irrigation infrastructure and the hallowed place of yeomanry in Australian folk law have made for policy inertia. The objectives of irrigation policy have for the most part been social – closer settlement and inland population growth. As the giant of early Australian water history, Alfred Deakin (quoted in Powell, 1989: 108-9), claimed that:

> *If Victoria is to progress in the settlement of her people upon lands and the multiplication of her resources by the conquest of areas hitherto regarded as worthless... it must be by means of irrigation. No price, it may be said, is too high for such a promise of progress.*

Economic considerations have only relatively recently been brought to the forefront. In writing, at least, policy makers now inquire into the price and who might pay. The reforms of the Council of Australian Government (CoAG, 1994) have been admirable in their attempts to bring questions of benefit and cost to the table. Yet, after at least 15 years of trying to reform water policy, the federal government felt it necessary to attempt a broad sweep of the rural water sector, offering substantial sweeteners to irrigators in the form of $6 billion worth of infrastructure renewal, while hinting at the prospect of compulsory, fairly compensated acquisition of water allocations in an attempt to reverse some of the wrongs from past policy decisions (Howard, 2007). While the sweetener received high praise from economists (see, for instance Watson (2007b) and Young and McColl (2007)), the buy-back was immediately pounced upon as an affront to the hard working farmers (NIC, 2007). Reform of the Australian rural water sector is likely to be slow and painful, thanks to the long half-life of policy decisions made decades ago.

The history of urban water is equally tied to policies of past governments. However, unlike irrigation policies, the urban water sector grew through time to resemble an attractive and extremely reliable source of quasi taxation (Watson, 2007). Urban water utilities have always been monopolistic in structure, justified at various times through appeals to economies of scale and the importance of public health. Regardless, monopolies have a history of succumbing to the temptations of being a price maker. Although state governments have attempted to regulate prices throughout the years, the regulated have a far more powerful incentive to fool the system.

Urban water utilities, particularly those servicing the capital cities, came under renewed pressure during the 1990s to reform their operations in the name of economic efficiency (SECITARC, 2002). Checks and balances were introduced to curb engineering excess and padding of workforces, with prices to be set with a least some reference to the cost of supply (CoAG, 1994). In essence, the reforms of the 1990s were aimed at reducing economic inefficiency. The underlying principle was for water and wastewater services to be supplied at the least attainable cost. Treating utilities as business units with corporate structures that promoted the attainment of goals – such as reasonable rates of return – quickly became the hallmark of microeconomic reform. One thing stayed the same: state governments maintained their enthusiasm to tax urban water (Watson, 2007). Rather than simply transferring excess revenue to the state treasury, water corporations took to paying dividends to their owner, which just happened to be the relevant state treasury[4].

While the implementation encountered problems, at least the due deference to the concept of economic efficiency was admirable. Since storages began declining in the first part of the 2000s, the term 'efficiency' has taken on a strange new meaning. Policy makers at all levels of government now speak of water use efficiency, and chase the attainment of this nirvana in the spirit of Alfred Deakin's pursuit of an irrigated nation 100 years earlier (see, for instance, NWC, 2007a, and QWC, 2007). Water use efficiency comes at a cost, both in terms of budget expenditure diverted to subsidise water saving appliances, and the revenue lost by utilities forced to implement this new policy panacea to our urban water woes.

A few examples serve to illustrate the implied marginal value of urban water in this new paradigm. Watson (2007:8) reports that "the Victorian Water Trust recently contributed to the $1.2 million spent installing greywater recycling in a deprived public housing estate in Melbourne to save two megalitres of water" while Crase and Dollery (2006) show that the implied value of a megalitre of water 'saved' by water use efficient dishwashers is a staggering $33,000[5].

Of significance to the current research is that the cumulative impact of water use restrictions and policies to encourage urban water consumption is likely to have

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[4] As will be established, water utilities in regional NSW are in almost every instance owned by local government, not state government. Thus, this statement is of less direct relevance to that sector of the urban water industry in NSW.

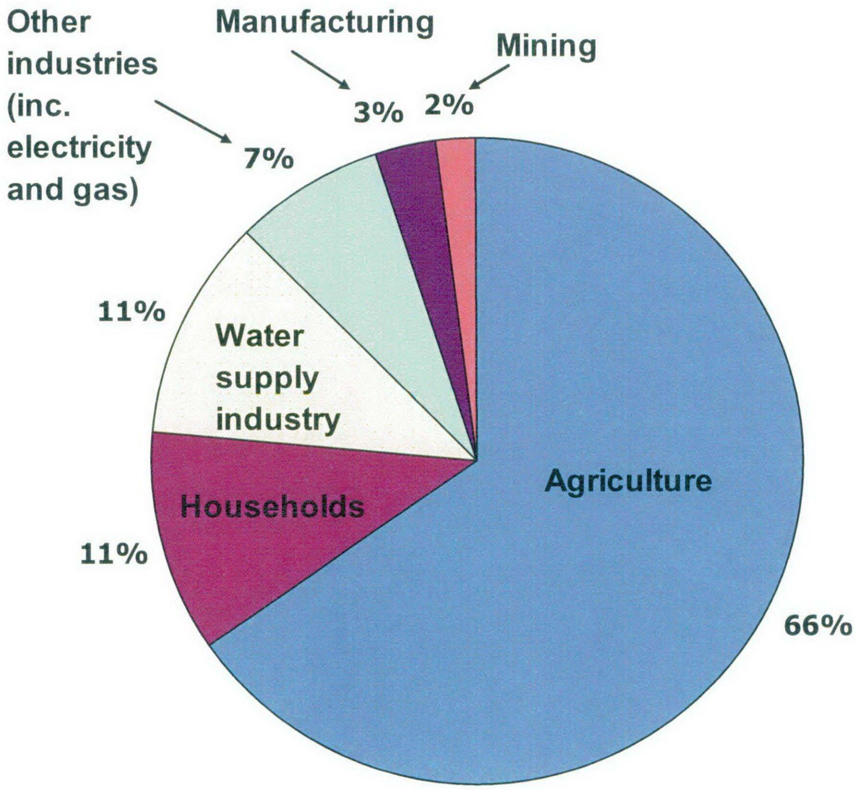
[5] Permanent 'rural' water allocations were trading at the time from between $1,000 and $2,000 a megalitre.

reduced relative efficiency. The revenue generated by water utilities from the supply of marginal water is likely to be fairly lucrative, since the fixed costs of infrastructure will have largely been covered. Thus, while watering the garden may be seen as a 'waste' by some, water utility managers rely upon the marginal revenue for investment in infrastructure renewal and similar activities.

## 1.4 Sectoral differences

Until recently the story of water policy in Australia centred on regulating rivers in order to supply water in pursuit of irrigated agriculture. It follows that the focus of policymakers has been almost entirely on options to rectify past errors in arenas such as water rights allocations, property rights certainty, reform to remove the barriers to trade in water entitlements, and pricing water via a regime that at least approximated a competitive market. The reform agenda produced in 1994 by CoAG included urban water matters; however, the difficulties encountered in implementing that suite of policies resided overwhelmingly in the rural water sector. This can be partially explained simply by the proportion of water consumption attributable to the irrigated agriculture sector. In 2004–05, of all water consumed in Australia, just under 60 per cent went to agricultural pursuits requiring irrigation (Figure 1.6).

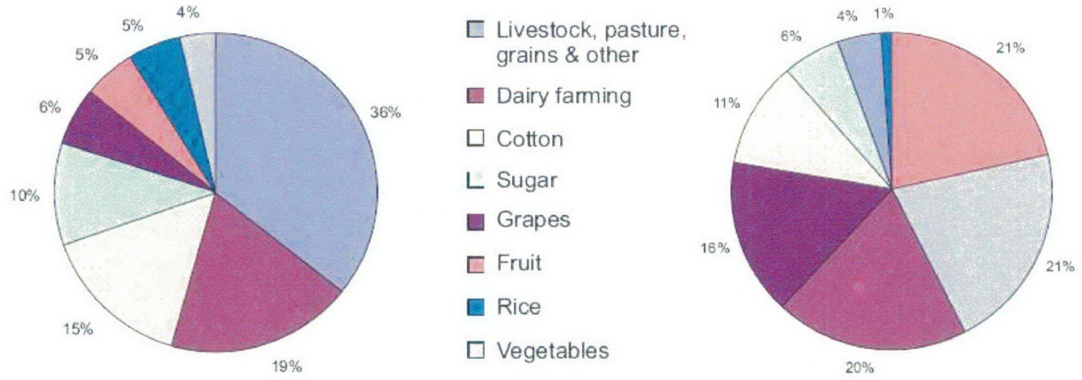
Figure 1.6: Water consumption by sector: 2004–05




Source: NWC (2006)

Within the irrigated agriculture sector the proportion of total water consumed is generally not proportionally matched by gross value added, as illustrated in Figure 1.7.

Figure 1.7: Percentage of agricultural water consumption and gross value added




*Percentage of agricultural water consumption*

*Gross value added*

Source: NWC (2006)

A number of examples serve to illustrate. While pasture irrigation consumes around 36 per cent of the total water consumed by irrigation, it contributes only four per cent of the gross value of the irrigated agriculture industry. In contrast, vegetable cultivation requires four per cent of the water consumed in irrigated agriculture, yet contributes 21 per cent of the gross value added. Against this background, it is little wonder that the focus of recent reform efforts in rural water has been on removing barriers to the trade of permanent water entitlements from agricultural pursuits of relatively low value added to those with higher average returns per unit of water consumed.

The limited attention given to the economic efficiency of water and wastewater utilities during the 1990s can largely be explained by the relative insignificance of the sector. Although ranked second in terms of water consumption, the sector uses around one sixth of that consumed by agriculture (NWC, 2006). Thus, the efficient use of water in terms of value added has not been of primary concern, simply due to the historically abundant supply and the dominant use of water by agriculture. Furthermore, and perhaps more importantly, a policy of distributing urban water according to the marginal economic contribution of the consumer is often seen as morally unacceptable, given that potable water is an essential service in any society (Byrnes et al., 2006). Welfare enhancement in this context was to be achieved by ensuring reliable and safe supply in an economically efficient manner.

## 1.5 Regulatory differences between the states

Substantial differences exist in the regulatory regimes in place for the management of water resources in NSW and Victoria, both in an urban and rural context. However, the focus of this thesis is on the urban sector and thus most attention is given to an analysis of the differences in that context.

For the vast majority of the last century, the provision of urban water in both NSW and Victoria was a function of either local government or water boards established by the relevant state government. This continues to be the case in NSW, where water and wastewater services provided outside of the state capital (Sydney) and two satellite regions (the Central Coast and Hunter districts) are largely the responsibility of councils. In Victoria, widespread microeconomic reform throughout the early 1990s by the (then) Kennett state government resulted in responsibility for water and wastewater provision being transferred to regional boards, appointed by and responsible to the state government. Eighteen regional districts were established

(Smith, 2004), a substantial rationalisation of the sector which at one point had no less than 400 bodies with some role to play in the regulatory framework (World Bank, 2004). The usual refrain of benefits arising from scale economies and a business-like structure was advanced as justification for the reform (Kiss, in Dollery and Marshall, 1997).

In one sense it might be argued that this represents the main point of difference between the institutional structure of urban water and wastewater provision in the two states. While a series of local government amalgamations have since taken place in NSW (Dollery et al., 2006), reducing the number of councils with water and wastewater responsibilities, the number of utilities providing those services in NSW is around five times greater than that in Victoria. Perhaps of most significance, the regional water authorities in Victoria are directly regulated by an independent competition watchdog, while councils in NSW are indirectly monitored by a state government department. Furthermore, while the executive of Victorian Regional Urban Water Authorities (RUWAs) are focused on running a water and wastewater business, the managers of NSW utilities can potentially be distracted by the broader concerns of local government operations and, of course, politics.

## 1.6 Key research questions

It is against this background that the key research questions of this thesis are set. The questions to be investigated revolve around the differences in regulatory structure outlined in Section 1.5. More specifically, the thesis examines the relationship between institutional structure and the economic efficiency of urban water utilities in regional NSW and Victoria. The first task is to establish whether a relation exists. Second, if evidence of a link exists, what form does it take? Are the larger utilities in Victoria relatively more or less economically efficient and, if so, can the determinants of the relative advantage or disadvantage be identified? Finally, do the results suggest a course of action that policymakers should pursue in order to reduce relative inefficiencies in the provision of urban water in regional NSW and Victoria?

Given the unprecedented interest in water policy in Australia, it is important to outline the areas not considered in this thesis. First, this thesis specifically excludes consideration of the relation between climate change and water resource sustainability, despite a growing and vibrant literature on this topic (see, for instance, Arnell (2004), Payne et al. (2004), Robinson and Cohen (2003) and Pahl-Wostl (2002)). Furthermore, questions relating to the very pressing need of securing additional supplies in urban water are not considered, even though this represents one of the most troubling aspects facing the sector at present. Finally, this study does not consider matters relating to the efficient pricing of urban water and wastewater services, even though there is considerable debate regarding the most efficient method available to policy makers in setting urban water and wastewater charges.

## 1.7 Thesis outline

The thesis is composed of ten main chapters. Chapter 2 constructs an appropriate framework for the empirical measurement of the relative technical efficiency and productivity of water and wastewater utilities in regional NSW and Victoria. It examines the institutional profile of the water and wastewater section in question, and draws attention to the relevant contrasts between the states.

The theoretical approaches to the measurement of relative efficiency are reviewed in Chapter 3, which examines the theoretical underpinnings of microeconomic efficiency measurement. The appropriate terms, concepts and methodologies are described. This chapter implements an appropriate econometric framework for the measurement of relative efficiency and productivity.

Chapter 4 is a review of past empirical approaches to the measurement of relative efficiency in water and wastewater industries worldwide. Particular attention is given to those studies examining regional utilities, the role of regulatory regimes and the water and wastewater sectors in Australia. The purpose of this chapter is to situate the thesis in the extant literature, and to assess and evaluate previous approaches to the topic of interest.

Chapter 5 establishes the rationale underlying the chosen approach for the measurement of relative efficiency and productivity. A technique for the analysis of relative efficiency scores is also discussed and specified.

Chapter 6 presents in detail the input and output combinations for inclusion in the econometric model discussed in Chapter 5. The range of exogenous variables thought to influence the relative efficiency of water utilities (as opposed to wastewater functions) are also outlined, along with a précis of the descriptive statistics relating to the input, output and exogenous variables. The aim of Chapter 7 is to describe the input, output and exogenous variables for inclusion in the analysis of relative efficiency in the wastewater sector.

In Chapter 8 the results of the model constructed in Chapter 5 and specified in Chapter 6 (water utilities) are examined, while those pertaining to the model specified in Chapter 7 (wastewater utilities) are analysed in Chapter 9. Finally, Chapter 10 provides a discussion of the main findings and results, which have the potential to inform policy formulation in arenas related to the urban water and wastewater sectors.

# Chapter 2. Institutional Features of Urban Water and Wastewater Provision in Regional NSW and Victoria

## 2.1 Introduction

Chapter 1 provided a broad overview of the water sector in Australia with the aim of setting the context for the main research question investigated by this thesis. It was established that while there are a number of common attributes to water resource management in each of the states, it is equally valid to argue that considerable diversity pervades the sector. A disproportionate quantity of water is used by the agricultural sector with a vast array of regulatory structures governing the resource.

This chapter examines the regulation of urban water and wastewater provision in regional NSW and Victoria. It highlights the divergent structures for the regulation of this sector implemented by each state, in order to establish the rationale for the research reported in the following chapters.

The chapter is broken into seven main parts. Section 2.2 gives an overview of the major water institutions in the Commonwealth jurisdiction. The discussion then turns to the 1994 CoAG agreement, the first of the two major federal policies on water. This agreement is reviewed in detail in Section 2.3. A review of the factors that led to the formulation of the most recent water policy (the NWI) is provided in Section 2.4, while the NWI itself is outlined in Section 2.5. The major institutions responsible for water matters at the state level for NSW and Victoria are outlined in Section 2.6. The chapter ends with some brief concluding remarks in Section 2.7.

## 2.2 Commonwealth water institutions

For the majority of the previous century, the regulation of water resources in Australia was a matter vested in the states (Pigram, 2006). Although CoAG has been the central body driving reform in the sector, the Commonwealth has increased its presence in the regulatory environment via a number of other inter-governmental institutions and councils. Chief among these is the Murray–Darling Basin Ministerial Council (MDBMC), which is charged with management of the Murray–Darling Basin. It is far from new, with roots stretching back as far as 1915.

Commonwealth involvement, particularly with a view to influencing more encompassing environmental outcomes, has also been shaped by the National Resources Management Ministerial Council (NRMMC), established in 2001 to bring together all of the environment, agriculture and natural resource ministers from the Commonwealth, state and territory governments. It was envisaged as a coordinating body with the lofty aim of taking responsibility for sustainable management of land, water, vegetation and other natural resource issues. The success or otherwise of this unlikely collection of government ministers and officials can be judged with reference to decisions taken in relation to the National Action Plan on Water Quality and Salinity and the National Heritage Trust.

However, the passage of two pieces of legislation blurred the lines of responsibility somewhat, such that arguably the two pre-eminent 'water institutions' in Australia at present are creatures of the executive of the Commonwealth Government.

The National Water Commission (NWC) was established following the signing of the National Water Initiative (NWI) at a CoAG meeting in 2004, and the subsequent passage of the National Water Commission Act 2004. While a much more detailed analysis of the NWI follows in this chapter, a brief review of the roles of the NWC is given here. At the time of its creation, the NWC was directly responsible to the Prime Minister, such was the importance given to its role. It is now a statutory body in the environment and water resources portfolio of the Commonwealth Government. The role of the NWC is, in essence, to oversee the implementation of the NWI. This is achieved along three fronts. First, the NWC assesses the extent to which the states have met the various requirements of the NWI, through biennial 'assessments'. This task was originally undertaken by the National Competition Council, and was transferred to the NWC when it was established.

Second, the NWC assists the states to meet their obligations under the NWI, by providing advice, commissioning experts' reports on various matters, and providing ad-hoc funding where this is deemed necessary. Finally, a $2 billion fund established[6] by the Commonwealth to improve the management and use of Australia's water resources is administered by the NWC by means of a competitive grants process.

The passage of the Water Act 2007 allowed for the establishment of the Murray–Darling Basin Authority (MDBA). While not yet established, the various functions it has been tasked with providing suggest it will be one of the most influential voices in the implementation of water resource policy in the years to come. The primary role of the MDBA will be to establish a 'Basin Plan', the aim of which will be to ensure extractions of surface and groundwater from the

[6] The $2 billion dollar fund consists of payments that were due to be made to the states as a result of their meeting a number of obligations resulting from the National Competition Policy reforms. Thus, the funds were not 'new' as such.

Murray–Darling Basin are 'sustainable' (Turnbull, 2007). The MDBA will also enforce the Basin Plan.

The NWC and MDBA are but two of a vast array of bodies, committees, expert panels and the like to have been established under the auspices of the Commonwealth Government in its attempts to regulate matters relating to the use and quality of Australia's water resources. To mention a few, the Murray–Darling Basin Commission is responsible for the implementation of: the Murray–Darling Basin Agreement, the Living Murray Initiative, the Integrated Catchment Management Policy Statement (2001–2010), the Basin Management Strategy (2001–2015) and the Heartlands Initiative, while policies to have emanated from the MDBC include the Algal Management Strategy, the Floodplain Wetlands Management Strategy, the Native Fish Strategy and the national Action Plan for Salinity and Water Quality (DEWR, 2007). Clearly, the Commonwealth cannot be accused of not devoting its administrative prowess to the task. Yet, as Malcolm Turnbull (2007: 3), the Minister responsible for water resources claimed recently

> *The lowest-common denominator governance model established almost a century ago cannot address today's problems in the Basin. Reform is needed to ensure a governance model that is responsive to the current and future challenges facing water management in the Basin. Reform is needed to ensure the viability of the Basin's water dependent industries, to ensure healthy and vibrant communities and to ensure the sustainability of the Basin's natural environment.*

One could argue that the multitude of institutions outlined above have their antecedents in the work of CoAG in the early 1990s to reform the management of water in Australia. In seems worthwhile to dedicate some of this chapter to a review of that work.

## 2.3 1994 CoAG agreement

During the past 15 years, the Commonwealth Government has become increasingly involved in policy matters related to natural resource management in general and water systems in particular. The Hawke/Keating government is widely thought to have retained power at the 1990 federal election through garnering support of the so-called 'Green' parties, through an emphasis, in rhetoric at least, on the declining health of the environment, where water resources played an important role (Kelly, 1994). The 1990s saw a gradual increase in the number of Commonwealth Government departments with at least some responsibility for environmental matters.

With respect to the issue of water, in both rural and urban settings, the Commonwealth is perhaps best known for its policy role through CoAG. In 1992, the Council called for a report on the "current state of play in both urban and rural water use, as a basis for considering the need for greater impetus to be given to reform in key areas" (CoAG, 1992). Discussion of the findings of this report at the 1993 meeting led to the formation of a working group, charged with providing a "report on a strategic framework for efficient and sustainable reform of the water industry" (CoAG, 1993). The result was the Water Resource Policy, a relatively detailed document that has formed the basis for much of the reform agenda pursued by both the Commonwealth and states and territories throughout the 1990s.

Although water management in Australia is a controversial issue in many respects, there is little controversy when it comes to acknowledging the 1994 CoAG agreement on water reform as the genesis for the dramatic change witnessed in the management of Australia's water resources over the past two decades. Although scientists and environmentalists had been concerned about the impact from the pursuit of the so-called 'development agenda' and the effect this was having on the environment since at least the 1960s, it took this landmark agreement to drive the institutional reform seen since 1995.

In February 1994, a major milestone was reached in Australian water policy when CoAG agreed to the Water Resource Policy (CoAG, 1994). The policy was an Australia-wide effort to turn back the tide on the natural resource degradation that had resulted from a century of exploitation of the national water resource. In essence, the new mantra to arise from this policy was 'efficiency and sustainability' – a catchcry that has permeated the Australian water debate ever since, even though the meaning attached to the two terms has changed since then.

Nevertheless, it is difficult not to admire the central intent of the policy. It brought together the national drive for microeconomic reform, particularly in the state-owned enterprise arena, and the recent yet growing awareness of the need for sustainable natural resource management. While it might have been tempting to express these goals in a series of 'motherhood' statements, in order for the agreement to have a reasonable chance of success, the authors thought it essential that the plan was a comprehensive framework, with policy targets that could demonstrably be met and outcomes that could be measured. The result was a document that, when read in the political milieu of its time, must be commended for its genuine attempt at achieving widespread reform.

### 2.3.1 Overview of the agreement

In many respects the CoAG agreement can be viewed as a systematic dismantling of the pillars that upheld the so-called development paradigm. First, institutional structures were to be reformed. During much of the 20th century government departments responsible for the rural water industry were key supporters of inland development. In an attempt to remedy this, the framework called for a separation of the institutional responsibility for resource management and service provision (CoAG, 1994: 3). In practice, this meant that decisions regarding building dams and the like were no longer made by those supplying water to irrigators.

Second, providers of bulk water were to take a commercial rather than development, focus. The assets of the water industry (both urban and rural) were to earn a positive rate of return, necessitating, in many instances, an increase in the price of water (CoAG, 1994: 1).

The Third pillar to be challenged was the view that title to land came with an automatic entitlement to water for that land. By establishing a system whereby an entitlement to an allocation of water would no longer be directly linked to ownership of land, this longstanding nexus was to be broken (CoAG, 1994: 2).

It was hoped the implications would be significant. First, by separating water title, water allocations would become portable. Thus, if the returns from irrigation on a particular parcel of land where relatively low compared with another farming enterprise, the holder of the right to the relatively less productive water allocation could sell it to the more productive farmer. Thus, the 1994 policy sought to create a legal framework by which water could move to its most valuable use. It was hoped that, as a consequence, the opportunity cost of unproductive irrigation would increase, encouraging the cessation of relatively inefficient water use.

While the CoAG (1994) framework attempted to address perceived market failures across multiple aspects of water policy, only those of direct bearing on the topic of this thesis are examined here. More specifically, pricing reform and institutional change are briefly addressed here.

### *Pricing*

Reform of pricing was arguably the primary focus of the policy in 1994. CoAG was in the throes of dealing with the challenges presented by the findings of the Hilmer Inquiry and, in particular, the implications of National Competition Policy (NCP). The underlying aim of the CoAG agreement with respect to the pricing of water was for the resource to be treated much like any other commodity with prices recovering the costs of 'production', and to change the perception that the use of water was costless, and should no longer be priced as such.

The CoAG agreement established three principles to be employed in the pricing of water. First, water pricing was to be consumption-based. Second, prices were to be set such that the full cost of provision was recovered. Third, although subsidies were generally frowned upon, if they were to be maintained, the agreement called for them to be made transparent (CoAG, 1994: 1).

The pricing principles were to be applied across both urban and rural water services. In keeping with the principle of consumption-based pricing, urban authorities were to establish billing systems whereby end users would be charged separately for connection to the system and consumption of water, ending the decades-long practice of many urban water providers charging a fixed connection fee based on the value of land, then a minimum charge for 'excess' water use (Pigram, 2006: 114). As an aside, it is interesting to note an emerging literature questioning the wisdom of abandoning this approach (see, for instance, Dwyer, 2006).

***Institutional reform***

The CoAG agreement heralded a new discourse with respect to natural resource management. The policy called for an integrated approach. In particular, separate institutions were to be responsible for the management of water resources, the setting of various standards and rules, the enforcement of regulations and the provision of various services such as urban water and bulk water (CoAG, 1994: 3). Institutions responsible for the delivery of water, particularly in metropolitan centres, were expected to take on a commercial focus. As will be argued in later sections, the state of Victoria took to this with relatively more enthusiasm than other states and territories. Of particular note, the institutions charged with implementing the CoAG agreement were to engage in extensive consultation and water agencies were expected to develop public education programs "with a view to promoting levels of service that represent the best value for money to the community" (CoAG, 1994: 4).

## 2.4 Policy developments during the 1990s

Following the signing of this historic agreement between governments at the state and federal levels, CoAG decided in 1995 to add a financial incentive for the implementation of policy aims that, although well intentioned, were likely to meet stiff political opposition. A key element to convincing the states to reform their monopoly markets in water, gas and electricity as part of the National Competition Policy reforms was a series of 'competition payments', deliverable upon the completion of a number of microeconomic reforms. The second tranche was payable by the Commonwealth in 1999. The CoAG meeting of 1995 decided that the payment of this tranche should be linked to the achievement of a number of the reform 'milestones' from the water reform agenda (CoAG, 1995).

With the first assessment by the National Competition Council (NCC) looming, a high-level ministerial group (the so-called High-Level Steering Group on Water) produced a report in 1999 assessing the states' progress in implementing the 1994 agreement (HLSGW, 1999). Perhaps not surprisingly, it found that the various states had made differing degrees of progress in implementation. However, reform of urban water pricing was deemed on target to meet the CoAG deadline. Rural water reform, on the other hand, had stalled along a number of fronts. The group argued the most serious impediment related to implementing the necessary changes to water entitlements and allocations required to provide a 'flow' to the environment (HLSGW, 1999: 6). Although all the states had made the necessary arrangements to enable water rights to be separated from land title, the efficiency and, in some cases, the mere operation of markets by which those entitlements were to be traded were being hampered by uncertainty regarding the allocations of water to the environment (HLSGW, 1999: 6).

## 2.5 The National Water Initiative

At the August 2003 CoAG meeting, it was agreed that the 1994 water reform framework needed re-invigorating, notwithstanding the significant progress that had been made on some fronts. In essence, the National Water Initiative (NWI) was seen as a means of ending the paralysis that had beset a number of specific elements in the implementation of the CoAG (1994) agreement.

Whilst the draft NWI essentially covered the same areas as the 1994 agreement, three new measures emerged from the initiative: the development of institutional arrangements to deal with the catchment as a whole; the establishment of a robust, transparent regulatory water accounting framework; and a focus on urban water use as a whole rather than the narrow approach of 'just pricing' under the 1994 framework.

### 2.5.1 Urban water reform in the NWI

The purported aim of the NWI with regard to urban water reform was to encourage the reclamation, re-use and recycling of wastewater, render water trading between rural and urban users viable, increase water use efficiency and improve pricing for metropolitan water (CoAG, 2004: 19-20). The means by which the states and territories were to meet these objectives were broadly separated into efforts designed to reduce demand and policies to encourage 'innovation' in water use.

Four measures were to be implemented under the heading of demand management. First, the 'Water Efficiency Labelling Scheme' was to come into effect, requiring mandatory labelling and minimum standards for certain household appliances.

Second, the states were to implement a 'Smart Water Mark' for appliances and products used in household gardens. Third, jurisdictions were to give consideration to the transformation of temporary water restrictions and associated public education strategies into permanent low level arrangements. Finally, water authorities were to upgrade supply and discharge systems, including the repair of leaks and overflows[7] (CoAG, 2004: 19-20).

In terms of innovation, the parties agreed to: a) develop national guidelines for the use of recycled water and stormwater; b) implement a nationwide framework for so-called 'water sensitive urban developments'; c) evaluate existing water sensitive urban developments (such as Greensquare and Rouse Hill in Sydney); d) review the institutional models in place for achieving integrated urban water cycle planning and management; and e) evaluate incentives to stimulate innovation in urban water use (CoAG, 2004: 20).

States and territories were expected to continue with the implementation of uniform pricing policies for urban and rural systems, such that pricing of water was consumption-based and ensured full cost recovery. Reflecting the significant work already done, the aim of the NWI in this area was to increase transparency (CoAG, 2004: 14).

In contrast to the limited focus of the 1994 CoAG agreement, urban water policy was no longer a question of reforming monopoly industry structures. The term 'efficiency' appears to have undergone a subtle yet significant metamorphosis between 1994 and 2003. Whereas efficiency originally implied the most efficient use

[7] It is not immediately obvious how this constitutes 'demand management', since the repair and renewal of infrastructure is more appropriately classified as an effort to secure urban water supplies.

of resources to produce water services, the emphasis changed to 'making every drop count' from the water produced. As Crase and Dollery (2006) make plain, the opportunity cost of producing water, measured by the subsidy paid from governments to residents to install 'water saving devices', seems now to be a secondary consideration. It is in this context that the bulk of recent attention from policy makers in the urban water sector has turned to so-called 'Integrated Water Cycle Management' (IWCM) and the aforementioned 'Water Sensitive Urban Design' (WSUD).

### 2.5.2 State responses to NWI urban water reform requirements

The responses of most state governments to the NWI's broader requirements on urban water reform can be summarised as being aimed at managing demand through implementation of IWCM and WSUD principles. The focus of IWCM is on creating a loop within the existing water supply, sewerage and stormwater network, with the aim of making optimal use of treated water. For instance, by following a 'fit-for-purpose' principle to guide water use, policymakers intend that partially treated stormwater should be used for the irrigation of playing fields and the like, thus reducing the portion of potable water consumed in this activity. Other examples include increased use of roof runoff and the implementation of water conservation measures (ACIL Tasman, 2005).

The aim of WSUD is to neutralise the effect of new urban development of the 'water balance'. Examples include the installation of so-called 'third pipe' schemes, whereby wastewater from a relatively small suburb is treated locally, and then piped back to households for outdoor use, via a third pipe that prevents crosscontamination with the potable water network. Clearly, replumbing an existing neighbourhood to incorporate third pipes would be extremely costly. However, in new developments the third pipe network can be laid alongside the potable water and sewerage pipes.

A précis of the policies implemented in NSW and Victoria to meet the requirements of the NWI with respect to urban water reform is presented in Table 2.1. ACIL Tasman (2005) note the following prominent examples:

> *State governments, water authorities and economic regulators are overseeing pricing reforms to better reflect the value of water (e.g. higher volumetric tariffs, often with increasing blocks as consumption rises); Public education programs promoting water conservation and efficiency are being undertaken; Increasingly stringent water restrictions are being adopted (e.g. 'permanent' water savings measure in Victoria prohibiting certain water uses); and governments across Australia have developed formal policies and/or action plans to promote recycled water projects, often with financial subsidies, public education and awareness programs, and in some cases through mandating specific targets for recycled water.*

Not noted in the NWI or the various state government policy responses is the likely detrimental effect that pursuit of the urban water reform agenda will have on the performance of urban water utilities. Policies that encourage a reduction in the consumption of the commodity that water utilities sell can only result in relative decline in revenue, and since the marginal cost of supplying water is negligible, the opportunity cost associated with each kilolitre of water not billed is likely to be relatively high. One of the secondary aims of this thesis is to determine whether reductions in per capita urban water consumption are correlated with relative technical inefficiency.

Table 2.1: Policies implemented in NSW and Victoria to meet the requirements of the NWI

| Jurisdiction | NSW | Victoria |
|---|---|---|
| **Policies and legislation** | ***Water management act (2000)***<br>The Minister for DNR may request an IWCM strategy as a condition of use.<br>**State water management outcomes plan (SWMOP)**<br>The SWMOP has five-year operational targets that include targets for integrated water cycle Management.<br>***NSW the water conservation strategy (2000).***<br>Reduce per capita consumption by 35%.<br>***Metropolitan water plan-meeting the challenges: securing Sydney's water future***<br>Includes commitments to increase recycling, reduced demand and increased water efficiency. The recycled water strategy aims "to develop a series of market driven recycled water projects with the potential to deliver around 800 GL per annum of potable water savings by 2029". | ***Our Water Our Future***<br>Reduce portable water use by 15%. Reuse 20% of water by 2010.<br>***Smart water fund***<br>Aimed at encouraging and supporting innovative development of sustainable water use projects throughout the geographic areas of greater metropolitan Melbourne and regional urban Victoria. |
| **Regulations** | ***Building sustainability index (BASIX)***<br>Water and stormwater targets set by BASIX mandatory requirements for new development in the Sydney region, as from 1 July 2004. | ***Sustainable suburbs-proposed changes to the Victorian planning provisions, clause 56 (consultation phase currently in the process)***<br>Proposed provisions include integrated water management and applied to the assessment of residential subdivisions. |
| **Guidelines** | ***Best practice management of water supply and sewage guidelines, DEUS, 2004***<br>Requires local water utilities to adopt best practices and achieve specified outcomes, including the preparation of an IWCM strategy plan.<br>The local water utilities must adopt these best practices in order to be eligible for payment of a dividend from the surplus of their water supply or sewerage businesses.<br>***Integrated water cycle Management guidelines for NSW local water utilities, DEUS, October 2004***<br>Provides LWUs with a six-step process for achieving IWCM.<br>A water sensitive planning guide for the Sydney region provides councils with practical guidance on how to promote water sensitive urban design at both the plan making and development assessment stages of the planning process. The framework is compatible with the building sustainability index (BASIX). | ***Best practice environmental guidelines for urban stormwater***<br>This water-sensitive urban design was developed by the Victorian stormwater committee in 1999.<br>***Our Water Our Future*** commits government to preparing WSUD guidelines to assist developers, industry and local government to achieve the 25% target water savings in new developments. |

Source: ACIL Tasman (2005:14-15)

### 2.5.3 Institutional reform in the NWI

The NWI reaffirmed the requirement laid down in the 1994 reforms that the states separate the management of natural resources from the provision of water. Although all states and territories had complied with this section of the CoAG (1994) Water Resources Policy by 2004, the degree of separation varied among the states, and the timing of reform was not uniform across the different jurisdictions.

Two new requirements of the states in terms of institutional reform were stipulated in the NWI. First, the states have agreed to use independent bodies to determine whether the pricing of urban and rural water meets the requirements in the NWI. Most states have long since transferred price setting responsibilities to independent bodies[8], with the notable exception of South Australia, which still leaves this to the discretion of the state government cabinet, acting partly on the advice of SA Water and the Essential Services Commission of South Australia (ESCSA).

Second, the states agreed to develop a nationally consistent framework for the benchmarking of pricing and service quality for metropolitan, non-metropolitan and rural water delivery agencies. Although a number of organisations had been benchmarking the performance of urban water utilities since the early to mid 1990s, the NWI required the benchmarking studies be made publicly available and the associated costs recovered through water pricing (CoAG, 2004: 13-14). In practice, this has resulted in slight changes to the existing performance reports in an attempt to bring uniformity to the definitions of the performance measures, to enable comparisons among the states. The National Water Commission released the first nationwide performance benchmarking reports in May 2007 (NWC, 2007a, b).

Utilities were segregated according to size (measured by the number of connected properties a utility serves). Those utilities in the large category (so-called 'Major

[8] The premier of Victoria recently suspended the current review of urban water prices in Victoria in order for two bodies (the ESC and the Victorian Competition and Efficiency Commission) to undertake broader reviews of the sector.

Urban Utilities') had in excess of 50,000 connected properties, while utilities with between 10,000 and 50,000 connected properties were in the small size category (Non-Major Urban Utilities). The next report, due for release in May 2008, will combine the two, since the small utilities will be required to report accurately on the same criteria that applied to large utilities in 2007.

It is interesting to note that those utilities with fewer than 10,000 connected properties will not be subject to the stringent reporting requirements determined by the NWC. As ACIL Tasman (2005:31) note "Australia's urban water industry comprises approximately 300 utilities. Approximately 70 per cent of Australia's population are serviced by 26 utilities, while the 200 smallest utilities collectively services only 3 million customers". The implication of this is that utilities with fewer than 10,000 connections exist primarily in order to provide essential services and should not be subject to scrutiny with respect to the efficiency of their operations. However, as will be established in Chapter 6, of the LWUs in NSW, only around 25 percent will be classified as 'Non-Major'. This serves to highlight the benefit of this thesis to the water policy debate in Australia, since it constitutes the first detailed study of the economic efficiency of the majority of NSW water utilities that will not be subject to future performance audits.

## 2.6 State water institutional frameworks

Many of the frustrations arising from the implementation of 1994 agreement can be traced back to the different legal and institutional frameworks in place across the states and territories. The implementation of a national framework will obviously be hampered by divergence in the rate of implementation and the order in which the reforms are undertaken. This is particularly so in the Murray–Darling Basin, given that it spans four states and the Australian Capital Territory. This section examines the water institutional framework in NSW and Victoria with the aim of highlighting the existing structures. The regulatory frameworks are analysed along functional categories: natural resource management, service delivery and urban water supply.

### 2.6.1 Natural resource management

In NSW the overarching management of natural resources, including water, is governed by the NSW Department of Natural Resources. Deriving many of its powers from the Water Management Act 2000, the department manages the catchment as a whole via Water Sharing Plans (WSP). The plans act as a 'rule book' of sorts for the use of the water resource within the catchment. Under a WSP, water can be drawn from a resource only where an entitlement to take water has been issued by the department, or where a right to draw water is recognised in statute, as is the case with so-called 'stock and domestic' water. Entitlements are expressed as a share of the total resource, rather than a pre-determined and guaranteed volumetric measure. At various times the volume of water available in a particular catchment is declared, and entitlement holders may receive a pre-determined share of that volume of water. This share itself is subject to a number of other caveats, such as a reduction in volume during periods of drought and revision after the expiry of the plan.

Responsibility for the management of natural resources in Victoria is vested in the Department of Sustainability and Environment (DSE), reporting to the Minister for the Environment and Climate Change and the Minister for Water. With respect to water management, the department derives many of its powers from the Water Act 1989. This act establishes the necessary legislative framework for the allocation of water between so-called consumptive and non-consumptive uses. Accordingly, the Water Act is the primary means by which water from a particular resource is divided between irrigators and other water consumers, such as metropolitan water suppliers, and the needs of the riverine environment for water flows.

The Water Act also allows for the creation of statutory water authorities. Bulk water is supplied to its users (such as irrigators and urban water utilities) through Rural Water Authorities (RWAs). The act makes provision for the allocation of water to these authorities.

The RWAs also have responsibility for management of the various licenses that can be granted under the legislation. These entitle holders to a share of a given resource. Resource managers, appointed to oversee compliance with bulk entitlements, determine the size of the water resource. Some RWAs are also resource managers.

### 2.6.2 Service delivery

In an effort to comply with the requirements of the 1994 CoAG agreement, the NSW Government established State Water within the Department of Land and Water Conservation in 1997. State Water was statutorily separated from the department, and operated as a business unit, allowing cost and water accounting to be separated along catchment lines. State Water was essentially responsible for the supply of bulk water downstream from the major dams in NSW, as well as the maintenance of the infrastructure that allowed regulation of the relevant water sources. In this guise, State Water was still subject to direct control by the relevant minister, and the NCC expressed concerns in its 1999 assessment that State Water was not sufficiently separate from the minister to comply with the requirements of the CoAG agreement (NCC, 1999: 310).

To rectify this situation, the state government corporatised State Water through the passage of the State Water Corporatisation Act 2004. It operates under a license issued by the Department of Energy, Utilities and Sustainability (DEUS). State Water is responsible for the provision of bulk water to irrigators, rural and regional urban water authorities (known as Local Water Utilities (LWUs)), farms, mines and electricity generators. Outside of the areas under the control of the Sydney Catchment Authority and the Hunter Water Corporation, State Water is in essence the monopoly supplier of bulk water in NSW, although a number of LWUs own and manage their bulk water storage. The regulator of LWUs has suggested that the additional responsibilities associating with maintaining bulk water supplies put those LWUs at an operational disadvantage (DEUS, 2004). That claim is tested in this thesis.

A slightly less centralised system is in place in Victoria. Three RWAs exist in order to manage the bulk water entitlements of the state: the First Mildura Irrigation Trust; Gippsland and Southern Rural Water; and Goulburn–Murray Rural Water. The role of a RWA is set out in the Water Act, and includes:

- Managing and operating water storage and storage infrastructure within its district;
- providing entitlements to irrigation districts, stock and domestic users and private diverters;

- supplying bulk water to Regional Urban Water Authorities (now called 'Corporations'); and
- constructing and maintaining delivery and drainage services.

RWAs also administer the licensing regime that exists in Victoria, and facilitate the transfer of license entitlements between irrigation districts.

### 2.6.3 Urban water supply

As mentioned above in the context of non-metropolitan urban water in NSW, the provision of water and wastewater is usually a function carried out by LWUs. Almost all LWUs are business units of NSW councils. Indeed, the function of water and wastewater provision is conferred upon local government by chapter 6 of the Local Government Act 1993.

Under the National Competition Policy agreement, local governments are required to operate LWUs following a corporatisation model, where the LWU is financially 'ringfenced', meaning it is to be run as a separate entity, providing a separate financial statement from Council. Moneys cannot be diverted from it for other purposes except in the form of a dividend. DEUS is the agency responsible for assessing a LWU against this criterion.

In 2003–2004 in NSW, 126 LWUs provided water and wastewater services outside of the metropolitan regions. Of those, 121 were local government councils, providing the service under the Local Government Act, while five were classified as LWUs operating under the provisions of the Water Management Act. Of the 126 LWUs, 105 were responsible for provision of both water and sewerage services, eight provided water only and 13 provided sewerage only. Total turnover for this sector was $806 million and aggregate assets under management were $10.6 billion. Fifty-one of the LWUs were classified as Category One under the NCP framework (i.e. have a turnover in excess of $2 million a year) and are therefore required by statute to, among other things, apply corporatisation principles to their operations (DEUS, 2005a: 123).

The average economic real rate of return[9] was 2.7 per cent for water supply and sewerage; this was lower than the rate achieved in metropolitan NSW, but higher than equivalent businesses in country Victoria. Returns have remained steady over the last 10 years. A positive return was generated by 75 per cent of LWUs. The top 20 per cent earn an average of 4.5 per cent, while the bottom 20 per cent earn an average 0.5 per cent (DEUS, 2005b: 112).

LWUs are third in line in terms of security to the water resource within a given catchment, ranking behind allocations to the natural environment and stock and domestic entitlements. However, allocations to LWUs are treated differently from all other allocations in that they are guaranteed and expressed in volumetric terms, regardless of the size of the catchment volume. This is essentially due to the nature of the activity of LWUs – the provision of non-metropolitan urban water.

The delivery of water and wastewater services to urban communities across regional Victoria for household, commercial and industrial use is the responsibility of

[9] The economic significance of Rate of Return in this context is questionable, since rate of return can be influenced by the accuracy of the asset valuation process. The so-called Allan-report (2006) established that councils in NSW have a relatively poor record in terms of accurately valuing infrastructure.

Regional Urban Water Authorities[10] (RUWA), that have no connection with local government. However, this has not always been the case. The Victorian water industry experienced substantial reform during the early 1990s following the election of the Kennett government. Through a series of council amalgamations around 400 local government (non-metropolitan) utilities were consolidated into 15[11] regional utilities (World Bank, 2004: 6).

Each RUWA is responsible for a well defined district. The powers of a RUWA are established via the Water Act 1989. The nature of the services provided, and the environment within which those services are provided, vary considerably among the 15 authorities, as is illustrated in Table 2.2. For example, Barwon Water provides water to around 117,000 properties, while Glenelg Water is responsible for only 8,284.

In contrast to the NSW model, the management of RUWAs is not the responsibility of a directly elected council. The relevant state minister appoints the Board of each RUWA and that Board reports to the Minister through, *inter alia*, an annual report. Governance is by way of a Water Service Agreement made between the minister responsible for water and each RUWA. These agreements contain the government's expectations of each authority and the obligations of the RUWA to the various customers it serves.

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[10] Regional urban water authorities were recently re-named regional urban water corporations.
[11] Two urban rural water authorities provide combined water, sewerage, irrigation and domestic and stock services; Grampians Wimmera Mallee Water and Lower Murray Urban and Rural Water.

Table 2.2: Selected characteristics of Victorian regional urban water authorities, 2003–04

| RUWA | Properties connected (water) | Properties connected (sewerage) | Total water supplied (ML) | Total revenue ($'000s) |
|---|---|---|---|---|
| Barwon Water | 117,658 | 105,784 | 41,291 | 99,851 |
| Central Highlands Water | 53,281 | 43,682 | 19,749 | 47,684 |
| Coliban Water | 60,331 | 49,616 | 26,188 | 45,594 |
| Gippsland Water | 57,450 | 49,168 | 65,404 | 47,444 |
| Goulburn Valley Water | 49,035 | 42,764 | 30,468 | 51,658 |
| North East Water | 39,797 | 34,413 | 23,939 | 28,551 |
| Western Water | 47,449 | 37,951 | 14,432 | 50,078 |
| East Gippsland Water | 18,614 | 14,846 | 6,997 | 13,895 |
| Glenelg Water | 8,284 | 5,989 | 2,655 | 5,240 |
| Grampians Water | 30,037 | 22,866 | 10,228 | 26,634 |
| Lower Murray Water | 28,269 | 23,742 | 21,878 | 22,538 |
| Portland Coast Water | 7,572 | 7,035 | 2,847 | 6,082 |
| South Gippsland Water | 15,710 | 12,726 | 6,575 | 13,413 |
| South West Water | 20,565 | 17,525 | 10,501 | 15,690 |
| Westernport Water | 12,575 | 10,718 | 2,165 | 12,597 |

Source: VicWater (2005)

### *Environmental protection*

In NSW, the NSW Environment Protection Authority[12] (NSW EPA) seeks to protect, restore and enhance the environment in NSW, reduce environmental risk to human health, and prevent the degradation of the natural environment. In particular, the NSW EPA monitors air and water quality, contaminated land, noise, pesticides, hazardous chemicals, dangerous goods, radiation and waste (NSW EPA, 2003:2). The NSW EPA is generally involved in resource management through co-operation with other agencies in the monitoring of riverine health and the effect of stormwater on water courses and beaches.

As noted earlier, all but eight of the LWUs provide both wastewater and potable water services. The degree to which sewerage is treated varies among the wastewater

[12] Since April 2007 part of the Department of Environment and Climate Change NSW (DECC), and formerly known as the Environmental Protection Agency.

providers; however, all must meet a minimum standard of treatment. The NSW EPA issues licenses for sewerage treatment systems including pipes, treatment works and mechanisms designed to dispose of treated waste. Treatment systems servicing more than 2,500 persons or treating 750 kilolitres per day require a license, although smaller facilities that discharge into a waterway require a license regardless of size (NSW EPA, 2003:2). All of the 108 LWUs that provide sewerage services in NSW are licensed by the NSW EPA.

Environmental regulation in Victoria falls primarily to the Victorian Environment Protection Authority (Vic EPA), which derives its powers from the Environment Protection Act 1970. The role of the Vic EPA is to monitor the water industry's efforts to minimise waste, recycle effluent and biosolids, manage waste discharges, manage odour and greenhouse gas emissions, and prevent pollution of groundwater and surface waters. The key regulatory instrument is the State Environment Protection Policy (SEPP) (Waters of Victoria) 2003 (Vic EPA, 2003: 2).

In Victoria, wastewater treatment plants are classified as Schedule 2 premises under the legislation and require an approval for their construction or alteration, as well as an on-going license for their operation. License conditions vary from location to location; however, they generally include provisions regarding limits on the discharge of various substances, monitoring requirements, housekeeping conditions, reporting of incidents and monitoring data.

***Economic regulation***

Economic regulation in NSW is principally the responsibility of the Independent Pricing and Regulatory Tribunal (IPART). This body is independent of the government, and *inter alia* regulates the prices that various utilities can charge for their services. In terms of water, IPART regulates the metropolitan water utilities (i.e. Sydney Water Corporation, Hunter Water Corporation and Gosford and Wyong Water Corporation) and State Water, the supplier of bulk water outside of those areas.

The Department of Energy, Utilities and Sustainability (DEUS) regulates pricing of water and wastewater by LWUs in regional NSW. While IPART often makes determinations on price regimes for the utilities it regulates, DEUS benchmarks local water utilities against a set of best-practice management principles rather than directly prescribing pricing regimes. Compared with the form of regulation in Victoria, this constitutes 'soft' regulation. Economic regulation of water and wastewater utilities in NSW by IPART is for only four utilities, as opposed to the role of the Essential Services Commission (ESC) in Victoria, who regulate all RUWAs. This point represents another potential benefit of the research to be presented in this thesis. If it can be determined that utilities of a comparable size in Victoria are relatively more efficient, this may lend support to the argument that IPART should consider drawing the largest LWUs in NSW within its regulatory gamut.

In order for an LWU to pay a dividend to council it must comply with a number of Best-Practice Management (BPM) Guidelines (DEUS, 2005b: 4). They include:

- Strategic business planning and long-term financial planning;
- water supply and sewerage pricing and developer charges;
- demand management;
- drought management;

- annual performance monitoring; and
- integrated water cycle management.

These requirements are quite ambitious and some of the items are not strictly economic matters. Thus, even if an LWU reduces costs or increases revenues such that it earns a positive rate of return to council, a dividend cannot be paid unless the LWU has carried out the required social and environmental functions. In fact, in 2003–04 only 10 per cent of LWUs were able to report compliance with the BPM guidelines, and were thus eligible to pay a dividend, with only 3.4 per cent actually paying a dividend (DEUS, 2005a: vi).

In Victoria, the ESC is the economic regulator of all water and waster utilities in the state, including RUWAs. This contrasts with the situation in NSW, where economic regulation is undertaken by a government department rather than an independent tribunal. The ESC undertakes pricing reviews in order to determine a 'reasonable' tariff structure for each RUWA to apply. Matters considered by the ESC include infrastructure renewal expense and relative water demand. RUWAs are also monitored with respect to the various service obligations embedded within their operating licence. RUWAs are not required to comply with the equivalent of the Best-Practice Management Guidelines; however, all RUWAs are expected to develop strategic plans with a 50-year time horizon.

## 2.7 Concluding remarks

The discussion in this chapter has encompassed four main points. First, Australian urban water provision is characterised by diversity. This multifariousness exists both interstate, due to manifest state-based legislation and varying federal/state/local relationships, and intrastate, where non-metropolitan urban water providers are responsible for widely differing areas and associated populations.

Second, despite attempts to develop a uniform policy response to the perceived perilous state of the nation's water resource, the reality of operating within a federation has seen the vision of a uniform response diminish to a puzzle of overlapping legislative and regulatory controls of water resources, particularly in the Murray–Darling Basin. Furthermore, the patchwork of institutional structures may well have a measurable effect on the relative efficiency with which the water and wastewater industries in the basin operate.

Third, despite the focus of earlier reforms in the urban water and wastewater sectors in Australia on the traditionally defined concept of economic efficiency, a subtle change has occurred in the policy area. Efficiency no longer emphasises the production of water at least cost, but rather the most frugal use of water – at least in an urban setting – encapsulated by the phrase 'every drop counts'.

Finally, urban water and wastewater utilities in regional NSW and Victoria can be distinguished along a number of fronts. Of most relevance to this thesis is the divergent governance structures in place and the relatively 'harder' economic regulation imposed on Victorian utilities. In the following chapter, attention turns to an examination of the various techniques by which relative efficiency in production can be measured.

# Chapter 3. The Theory of Efficiency Measurement

## 3.1 Introduction

The urban water and wastewater sectors in NSW and Victoria can be differentiated primarily with respect to the regulatory structure pertaining to each. The central aim of this thesis is to investigate relationships between the relative performance of individual utilities in each of the states, and the aforementioned regulatory contrast. A first step in this process is to define the rather loose concept of performance. In this thesis performance is measured with relation to the economic principle of relative efficiency. In subsequent chapters the results of an analysis of the relative efficiency of water and wastewater utilities in South East Australia are reported; first, the theoretic underpinnings of that research are considered.

This chapter outlines and examines the tools most frequently used to measure efficiency in production. Much of the material discussed is theoretical and not strongly related to the water industry per se, although the chapter emphasises techniques particularly applicable to the analysis of the water industry.

Economic efficiency is a strictly defined concept, despite regular use and abuse of the term outside of the economics discipline. In the simplest terms, efficiency consists of three elements: technical, allocative and dynamic efficiency. In this thesis, for reasons to be outlined in later sections of this chapter, no attempt is made to measure allocative efficiency; rather, the review concentrates on technical and dynamic efficiency. Technical efficiency is an examination of the relationship between the inputs and resultant outputs in a productive process. Two related yet separate econometric techniques have been developed to measure technical efficiency: Stochastic Frontier Analysis (SFA) and Data Envelopment Analysis (DEA). Each technique is examined in detail in this chapter. Dynamic efficiency relates to the change in efficiency through time, and can also be referred to as productivity change. A number of techniques have been suggested to measure productivity change; however, this chapter deals with only one of the competing approaches, the so-called 'Malmquist Productivity Index' technique.

The chapter consists of eight main parts. Section 3.2 provides an introduction to the economic meaning of efficiency. Since the main focus of this thesis is efficiency in production, Section 3.3 expands on this topic, with particular reference to the groundbreaking work of Farrell (1957) on the decomposition of efficiency into technical and allocative components. Section 3.4 outlines the main characteristic of SFA and DEA. Sections 3.5 and 3.6 examine the main extensions to the two approaches. The focus is on techniques that have potential to enrich the analysis of water and wastewater services in NSW and Victoria. Section 3.7 introduces the concept of measuring changes in efficiency through time. The chapter concludes with some brief remarks in Section 3.8.

## 3.2 Economic meaning of efficiency

Economists assume that consumers and producers inadvertently seek to attain a state of 'efficiency' by pursuing their self-interest. In the broader community, efficiency can mean different things to different people. However, in economic discourse it carries a precise meaning. The orthodox approach is Pareto efficiency, named after the Italian economist Vilfredo Pareto (1848 - 1923); an efficient allocation of resources is one from which no person can be made better off without making another worse off (Friedman 2002: 45). This implies that there is no waste in resource use.

Economists have sought to apply the Pareto principle of efficiency to most situations in which resources are used. In general, three 'high-level' efficiency conditions can be identified: efficiency in exchange, efficiency in production and simultaneous efficiency in consumption and production. Since this thesis is concerned primarily with efficiency in the provision of water and wastewater services, the focus of the discussion in this chapter will be on efficiency in production.

## 3.3 Efficiency in production

### 3.3.1 The production function

One of the more important relationships a firm considers when producing a commodity is that between the quantity of inputs a firm uses in production and the resultant output. This relationship can be expressed by a production function.

Production functions can take many forms, ranging from the famous Cobb–Douglas to the translog. However, in its most basic incarnation, it takes the familiar form:

$$Y = f(x_1, x_2, ..., x_n) \tag{3.1}$$

where $(x_1, x_2, ..., x_n)$ are the quantities of different inputs employed and $Y$ is the maximum output attainable, per period, in the transformation of those inputs.

Greene (1995: 83) referred to the function itself "as simply a body of knowledge" that reveals the various parameters that govern the transformation of inputs to one or more outputs. The production function can also serve the very useful purpose of defining the maximum attainable output given a particular combination of inputs. Thus, the production function often does not describe every firm in an industry, but only those firms that are 'efficient' at what they do, in the sense that they cannot produce a greater quantum given the inputs. Put differently, for a given set of inputs the quantity of output is maximised.

Analysis of productive efficiency can be traced to Adam Smith's pin factory. However, the fathers of modern attempts at measuring efficiency in production are Koopmans (1951) and Debreau (1951). Koopmans (1951:60) was the first to provide a definition of technical efficiency: that is, a producer is technically inefficient if it could produce more of at least one output. Debreu (1951: 285) formally introduced the concept of degrees of inefficiency by invoking the notion of equi-proportionate reductions in inputs for a given output, or the equi-proportionate expansion of all outputs.

However, the seminal work of Farrell (1957) is seen by many as the foundation of most efficiency studies. Farrell's (1957) work is distinguished from that of Koopmans (1951) and Debreau (1951) through the decomposition of productive efficiency into technical efficiency, in which a firm cannot produce more output given a set of inputs, and allocative efficiency, in which a firm reaches the optimal combination of inputs and outputs, given their relative prices. Farrell (1957) also argued that a state of productive nirvana could be attained, where a firm was both technically and allocatively efficient. He termed this point 'overall economic' efficiency.

A further measure of efficiency was advanced by Leibenstein (1966) who argued that, while the deterministic nature of allocative efficiency may be of interest, it was what he called 'X-inefficiency' that was most important. This type of inefficiency saw production fall within the bounds of the production function, due to a number of factors that prevented firms from maximising output. Leibenstein's (1966) main critique of the neo-classical approach was that it tended to assume production occurred on the frontier, and most effort should be directed toward moving to the allocatively efficient point, when, in fact, decreasing X-inefficiency was far more significant in terms of increasing welfare.

Most measures of productive efficiency rely heavily on the work of Farrell (1957). His argument can be succinctly summarised in Figure 3.1.

Figure 3.1: Technical, allocative and total economic efficiency

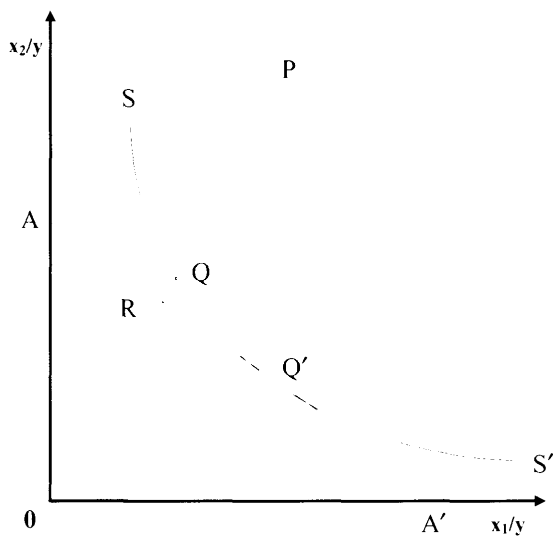


Figure 3.1 makes use of an isoquant and budget constraint to illustrate the concepts of technical, allocative and economic efficiency. The firm produces a single output y, through the utilisation of two inputs, x1 and x2.

### *Technical efficiency*

The firm is technically efficient if it produces at some point along the fully efficient isoquant SS'. However, for a firm that produces at point P, with a sub-optimal combination of inputs (x1*/y, x2*/y), the degree of technical efficiency is given by the ratio OQ/OP. It follows that the degree of technical inefficiency is 1 – (OQ/OP), and represents the proportional reduction in inputs that could be achieved without reducing output.

### *Allocative efficiency*

While the firm may be at a technically efficient point when producing along the isoquant SS', the degree of allocative efficiency can be measured if the input price ratio AA' is known. Suppose the firm again consumes the input mix defined by point P. Given the respective input prices at point P, the degree of allocative efficiency is given by the ratio OR/OQ, and the degree of allocative inefficiency is given by 1 – (OR/OQ). By increasing consumption of x1 in favour of x2, the same output could be produced at lower cost. Thus, the distance RQ represents the minimisation of cost available to the firm from producing at Q', even though technical efficiency could be reached at Q.

***Total economic efficiency***

Total economic efficiency (referred to by Farrell (1957) as overall efficiency) is given by the product of technical and allocative efficiency (OR/OP). Conceptually this is the equivalent of being on the point of the isoquant SS' at which the slope of the input price ratio is equal to the marginal rate of technical substitution between the two inputs, given by the slope of the isoquant:

$$MRTS_{x_2,x_1} = \frac{P_{x_1}}{P_{x_2}} \tag{3.2}$$

The degree of total economic inefficiency is given by 1 – OR/OP and indicates the total reduction in cost that could be achieved by the firm should it achieve both technical and allocative efficiency.

***Dynamic efficiency***

The inherent weakness of Farrell's (1957) measures of technical, allocative and economic efficiency is that they are a snapshot of the firm at a particular point in time. A fourth measure of efficiency, not explicitly developed by Farrell, is that of changes in efficiency over time. This sometimes goes by the term 'dynamic efficiency', used to measure technical and/or allocative improvement or deterioration as a function of changes in inputs, outputs and time. In the current context, the favoured approach to achieving this has been through the use of index numbers. This technique is discussed below in Section 3.7.

## 3.4 Measuring production efficiency

In stark contrast with the theory that underlines the production function, early attempts at measuring productive efficiency were primarily exercises in least squares (LS) estimation; they sought to find a line of 'best-fit' that ran through the data. This flies in the face of the concept of production maximisation argued by Debreau (1951), Koopmans (1951), Farrell (1957) and others. More recent efforts, beginning with Aigner and Chui (1968), have embraced the concept of a production frontier by developing techniques that seek to envelope the data, rather than pass through it. This aligns with the assumption inherent in the production function itself, that for a given combination of inputs, production can occur on or below the production function, but not beyond it. The frontier thus forms a benchmark against which all observed firms can be measured.

Attempts at frontier analysis generally fall into two broad categories. In the first, the parameters of a given functional form are estimated with the aim of measuring relative firm efficiency with reference to the estimated frontier. Within this group are two subsets. The first defines any observed departure from the frontier as inefficiency (deterministic), while the second allows for both technical inefficiency and matters outside the control of a firm (non-deterministic) (Coelli et al., 2005).

The second approach to frontier analysis makes no assumptions regarding the parameters of the production function, preferring to make use of mathematical programming to determine the frontier as a function of the dataset itself. A hull is constructed around the data, and this is assumed to be the efficient frontier (Zhu, 2003). Firms can produce within and on the frontier, but not beyond it. In the parlance of production economics, the frontier is said to represent the feasible set of production points and equates to the observed 'best-practice' benchmark against which firms within the industry are judged.

A perceived weakness of this approach is the difficulties associated with incorporating allowances for statistical noise as a result of sampling error or other factors beyond the realm of 'pure' inputs and outputs. The resultant implication is that any departure from the frontier is due to inefficiency (Fried et al., 2002). The main analytical tool developed from this school of thought is DEA. Although a conceptually similar technique, known as the Free-Disposal Hull Approach (FDH), has recently been developed, it has not as yet received the degree of acceptance among practitioners as DEA (Forsund and Sarafoglou, 2002). As a result the FDH approach is not discussed in this chapter.

### 3.4.1 A general production framework

As described by Lovell (1993), a well-defined production function can be smooth, continuous, continuously differentiable and quasi-concave. Input prices are assumed exogenous, implying producers are price takers. The production function takes the following form:

$$Q_i = f(x_i, \beta) \tag{3.3}$$

Where $Q$ represents output, $x$ is a set of inputs, $\beta$ encompasses the parameters of the function and $i$ indexes the firms to be observed. As noted by Lovell (1993) and Greene (1995), most applications of the model are linear in the logs of output and a set of independent variables. Equation 3.3 can thus be re-written as:

$$Y_i = \ln Q_i = \alpha + \beta' x_i \tag{3.4}$$

Greene (1995) argues that the parametric form is of little interest in the current context, except to the extent that a particular specification imposes restrictions that later distort measures of efficiency. The primary focus therefore is the relationship between the set of inputs $x_i$ and the associated output $Y_i$.

The formal econometric analysis of production frontiers begins with Aigner and Chu's (1968) re-formulation of a Cobb–Douglas production function. However, the work of Charnes et al. (1978) was arguably the first to take Farrell's (1957) framework of an isoquant and budget constraint and apply it in an empirical setting. Productive efficiency research has essentially proceeded along the lines of Aigner and Chiu (1968) or Charnes et al. (1978) ever since. However, as will be shown, the two schools have recently crossed paths in an attempt to add depth to production analysis. The following discussion presents more detailed analysis of each approach.

### 3.4.2 Parametric approaches

The so-called parametric approach makes use of the standard production function in order to establish a fully efficient frontier against which all firms in an industry can be measured. The approaches can be separated into non-stochastic and stochastic models.

***Non-stochastic (deterministic) functions***

Following Coelli et al. (2005: 242-45), it is possible to develop a model that seeks to measure the degree to which a Decision Making Unit's (DMU) productive process deviates from the best attainable. Given a dataset pertaining to production, consisting of $I$ firms for a single time period, one method of conducting productivity analysis is to envelope the data points in a suitable function. This approach was pioneered by Aigner and Chu (1968), who chose a Cobb–Douglas production frontier of the form:

$$\ln q_i = x_i^{'}\beta - \mu_i \qquad I = 1,\ldots,i \tag{3.5}$$

Where $q_i$ represents the output of the $i$th firm, $x_i^{'}$ is a vector containing the logarithm of inputs, $\beta$ is a vector of unknown parameters, and $\mu_i$ is a non-negative variable employed to measure technical inefficiency of the $i$th .

Equation 3.5 is deterministic in the sense that any deviation from the fully efficient frontier, $\beta$ , is entirely contained in the technical inefficiency estimator, $\mu_i$ . The result of this is that each and every deviation is attributed to technical inefficiency. The model does not allow for exogenous shocks, such as weather or disease, that lie outside of the DMU's control. Furthermore, mis-specification and data errors are erroneously captured in the technical inefficiency measure.

The inflexibility of this model can lead to unduly harsh conclusions regarding the efficiency of DMUs, and was the motivating force behind the development of a model capable of capturing the exogenous influences upon production. Through the introduction of a second random variable term, the *stochastic* production function allows for a more flexible means of measuring productive efficiency.

***Stochastic (non-deterministic) functions***

The so-called Stochastic Frontier Analysis (SFA) model was developed independently by Aigner et al. (1977) and Meeusen and van den Broeck (1977) (Forsund and Sarafoglou, 2002: 29). It incorporates the concept that some factors likely to affect production are beyond the control of the DMU. Furthermore, errors resulting from estimation error on behalf of the analyst are incorporated in a separately defined error term, partly negating the possibility of deviations from the production function as a result of analytical error being erroneously included in estimates of DMU inefficiency.

In essence, the model is very similar to the deterministic method. The departure point is in the specification of the random variable $u_i$. The SFA approach splits the measure of technical inefficiency by retaining $u_i$ as a non-negative term, performing the original function of measuring deviations from the frontier associated with technical inefficiency, while adding a second term, $v_i$, that "embodies measurement errors, any other statistical noise, and random variation of the frontier across firms" (Greene 1995: 99).

The stochastic frontier production function model takes the following form:

$$\ln q_i = x_i^{'}\beta + v_i - \mu_i \qquad (3.6)$$

In contrast to $u_i$, the random variable $v_i$ can take positive *or* negative values. This allows for unobserved outputs that appear above the fully efficient frontier, an observation that does not sit well in the deterministic framework. Coelli et al. (2005: 243) highlighted the virtues of the SFA model by re-arranging a Cobb–Douglas stochastic frontier model to take the form:

$$\begin{aligned} &\ln q_i = \beta_0 + \beta_1 \ln x_i + v_i - u_i \\ &\text{or } q_i = \exp(\beta_0 + \beta_1 \ln x_i + v_i - u_i) \\ &\text{or } q_i = \underbrace{\exp(\beta_0 + \beta_1 \ln x_i)}_{\text{deterministic component}} \times \underbrace{\exp(v_i)}_{\text{noise}} \times \underbrace{\exp(-u_i)}_{\text{inefficiency}} \end{aligned} \quad (3.7)$$

where $\exp(\beta_0 + \beta_1 \ln x_i)$ is the deterministic component, $\exp(v_i)$ measures noise and $\exp(-u_i)$ is attributable to inefficiency.

While the incorporation of a measure to account for stochastic factors is valuable, its main contribution is to add richness to the inefficiency measure. After all, policy makers are generally more interested in what the firm can control rather that what it cannot. As a result, much of the focus is on estimating inefficiency effects. Unsurprisingly, the most common tool establishes the ratio between the observed output and the stochastic frontier output:

$$TE_i = \frac{q_i}{\exp(\mathrm{x}_i'\beta + v_i)} = \frac{\exp(\mathrm{x}_i'\beta + v_i - u_i)}{\exp(\mathrm{x}_i'\beta + v_i)} = \exp(-u_i) \quad 0 \leq TE_i \leq 1 \quad (3.8)$$

*Parameter Estimation*

Of crucial importance to this technique is the estimation of the parameters, since they define the technical efficiency measure. However, the process is complicated by the need to estimate the composed error function. The essential difference between $u_i$ and $v_i$ is the assumption that $u_i$ has a non-zero mean, the implication of which is manifest in the relative position of the frontier itself.

Although consistent estimates of $\beta$ can be obtained, $\beta_0$ (i.e. the intercept) is biased downward. This is unfortunate, because the frontier then becomes, somewhat paradoxically, an 'average' frontier that runs through the data. Since the purpose of frontier analysis is to make relative comparisons against a frontier forming an envelope of the data, the downward bias in the intercept tends to defeat the purpose of conducting SFA. Two methods have been suggested to overcome this problem. In the first place, Corrected Ordinary Least Squares (COLS) simply shifts the intercept up until all but one of the residuals is below the frontier. The highest residual is that from which the frontier hangs. Although Winston (1957) was the first to suggest such a correction, proofs of the consistency of the COLS estimator can be found in the work of Gabrielsen (1975) and Greene (1980).

The second approach is to impose assumptions regarding the distribution of the $u_i$ on the model and to shift the frontier in accordance with these. This method is known as Modified Ordinary Least Squares (MOLS). The question of error term distributions would be a short-lived affair if both error terms in the stochastic frontier model could be assumed normally distributed. However, the requirement that the measure of technical efficiency only return positive values, since it is assumed impossible for a firm to produce beyond the frontier, has necessitated a debate on the correct distributional form of the error term $u_i$.

As Worthington (1998: 21) observes:

> *A large number of alternative distributions have been assumed. Of these, the most commonly assumed distribution has been half-normal (Aigner, Lovell and Schmidt 1977) - although more generally distributed forms, such as the truncated-normal (Stevenson 1980), exponential (Meeusen and van den Broeck 1977) and the two-parameter gamma (Greene 1990), have also been used.*

An excellent review of the various models is given by Kumbhakar and Lovell (2000: 74-90).

Decisions regarding which distributional assumption to take should ideally be based on economic reasoning. For example, Coelli (2005: 252) notes that some researchers avoid the half normal and exponential distributions because they have means close to 0, implying that a large proportion of firms are efficient, yielding technical efficiency scores close to 1. If one assumes a wider distribution of efficiency scores, a better distribution would be the truncated normal or gamma since they allow a wider range of distributional shapes. However, as Kumbhakar and Lovell (2000: 90) note:

> *What is not clear is whether a ranking of producers by their individual efficiency scores, or the composition of the top and bottom efficiency deciles, is sensitive to distributional assumptions. Indeed there is some evidence that neither rankings nor decile compositions are particularly sensitive.*

### 3.4.3 Non-parametric approaches

In contrast to the parametric approaches to frontier analysis, non-paramatric techniques do not explicitly estimate the functional form of the efficient frontier. Rather, the data are said to determine the frontier. Proponents of non-parametric approaches argue that the benchmark against which the efficiency of firms is measured is based in empiricism as opposed to assumptions founded in production theory. Chief among the non-paramatric approaches is DEA.

***Data envelopment analysis***

DEA is a mathematical programming approach to investigating Farrell's (1957) concepts of technical and allocative efficiency. Farrell (1957) himself identified the problem of locating and estimating the frontier that defines the fully efficiency firm/s. He suggested two approaches to the problem. The first was to estimate the frontier via standard econometric analysis while the second involved enveloping the data in a non-parametric piece-wise linear convex isoquant. This has come to be known as Data Envelopment Analysis (DEA).

In conceptual terms, both DEA and SFA define the 'fully efficient' function against which all firms in a given sample can be measured. The main distinction between the two is the non-parametric approach employed in DEA. While SFA incorporates an error term in order to account for errors in estimating the correct specification of the production function, DEA avoids the need to estimate an additional parameter by simply not specifying a function form to be estimated. The pioneers of DEA, Charnes et al. (1978), were the first to implement Farrell's idea of a non-parametric model.

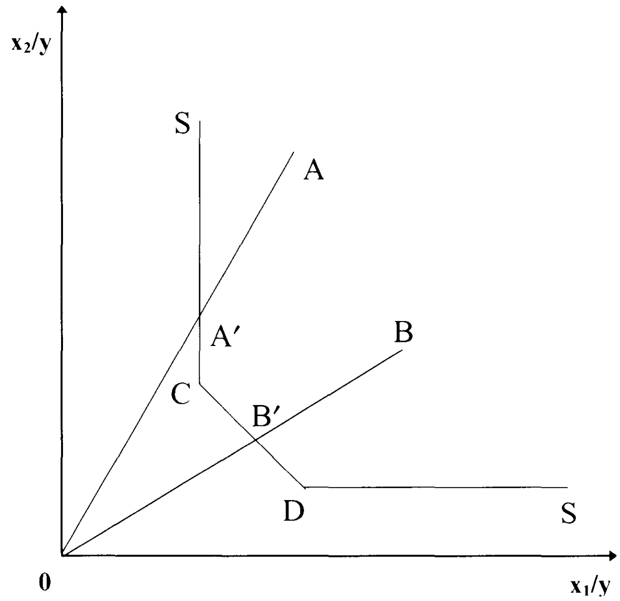
In essence, the aim of the DEA approach is to identify the most efficient DMUs contained within a sample and then to make use of those observations to form a piece-wise linear isoquant, thus forming the efficient frontier. It is against this frontier that all other DMUs in the sample can be measured.

The procedure is intuitively appealing. Taking as an example a situation in which output is exogenous[13], the first task is to radially contract the set of inputs for each firm as much as is possible. The extent to which this takes place is defined by the feasible input set. Once this task is complete for all firms in the sample, the 'frontier' can be constructed. In DEA, this is simply the set of firms that had their input set reduced the most, relative to the origin and given the firm's relative input consumption. This forms the conceptual equivalent to Farrell's (1957) isoquant. Once the piece-wise linear isoquant is constructed, the efficiency measurement operations proposed by Farrell can be conducted. This is achieved by projecting inefficient firms onto the frontier. Inefficient firms are thus able to measure the extent of their technical inefficiency, with reference to the efficient firms forming the frontier.

Complications arise due to the construction process. For example, the piece-wise linear nature of the frontier gives rise to the possibility of certain firms appearing on the frontier, even though it would be possible for them to reduce the quantity of one input without reducing output. This is illustrated in Figure 3.2, by the distance CA'. In the literature these are called 'slacks', and it is conventional to report them along with the efficiency ratios proposed by Farrell (1957).

[13] It is equally possible to examine input exogeneity. However, managers in the water and wastewater industry typically do not control output, since this would raise serious equity objections. Thus, it is the role of the manager to minimise input consumption for a given output.

Figure 3.2: Efficiency measurement and input slacks




It would be misleading to compare a firm aiming to produce along the segment DS to a firm targeting production along segment CD. In DEA, those firms that should be producing somewhere along the same linear section of the piece-wise isoquant are referred to as peers, and comparison of the *i*th firm's technical efficiency is usually expressed with reference to peer groups rather than the entire sample of firms.

*The DEA model*

Following the outline of the model in an intuitive sense, this section presents a formal exposition of the model, following Coelli et al. (1998: 140-43). For convenience, development of the model will take place under the assumption of constant returns to scale. However, DEA is capable of accommodating variable returns to scale, and that model will be introduced in following sections.

Assume data is obtained relating to inputs K and outputs M for a sample of N firms. For the $i$th firm these can be represented by the column vectors $x_i$ and $y_i$, respectively. The dataset consists of the input vector KxN = $X$ and output vector MxN = $Y$.

The objective is to measure the relative efficiency of each firm in the sample. This is achieved by obtaining the ratio of all outputs to all inputs for the firm. Given that not all firms will employ identical proportions of available inputs, the model must incorporate a variable that accounts for input proportion variance among firms. Optimal weights for each of the inputs and outputs are derived, such that:

$$\begin{aligned}
&\max_{u,v}\left(u'y_i / v'x_i\right),\\
&\text{s.t.}\\
&u'y_j / v'x_j \leq 1, \quad \mathrm{j}=1,2,\ldots,\mathrm{N},\\
&u,v \geq 0.
\end{aligned} \tag{3.9}$$

where $u'$ is the set of weights applicable to the outputs, and $v'$ the set of weights applicable to the inputs. The basic problem to be solved then is to find weights that will maximise the efficiency measure (the objective function), subject to the constraint that no efficiency score be greater than one (Coelli et al., 1998: 141). Efficiency scores range from 0 to 1, with a score approaching 1 indicating increasing efficiency, relative to the benchmark firms (Woodbury, 2001: 42).

A problem with equation 3.9 is that it contains an infinite number of solutions. A way of correcting this is to impose the constraint $v'x = 1$, such that:

$$\max_{\mu,\nu} (\mu' y_i),$$
$$\text{s.t.}$$
$$\nu' x_i = 1, \qquad (3.10)$$
$$\mu' y_j - \nu' x_j \le 0, \quad j=1,2,...,N,$$
$$\mu, \nu \ge 0.$$

This is known as the multiplier form of DEA. Although this elementary model of DEA is useful by way of background, its application to the minimisation problem is of more relevance to the current research. Through exploitation of the duality in linear programming, the equivalent envelopment form of the problem is developed as follows:

$$\min_{\theta,\lambda} \theta,$$
$$\text{s.t.}$$
$$-y_i + Y\lambda \ge 0, \qquad (3.11)$$
$$\theta x_i - X\lambda \ge 0,$$
$$\lambda \ge 0.$$

This is the basic form of the problem to be solved in DEA. The minimisation task is achieved by $\theta$ while $\lambda$ is a Nx1 vector of constants that locates points on the frontier. Technical (in)efficiency is given by score obtained in $\theta$, relative to $\lambda$. Note that $\theta$ is the objective function, and operates only with respect to inputs. The linear programming problem must be solved N times, once for each firm in the sample, obtaining an efficiency score for each firm.

As noted above, portions of the piece-wise linear frontier run parallel to either axes. This allows a firm to be located on the frontier, implying technical efficiency, while simultaneously having potential to reduce consumption of at least one input without decreasing output. It can be said that no input slacks exist if $\theta x_i - X\lambda = 0$, given the optimal values of $\theta$ and $\lambda$.

The importance of slacks can be overstated (Coelli et al., 1998: 143). The existence of slacks is in essence an undesirable, yet difficult to avoid, function of the linear nature of the model. Indeed, Ferrier and Lovell (1990) argue that slacks are equivalent to allocative inefficiency, and since allocative efficiency is of secondary importance to most firms, slacks are of secondary importance in DEA analysis. Notwithstanding, attempts have been made to incorporate the information imbedded in slacks in recent extensions of the DEA model, as discussed in Section 3.6.1.

*Variable returns to scale (VRS)*

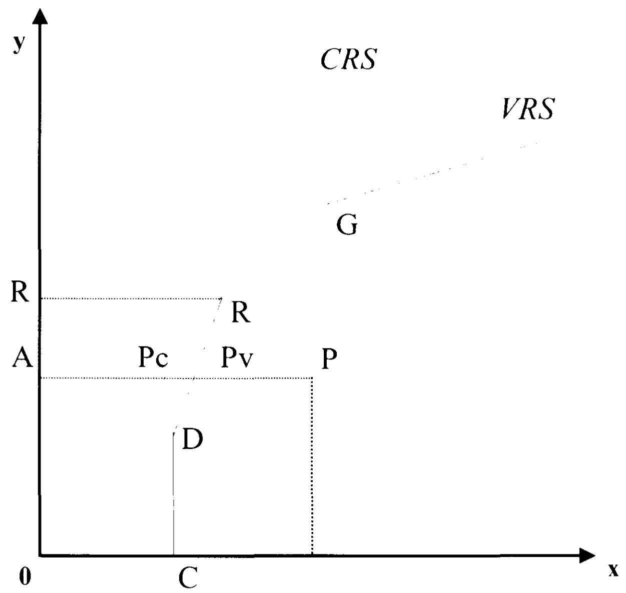
Thus far it has been assumed that a given increase in inputs will result in an equi-proportionate increase in output, implying constant returns to scale. However, countless empirical studies have shown that certain industries benefit from variable returns to scale. To assume an industry operates under constant returns to scale, when in fact some relative efficiency could be gained through variation in scale, gives rise to the concept of scale inefficiency. Thus, technical inefficiency can be overstated when an allowance for scale inefficiency has not been incorporated in the model.

The basic model of DEA can be extended to allow for the calculation of technical efficiency devoid of scale effects through the addition of a convexity constraint, $N1'\lambda = 1$, to provide:

$$
\begin{aligned}
&\min_{\theta,\lambda} \theta, \\
&\text{s.t.} \\
&-y_i + Y\lambda \geq 0, \\
&\theta x_i - X\lambda \geq 0, \qquad\qquad (3.12)\\
&N1'\lambda = 1, \\
&\lambda \geq 0.
\end{aligned}
$$

where $N1'$ is an $N \times 1$ vector of ones. The effect of the constraint is to restrict firms from being compared with firms of differing scale. The constraint gives a relatively tighter envelopment frontier that is more convex than that obtained in the constant returns to scale model. As a result, the efficiency scores obtained for the firms under the variable returns to scale model will be greater than or equal to those measured in the constant returns case. This is intuitively appealing, since it is now a matter of comparing the scores obtained from both models to obtain a measure of the scale efficiency effect. Figure 3.3 demonstrates this well.

Figure 3.3: Variable and constant returns to scale in DEA




Adapted from Coelli et al. (2005)

Figure 3.3 considers the simple case of a one input, one output industry. Firm R is producing at the optimal scale, defined in a geometric sense where the constant returns to scale and variable returns to scale frontiers are tangent. However, consider a firm such as P operating below both frontiers. Under the constant returns to scale frontier firm P is said to be technically inefficient by the distance PPc. The relative degree of technical inefficiency under the assumption of variable returns to scale is less for this firm, and the extent to which technical inefficiency has been overstated is given by the distance PvPc. Allowing for scale effects in this instance resulted in a more precise measure of so-called 'pure' technical efficiency. It is for this reason that most DEA studies since the late 1990s have employed the variable returns to scale model (Coelli, 1998: 150).

A weakness of the variable returns to scale model is that the nature of the variation is not measured, since it is not possible to determine whether the firm's scale efficiency derives from increasing of decreasing returns to scale. A method to correct for this is to impose the restriction, $\mathrm{N}1'\lambda \leq 1$, such that:

$$\begin{aligned}
&\min_{\theta,\lambda} \theta, \\
&\text{s.t.} \\
&-y_i + Y\lambda \geq 0, \\
&\theta x_i - X\lambda \geq 0, \\
&\mathrm{N}1'\lambda \leq 1, \\
&\lambda \geq 0.
\end{aligned} \tag{3.13}$$

Figure 3.3 illustrates the effect of the restriction. The non-increasing returns to scale frontier is equal to the constant returns to scale frontier up until point R, where the firm is operating at the optimum scale. At output and input points greater than R, the non-increasing returns to scale frontier departs from the constant returns to scale frontier. By comparing the technical efficiency scores obtained under the variable returns to scale and non-increasing returns to scale models, it can determined whether scale inefficiency is due to increasing or decreasing returns. Where there is a difference between the scores obtained in the two models, it is concluded that the scale inefficiency is a result of increasing returns to scale. However, when the scores are equal, the inefficiency is attributed to the influence of decreasing returns to scale. It is interesting to note that this approach results in a firm not being compared with another firm that is substantially larger than itself. However, the nature of the constraint does allow for comparison with smaller firms. This is of particular importance to this thesis, since the difference in size observed between firms is reasonably large.

*Allocative efficiency*

At this stage efficiency has been expressed without reference to the influence of price. DEA can be modified to incorporate knowledge of input prices. and thus calculate allocative efficiency as well as overall efficiency. However, data pertaining to the various inputs consumed in the provision of water and wastewater in the Australian water industry are not available in a sufficiently disaggregated form to warrant an analysis of allocative efficiency.

### 3.4.4 Summary of alternative models to measure relative efficiency

Up to this point the nature of both the SFA approach and DEA approach to efficiency measurement have been briefly outlined. The delineating factor between the two methods is the allowance for statistical noise and other errors in the measure of efficiency. However, other, more subtle differences have also been highlighted. Table 3.1 outlines the main features, strengths and weaknesses of each of the approaches. The remainder of this chapter examines the most relevant extensions to the models in the current context.

Table 3.1: Efficiency measurement techniques (Adapted from Dollery et al., 2006: 202-3)

| Approaches | | | Features | Strengths | Weaknesses |
|---|---|---|---|---|---|
| Non-Frontier Approach | | Least Squares Model Estimation | Employs regression analysis to estimate cost, production or profit functions using data from several authorities or over several years.<br>Residuals from regression used to adjudge efficiency. | Relative ease of computation.<br><br>Interpretability. | Emphasis on 'average' can produce spurious comparisons between decision making units. |
| Frontier-estimation Approaches | Statistical | Stochastic Frontier Approach | A frontier is estimated using econometric estimation usually of the form:<br>$Y_i = g(X_i, \beta) + vi - \mu_i$<br>where $Y$ represents observed output, $g$ is a production functions using $X$ inputs specified in form $\beta$, noise is capture by $v$ (frequently assumed normally distributed) and $\mu$ represents inefficiency (usually assumed half-normally distributed and restricted to be non-negative). | Stochastic such that noise is separable from inefficiency.<br><br>Amenable to conventional hypothesis testing.<br><br>Usually results in smooth differentiable function i.e. able to compute elasticities. | Parametric in nature – i.e. a functional form is required in advance giving rise to potential for mis-specification.<br><br>Mis-specification error increases in public sector where conventional function forms applicable in private sector analysis may not be well suited to public production. |
| | Non-statistical/Mathematical Programming | Data Envelopment Analysis | Mathematical programming used to construct best-practice benchmark frontier from observed data on inputs and outputs - typically an amalgam of the best practice of several decision making units.<br><br>Attempts to measure the distance between observed production and the frontier of a convex envelop of data.<br>Assumes:<br>1. observed production belongs to the production plan set (deterministic)<br>2. unobserved production that is weakly dominated by another production plan is part of the production set (free disposability)<br>3. either constant, increasing or decreasing returns to scale (i.e. 3 alternative methodologies). | Avoids mis-specification error, although there is an implicit assumption of piece-wise linearity (Ebersberger, Canter and Hanusch 2000).<br><br>More likely to capture nuances of public production if they differ considerably from other assumed functional forms that map private production. | Non-parametric and Non-stochastic – any deviation from efficiency emerging from the data is presumed to be evidence of inefficiency – i.e. no way of distinguish between environmental heterogeneity, external shocks and the like[14].<br><br>Gives rise to a production frontier comprising several edges and vertices making it non-differentiable for the domain i.e. unique inelasticities cannot be determined.<br><br>By comparison to FDH, inclined to declare a large number of cases as inefficient because of convexity assumption i.e. propensity to compare decision making units to "an unobserved and fictitious linear combination of efficient observations" (Henderson 2003, p. 7). |
| | | Free-Disposal Hull Approach | Mathematical programming technique similar to DEA that relaxes assumption 3.<br>Main difference is that FDH is more concerned with dominance than distance, (as per DEA). Thus, it relates each inefficient observation to a single dominating observation. | Similar to above.<br><br>Less susceptible to adjudging decision making units inefficient compared to DEA. | As above but more inclined to adjudge decision making units as efficient i.e. "an observation with epsilon amount less of a particular input and a substantial amount less of output than an efficient firm may be deemed efficient" (Henderson 2003, p. 7). |

[14] Some recent work has focused upon the development of statistical inference techniques for DEA and FDH methodologies (see, for example, Simar and Wilson 2000)

## 3.5 Extensions to SFA

### 3.5.1 Cost and profit functions

The standard SFA approach is cast in terms of a maximisation objective where output is to be maximised, given a set of inputs. Hence, the frontier of interest takes the shape of a standard total product curve. This is well suited to an analysis of technical efficiency. However, situations arise where output is exogenous, with the provision of water and wastewater being a prime example. In this setting, the objective becomes one of minimising cost for a given output, implying minimising input use, given information on relative input prices.

A third objective is that of profit maximisation. This underpins much of the microeconomic theory of the firm and is a central assumption in many models that seek to explain market behaviour. This setting is of little relevance to the public sector, and in particular public utilities, since profit maximisation is not often an overtly stated objective, despite the historical tendency for state and local governments to derive economic rents from water and wastewater utilities in the form of dividends (see, for instance, Dwyer, 2006). As will be outlined in Chapter 4, which reviews the literature pertaining to water utility efficiency, the majority of studies regarding water utility efficiency are expressed in terms of a cost function, which is briefly outlined here.

The underlying assumption of this model is that firms seek to minimise the cost of producing output, in the face of an increasing vector of input prices, yielding the standard positively sloped cost frontiers. They are frontiers in the sense that a firm cannot produce a given output at a cost, whether it be marginal, average or total, less than that given by the frontier. Firms that are inefficient produce at a cost that is represented by coordinates above the frontier, and the stochastic nature of the model is achieved along familiar lines.

A weakness with this model in the setting of the present study is neatly summarised by Worthington (1998:24):

> *[The model] does permit the measurement of both technical and allocative efficiency, and can be extended to allow for multiple outputs. However, apart from the issue of functional forms discussed above, it requires input price data to be observable and to vary amongst firms. In many cases, firms in a selected industry may face the same prices, or, if they do not face the same prices, price data may be difficult, or even impossible to collect.*

Water and wastewater services in NSW and Victoria are beset by the issues Worthington (1998) outlines above. In particular, the issue of the pricing of raw water as an input is likely to be insurmountable. As a result, cost minimisation frontiers are avoided in this study.

## 3.6 Extensions to DEA

### 3.6.1 Adjusting for environment

The underlying assumption of the DEA model outlined in Section 3.4.3 is that all inputs and outputs are able to be manipulated by managers. However, it is often the case that managers operate in the face of exogenous variables. For example, agricultural producers face variations in weather, while water and wastewater service providers are often subject to a raft of changing regulatory requirements. The standard DEA model is violated by the existence of exogenous variables. At least three methods have been proposed to correct the model to account for what is loosely described as the 'environment'. They can be classified as imposing constraints, adjusting inputs and using SFA to adjust for the environment.

***Imposing constraints***

The first method essentially seeks to compare 'like with like' and was first advanced by Banker and Morey (1986). Firms that face identical exogenous constraints are ranked on efficiency scores, given those constraints. The procedure is to rank the environmental variables from least to most detrimental upon efficiency. The efficiency score of the $i$th firm is then compared with those firms that have a value on the environmental variable which is less than or equal to the $i$th firm. For example, consider the analysis of water and wastewater. An exogenous variable might be the topography of the service area. This approach ensures only LWUs facing roughly the same topography are compared with each other, since it would not be fair to rank a flat area with a hilly area given the impact of topography on pumping costs and the like.

This method relies on the ability to rank environmental variables, implying a knowledge of the direction of influence on efficiency (i.e. negative or positive). However, this may not always be the case due to simply not having sufficient information to make a judgement, or the analyst may wish to determine the impact of a variable through empiricism.

The second method, advanced by Charnes et al. (1981), is applicable when the effect of the variable on efficiency cannot be determined *a priori*, or if it is not desirable to do so. This technique splits the sample into sub-groups, estimates the frontier for each sub group, projects firms onto their relevant frontier and then compares *mean* efficiency scores obtained from the two groups. For example, in examining the role of ownership structure on a firm's performance, one can split the sample into publicly owned and privately owned; if the privately owned group returns a higher mean efficiency score, one could conclude that ownership structure does contribute to efficiency, and that public ownership has a negative effect.

Both these methods suffer from problems associated with reducing the sample size of the sub groups. While DEA does not rely on an 'adequate' sample in terms of statistical inference, reducing the number of firms in a reference group can result in an inflated proportion of firms being declared efficient (Cubbin and Tzanidakis, 1998).

The third approach is to enter the exogenous variables into the linear programming formulation. There are three ways in which this can be achieved. First, if the effect of the variable on relative efficiency (i.e. positive or negative) is unclear, it then can enter as a non-discretionary, neutral variable. Alternatively, if the variable is assumed to have a non-zero sign and can be reduced radially like other inputs, it can enter as a discretionary input. Finally, when the environmental variable is assumed non-zero but, incapable of being radially reduced, it enters as a non-discretionary input. Each of these options is modelled below.

Option 1:

$$
\begin{aligned}
&\min_{\theta.\lambda} \theta,\\
&\text{s.t.}\\
&-y_i + Y\lambda \geq 0,\\
&\theta x_i - X\lambda \geq 0,\\
&\mathrm{z_i} - Z\lambda = 0,\\
&\mathrm{N}1'\lambda \leq 1,\\
&\lambda \geq 0.
\end{aligned} \tag{3.14}
$$

The addition of the constraint $\mathrm{z_i} - Z\lambda = 0$ represents the environmental variable(s). In this case $z_i$ is a Lx1 vector, where L are the environmental variables. Z is a LxN matrix for the full sample.

Option 2:

$$
\begin{aligned}
&\min_{\theta.\lambda} \theta,\\
&\text{s.t.}\\
&-y_i + Y\lambda \geq 0,\\
&\theta x_i - X\lambda \geq 0,\\
&\theta \mathrm{z_i} - Z\lambda = 0,\\
&\mathrm{N}1'\lambda = 1,\\
&\lambda \geq 0.
\end{aligned} \tag{3.15}
$$

Note the addition of theta, $\theta$, to the exogenous variable constraint, and the assumption of a non-negative sign.

Option 3:

$$
\begin{aligned}
&\min_{\theta.\lambda} \theta,\\
&\text{s.t.}\\
&-y_i + Y\lambda \geq 0,\\
&\theta x_i - X\lambda \geq 0,\\
&\mathrm{z_i} - Z\lambda = 0,\\
&\mathrm{N}1'\lambda = 1,\\
&\lambda \geq 0.
\end{aligned} \tag{3.16}
$$

The only alteration to Option 3.15 is the removal of $\theta$, since it is assumed that the variable cannot be radially reduced.

Critiques of the various incarnations of the third method proceed along similar lines to those for methods 1 and 2. Options 2 and 3 rely upon the analyst making *a priori* judgements regarding the sign of the environmental variables, when this may not always be desirable. Of course, Option 1 is a convenient means of avoiding this problem.

Situations may arise where one is interested in whether an environmental variable has any influence on efficiency, and if so, whether that is a positive or negative influence. The three methods outlined above do not assist in carrying out this task. The method for including environmental variables is a two-stage process that regresses the efficiency scores against the environmental variables in order to detect their influence, should any exist.

The first stage is to run the standard DEA analysis with traditional inputs and outputs. In the second stage, the efficiency scores are regressed against the environmental variables, making use of a Tobit regression in order to accommodate the truncated data ( $0 \leq \theta \leq 1$ ). Interpretation of the resulting estimates proceeds along conventional lines, with the sign of the coefficient indicating a negative or positive influence. Furthermore, standard statistical analysis can be carried out. The efficiency scores obtained in the first stage can then be corrected to allow for the exogenous environmental factors.

### *Employing SFA*

In a three-step procedure, Fried et al. (2002) first calculate standard DEA efficiency scores then make use of SFA to regress first stage slacks (both radial and non-radial) against a set of environmental variables, thereby generating "a three-way decomposition of the variation in performance into a part attributable to environmental effects, a part attributable to managerial inefficiency, and a part attributable to statistical noise" (Fried et al., 2002: 157). The results are then used to adjust inputs or outputs in order to compensate for environmental factors and the presence of statistical noise, leaving only managerial effects in the newly created dataset. Standard DEA measures are then re-calculated, yielding a 'management only' efficiency measure.

The first step of the procedure follows the standard DEA approach of solving the linear programming problem of minimising input use for a given output. This yields efficiency scores (defined by 'radial slacks', should they exist) and, due to the piece-wise linear nature of the frontier, input slacks (sometimes referred to as 'non-radial'), as described in Section 3.4.3 above. Rather than regressing variables against only the efficiency scores, this technique makes use of both radial and non-radial slacks, and the sum of these for each DMU forms the dependent variable in the SFA model. The stage two SFA regressions take the general form:

$$s_{ni} = f^{n}(z_i;\beta^{n}) + v_{ni} + u_{ni}, \qquad n = 1,\dots,N, \;\; i = 1,\dots,I, \tag{3.17}$$

where $f^{n}(z_i;\beta^{n})$ are deterministic feasible slack frontiers with parameter vectors $\beta^{n}$ to be estimated and composed error structure $(v_{ni} + u_{ni})$. Following the standard SFA approach, $v_{ni}$ is assumed to be normally distributed and captures the 'noise' in the model, while $u_{ni}$ is assumed to be a normal distribution truncated at zero, yielding only positive values, and reflects managerial inefficiency. Assuming the error terms are independent of each other and of the environmental variables, the model can be estimated using maximum likelihood techniques.

The model is interpreted as follows: the $\left[f^n(z_i;\beta^n)+v_{ni}\right]$ represent the minimum slacks that can be achieved given the environmental constraints beyond management control and any noise in the data. This forms a Stochastic Feasible Slack Frontier (SFSF). Any slacks beyond this are entirely attributable to managerial inefficiency, as captured by the non-negative error term $u_{ni}$.

In an analogous exercise, Fried et al.(2002) seek to make use of the results obtained in Step 2 in order to 'level the playing field', by adjusting upward the input use of those firms that have been advantaged by the favourable environmental conditions, relative good luck, or both.

The final step is to re-run the DEA model with respect to the adjusted dataset. The output of Step 3 "is a DEA-based evaluation of producer performance couched solely in terms of managerial efficiency, purged of the effects of the operating environment and statistical noise" (Fried et al., 2002: 164).

### 3.6.2 Non-discretionary variables

Standard DEA methods assume that all inputs and outputs are variable. Section 3.6.1 outlined techniques to allow for exogenous variables. Banker and Morey (1986) and Kopp (1981) developed a method to allow for situations where an input is fixed. This is often assumed to be the case in short-run production analysis, where capital is assumed fixed. However, labour can be controlled by management.

The technique to deal with so-called non-discretionary variables is to divide the input set into discretionary and non-discretionary inputs (denoted by $X^D$ and $X^{ND}$). This is outlined below:

$$\begin{aligned}
&\min_{\theta,\lambda} \theta, \\
\text{st} \quad & -y_i + Y\lambda \geq 0, \\
& \theta x_i^D - X^D\lambda \geq 0, \\
& x_i^{ND} - X^{ND}\lambda \geq 0, \\
& \mathrm{N}1'\lambda = 1 \\
& \lambda \geq 0
\end{aligned} \qquad (3.18)$$

The important point to note is that $\theta$ applies only to the discretionary inputs. Thus, if there are only two inputs, labour and capital, and capital is assumed fixed, the radial reduction in inputs would be an operation only on the labour input.

### 3.6.3 Hierarchies and groups in DEA

While the variable returns to scale model allows analysis of DMUs that vary in size, it retains the assumption that input use and outputs produced are relatively homogeneous across firms. Furthermore, Banker et al. (1986) have shown that categorical grouping of DMUs can determine efficiencies among piers more accurately. However, this grouping relies on a natural ordering in the sample. Some situations can arise where the industry of interest cannot be grouped in such a neat fashion. Water and wastewater services are an excellent example. As shown in Chapter 2, the regulation of these services in NSW is in stark contrast to that in

Victoria. In addition, some providers maintain a water storage as well as providing potable water, whereas others are not responsible for the dam from which they draw the water supply. Others face steep cost structures as a result of difficult topography or poor raw water resource quality. It is important to account for these differences in any efficiency analysis. A measure of efficiency must be identified not only for each individual DMU, but also for each identified group of units.

Cook et al. (1998) developed a model that attempts to measure the efficiency of groups within larger hierarchical structures, to judge the ability of managers to 'manage' the resource they control. Using the example of highway patrol units in Canada, Cook et al. (1998) show that micro-decisions such as whether to patch a road or re-seal it are made at a road patrol level, while decisions regarding whether a patrol should be publicly or privately provided are made at a district level. Cook et al. (1998:182) argue that "there is a need to recognize that in addition to those *unit level* inputs and outputs as discussed earlier (traffic, road conditions, and so on), there are factors which are generally constant within any group but which are variable between groups", and that a DEA model which seeks to analyse a situation such as this must attempt to account for such differences.

Cook et al. (1998) presented a rather detailed model in order to demonstrate how DEA can be extended to meet their aims. In the interests of parsimony the model will not be expounded here. While the numerical example of the model presented by Cook et al. (1998) produced robust results, there appear to be no other applications of the model in the literature. Since the primary aim of this thesis is to measure relative efficiency in a specific context, rather than experiment with untried empirical techniques, the paucity of empirical applications precludes the use of the model in this instance.

## 3.7 The Malmquist Productivity Index and DEA

Up to this point, the focus has been on tools to measure various categories of relative efficiency. Relative efficiency is a static concept, in that the measurement of a given firm's efficiency is measured relative to the best performing peer of that firm, at a given point in time. While various techniques measure productivity change through time, this section focuses on one in particular: the so-called 'Malmquist Productivity Index', because it makes use of distance functions calculated in both stochastic frontier and data envelopment analysis.

The Malmquist Productivity Index is a technique well suited to the task of analysing productivity changes in industries where firms produce multiple outputs with multiple inputs. The need to aggregate inputs and/or outputs gives rise to the use of index numbers (for a concise introduction to the theory of index numbers see Coelli et al., 2005). Since productivity in this context relates to the deployment of multiple input factors, it is common in the literature to refer to measures of productivity in these industries as total factor productivity (TFP) indices. The Malmquist TFP Index was first introduced by Caves et al. (1982a, b). The reference to 'Malmquist' results from the exploitation of so-called 'Malmquist distance functions' to measure productivity change relative to a given technology. In this context, the term 'technology' alludes to the best-practice production frontier at a chosen point in time (Coelli et al., 2005).

If panel data are acquired, Malmquist TFP measures can be calculated by use of DEA efficiency scores calculated for firms in different periods. Productivity changes are measured by changes in an index number. Specifically, if DEA scores are calculated for a firm $i$, in two periods $s$ and $t$, an input-oriented Malmquist TFP change index can be calculated. Taking period $t$ as the reference point, the index can be expressed as:

$$M_i^t(y_s, x_s, y_t, x_t) = \frac{d_i^t(y_t, x_t)}{d_i^t(y_s, x_s)} \tag{3.19}$$

where

$M_i^t$ = the Malmquist index

$y_s$ = output in period $s$

$x_s$ = input in period $s$

$y_t$ = output in period $t$

$x_t$ = input in period $t$

$d_i^t$ = the distance function

where $d_i^t(y_t, x_t)$ represents the distance function from period $t$ observation relative to the period $t$ technology. In other words, this is the DEA input oriented efficiency score defined in Section 3.4.3. On the other hand, $d_i^t(y_s, x_s)$ is the distance function from period $s$ observation relative to period $t$ technology. It is this that allows changes in productivity to be measured.

It is equally valid to measure the relevant distance functions relative to the period $s$ technology, such that:

$$M_i^s(y_s, x_s, y_t, x_t) = \frac{d_i^s(y_t, x_t)}{d_i^s(y_s, x_s)} \tag{3.20}$$

Regardless of which technology period is chosen as the base, a value of $M_i > 1$ indicates an increase in productivity, and a value of $M_i < 1$ will be interpreted as a decline in productivity between the periods.

Deciding on the most appropriate technology from which changes should be measured is somewhat arbitrary, and arguments could be made in favour of each. To circumvent this issue, it is customary to take the geometric mean of these two indices, as follows:

$$M_i\left(y_s, x_s, y_t, x_t\right) = \left[\frac{d_i^s(y_t, x_t)}{d_i^s(y_s, x_s)} \text{x} \frac{d_i^t(y_t, x_t)}{d_i^t(y_s, x_s)}\right]^{\frac{1}{2}} \qquad (3.21)$$

By rearranging this equation, the intuitive appeal of making use of DEA scores from two periods in order to calculate productivity change between the periods is made clear. Equation 3.21can be expressed alternatively as:

$$M_i\left(y_s, x_s, y_t, x_t\right) = \frac{d_i^t(y_t, x_t)}{d_i^s(y_s, x_s)}\left[\frac{d_i^s(y_t, x_t)}{d_i^t(y_t, x_t)} \text{x} \frac{d_i^s(y_s, x_s)}{d_i^t(y_s, x_s)}\right]^{\frac{1}{2}} \qquad (3.22)$$

The first term outside the bracket on the right hand side of equation 3.22 is the ratio of DEA efficiency scores calculated in periods $t$ and $s$. The term inside the brackets is the geometric mean of the shift in technology (or the efficient frontier) between the periods $t$ and $s$. Having determined the efficient frontier given observations in two periods $s$ and $t$, and calculated relative efficiency scores with reference to those frontiers, equation 3.22 demonstrates how those calculations can be exploited to measure TFP changes.

The construction of equation 3.22 suggests that, in the absence of any shift in the technology between the periods, changes in TFP are due entirely to relative efficiency changes. Likewise, given an assumption of zero change in relative efficiency between the periods in question, changes observed in TFP are entirely a result of shifts in the technology.

A useful consequence is that observed changes in TFP can be decomposed into the two constituent parts of equation 3.22 such that

$$\frac{d_i^t(y_t, x_t)}{d_i^s(y_s, x_s)} = \text{overall efficiency change}$$

and

$$\left[\frac{d_i^s(y_t, x_t)}{d_i^t(y_t, x_t)} \text{x} \frac{d_i^s(y_s, x_s)}{d_i^t(y_s, x_s)}\right]^{\frac{1}{2}} = \text{technology change}$$

Given the four distance functions in equation 3.22 four linear programming problems must be calculated in order to measure TFP for a firm, and by definition, its constituent parts. They are:

$$\begin{aligned} & d_i^t(y_t, x_t) = \min_{\theta.\lambda}\theta, \\ & \text{st -y}_{it} + Y_t\lambda \geq 0, \\ & \theta x_{it} - X_t\lambda \geq 0, \\ & \lambda \geq 0, \end{aligned} \qquad (3.23)$$

$$\begin{aligned} & d_i^s(y_s, x_s) = \min_{\theta.\lambda}\theta, \\ & \text{st -y}_{is} + Y_s\lambda \geq 0, \\ & \theta x_{is} - X_s\lambda \geq 0, \\ & \lambda \geq 0, \end{aligned} \qquad (3.24)$$

$$
\begin{aligned}
& d_i^t\left(\mathrm{y}_s, \mathrm{x}_s\right) = \min_{\theta,\lambda} \theta, \\
& \text{st } -\mathrm{y}_{is} + \mathrm{Y}_t \lambda \geq 0, \\
& \theta \mathrm{x}_{is} - \mathrm{X}_t \lambda \geq 0, \\
& \lambda \geq 0,
\end{aligned} \qquad (3.25)
$$

and

$$
\begin{aligned}
& d_i^s\left(\mathrm{y}_t, \mathrm{x}_t\right) = \min_{\theta,\lambda} \theta, \\
& \text{st } -\mathrm{y}_{it} + \mathrm{Y}_s \lambda \geq 0, \\
& \theta \mathrm{x}_{it} - \mathrm{X}_s \lambda \geq 0, \\
& \lambda \geq 0.
\end{aligned} \qquad (3.26)
$$

The four linear programming problems are to be solved for each firm in the sample.

## 3.8 Concluding remarks

This chapter has provided a selective theoretical survey of the recent history in the measurement of productive efficiency. This survey has outlined the economic and econometric underpinnings of the applied research described in the subsequent chapters. The aim was to focus only on those techniques that could potentially be applied to the analysis of urban water and wastewater efficiency, and thus many contributions to the vast literature that has emerged on efficiency measurement have not been given attention here.

Section 3.2 discussed the particular meaning of the term ‘efficiency’ in the context of the economic discipline, noting that this study has as a particular focus on productive efficiency. Section 3.3 examined the economic theory of productive efficiency with weight given to the pioneering work of Farrell (1957) in decomposing productive efficiency into three separate measures: technical, allocative and overall or economic efficiency.

Section 3.4 assessed the major attempts to 'operationalise' Farrell's insights regarding the nature of efficiency in production, focusing on the two main approaches to the problem, the so-called SFA and DEA approaches. It was noted that while both attempt to incorporate the concept of a fully efficient frontier against which firms in an industry could benchmark themselves, the major delineating point is whether the technique allows for the existence of statistical noise.

Sections 3.5 outlined the major extensions to SFA and, in particular, attempts to explain why a firm is observed to be operating off the frontier, rather than simply making that observation. In a similar vein, Section 3.6 surveyed recent advances in DEA, and in particular, attempts to allow for exogenous influences on production that are beyond the control of managers to influence.

The review of theoretical methods available for the analysis of relative efficiency in production has introduced the two main methodologies. Chapter 4 reviews the literature pertaining to relative efficiency measure in the water and wastewater sector, both in the Australian context and abroad.

# Chapter 4. Review of the Empirical Literature Measuring the Efficiency of Water and Wastewater Utilities

## 4.1 Introduction

Previous chapters have addressed the institutional settings that underpin the provision of water and wastewater services in regional NSW and Victoria, and the theoretical frameworks within which the relative efficiency of utilities might be analysed. This chapter considers the empirical evidence regarding relative efficiency of urban water and wastewater sectors.

While the Australian Government's National Water Initiative is considered in some sections to be 'world best practice' in terms of policies aimed at reforming water markets (see, for instance, WGCS, 2006: 1), in many respects the Australian urban water setting is not dissimilar to those in other developed economies. In particular, water delivery networks and sewerage treatment systems in the United Kingdom (UK) and the United States (US) share a number of similarities with their Australian counterparts. However, one important differentiating aspect is the ownership structure.

Much of the water and wastewater sector in the UK is privately owned as a result of a broader government strategy to convert utilities from government ownership to private industry. In the US, the water and wastewater industry consists of both publicly and privately owned utilities. In this respect, the Australian system is relatively unique. As observed in Chapter 2, although varying degrees of corporatisation exist, almost the entire urban water and wastewater sector in NSW and Victoria is owned by some form of government.

This characteristic limits to some extent the degree to which the existing empirical literature reviewed in this chapter informs the analysis of this thesis, since the vast majority of studies reviewed here focus on the effect of differing ownership (as opposed to regulatory) regimes on the efficiency of water and wastewater utilities. Nevertheless, since the aim of this thesis is to measure the impact of divergent regulatory structures on efficiency, some useful analogies can be drawn. Furthermore, since the econometric framework employed in this thesis draws heavily upon the empirical techniques examined here, a review of the relative efficiency of water and wastewater utilities is warranted. Moreover, this survey also helps to situate the empirical component of this thesis and highlights its contribution to the measurement of the relative efficiency of water and wastewater providers.

In this chapter, the studies are categorised along a number of divergent lines. The review begins in Section 4.2 with a brief synopsis of the evidence regarding the role of ownership in the relative efficiency of water and wastewater utility operations. While not directly related to the prime research question of this thesis, the majority of efficiency studies relating to the water and wastewater sectors have been in this context.

Next, a short analysis of studies examining the evidence for scale and scope economies in water and wastewater industries is presented in Section 4.3. Again, while scale and scope economies are of limited relevance to the topic at hand, any production model should account for scale, scope and density influences, so they are not erroneously attributed to relative efficiency, and in particular, managerial inefficiency.

The bulk of this chapter is devoted to the categorisation of studies along specification lines. Section 4.4 analyses parametric and non-parametric models, the suite of input and output variables employed, and the range of exogenous variables utilised in past research efforts. In Section 4.5 particular attention is given to models that have attempted to test for regulatory regime influences. In Section 4.6 a relatively detailed review of the one international study to have focused on regional water utilities is presented, followed by an examination of the two known academic investigations of relative efficiency of water and wastewater utilities in Australia in Section 4.7. The chapter ends with some concluding remarks in Section 4.8.

## 4.2 The role of ownership

One of the most enduring themes in the literature on water and wastewater relative efficiency has been the testing of hypotheses about the existence of ownership effects, and in particular public versus private ownership. The majority of studies are situated in the context of either the UK or the US.

### 4.2.1 England and Wales

As outlined by Lynk (1993) and Saal and Parker (2000), the water and wastewater industry in England and Wales experienced major reform in 1989, with widespread privatisation of the industry as part of the microeconomic reform agenda pursued with vigour in the 1980s by the Thatcher government. Prior to this era, however, the broader water sector underwent an earlier period of reorganisation in 1973. This involved the amalgamation of multifarious regulatory and service provision authorities, variously responsible for "water supply, sewerage, sewage disposal, water resource planning, pollution, fisheries, flood protection and land drainage, water recreation and environmental conservation" (Lynk 1993: 100), under the one organisational umbrella. This led to the establishment of ten regional water authorities (RWA). Operating alongside the RWAs were 28 statutory privately owned water companies which were, in most part, responsible only for water supply. These companies were heavily regulated in order to prevent the potential abuse of market power.

In 1983, the British Government reorganised the RWAs with a view to reducing overall cost inefficiencies. However, Lynk (1993) argues that this process resulted in an under-investment in capital and weakened the resolve of the authorities to maintain environmental standards. Along with privatisation in 1989 came the establishment of two new regulators; one with environmental responsibilities (the National Rivers Authority (NRA)) and the other with an economic focus (the Office of Water Services (OFWAT)).

Following privatisation, the 10 RWAs were subject to a new regulatory regime designed to promote efficiency within the industry while simultaneously maintaining water quality and environmental standards. OFWAT implemented a regulatory structure by which water prices increased in line with costs, plus an allowance for a capital investment program (the so-called RPI+K system). The infrastructure investment was made necessary by a requirement for water authorities to meet a legally mandated quality improvement program. However, the firms were also subject to so-called 'yardstick competition'. The basic premise of this system was that firms could recover the costs of the 'best-practice' firm, not the actual costs of the firm in question. This created a strong incentive for relatively inefficient firms to improve their performance in line with that of the best performing firms in the industry (Bottasso and Conti, 2003: 4). This period of reform created a 'test laboratory' in which researchers could determine whether the privatisation of public utilities had led to improvements in performance.

Lynk (1993) claimed to be the first since the reforms to have investigated the possible effects of privatisation on the water and sewerage industry in England and Wales with recourse to empirical evidence. The primary aim of the analysis was to assess the efficiency levels of private and publicly-owned utilities in the water industry *prior* to privatisation. This was achieved by examining two separate datasets: private firms and public firms. Results were then compared to draw conclusions regarding the role of ownership as a determinant of industry cost. However, Lynk (1993) did not compare the resulting cost functions with a view to determining which of the two industry structures operated at least cost. As a result, he was unable to draw conclusions regarding the relative efficiency of private and public utilities in a comparative sense.

Turning first to the analysis of 10 public water utilities, Lynk (1993) analysed a dataset spanning 1980–1988, making use of a stochastic cost frontier in the trans-log form. Significant improvements in the efficiency of public utilities were detected over the period. However, Lynk (1993) suggested this was probably due to a reduction in capital expenditure associated with the cost-cutting program of the early to mid 1980s.

The private sector dataset covered a slightly shorter time frame (1985–1988); however, it included 22 authorities. Efficiency estimates suggested that, on average, private utilities were 11.5 per cent above their cost frontier, while public firms were, on average, only 1.86 per cent above their frontier. This finding suggested public utilities were more efficient on average, but only in relation to their peers within the public sector. Lynk (1993) was at pains to point out that this result did not support a conclusion that public firms were relatively more efficient than their counterparts in the private sector, since the relative positions of the two distinct frontiers were not estimated.

Saal and Parker (2000) examined the influence of privatisation on the industry by analysing data that spaned both the pre- and post- privatisation period (1985–1999). Two primary hypotheses were proposed with respect to the influence of ownership: that privatisation of the water industry led to significantly lower production costs; and that the imposition of a price regulator resulted in efficiency gains.

Although the authors found evidence of a decline in total cost, it was not related to the privatisation of the industry. Rather, the imposition of the price cap appeared to have been the primary factor. This is noteworthy since it indicated that thoughtful regulation rather than privatisation *per se* led to cost reductions in the industry. This is not to say that privatisation and efficiency gains are mutually exclusive. To be more precise, privatisation should be implemented with complementary regulation that motivates management to pursue reduced costs rather than increased profits.

Ashton (2000) examined the influence of privatisation upon productivity growth and technical change (as opposed to relative efficiency) over an unbalanced dataset for 1989–1997. Technical change was found to be negligible and total factor productivity growth suffered a minor decline for the industry as a whole over the period. In summary, Ashton (2000, p. 129) concluded that privatisation "does not appear to have raised the level of technical change or productivity growth since 1989".

In a follow-up to their earlier paper, Saal and Parker (2001) measured the total factor productivity of the water and wastewater industry in England and Wales over the period 1985–1999. It would appear that this study was independent of that carried out by Ashton (2000). However, similar evidence was found to suggest that privatisation had not led to a significant improvement in total factor productivity. In relation to the first hypothesis, total factor productivity did not grow relative to the pre-privatisation period. The results indicated that labour productivity increased; however, notable capital for labour substitution that occurred after privatisation may have explained this outcome. Saal and Parker (2001) found evidence of simultaneous increases in labour productivity and capital for labour substitution. The authors suggested the investment required to meet new quality guidelines following privatisation may have resulted in increased labour productivity muting the effects of total factor productivity, implying that it may have been unrealistic to expect total factor productivity increases so soon after privatisation.

In sum, the evidence from the UK suggests that privatisation was not an effective policy to deliver increases in the efficiency or productivity of the industry. In contrast, careful regulation appears to have resulted in some increase in efficiency. This result points to a relationship between regulatory regime and efficiency.

### 4.2.2 USA

In contrast to the UK, where the catalyst for research was a government policy of privatisation, was the experience of the US. In that country, interest in the water and wastewater sector was driven by economists' curiosity regarding the effect of different forms of ownership on the efficiency of public utilities, as a means of contributing to the debate surrounding private and public ownership of utilities in general. As outlined by Lambert et al. (1993), the debate centred on the ability of stakeholders to influence managers under public and private ownership regimes. Those in favour of private ownership argued that, should the manager of a private firm not operate the enterprise efficiently, stakeholders should be able to transfer their ownership share, and this would serve as a signal to the manager that improvement was required. Since stakeholders in publicly-owned companies were typically unable to transfer their share, the nexus between owners and managers was broken, and there was a consequent weakening of incentives.

This rationale broadly underpinned the privatisation of many government services on the assumption that private ownership would result in relatively less waste of scarce resources. The water and wastewater industry in the US made for an interesting case study since a proportion of the utilities have traditionally been held in private hands. Consequently, many economists with an interest in the private versus public ownership question have focused their attention on this sector.

Crain and Zardkoohi (1978), in a landmark contribution to economic literature, sought to examine the effect of ownership structure on relative efficiencies between publicly and privately-owned water utilities. The interest of the authors was not so much in water utilities *per se*, but rather in examining the property rights theory of the firm "which has a long and famous doctrinal history, (and) wants badly for a properly specified empirical test" (p. 397). The authors chose the water supply industry in the US as the guinea pig for their empirical test.

In essence, Crain and Zardkoohi (1978) sought to determine whether the cost functions for privately and publicly-owned firms were significantly different. They made use of a Cobb–Douglas cost function, incorporating a dummy variable to measure the influence of ownership. Although this would be considered a rather primitive specification by modern standards, it stands as a benchmark study in the literature. The authors found that ownership did influence cost, and that costs were lower for privately owned firms in this industry.

In order to further test this proposition a Chow test was employed (a step that has been replicated in a number of subsequent studies), the results of which provided evidence to suggest that the coefficients of the cost functions representing private and public firms were not equal. Specifically, the marginal productivities of labour for water utilities in the private sector were higher than those of the public sector (a result echoed in Saal and Parker's (2001) study of the effects of privatisation in the UK industry), suggesting that "to obtain equal expansions of output, public firms employ more incremental units of labour than private firms" (p. 404).

In sum, Crain and Zardkoohi (1978) found that publicly-owned firms had significantly higher costs, primarily as a result of lower labour productivity. They argued that this provided broad support for the theory that publicly-owned firms will be less productive than their privately owned counterparts.

Feigenbaum and Teeples (1983) were critical of previous studies that made use of simple Cobb–Douglas production functions, which cast water production as a function of two inputs: capital and labour. Feigenbaum and Teeples (1983) contended that the water supply process was far more complex. They argued for the incorporation of variables that take into account the vast quality difference in water supplied by different utilities, reasoning that "this multidimensional nature of utility activities must be controlled for in any attempt to measure the effect of ownership on operation costs" (p. 673). The relative complexity of models that followed this exhortation suggests their plea was well received.

Feigenbaum and Teeples (1983) introduced a hedonic cost function for water production in the trans-log form, estimated by a non-linear, maximum likelihood technique. Regardless of the various conditions imposed on the model (unitary elasticity of substitution, homotheticity and homogeneity), the results indicated that there was no significant difference between the cost functions of government and privately owned utilities.

Specifying the model in non-hedonic terms resulted in two interesting findings. First, pooling of private and public utilities was rejected, suggesting ownership was a relevant determinant of costs. Second, and in contrast to the hedonic specification, the non-hedonic estimates suggested water delivery technology was not homogenous. This led the authors to conclude that a "Cobb–Douglas specification appears appropriate only when output is defined in hedonic terms" (p. 675), implying that the findings of Crain and Zardkoohi (1978), that private utilities were relatively more efficient, were as a result of model mis-specification.

Fox and Hofler (1986) represented another seminal contribution to the investigation of the efficiency of the US urban water industry. While the importance of the study was its two innovations relating to specification, the results also contributed to the literature on the public vs private ownership debate. Analysing a dataset that contained 156 public water utilities and 20 private water utilities in 1981, the authors estimated a production function in order to measure technical (in)efficiency and a cost function for the analysis of allocative (in)efficiency.

Fox and Hofler (1986) found "firms from both groups were found to have statistically significant and equal technical inefficiency" (p. 474). In contrast to the evidence regarding technical efficiency, private utilities were found to have significantly higher allocative inefficiency (45.9 per cent on average) than their publicly owned counterparts (38.6 per cent on average). This stemmed from relative over-capitalisation by private firms. This result sits well with other findings (such as Crain and Zardkoohi, 1978, and Feigenbaum and Teeples, 1983) of relatively higher labour productivity in private utilities.

In a step that has been omitted from many other studies, Fox and Hofler (1986) attempted to quantify the impact on costs of the various inefficiencies. They found that:

> *45.8 per cent of private firms costs and 43.3 per cent of public firms costs is the result of inefficiency. Furthermore, the costs attributable to allocative inefficiency are roughly twice the size of those arising from technical inefficiency for each ownership group (p.476).*

Byrnes et al. (1986), noting the conflicting results regarding ownership effects up to this point, introduced DEA as an alternative estimation technique. They established that private utilities were marginally more efficient than their public counterparts, although the evidence was of limited power since the difference was not statistically significant. Lambert et al. (1993) also made use of DEA, finding "publicly-owned utilities exhibiting greater technical and overall efficiency in water delivery" (p. 1576).

In a critique of their own work, Lambert et al. (1993) highlighted that environmental variables such as topography were not controlled for in the specification. They noted that this may have biased the results and was an area for further study.

Bhattacharyya et al. (1994, 1995a) analysed a sample of public and private utilities in 1992 in order to contribute to the public versus private debate. Bhattacharyya et al. (1994) made use of a deterministic generalised cost function that excluded the capital stock as an input. Bhattacharyya et al. (1995a) employed a stochastic cost frontier, allowing the stock of capital to enter as a variable.

The central question of each paper was the role of ownership as a determinant of relative efficiency. Despite the differences in estimation techniques and input specification, Bhattacharyya et al. (1994, 1995a) found evidence that public utilities were, at the very least, not less efficient than private utilities. Summarising the findings of their Bhattacharyya et al. (1995a) study, the authors argue that:

> *these findings are consistent with a growing body of empirical evidence that alternative institutional arrangements are important in determining the outcome of conduct and performance of the water utilities involved. In the case of the water industry, it appears that attenuation and non-transferability of ownership share in public firms have not resulted in any inferior process for water production as compared with private firms... (p. 780).*

Bhattacharyya et al. (1995b) focused on a subset of the 1992 dataset that included only small rural water authorities in Nevada.

Of the categories of firms based on ownership, privately-owned utilities were on average the most technically efficient (average 91.3 per cent). Various classes of public ownership were modelled and, of these, those operated by a municipality ranked highest when taken as a group (90 per cent on average). It would appear that in the case of small rural utilities, private ownership yields advantages in terms of relative efficiency. Given the relevance of this study to the present research, a detailed examination is presented in Section 4.5.

In summary, the evidence regarding the influence of ownership as a determinant of relative efficiency is best described as mixed. To the extent that studies did find a relationship, it was either statistically or economically insignificant with the notable exception of rural water authorities in Nevada.

### 4.2.3 Other contexts

Studies into the influence of ownership on the relative efficiency of water and wastewater utilities have not been confined to the UK and US. In an interesting study that examined 50 water companies in Asia and the Pacific region, Estache and Rossi (2002) employed SFA to analyse data from a survey carried out in 1995 in order to determine whether publicly or privately-owned utilities were more efficient, or if indeed there was any difference between the two categories of firms with respect to efficiency. The overall result was that efficiency was not significantly different between private and public firms.

The privatisation of sections of the water and sewerage industry during the last two decades of the twentieth century was not confined to the UK. As outlined by Faria et al. (2005), Brazilian authorities also embarked on a program of institutional reform, which *inter alia* resulted in the provision of water and wastewater services by the private sector in some parts of Brazil. This study attempted to measure the benefits and costs of the policy with reference to the impact upon the relative efficiency of firms within the industry.

The dataset was taken from 2002 and consisted of 148 firms, 138 of which were publicly-owned and 13 were from the private sector. The coefficient on the dummy variable for ownership implied private firms were more efficient; however, the estimated parameter was not of statistical significance. The average efficiency score of private utilities was 88 per cent, while public utilities on average returned an efficiency score of 72 per cent.

Garcia-Sanchez (2006) examined the behaviour of Spanish water utilities in order to determine whether differing ownership characteristics were a relevant determinant of utility efficiency. A DEA model was employed to estimate the relative efficiency of 24 utilities in 1999. The author tested for the influence of ownership by estimating separate DEA models for public and private utilities. The results of a Mann–Whitney test indicated that there was no difference between the two groups, leading the author to conclude that ownership was not a significant influence upon efficiency in this industry.

### 4.2.4 Synopsis of findings relating to ownership effects

If one was hoping to find consistent empirical evidence as to the influence of ownership on relative efficiency, the results of the studies reviewed here would disappoint. The implications of these findings for this thesis are not direct, since the purpose of this research is to examine the role of regulatory regime rather than ownership. However, in an indirect sense, the results are instructive in that they suggest it is important to capture the essential characteristics of the industry in question.

## 4.3 Scale efficiency, scope economies and productivity

A second theme running through the analysis of water and wastewater industries is related to the detection of various laws of production, such as economies of scale and scope, and returns to production, customer and population density. This section presents a brief synopsis of the most relevant of those studies.

In his study of the effects of privatisation on the water and sewerage industry in England and Wales, Lynk (1993) found evidence of scope economies with respect to the production of water and the provision of wastewater services in the public sector. A similar relationship was found between water production and the performance of RWAs' environmental regulation responsibilities.

Ashton's (2000) model to measure productivity growth and technical change in the UK water and wastewater sector specified a trans-log average cost function in which water and sewerage functions were joint products of the one enterprise. Results revealed substantial evidence for economies of scale, finding that a doubling of output would result in only a 67.8 per cent increase in total costs. The author argued the evidence concerning scale economies suggested that water and wastewater services were best left in public hands, given the evidence that privatisation had not yet delivered substantial benefits.

In an attempt to incorporate the extent to which water and wastewater outputs must meet quality standards, Saal and Parker (2000) estimated a trans-log multiple output cost function model that included quality variables to account for the impact upon total cost of maintaining drinking water and environmental quality standards. One of the hypotheses tested for evidence of economies of scope in water services production. There was evidence for nonjointness in production, suggesting economies of scope did not exist. This finding was significant, since previous studies (Lynk, 1993; Hunt and Lynk, 1995) found the opposite. Nevertheless, an important point made in this study was that the cost function for the utilities in question was characterised by non-separability, implying that studies of these utilities must at least consider both water and wastewater services together, even though scope economies appeared not to exist.

In spite of the conclusion that scope economies are not present, when the model included the quality adjusted output parameters, evidence for jointness appeared. This was an important finding which the authors interpreted:

> *as suggesting the possible existence of 'quality-driven scope economies', in which an improvement in the quality of one output may reduce the cost of producing the other. The presence of such economies would imply that some of the substantial costs born since privatisation in order to improve drinking water and sewage treatment quality have been offset by a reduction in other costs (p. 265).*

Although the primary aim of Bottasso and Conti (2003) was to determine whether overall industry cost inefficiency changed following an adjustment made to a 'price cap formula' used by regulators in the UK to incorporate so-called yardstick competition as part of the estimation process, the authors found evidence to suggest the presence of economies of scale in water provision up to a point. Costs appeared to be constant thereafter (suggesting an L-shaped average cost curve), intimating that if mergers were to take place in this industry, they should be between relatively smaller utilities.

Fox and Hofler (1986) modelled the US water industry as a dual output production function measuring both production and distribution. The parameter included to determine whether the dual output specification of the production function was necessary found that production and distribution must be modelled as distinct outputs, at least in this context. Second, evidence was found to suggest that water is both produced and delivered under homothetic technology. This was advantageous since it allowed for nonlinear average cost curves and returns to scale that varied with output, giving rise to one of the most interesting findings of the paper. When testing for evidence of scale economies in both production and distribution, slight diseconomies of scale were found for water production, while large economies of scale where found in the distribution of water.

A by-product of the Bhattacharyya et al. (1994) attempt to determine the role of ownership in relative efficiency was an interesting finding regarding scale economies. Reflecting a general deference to production theory that permeated the study, the model was tested for compliance with homogeneity, homotheticity and constant returns to scale restrictions. Evidence was found for significant scale economies in distribution. Both publicly and privately owned utilities were found to be scale inefficient with the average public utility found to be only 64 per cent scale efficient and private utilities 67 per cent scale efficient. Public utilities were generally in the diseconomies range of output, while private utilities could have benefited from returns to scale by increasing output.

Bhattacharyya et al. (1995b) estimated an indirect production function, in the trans-log form, which took into account both provision and production decisions of small rural water utilities in Nevada. This had the effect of testing for scope economies. The positive coefficient on the length of mains suggested the larger the size of the network the larger was the technical efficiency of the utility. Furthermore, utilities that provided both water supply and sewage treatment services were technically more efficient than those that didn't, suggesting the existence of economies of scope in this relatively small sector of the water industry in the US.

Aubert and Reynaud (2005) examined the impact of regulatory regimes on the efficiency of water service providers in the State of Wisconsin in the US. Using a panel of 211 water utilities from 1998 to 2000, Aubert and Reynaud (2005) specify a stochastic cost frontier in a trans-log functional form. The resultant econometric model was first employed in order to test for evidence of economies of density and scale. There was evidence for significant economies of density and scale in the short run. However, this did not extend to the longer run, with the exception of very small utilities. Furthermore, such economies were unrelated to regulatory type.

Perhaps the most comprehensive and influential study of scale and scope effects in the water and wastewater industry was conducted by Garcia and Thomas (2001). The authors attempted to characterise the essential elements of water and wastewater industry in France. The focus of the study was quantifying the economic landmarks that underpin the network, rather than the economic efficiency of utilities. The authors sought to measure four main indicators: economies of scope, returns to production and customer densities, both in the short and long run, and economies of scale.

Considerable effort was devoted to correctly specifying network returns via a trans-log cost function and overcoming the hurdles encountered when analysing the panel dataset. The most interesting finding stemmed from the treatment of output in the model. It was partitioned into water delivered to households and water lost as a result of leakages in the system. This gave rise to estimates of scope economies in the joint production of both 'desirable' and 'non-desirable' water.

The strong evidence of scope economies in the production of both classes of water had powerful policy conclusions. This result suggested that tolerating leakages in the system was economically preferable to repairing the network, primarily due to the low cost of water and the relatively cheaper cost of producing more water as opposed to repairing the network. In particular:

> *production of an additional unit of the non-desired water volume increases variable cost less than an increase in the sold water quantity does. This confirms the intuition that minimising water losses is not a priority, especially if repairing leaks is very costly (p. 25).*

The results relating to the other network characteristics were less surprising. There was clear evidence of scale economies up to a certain point, suggesting a number of the smaller utilities would benefit from amalgamation, while returns relating to production and customer density were found to be constant.

### 4.3.1 Synopsis of findings relating to scale, scope and productivity

The studies outlined in this section do not represent a comprehensive review of the evidence regarding economies of scope, scale and density. However, their results suggest that scale economies do exist in the distribution of potable water. There is also sufficient evidence to point to the existence of scope economies, at least when defined in terms of producing both desired and so-called non-desired water. The picture is less clear with respect to the joint production of water and wastewater services. Finally, returns to production and customer density appear at least to be constant; however, as will be established in the following section, the extent to which this translates into relative efficiency is far from conclusive.

## 4.4 Specification considerations

### 4.4.1 DEA, SFA and Tobit regression

In Chapter 3 it was established that two generic approaches exist to measure relative efficiency. The first, SFA, has its antecedents in production theory, and is built around the specification of a production function or frontier against which the relative performance of firms is benchmarked. A crucial step in SFA is the estimation of various parameters that define the functional form of the frontier. The alternative approach, DEA, is said to be more flexible in that the data itself define the frontier by which firms are judged.

Extant relative efficiency studies of the water and wastewater sectors generally fall into either of these categories. Table 4.1 provides a summary of the studies along estimation technique lines, and also contains the main findings of each study.

Table 4.1: Alternative approaches to the measurement of the relative technical efficiency of water and wastewater utilities

| Author | Data | Method | Results |
|---|---|---|---|
| Byrnes, Groskopf & Hayes (1986) | 59 private and 68 public firms - 1976 | DEA | No significant difference in inefficiency as a result of ownership |
| Lambert, Dichev and Raffiee (1993) | 33 private and 238 public - 1989 | DEA | Public firms have greater technical and allocative efficiency |
| Woodbury and Dollery (2004) | 73 water supply authorities – 1998-2000 | DEA | scope for general improvement in the performance of regional water utilities |
| Coelli and Walding (2005) | 18 water utilities – 1996-2003 | DEA | In order for regulators to make use of efficiency estimates, data quality must improve |
| Tupper and Resende (2004) | 20 water sewerage companies - 1996-2000 | DEA | Exogenous variables had significant influence on efficiency |
| Garcia-Sanchez (2006) | 24 water utilities - 1999 | DEA | Ownership not a significant influence on efficiency |
| Anwandter and Ozuna (2002) | 110 water and sewerage utilities - 1995 | DEA | Regulatory reform must introduce competitive pressures and reduce information asymmetries to be effective |
| Cubbin and Tzanidakis (1998) | 29 water firms from the regulated water industry – 1993-1995 | DEA and COLS (cost function) | Each method returns substantially different efficiency measures |
| Lynk (1993) | 10 public water utilities – 1980-88;<br>22 private water utilities – 1985-88 | SFA | Scope economies;<br>Private firms appeared less efficient than public firms |
| Bottasso and Conti (2003) | Unbalanced panel of 28 to 21 firms - 1995-2001 | SFA | Limited economies of scale;<br>average cost inefficiency has steadily decreased over time |
| Fox and Hofler (1986) | 20 private and 156 public - 1981 | SFA | Equal technical inefficiency however private utilities had significantly higher allocation inefficiency |
| Byrnes (1991) | 49 private and 105 public - 1976 | SFA | Models that measure ownership effects must first account for selectivity bias to yield accurate results |
| Bhattacharyya , Harris, Narayanan and Raffiee (1995a) | 31 private and 190 public - 1992 | SFA | Public firms not disadvantaged in terms of efficiency |
| Bhattacharyya, Harris, Narayanan and Raffiee (1995b) | 26 rural water utilities - 1992 | SFA | Private firms are most efficient, of government utilities, municipality owned are most efficient on average |
| Aubert and Reynaud (2005) | 211 water utilities – 1998-2000 | SFA | Regulatory regime is important to efficiency |
| Estache and Rossi (2002) | 50 water companies - 1995 | SFA | Efficiency unaffected by ownership structure |
| Faria, Souza and Moreira (2005) | 13 private and 148 public - 2002 | SFA | Neither location of ownership significantly influenced efficiency |
| Estache and Kouassi (2002) | 21 water utilities – 1995-97 | SFA | Relatively low efficiency explained by pervasive corruption and poor governance arrangements |

The studies reported in Table 4.1 have largely been reviewed above. The table is included in order to provide a précis of the existing literature, with the aim of establishing the reasonably long history of each technique in the current context. Furthermore, there appears not to have been a preference for one technique. It can be concluded that each technique seems reasonably well suited to the purpose of this thesis, and the choice regarding which to employ should be made with respect to the available data.

In Chapter 3 reference was also made to the use of Tobit regression in order to analyse the determinants of relative efficiency with respect to exogenous variables. This technique has received support in the analysis of technical efficiency within the water and wastewater sector, calculated following the DEA specification. The results, measured with respect to significant coefficients, have been mixed and a summary appears in Table 4.2. For example, Coelli and Walding (2005) were unable to detect any significant relationship, while Woodbury and Dollery (2004) found success only with respect to one of seven variables included in the equation.

Two studies are particularly instructive in terms of cautionary tales regarding specification of efficiency models. Cubbin and Tzanidakis (1998) focused on the relative merits of the econometric instruments used to draw conclusions regarding this industry. Motivated by a general perception among policy practitioners that regression analysis techniques and DEA were essentially interchangeable in terms of arriving at measures of relative efficiency, Cubbin and Tzanidakis (1998) used data pertaining to the English and Welsh water industry to demonstrate the virtues of the two techniques. Applying both a DEA and Corrected Ordinary Least Squares (COLS) specification to an identical dataset, the two models returned substantively different results.

Table 4.2: Tobit regression used to explain variation in scores

| Author | Tobit Variables | Efficiency technique | Results of Tobit Regression |
|---|---|---|---|
| Woodbury and Dollery (2004) | Population, properties per km of main, coastal location, rainfall, percentage of residential customers, filtered water and groundwater source. | DEA | Only the dummy variable for groundwater as a source of raw water was found to be statistically significant (positively correlated) |
| Coelli and Walding (2005) | Percentage on non-residential connections, percentage of water from non-catchment sources, average annual rainfall, average maximum temperature, peak to average flow and electricity consumption. | DEA | None of the variables were found to be statistically significant. |
| Tupper and Resende (2004) | Population density (with respect to both the water and sewer networks) and water loss. | DEA | Both population density (water) and water losses positively correlated with technical efficiency. Population density (wastewater) negatively correlated. |
| Garcia-Sanchez (2006) | Population, average people per house, municipal area, tourist index, average temperature, level of income, size of 'greenbelt', economic activity, number of houses and population density. | DEA | All variables with the exception of population density found to be statistically insignificant. Population density positively correlated with relative efficiency. |
| Anwandter and Ozuna (2002) | Municipal owned utility, independently regulated, cutting water service permitted, unaccounted for water, population density and non-residential users. | DEA | Only unaccounted for water (negatively correlated) and the percentage of non-residential water users (positively correlated) were found to be significant. |
| Estache and Kouassi (2002) | Indexes of corruption and governance and ownership (privatisiation). | SFA | Corruption negatively correlated with relative efficiency, Governance positively correlated. Private utilities less efficient. |

Using a technique known as 'general to specific econometric methodology', the authors whittled down a list of possible variables from 10 to three for inclusion in a cost equation estimated by Ordinary Least Squares (OLS). The model had as its dependent variable operating expenditure and as explanatory variables the amount of water delivered, the length of mains and the proportion of water delivered to measured non-households.

All variables were statistically significant at the five per cent level and had the expected signs. The authors employed the COLS technique, which essentially shifted down the cost function until it reached the firm with the lowest residual. As outlined in Section 3.4.2 of Chapter 3, this converts the cost function from one that runs through the middle of the data to a cost frontier, since it now relates to the most efficient firm in the sample. This enables the calculation of relative efficiency indexes.

One firm was found to be fully efficient, while the least efficient firm had a score of 0.572, suggesting it could reduce its operating expenditure by 42.8 per cent without sacrificing output. Ten firms were found to have scores between 0.7 and 0.8, nine had scores between 0.8 and 0.9, five had scores between 0.6 and 0.7 and two firms had scores between 0.9 and 1 and 0.5 and 0.6.

The next step was to estimate CRS and VRS DEA models. Both models had one input (operating expenditure), two outputs (water delivered and length of mains) and an exogenous variable (proportion of water distributed to non-households). For the CRS specification, three firms were found to be fully efficient; that is, they received an efficiency score of 1. However, none of the corresponding firms was efficient under the regression analysis. In fact, one firm found to be fully efficient by the DEA model returned an efficiency score of 0.619 when measured by COLS.

The VRS model returned 13 fully efficient firms, which is to be expected since this model wraps the frontier relatively more closely to the data. It could be expected that the identified firms would correspond with those found to be relatively more efficient under the COLS specification. However, the fully efficient firms under the VRS

DEA specification were evenly spread in relation to the efficiency scores calculated under the COLS model.

In addition, Cubbin and Tzanidakis (1998) drew attention to the effects of adding variables to the DEA model. Two variables, which were found to be marginally significant under regression analysis, were added to the DEA model with disturbing consequences. The net effect was that a firm found to be relatively inefficient under the original specification became fully efficient.

In sum, vast differences between rankings of firms under the COLS and DEA models were established, even though an identical dataset was utilised. Unfortunately, a test for the statistical significance of the difference in ranks was not performed. To that extent it is uncertain whether the observed differences were simply a result of chance. Nevertheless, the authors present a convincing argument, based on their evidence, that the main weakness with DEA is its susceptibility to the addition of variables. This derives from the fact that individual weights pertaining to the inputs and outputs of each firm are calculated in DEA, whereas regression analysis calculates common weights, which provides stability to the parameter estimates when marginally significant variables are added to the model. This result has obvious implications for the specification of the various DEA models to be estimated in this thesis.

Teeples and Glyer (1987) applied the models previously employed by Crain and Zardkoohi (1978), Feigenbaum and Teeples (1983) and Teeples and Glyer (1986) to a single dataset in order to trace the source of divergences. In essence, the authors found that as restrictions on the models were progressively removed, and explanatory variables were added, the influence of ownership diminished. They concluded that previous studies finding ownership to be of significance did so merely due to mis-specification.

Teeples and Glyer (1987) outlined in some detail how the explanatory or exogenous variables may have had statistically significant impacts upon cost. First, they argued that omitting inputs that varied in price along with a variable reflecting ownership structure may have inappropriately assigned significance to ownership properties, when in fact the significance may have been due to the influence of the omitted variable. For example, public firms are often able to source capital at discounted rates, compared with private firms, simply due to their ownership by governments with taxation powers, not because they represent a lower risk *per se*. Second, some public institutions may not include input costs explicitly in their accounts. For example, many publicly-owned utilities 'purchase' raw water from a publicly-owned bulk water supply, yet do not include a 'shadow cost' of this water in their accounts. In contrast, privately-owned institutions typically record the cost of purchasing water from similar institutions. The previous studies examined by the authors typically did not include such variables.

Teeples and Glyer (1987) considered data from a private survey of Southern Californian water authorities in 1980, supplemented by data from public sources. The authors outlined in some detail how the data was adjusted in order to accord a degree of homogeneity. The authors began with the most restrictive of the models – Crain and Zardkoohi (1978) – and worked through the remainder in order of flexibility and model completeness (measured by the $R^2$ score). They found that "estimated differentials in overall efficiency diminish uniformly, and precision increases as the model specification is made more complete" (p.403). The model with the highest $R^2$

score of 0.99 returned economically and statistically insignificant estimates of overall efficiency differences due to ownership.

The overall significance of this study was to argue that models of water delivery cost must take into account a large number of variables that accurately reflect the production conditions under which water utilities operate.

In summary, it should be noted that the use of SFA or DEA as an analytical tool is roughly evenly split, and there is little to suggest either is a natural choice in terms of drastically improved results. Thus, the choice between SFA or DEA would appear to be one best made with considerable weight given to the particular characteristics of the industry being analysed. For example, one could consider whether previous studies provide evidence regarding the particular shape of the functional form.

Second, a recent innovation in this field has been the use of Tobit regression equations in order to analyse the determinants of technical efficiency. Although this has primarily been in the context of DEA studies, there is one example of the use of Tobit to analyse SFA.

Having established that SFA and DEA have a long history in analysis of water and wastewater industries, the discussion turns to the input and output variables employed in those studies.

### 4.4.2 Inputs and outputs

As noted in Chapter 3, relative efficiency scores are typically calculated by the examination of the inputs consumed by a firm in the production of outputs. It follows that the mix of input and output variables entering relative efficiency models will have a significant influence on the results generated. This section reviews the specification of inputs and outputs previously employed in empirical studies of relative efficiency in the water and wastewater industry. The aim is to gain some insight regarding those variables that have proved successful in the past, and to benefit from the experience of those who have encountered difficulties related to matters such as unavailable and inadequate data. A summary of the literature in this field appears as Table 4.3.

Table 4.3: Inputs employed in relative efficiency studies of water and wastewater utilities

| Capital | Labour | Material |
|---|---|---|
| Cubbin and Tzanidakis (1993) length of mains | Saal and Parker (2000) | Saal and Parker (2000) |
| Saal and Parker (2000) | Ashton (2000) | Ashton (2000) |
| Ashton (2000) | Bottasso and Conti (2003) | Feigenbaum and Teeples (1983) |
| Bottasso and Conti (2003) | Feigenbaum and Teeples (1983) | Byrnes (1986) – water |
| Feigenbaum and Teeples (1983) | Byrnes (1986) | Raffie et al. (1993) |
| Byrnes (1986) - pipeline length | Fox and Hofler (1986) | Lambert et al. (1993) |
| Fox and Hofler (1986) | Lambert et al. (1993) | Bhattacharyya et al. (1995a) |
| Raffie et al. (1993) | Bhattacharyya et al. (1994) | Bhattacharyya et al. (1995b) |
| Lambert et al. (1993) | Bhattacharyya et al. (1995a) | Aubert and Reynaud (2005) |
| Bhattacharyya et al. (1994) – fixed | Bhattacharyya et al. (1995b) | Woodbury and Dollery (2004) |
| Bhattacharyya et al. (1995a) | Aubert and Reynaud (2005) | Estache and Kouassi (2002) |
| Aubert and Reynaud (2005) | Woodbury and Dollery (2004) | Garcia-Sanchez (2006) |
| Woodbury and Dollery (2004) | Estache and Rossi (2002) | Anwandter and Ozuna (2002) |
| Coelli and Walding (2005) – length of mains | Tupper and Resende (2004) | |
| | Faria et al (2005) | |
| | Estache and Kouassi (2002) | |
| | Garcia-Sanchez (2006) | |

As indicated in Table 4.3, most of the studies implemented the traditional mix of inputs suggested by production theory: capital, labour and various proxies for materials[15]. An alternative approach has been to substitute individual measures of capital, labour and materials with a 'catch-all' variable, typically in the form of total operating cost or expenditure. Of course, cost functions have the advantage of expressing total cost as a function of both inputs and outputs. In a rather unique approach, Estache and Kouassii (2002) cast the number of serviced connections as an input, rather than an output.

Capital has typically been proxied by the value of capital stock or a physical measure such as the length of water and/or sewer mains. The advantage of the first approach is that all the components of the capital stock can be included in the model, while the latter has typically measured only one part of the infrastructure in question. Employing a physical measure has often been necessitated by poor measures of the value of capital. Indeed, it was this complication that led Coelli and Walding (2005) to model both the written down value of capital and the length of mains in order to account for the relatively poor quality of the value of capital stock in Australian water utilities.

Likewise, surrogates of labour have typically been divided into those measuring the value of labour (aggregate wages for example) or the quantity of labour (aggregate full-time equivalents and the like). A complication not often taken into account in using a physical proxy is the relative cost of labour between regions. A unit of labour performing essentially the same task is likely to attract a higher marginal cost in a city when compared with a regional centre.

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[15] For a useful guide as to the most relevant inputs and outputs in efficiency and productivity analysis, see Coelli et al. (2005).

A variety of variables have been identified to substitute for material inputs. Perhaps the most common has been the cost of energy, since the movement of water and the treatment of wastewater is a relatively energy intensive process (Twort et al., 2000). Others have included a variable to reflect the consumption of chemicals for the treatment of both potable water and sewerage, and a 'catch-all' to account for the combination of residual inputs not captured by capital or labour.

Efforts to model the output of water and wastewater utilities have understandably focused on the total water produced and total wastewater treated. In a number of studies where one of the aims of the research was to investigate scope economies, authors have differentiated between water production and distribution, water consumed and lost, and water produced combined with regulatory functions not directly related to production, such as environmental protection. Others have incorporated dual outputs, such as the volume of water produced and the number of properties connected.

Starting with Feigenbaum and Teeples (1983), a number of studies have incorporated hedonic variables in order to reflect the relative quality of water and/or wastewater (see Table 4.4). The justification for this has typically progressed along the lines that providing water of a higher quality is likely to incur increased costs.

Table 4.4: Outputs employed in relative efficiency studies of water and wastewater utilities

| Volume of water/wastewater | Dual outputs | Quality adjusted outputs |
|---|---|---|
| Cubbin and Tzanidakis (1993) | Fox and Hofler (1986) | Woodbury and Dollery (2004) |
| Saal and Parker (2000) | Bhattacharyya et al. (1995b) | Garcia-Sanchez (2006) |
| Bottasso and Conti (2003) | Aubert and Reynaud (2005) | Anwandter and Ozuna (2002) |
| Byrnes et al. (1986) | Coelli and Walding (2005) | Saal and Parker (2000) |
| Lambert et al. (1993) | Tupper and Resende (2004) | Saal and Parker (2001) |
| Bhattacharyya et al. (1995a) | | Feigenbaum and Teeples (1983) |
| Estache and Rossi (2002) | | |
| Faria et al (2005) | | |
| Estache and Kouassi (2002) | | |

### 4.4.3 Exogenous variables

It was established in Chapter 3 that a relative advantage of SFA models is the ability to control for exogenous influences on the production of potable water and the treatment of wastewater directly in the production or cost frontier without the need to form assumptions regarding the direction of the influence each will take. In contrast, although DEA models generally allow for the direct inclusion of exogenous influences, *a priori* expectations of varying degrees must first be formed. An alternative approach often employed has been to cast DEA efficiency scores as the dependent variable to be regressed against a set of exogenous variables. While *a priori* expectations provide the underlying motive for inclusion, it is not a pre-requisite step in the process. The suite of exogenous variables modelled in the analysis of relative efficiency in this industry are summarised in this section (Table 4.5), along with the studies that make use of each.

Table 4.5: Exogenous variables previously employed in efficiency studies of water and wastewater utilities

| | |
|---|---|
| ***Water Source*** | |
| Bottasso and Conti (2003) | River source positively correlated with technical efficiency |
| Bhattacharyya et al. (1995b) | Groundwater positively correlated with technical efficiency |
| Aubert and Reynaud (2005) | Surface water positively correlated with total cost |
| Woodbury and Dollery (2004) | Groundwater positively correlated with technical efficiency |
| Estache and Rossi (2002) | Coefficient not statistically significant |
| Coelli and Walding (2005) | Coefficient not statistically significant |
| ***Industrial Use*** | |
| Bottasso and Conti (2003) | Higher proportions of water supplied to industrial consumers negatively correlated with technical efficiency |
| Fox and Hofler (1986) | Higher proportions of water supplied to industrial consumers positively correlated with total product |
| Woodbury and Dollery (2004) | Coefficient not statistically significant |
| Coelli and Walding (2005) | Coefficient not statistically significant |
| Garcia-Sanchez (2006) | Higher proportions of water supplied to industrial consumers negatively correlated with technical efficiency, although statistically insignificant |
| Anwandter and Ozuna (2002) | Higher proportions of water supplied to industrial consumers positively correlated with technical efficiency |
| ***Climate*** | |
| Woodbury and Dollery (2004) | Coefficient not statistically significant |
| Coelli and Walding (2005) | Coefficient not statistically significant |
| Garcia-Sanchez (2006) | Temperature positively correlated with technically efficiency, although statistically insignificant |
| ***Water loss*** | |
| Bhattacharyya et al. (1995b): | negatively correlated with technical efficiency |
| ***Utility Size*** | |
| Bottasso and Conti (2003): | technical inefficiency decreases with size |
| Bhattacharyya et al. (1995b): | technical inefficiency decreases with size |
| ***Treatment*** | |
| Feigenbaum and Teeples (1983) | Higher degree of treatment positively associated with total cost |
| Byrnes (1991) | Utilities that treat to a higher degree more likely to be publicly owned |
| Bhattacharyya et al. (1995b) | Higher degree of treatment negatively correlated with technical efficiency |
| Woodbury and Dollery (2004) | Coefficient not statistically significant |
| Estache and Rossi (2002) | Higher degree of treatment positively associated with total cost |
| ***Water metered*** | |
| Feigenbaum and Teeples (1983) | Higher proportion of water consumption metered positively correlated with total cost |
| Estache and Rossi (2002) | Higher proportion of water consumption metered positively correlated with total cost |
| Bhattacharyya et al. (1995b) | Higher proportion of water consumption metered positively correlated with technical efficiency |
| ***Customer/Population Density*** | |
| Bottasso and Conti (2003) | Higher degree of population density positively correlated with cost efficiency |
| Feigenbaum and Teeples (1983) | Higher degree of population density positively correlated with total cost |
| Woodbury and Dollery (2004) | Coefficient not statistically significant |
| Estache and Rossi (2002): ) | Higher degree of population density negatively correlated with total cost |
| Garcia-Sanchez (2006) | Higher degree of population density negatively correlated with technical efficiency |
| Anwandter and Ozuna (2002) | Higher degree of population density positively correlated with technical efficiency, although statistically insignificant |
| ***Production Density*** | |
| Feigenbaum and Teeples (1983) | Higher degree of population density negatively correlated with total cost |

A reasonably clear pattern emerged from the results measuring the effect of various water sources on the technical efficiency of water utilities. Groundwater, as a supply of raw water, was found to be significantly associated with higher levels of technical efficiency, while water from a surface source, such as a river or dam, was correlated with a relatively lower level of efficiency.

The evidence regarding the effect of supplying a greater proportion of water to industrial customers was mixed. Bottasso and Conti (2003) and Garcia-Sanchez (2006) found a negative relationship, although the latter was a statistically insignificant result. Anwandter and Ozuna (2002) concluded that the positive association between industrial consumption and technical efficiency was as a result of economies of scale in water production.

Attempts to measure the influence of climate variables were generally unsuccessful, with all studies included here finding insignificant coefficients. Bhattacharyya et al. (1995b) found that higher levels of water loss were associated with increased technical inefficiency, suggesting maintenance of water networks paid efficiency dividends.

The evidence regarding the role of relative size is in line with the body of evidence reviewed in Section 4.3. Larger utilities were generally found to be relatively more efficient. All but one of the studies to model treatment costs found a negative relationship with technical efficiency. This result suggests higher treatment expenses eventually lead to lower levels of technical efficiency.

Three studies attempted to measure the influence of metered connections on relative efficiency, hypothesising that metering incurs expenses related to measurement and billing. All three found a positive relationship between costs and higher levels of metered consumption.

One of the most frequently modelled sets of exogenous variables relates to customer and population density. The majority of the evidence reviewed here suggests higher levels of customer and/or population density are associated with increased technical efficiency, or lower costs. In a related finding, Feigenbaum and Teeples (1983) provided evidence to suggest greater production density was related to lower costs.

The results summarised above suggest the water, and to a lesser extent, wastewater industries are reasonably complex, and require carefully considered modelling prior to estimating relative technical efficiency. In particular, a reasonably wide range of exogenous variables appear to be related to technical efficiency, and any econometric model that does not incorporate these influences is likely to suffer misspecification as a result.

## 4.5 Measuring the effects of regulatory regime on the technical efficiency of water and wastewater utilities

The majority of studies reviewed up until this point had as their aim the detection of a relationship between relative technical efficiency and the ownership characteristics of the utility in question. As has already been noted, the extent to which the findings of these studies are of relevance to this thesis is limited, since the focus of this research is not ownership but regulatory and governance arrangements.

Fortunately, Aubert and Reynaud's (2005) study of water service providers in Wisconsin, US, sought to establish the relationship between varying degrees of regulatory oversight and relative efficiency. A relatively detailed review of Aubert and Reynaud (2005) is warranted, since the methodology employed and results reported are likely to inform the research process of this thesis.

In the study of water service providers in Wisconsin, US, by Aubert and Reynaud (2005), the interest in the relevance of regulatory regime stemmed from the unique and rather complex arrangements that apply to the utilities in question. Water utilities in this case were subject to varying degrees of rate of return regulation. In the first instance, a utility could request a price rise. However, that utility was then subject to an exhaustive examination of its accounts to determine the exact nature of the utility's capital base (the so-called rate of return regime). Alternatively, if the price rise requested was within a pre-determined band, utilities were permitted to increase prices without enduring the audit process (the so-called interim price regime). Utilities were also given the option of not requesting a price rise. In this case the maximum allowable prices were those set by the regulator at the last price increase. The advantage of selecting this pricing path was that any profit attained through a reduction in costs was retained by the utility (the so-called hybrid regime).

Aubert and Reynaud (2005) attempted to model this regulatory framework in order to test three conjectures:

- The extent to which the utility minimised cost was dependent upon the type of regime to which the utility was subject;
- utilities subject to the interim price regime and rate of return regime were more efficient than those under the hybrid regime; and

- utilities under the rate of return and interim price regimes had the same relative efficiency.

Employing a stochastic cost frontier, the model regressed variable cost as a function of two outputs, a number of inputs, and a vector of variables expected to explain exogenous factors. The two outputs were the volume of water produced and the number of customers, while the inputs were the level of capital (expressed in the short run), labour, electricity and a vector of input prices. The exogenous factors were dummy variables for water purchased and surface water, and a measure of the average pump depth, since the majority of water produced in Wisconsin was sourced from groundwater. The vast majority (between 76 and 80 per cent) of utilities were regulated under the interim price regime. In order to model inefficiency the authors included dummy variables for each type of regime.

Perhaps not surprisingly, evidence of over-investment in capital was found, reflecting that most utilities were reacting to rate of return regulation, with the standard consequences of capital for labour substitution. Moving to measures of inefficiency, the regulatory framework appeared to have a significant effect on the efficiency of regulated water utilities. To be more specific, utilities under the more intrusive rate of return regulation were found to be relatively more efficient, while those under the hybrid regime tended to be relatively inefficient. Aubert and Reynaud (2005, p. 402) also found that utilities "do not operate too far away from their cost efficient frontier on average", with the average firm experiencing costs 13 per cent higher than those on the frontier.

In seeking to explain why rate of return regulated utilities were the most efficient, Aubert and Reynaud (2005) pointed to the exhaustive nature of regulation under this regime, suggesting that the audit activities of regulators may have in fact enhanced the efficiency of operations of those utilities that were closely monitored. Second, rate of return regulated firms were typically overcapitalised, resulting in relatively less of their cost appearing in the variable cost equation and implying that these firms were relatively efficient as a result, at least in the short term.

The hybrid regime produced the most inefficient utilities, with the average firm 7.9 per cent more cost inefficient than those under an interim price regime and 10.7 per cent less efficient than those under the rate of return regime. Finally, those under an interim price regime were relatively efficient; however, this group contained extremes with both very efficient and very inefficient utilities observed. Aubert and Reynaud (2005) concluded that this may have been due to the influence of some very inefficient firms that may have preferred not to be scrutinised by the regulator for fear of revealing past errors, while at the other end of the spectrum, very efficient firms may have preferred to increase profits by driving down costs.

In sum, Aubert and Reynaud (2005) found that the regulatory regime was significantly related to the relative efficiency of water utilities. Regimes that required extensive information gathering by regulators resulted in higher levels of efficiency, while those with less information demands tended to be associated with less efficient utilities.

The relevance of this study to the current research task has already been mentioned. The findings of efficiency gains as a result of so-called 'hard' (as opposed to soft) regulation has important implications for the regulation of water and wastewater utilities in NSW and Victoria. As outlined in chapters 1 and 2, water authorities in Victoria are subject to regulatory oversight by the independent economic regulator, the Essential Services Commission. Formal pricing reviews are conducted in regular intervals, and are exhaustive in nature.

By contrast, LWUs in NSW are subject to so-called 'soft' regulation. The relevant government department reviewed the performance of utilities and developed guidelines to assist utilities in formulating structures and pricing regimes. However, utility managers were ultimately responsible for decisions regarding tariff structures and the like. The findings of Aubert and Reynaud (2005) suggest that the benefits of 'hard' regulation more than compensate for the additional cost of regulation. Whether this is the case in the current context is a matter for empirical investigation.

The work by Anwandter and Ozuna (2002) represents a second study of the relationship between regulatory regime and relative efficiency. However, since the context was the less comparable nation of Mexico, less attention is given to their study.

Noting policy makers' preference for privatisation as a means to deliver efficiency improvements in the urban water sector, Anwandter and Ozuna (2002) made use of a DEA model to determine whether "public sector reforms could improve the operational efficiency of water utilities as an alternative to privatisation" (p. 687). Mexico had recently undergone regulatory reform in the form of de facto decentralisation of water supply and sewage operations from the state level to municipalities, the creation of an independent regulator and the granting of rights to utilities to cut off water supply to non-paying customers. The dataset consisted of 110 urban water supply and sewerage utilities in 1995. Of those, 80 firms were under municipal control while the remainder were state-owned. In terms of regulation, 46 firms were under the auspices of the independent regulator, whereas the remaining

64 performed the dual roles of regulator and operator. Only 22 of the firms were permitted to cut water supply. Data were sourced from a questionnaire sent to the water utility manager.

The results indicated that 51 of the 110 firms were fully efficient; the next closest grouping was 12 firms with DEA scores between 0.6 and 0.7. The authors recognised this as an unsatisfactory result and examined the estimates, finding 17 of the 51 firms were being compared with themselves, while the remaining 34 acted as benchmarks for other firms.

In order to determine the influence of exogenous variables on the efficiency scores a second stage Tobit regression analysis was conducted. The insignificance of the dummy variables included to capture the influence of regulatory reform, when tested both individually and jointly, suggested that the three-pronged reform effort had not had the desired impact on efficiency.

A second test, known as the Brockett-Golany ranking test, indicated that the average rank of state firms was higher than those of municipal firms, suggesting that state firms were slightly more efficient. However, the two groups were found to be not statistically different. A similar test was conducted to determine whether an independent regulator produced more efficient utilities than self-regulation. In a similar vein, no statistically significant difference between the groups was found.

Anwandter and Ozuna (2002) argued that the policy implications of this study were that although the reforms were a step in the right direction, in order to achieve measurable reform it was important that regulators introduce competitive pressures; and information asymmetry needs to be reduced between the manager and the regulator of the local utilities.

## 4.6 Regional water and wastewater utilities – empirical evidence

In contrast to most other studies of American water and wastewater utilities, Bhattacharyya et al. (1995b) focused specifically on the performance of small rural water authorities in Nevada, making a number of contributions to the literature. First, while other authors typically reported inefficiency scores in and of themselves, Bhattacharyya et al. (1995b) sought to explain departures from the production frontier in terms of firm specific variables. Second, the distribution of the error term employed in the econometric model was empirically estimated in a two-step procedure, rather than assumed. Finally, the variation in efficiency scores among public utilities was examined to reveal information regarding the role of divergent regulatory regimes in the public sector.

The authors began by establishing an indirect production function, in the trans-log form, which took into account both provision and production decisions of water utilities. The dataset was constructed from a survey, conducted in 1992, of 26 rural Nevada water utilities, of which two were privately-owned while the remainder were state-owned operations. Total expenditure was regressed against energy, labour, materials and corresponding factor costs. The control variables included in the equation were water input (as a control for the unobservable factor price of water), capital and population density.

The variables employed to explain inefficiency scores in terms of firm specific parameters were percentage of metered connections, distribution pipeline length and system water loss. Three possible combinations of raw water source were also allowed for, represented by appropriate dummy variables: only surface, only ground, and both surface and ground. Additionally, dummy variables were incorporated to capture the treatment of water and provision of both water and wastewater services.

The average technical inefficiency of rural Nevada water utilities was found to be 88 per cent, implying excessive input use of 13 per cent. Of the categories of firms based on ownership, privately-owned utilities were the most technically efficient (average 91 per cent), while those owned by a water district were the most inefficient (average 85 per cent). Of the government-owned utilities, those operated by a municipality ranked highest when taken as a group (90 per cent on average). However, analysis of the spread of efficiency scores among this group indicated large variability in the efficiency scores, with the least efficient returning a score of 67 per cent, while the most efficient was on the frontier.

Of the explanatory variables used to estimate inefficiency in terms of firm specific characteristics, all were statistically significant except for system loss. The percentage of metered connections was found to be negative, indicating that increasing the number of metered connections would also increase technical efficiency. The positive coefficient on the length of mains suggested the larger the size of the network, the larger was the technical efficiency of the utility. Although the coefficient for system loss was found to be insignificant, it had a positive sign, indicating that firms could have increased their efficiency level through better maintenance of existing pipelines.

The parameter estimates for the dummy variables representing single sources of water were both positive and significant, suggesting that those firms that did not diversify their source of water were relatively more inefficient. Within this same group of firms, those that relied on surface water were less inefficient than those reliant on ground water. Perhaps not surprisingly, those firms that treated water were found to be more inefficient. Finally, utilities that provided both water supply and sewer treatment services were technically more efficient than those that didn't, suggesting the existence of economies of scope in the water industry.

## 4.7 Studies of the relative efficiency of Australian water and wastewater utilities

Woodbury and Dollery (2004) represented the first attempt at analysing the efficiency of water and wastewater providers in regional NSW. In addition, they made a significant contribution to the literature through the construction of water quality indices. These measures were incorporated into the DEA estimation framework in a number of novel ways: first by including water quality as an output, and second by adjusting the quantity of water consumed to take into account the quality of the water provided.

The authors embarked on a three-stage estimation procedure. The first stage was to convert the raw quality data into indices. Estimates of relative utility efficiency were then estimated via a DEA model. In the third stage, an attempt was made to analyse the resultant DEA scores with reference to a number of exogenous variables employing Tobit regression. The sample analysed consisted of data relating to 73 utilities over both one and three-year periods.

The quantity outputs included the number of residential assessments and the annual water consumption, while the quality outputs consisted of a water quality index and a water service index. The inputs employed were management costs, maintenance and operation costs, energy and chemical costs, and capital replacement costs for the one-year analysis. For the three-year analysis capital input was dropped due to data deficiencies.

Woodbury and Dollery (2004) estimated six alternative models. The first utilised only quantitative outputs, while the following five incorporated the quality indices in various combinations. Of these the first two included the quality indices as separate outputs while the following three adjusted qualitative outputs using the quality indices in various manners. Some specifications were more punitive in terms of penalising poor quality than others.

A surprising feature of the research was that the choice of model had relatively little impact on the results. For the constant returns to scale specification, the average technical efficiency of councils was 0.737, and for the variable returns to scale specification an average score of 0.79 was found when the qualitative indices were excluded. The efficiency scores marginally changed to 0.735 and 0.796 when qualitative outputs were adjusted using the quality indices. This was typical of most of the results acquired. It is of particular interest to note that when the average efficiency scores were weighted to reflect council size, the average score increased, suggesting that larger utilities were relatively more efficient.

The authors suggested that this curious outcome with respect to quality may have been as a result of the DEA procedure giving very little weight to consumption, the output variable upon which the indices were multiplied. Moreover, the excessive number of peers calculated by the model may have served to generally inflate the efficiency scores. An alternative explanation may have lain in compatible councils having very similar service quality indices, or finally, the quality indices may not have been sufficiently punitive. However, a possibility not considered by Woodbury and Dollery (2004) was that the raw data itself did not exhibit sufficient variability. For example, the percentage of time a utility met treatment standards in the sample typically fell between 98 and 100 per cent, with the vast majority of utilities achieving quality targets 100 per cent of the time.

The third stage of the procedure was to estimate a Tobit regression so as to take into account the impact of a number of exogenous variables that may be capable of explaining the relative efficiency scores. As outlined earlier in Table 4.5, the variables employed were population, properties per kilometre of main, location, rainfall, the percentage of residential assessments, whether the water was filtered or unfiltered, and whether water was sourced from groundwater. In somewhat of an anticlimax, the only variable found to be of significance was groundwater, suggesting that factors not included in the Tobit regression explained water utility efficiency.

Overall the results of this study suggested scope for general improvement in the performance of regional water utilities in NSW. It was no doubt disappointing to the authors that the innovative use of quality indices seemed to have very little impact upon the estimation of relative efficiency in the industry.

Coelli and Walding (2005) embarked on a study of the 18 largest urban water providers in Australia. This mainly involved an examination of urban water utilities in the Australian capital cities, although a number of the utilities were located in regional Victoria.

In essence their study was designed to aid policy makers when considering price-cap regulation problems. By examining the technical efficiency of the utilities, Coelli and

Walding hoped to "provide comprehensive performance information to help regulatory authorities set (so-called) CPI-X price paths that encourage efficient performance" (2005: 2). Using data sourced from *WSAAfacts* (WSAA, 2003), an industry-based publication of partial performance indicators, the authors employed a two-stage DEA model in order to determine the relative technical efficiency of the eighteen utilities in question. The data spanned a period of seven years, from 1995–96 to 2002–03. An analysis of productivity growth was also included in the study.

The first stage was the estimation of a standard DEA model employing two inputs (operating expenditure and total length of mains) and two outputs (number of properties connected and volume of water delivered). The authors considered using a number of alternative measures of capital, such as the written down replacement cost of capital. However, a detailed examination of the behaviour of the variables over time led them to reject the alternatives in favour of a purely physical measure, despite the obvious limitations this imposed. They found that the mean technical efficiency (TE) score of the utilities was 0.904, implying that the average firm could have reduced input consumption by 9.6 per cent without reducing output. Seven firms returned TE scores of 1, while the lowest score was 0.627.

In order to explain the variance in TE scores, Coelli and Walding (2005) ran a second-stage regression of the TE scores against a number of exogenous variables not included in the first stage thought to influence the efficiency of the sample utilities. The exogenous variables were the percentage of non-residential connections, percentage of water from non-catchment sources, average annual rainfall, average maximum temperature, peak to average flow and electricity consumption per connection. In a similar finding to that of Woodbury and Dollery (2004), none of the variables were found to be statistically significant at either the five or 10 per cent level.

In terms of Total Factor Productivity (TFP) growth, the authors found that the average annual TFP change over the eight-year period was a 1.2 per cent decline per year. This was attributed to a number of factors: the implementation of demand management policies during the sample period resulting in reduced output, which, when combined with a renewed focus on water quality, resulted in a proportionate increase in input use. On a more technical front, the greatest decline in TFP was recorded in the smallest utilities and, furthermore, the final year of the sample had the largest fall in TFP, somewhat distorting the average. After weighting the average, TFP growth increased from −1.2% to 0.0%, and when 'water delivered' was excluded from the output set in order to remove the impact of demand management policies, TFP growth increased to 0.4% per year.

The major conclusion from this study was that data of much more robust quality would be required before regulatory bodies could rely upon results from efficiency studies such as this, at least as far as it relates to the setting of prices. Coelli and Walding (2005) also suggested that a similar study of the industry be conducted employing SFA in order to test the sensitivity of the results to alternative methodological techniques.

## 4.8 Concluding remarks

While the question of ownership was of central relevance to the vast majority of studies examined here, the lessons regarding model design seem readily transferable to the analysis of the effect of divergent institutional settings carried out in subsequent chapters. In particular, since the use of DEA models has been relatively widely endorsed by past researchers, it would seem that employing a non-parametric framework in this thesis is supported by the existing evidence.

In terms of situating the current research, the review of the literature in this chapter suggests that a study of regional urban water utilities in NSW and Victoria is warranted. Apart from that of Woodbury and Dollery (2004), it appears that there has been no other academic study of the relative efficiency of urban water and wastewater authorities in regional NSW. Coelli and Walding (2005) included in their study only a selection of utilities from Victoria, and then analysed only the water operations of those utilities. Furthermore, it appears that the international literature is also lacking with respect to analysis of regional water and/or wastewater utilities, and particularly in terms of measuring the role of divergent institutional structures as a determinant of relative efficiency.

Furthermore, a consistent set of input and output variables appear to have been employed in previous studies, with a trend toward the inclusion of a quality dimension in the output vector. Finally, a relatively wide range of exogenous variables appear to have been employed in efforts to explain variation of relative efficiency among utilities. This suggests that a wide range of exogenous variables should be modeled in order to explain the relative efficiency scores calculated in this thesis.

# Chapter 5. Methodology Considerations in the Measurement of Relative Technical Efficiency in Water and Wastewater Utilities

## 5.1 Introduction

As the previous chapter established, efficiency analysis techniques have been a prominent feature in empirical research of water and wastewater industries both in Australia and abroad. However, the paucity of the research literature relating to the Australian milieu suggests that the relative efficiency of the Australian water and wastewater sector is worthy of further research. Furthermore, given the relative upheaval in regulation of the urban water and wastewater sectors in regional NSW and Victoria, it is timely to empirically analyse the impact of reform on the efficiency of the urban water and wastewater industry in the two states.

As was made clear in Chapter 2, however, there is a relatively high degree of diversity in the water and wastewater sectors, both between and within states. Any analysis therefore would do well to allow for all possible influences on efficiency, not simply variations in input and output use. This chapter outlines the general methodology employed to meet this aim: a two-stage procedure for the analysis of relative efficiency in both the urban water and wastewater sectors of regional NSW and Victoria.

The next two sections describe the models used in the analysis. Section 5.2 outlines the generic model employed in the first stage of the analysis, and states the rationale underlying the choice of this model over the alternatives presented earlier in Chapter 3. Section 5.3 briefly introduces the model employed for analysing variances in the relative efficiency scores generated by the DEA models.

## 5.2 Estimating relative technical efficiency in the water and wastewater sectors of NSW and Victoria

Chapter 2 outlined the significant reform in the water and wastewater sectors of regional NSW and Victoria during the last two decades. Although reform extended into all parts of the industry by means of the CoAG (1994) water policy, a separate reform process undertaken in Victoria by the Kennett government led to relatively more re-structuring in that state. This section outlines the methodology followed in the analysis of the impact of those reforms on the relative technical efficiency of the operations of water and wastewater providers in Victoria. For reasons outlined in the following section, a non-parametric framework is preferred in this context.

### 5.2.1 Non-parametric approach to measuring efficiency

Of the alternative approaches outlined to measure relative efficiency outlined in Chapter 3, Data Envelopment Analysis (DEA) was adopted for this study. DEA is a mathematical linear programming approach to the estimation of production frontiers, originally proposed by Charnes et al. (1978), and extended by Banker et al. (1984). This approach was chosen since Stochastic Frontier Analysis (SFA) would require the imposition of a number of assumptions regarding the shape of the production frontier. These assumptions could not be formulated with a sufficient degree of confidence in the current circumstances since, as was outlined in Chapter 4, there is a paucity of existing research with respect to the Australian water and wastewater sectors to guide the choice of specification, and this is particularly so at a regional level. The greater flexibility in the estimation of the frontier afforded by the DEA model was given substantial weight in considering which of the two competing approaches to follow in this thesis.

The DEA model brings a number of other advantages. First, it is not necessary to make any *a priori* assumptions regarding the parameters that define the shape of the production technology. Second, multiple outputs and inputs can be readily accommodated. While SFA can be manipulated to allow for multiple output and/or input industries, DEA does not require any additional steps. The advantage of this will become apparent as the nature of the model is outlined in the following section.

Notwithstanding the advantages of using DEA, a choice of this form carries costs. As also outlined in Chapter 3, DEA is an entirely deterministic model, necessitating additional econometric steps if one wishes to account for stochastic and exogenous influences. Furthermore, incorporating the extraneous information into the DEA specification is not a particularly flexible process, requiring a number of *a priori* assumptions to be imposed upon the direction in which factors influence relative efficiency.

On balance, it is argued here that the advantages of the generic DEA specification outweigh the disadvantages in this instance. As noted in Chapter 4, DEA has been used by both Coelli and Walding (2005) and Woodbury and Dollery (2004) to measure relative efficiency in the Australian water and wastewater sectors. Further details are given in Section 4.4 of Chapter 4. In the international literature, the DEA method has been employed by various researchers to investigate the relative efficiency of water and wastewater utilities in England and Wales, the United States and a number of other settings (see Chapter 4 for a summary of the studies). The choice of DEA as a methodology is therefore consistent with a non-trivial portion of the existing literature relating to water utility efficiency and provides a vehicle for comparing the results of this analysis with other studies.

### 5.2.2 An input-oriented model

An important consideration when modelling firms in a DEA framework is to decide whether to take an input- or output-oriented approach. An output-oriented approach suggests that firm management seeks to maximise output while using no more than the observed amount of any input. The alternative input orientation implies the firm's objective is to minimise inputs while producing at least the observed output (Cooper et al. 2006). For the purposes of this analysis, greater weight was placed on input minimisation by water and wastewater utility managers than output maximisation. This follows the approach of both Coelli and Walding (2005) and Woodbury and Dollery (2004).

The logic of this assumption is that the quantity of potable water consumed and effluent to be treated is to a considerable extent beyond the control of managers. Consumers rightly expect water to flow when turning on the tap, and for sewage to be transported safely and treated to an acceptable standard. Managers are thus left to minimise input consumption in the face of this constraint.

To the extent that managers have some indirect influence over output, state and even federal government policy initiatives to encourage water conservation in the urban setting are likely to have resulted in contractions, rather expansions, in output. For example, the customer charter for North East Water (NEW, 2005) contains a section committing the authority to sustainable water use, which in practice relates almost entirely to the implementation of 'permanent' water restrictions. In NSW, a condition to be met by LWUs prior to making a dividend payment is meeting a series of best practice management principles (outlined in Section 2.6.3), including the formulation of water conservation plans. A DEA model with an output orientation would measure performance on the assumption that managers were attempting to maximise output. Clearly, adherence to directives such as those highlighted above would not support an assumption of output maximisation.

Since there is considerable existing evidence regarding scale economies in water and wastewater systems (see, for instance, Garcia and Thomas, 2001; Mizutani and Urakami, 2001), both variable and constant returns to scale DEA models have been specified. An additional benefit from estimating both constant and variable returns to scale models lies in the potential to measure relative scale efficiency.

### 5.2.3 Specification of the constant and variable returns to scale DEA models

Following Zhu (2003), the author of the computer software program employed to calculate the various DEA efficiency measures reported in this thesis (DEA Frontier), the two DEA models to be solved are specified and presented in equations 5.1 (constant returns to scale) and 5.2 (variable returns to scale). If we consider N firms, producing a vector of outputs $y$ using a vector of inputs $x$, then the model can be specified thus:

$$
\begin{aligned}
&\min \theta - \varepsilon\left(\sum_{i=1}^{m} s_i^- + \sum_{r=1}^{s} s_r^+\right) \\
&\text{s.t.} \\
&\sum_{j=1}^{n} \lambda_j x_{ij} + s_i^- = \theta x_{io} \\
&\lambda_j \geq 0 \\
&i = 1, 2, \ldots, m; \\
&r = 1, 2, \ldots, s; \\
&j = 1, 2, \ldots, n.
\end{aligned}
\qquad (5.1)
$$

where $\theta$ is the objective to be minimised and $\varepsilon$ is the non-Archimedean, which permits the minimisation of $\theta$ to preempt the optimisation involving the slacks, $s_i^-$ and $s_i^+$. $\lambda_j$ represents the benchmark for a specific water or wastewater utility.

Incorporating the additional constraint $\sum_{j=1}^{n} \lambda_j = 1$ yields the variable returns to scale specification:

$$
\begin{aligned}
&\min \theta - \varepsilon\left(\sum_{i=1}^{m} s_i^- + \sum_{r=1}^{s} s_r^+\right) \\
&\text{s.t.} \\
&\sum_{j=1}^{n} \lambda_j x_{ij} + s_i^- = \theta x_{io} \\
&\sum_{j=1}^{n} \lambda_j = 1 \\
&\lambda_j \geq 0 \\
&i = 1, 2, \ldots, m; \\
&r = 1, 2, \ldots, s; \\
&j = 1, 2, \ldots, n.
\end{aligned}
\qquad (5.2)
$$

Chapter 3 described how the linear programming problem is to be solved once for each utility in the sample. Equations 5.1 and 5.2 will be solved in order to calculate relative efficiency scores for both water and wastewater utilities.

## 5.3 Specification of the model to analyse variance in relative technical efficiency

One of the weaknesses inherent in the DEA model is the limited degree to which external information can be incorporated into it. For example, while it is possible to include inputs and outputs that are outside the direct control of management, this typically requires a series of assumptions to be made regarding whether the variable will have a positive or negative influence. This is unfortunate because the role of a variable may be far from obvious on either theoretical, practical, or empirical grounds. Indeed, much of the value of empirical analysis lies in the detection of new significant relationships.

As outlined in Section 3.6.2, researchers have often embarked on an analysis of the results garnered from a DEA model in a second stage that seeks to explain variation of DEA scores with respect to a number of so-called 'environmental' variables (see, for instance, Andwanter and Azumma, 2002; Estachie and Kouassi, 2002; Woodbury and Dollery, 2004; Coelli and Walding, 2005; Garcia-Sanchez, 2006). However, alternatives exist. In Section 3.6.1 of Chapter 3 a model based on the novel application of SFA to decompose DEA scores into environmental effects, statistical noise and 'pure' managerial efficiency was outlined. As will be reported in Chapter

8, preliminary results from the implementation of this model in an earlier iteration of this research were disappointing. As a result a Tobit specification was employed.

Another reason to employ a second stage analysis is that including a relatively large number of explanatory variables in the DEA specification tends to mute the discriminatory power of the model (see Cubbin and Tzanidakis, 1998). It is argued here that the use of the second stage approach is justified on the grounds that the inclusion of a relatively large number of external variables in the DEA model would be likely to prove detrimental to the efficiency of the model. Since it was established in Chapter 4 that a relatively large number of explanatory variables have been found to influence relative technical efficiency in this industry, it seems sensible to first estimate DEA scores from a model with a relatively high degree of discriminatory power, and then analyse the results with respect to the relatively large suit of explanatory variables shown to be of significance in Chapter 4.

### 5.3.1 Tobit regression

It has long been argued that since DEA efficiency scores are bound by 0 and 1 the classic Ordinary Least Squares (OLS) regression model is inappropriate, since it is likely to produce biased estimates (Kennedy, 2003). Researchers have often turned to the Logit and Tobit regression models, since they were specifically designed for the analysis of datasets that have been censored and/or truncated at some numeric value.

Despite the widely held belief that a Tobit specification is well suited to the task, Hoff (2007: 428) argues that the Tobit model is not without limitations. Noting that DEA scores can be classified as so-called corner solution outcomes, he argues that:

> *A corner solution variable is continuous and limited from above or below or both of the boundaries with a positive probability. As DEA efficiency scores are continuous on the interval [0;1], and takes on the value 1 with positive probability, it seems obvious to use a two-limit tobit technique for modeling the scores as a function of the exogenous variables. Tobit has as such been adopted as the natural 'choice' for modeling DEA scores in second stage evaluations. The two-limit tobit technique is however mis-specified when applied to DEA scores, given that these take on the value 1 with positive probability (and not the opposite limiting value 0).*

Notwithstanding the above, Hoff (2007) demonstrates that although mis-specified, Tobit returns 'sensible' results and appears reasonably robust when compared with more technically correct but computationally taxing alternatives for analysing DEA scores. Noting Hoff's (2007) reservations and the limitations associated with this model, a Tobit model was estimated.

Following Green (2003), the Tobit model itself is specified in equation 5.3. The DEA scores returned after evaluation of equations 5.1 and 5.2 were cast as the dependent variables, to be regressed against a number of explanatory variables.

The standard Tobit model can be defined as a latent underlying regression of the form:

$$y_i^* = \beta' X_i + \varepsilon_i, \varepsilon_i \sim \mathrm{N}\left[0, \sigma^2\right]. \tag{5.3}$$

where $y_i^*$ is a latent variable (in this case the DEA efficiency score for each utility $i$), $\beta'$ is a vector of parameters to be estimated, and $X_i$ is a vector of explanatory variables observed for each utility $i$. The error term, $\varepsilon_i$ is assumed normally distributed, permitting estimation of the Tobit model by maximum likelihood.

The observed dependent variable was subject to censoring such that:

if $y_i^* \leq L_i$, then $y_i = L_i$ (lower tail censoring)
if $y_i^* \geq U_i$, then $y_i = U_i$ (upper tail censoring).

In this case both upper and lower tails were censored, to the effect that $L_i = 0$ and $U_i = 1$.

## 5.4 Concluding remarks

This chapter has outlined the rationale for selecting the non-parametric approach to relative efficiency analysis in order to measure the relative technical efficiency of water and wastewater utilities in NSW and Victoria. In essence, the flexibility of the generic DEA model proved appealing because the empirical literature provides limited guidance on the functional form relating to each of the sectors. A disadvantage associated with the non-parametric approach is that the discriminatory power of the model declines as variables are added. To address this weakness, a Tobit equation, incorporating a suite of explanatory variables used in the literature to incorporate factors that influence relative efficiency of water and wastewater utilities, was specified. The Tobit equation was employed with the aim of identifying the determinants of relative technical efficiency in this context.

Chapters 6 and 7 consider the variables included in the various models specified in this chapter. Chapter 6 examines the variables of importance to the analysis of water utilities, followed by a similar review relating to wastewater utilities in Chapter 7.

# Chapter 6. The Measurement of Relative Technical Efficiency in Water Utilities

## 6.1 Introduction

The methodological basis of the DEA model to be solved in this thesis was described in the preceding chapter. It was noted that the relative efficiency of utilities is assessed with reference to the set of inputs and outputs employed in the production process. The Tobit regression equation to be estimated was also specified, in order to examine the determinants of relative efficiency of the water and wastewater sectors in regional NSW and Victoria.

This chapter has two aims. First, the logical framework for the inputs, outputs and explanatory variables used in the DEA model and Tobit regression equations relating to the water sectors is outlined. Second, a synopsis of the descriptive statistics pertaining to each of those variables is presented.

The chapter consists of four main sections. Section 6.2 outlines the generic DEA model employed in the first stage of this analysis, and states the rationale underlying the choice of this model over the alternatives presented in Chapter 3. Section 6.3 introduces the input and output variables to be included in the DEA model, and presents the descriptive statistics in order to provide an overview of the data. Section 6.4 briefly introduces the model employed for analysing variances in the relative efficiency scores generated by the DEA models. The variables of the analysis, and the related descriptive statistics, are specified in Section 6.5. Chapter 6 closes with summarising remarks in Section 6.6.

## 6.2 Preliminary considerations

As was mentioned in Chapter 5, the water and wastewater operations of utilities are modelled separately in this analysis. An alternative would have been to model the utility as a 'firm' that produces both water and wastewater services. The former approach was chosen on the admittedly pragmatic grounds that the majority of data available are disaggregated between each function. Apart from the inclusion of regional urban water authorities from Victoria, this analysis follows the approach of Woodbury and Dollery (2004), providing some assurance of the appropriateness of this specification. While Coelli and Walding (2005) analysed only the water operations of major water utilities in Australia, this was because a relatively large proportion of the water authorities examined in that study were not responsible for wastewater services.

The period for analysis is the four financial years ending June 2001 to June 2004. Although data are available for financial years ending June 1999 and June 2000, the quality and coverage of these data are generally less than that for the chosen period. Data are also available for the 2004–05 financial year; however, due to a series of local government amalgamations in NSW during the latter half of the 2004 calendar year, comparing the newly formed local water utilities in NSW with those in Victoria would have been a dubious exercise. It is well known that substantial transition costs are associated with amalgamation in local government (see, for instance, Dollery et al., 2006), and since these were not specifically omitted from the operating expenses for NSW LWUs, this time period has been excluded.

A list of the authorities to be modelled and, perhaps more importantly, excluded from the panel, is contained in Appendix 1. The reason for exclusion is noted. The following sections outline the potential inputs and outputs for inclusion in a model designed to measure relative technical efficiency in the urban water industry. This synopsis is followed by a discussion of the data to be used in the model.

## 6.3 Specification of inputs, outputs and explanatory variables

### 6.3.1 Potential inputs

As discussed in Chapter 4, water authorities have typically been modelled as firms that consume the familiar mix of inputs (labour, capital, energy and materials) in order to produce potable water. There have been a number of notable exceptions to this, with some attempting to include measures related to the quality of service (for instance, Saal and Parker, 2000). Although in the present context data relating to both labour and fixed capital were available for both states, the input measure has been intentionally restricted to a single variable: Total Operating Cost. It was important to place a relatively heavy weight on parsimony from an econometric perspective. This imperative stems from the tendency for DEA models to lose discriminatory power as variables are added (Cubbin and Tzanidakis, 1998).

Labour was excluded as an input for a number of reasons. First, the measure of labour in Victoria was aggregated across the water and wastewater businesses, while in NSW it was disaggregated. This disparity presented the unenviable task of determining how to disaggregate the Victorian labour data[16]. A second limitation was that the data series relating to Victorian labour measures began only in 2003. Third, consultations with representatives from the urban water sector in Victoria revealed that management decisions to vary the labour force were not closely related to the quantity of total water supplied (C. Heiner, pers. comm., 27 April, 2007). Since the quantity of water supplies is one of the outputs in the model it seemed sensible both in theory and in the pursuit of parsimony to exclude labour as an input. Furthermore, the labour variable was a measure of the *number* of full-time equivalent employees, rather than the wages bill; this measure has been excluded since variation in wages was likely to be associated with operating cost. It is acknowledged that a model of water provision exclusive of labour as an input does not follow the majority of empirical studies outlined in Chapter 4.

The decision to exclude a measure of fixed capital was also based upon a mixture of theoretical and pragmatic grounds. Turning first to theoretical considerations, a number of scholars have previously noted that the infrastructure related to the provision of water services is a sunk cost, since it is difficult to conceive putting it to an alternative use (Sheil, 2000). If this is so, it calls into question the inclusion of various measures of fixed capital in a DEA model since management are unlikely to seek to minimise this input. Furthermore, while additions to capital through time are likely, the opposite is not. A decline in total water produced is rarely followed by the decommissioning of water mains or the dismantling of pumping and treating infrastructure. Of potentially more relevance to the estimation of relative technical efficiency are current capital expenses incurred as a result of renewals activities,

[16] In an earlier iteration of the research, the same proportional splits were applied between the two businesses observed in NSW to the Victorian measure of labour.

which is captured under operating costs. A number of existing empirical studies reviewed in Chapter 4 excluded a measure of fixed capital (see, for instance, Coelli and Walding, 2005).

A second theoretical justification rests on the assumption that the adoption of technological advances is relatively slow; since the time period being analysed is only four years, it is not reasonable to expect a utility to move toward an 'optimal' capital stock. In other words, the capital stock is assumed fixed in the short term. This approach follows that of both Garcia and Thomas (2001) and Bhuttaycha et al. (1994).

Justification on pragmatic grounds relates to the historically poor measurement of the value of infrastructure in NSW local government[17]. This particular problem was made painfully clear by an independent inquiry into the financial sustainability of NSW local government, the so-called Allen report (2006). The final report of this inquiry catalogued the systematic under-reporting of assets values and infrastructure condition over the past two decades. As testament to the seriousness with which the NSW Government has viewed this particular problem, the NSW Department for Local Government recently began the task of implementing a policy aimed at ensuring councils record infrastructure at fair value in their accounts (Department of Local Government, 2006). Considering the widespread lack of confidence in fixed infrastructure values, it was prudent to exclude this variable rather than attempt to adjust for the errors in the results. As an aside, this problem is not confined to regional utilities in NSW. Coelli and Walding (2005) argued somewhat caustically

[17] For a review of the problem in Australian local government data of this kind see Dollery et al. (2007).

that the major finding of their study was that data quality relating to the capital stock in the Australian water sector seriously hampered meaningful analysis.

An alternative to monetary measures of the capital stock was a physical indicator such as the kilometres of mains managed by the utility. Although this gave an indication of utility size, since it gave no indication of the relative quality of the main, it promised to be at best an inadequate measure and at worst a misleading indicator. Again, this variable had been utilised in earlier iterations of this research. However, industry practitioners suggested that variation in total potable water supplied was unlikely to be well correlated with a variable measuring the length of mains (C. Heiner, pers. comm., 27 April, 2007). For instance, a utility may well distribute a large volume of water to densely settled populations. Furthermore, the Victorian measure of length of mains was recorded only from 2003 onwards.

With respect to separate measures of energy and materials consumption, while the NSW data disaggregate operating costs into various classes, including administration, energy and materials, the Victorian data do not. Consequently, it was not possible to include separate input variables for materials and energy. This aspect is likely to limit the extent to which conclusions can be drawn regarding the relative efficiency of individual water authorities. For example, it would have been useful to observe the change in energy consumption by those LWUs or RUWAs that rely on groundwater as a source of raw water in order to investigate whether pumping costs had increased during the period of analysis, and the relative impact of this on technical efficiency.

After consideration of the limitations in the data outlined above, one input was selected in the form of Total Operating Costs. The definition of this variable for each state is given in Table 6.2. In summary, this variable included expenses related to the current operation of the water business, such as maintenance of the network, treatment, wages and salaries, administration and energy consumption. It is explicitly acknowledged that Total Operating Cost serves as a somewhat crude 'catch-all' measure of the variable inputs required to operate the water business. However, given the limitations of other variables outlined above, it appears to be the best of the available alternatives.

In order to aid comparison between years, and utilities in each state, the variable was inflated to reflect 2004 nominal values, by applying the headline consumer price index for Melbourne. The use of this less than ideal inflation factor was made necessary by data relating to Victorian water utilities being inflated prior to publication, whereas data for NSW utilities were published in nominal terms. The inflation factors are reported in Table 6.1.

Table 6.1: Annual inflation adjustment factor

| Year | 2001 | 2002 | 2003 | 2004 |
|---|---|---|---|---|
| Cumulative inflation factor | 1.085 | 1.056 | 1.022 | 1 |

Source: VicWater (2005:A2)

### 6.3.2 Potential outputs

In an earlier iteration of this research, output was restricted to total potable water supply. However, industry representatives (C. Heiner, pers. comm., 27 April, 2007; D. McGregor, pers. comm., 6 May, 2007) suggested that this reflected a rather narrow view of a water utility's operations. Although management were interested in the total quantity of water supplied, of arguably more importance was the reliable delivery of safe drinking water. In response, a second output was included, designed to capture quality and reliability dimensions. Furthermore, it was established in Chapter 4 that a number of authors made adjustments in order to allow for variance in both output and the quality of the output.

The constituent parts that form Total Potable Water Supplied were similar across both states, with the exception that RUWAs included environmental flows, whereas LWUs did not. However, only three of the 14 RUWAs recorded environmental flows during the period, and they accounted for a very small portion of the total.

A number of variables were available from which to construct a measure of water quality and reliable service. Industry practitioners (C. Heiner, pers. comm., 27 April, 2007) suggested the use of variables relating to the number of unplanned interruptions to supply and the average time taken to rectify supply. However, due to relatively poor reporting of this variable in NSW, following this advice would have resulted in the exclusion of a relatively large proportion of the LWUs, due to inadequate reporting on these variables alone.

An alternative measure of output quality was the number of customer complaints made per 1,000 connections. This was disaggregated between complaints relating to the quality of the water supplied (such as discolouration or odour) and the water supply service (related to reliability). While the two variables would appear to be reasonable general indicators of quality and reliability, they were not ideal for a number of reasons. First, in NSW the logging of complaints was not subject to audit or specific guidelines as to what constitutes a complaint (D. McGregor, pers. comm., 6 May, 2007). For example, a larger utility in NSW may record every phone call relating to the water supply as a complaint, while smaller utilities might not record this as a complaint until it has been passed onto the water engineer.

Furthermore, the relatively heavy weight placed on customer satisfaction by RUWAs' customer charters is likely to result in more stringent recording of complaints. Also of concern is the inherently immeasurable tendency for some communities to make complaints more readily than others. In other words, the fact that one utility has recorded fewer complaints relative to another may simply reflect a lower marginal propensity to complain by this customer base, rather than being an indication of higher quality water and/or service. The above limitations notwithstanding, the almost universal reporting of this variable both in NSW and Victoria made it a far more appealing, although decidedly flawed, measure of the extent to which a utility provides water of sufficient quality and with adequate reliability.

A further limitation in the deployment of this measure was the necessity to transform the variable in order for it to be included in the model. More specifically, given that the variable was to enter the model as an output, it was necessary to modify the data such that maximising the vector was akin to minimising *actual* complaints. One option was to simply invert the sum of complaints; however, this was likely to introduce unwarranted scale effects, due to the exponential growth in the variable that would result from taking the reciprocal. An alternative approach was taken by Zhu (2003: 106-7) and is detailed here.

Suppose it is desirable for an output to be minimised rather than maximised. The following procedure transforms the variable such that it can be included as a vector to be maximised. Increasing the desirable output $y^g_{rj}$ and minimising the undesirable output $y^b_{rj}$ proceeds as follows. The undesirable output is multiplied by '$-1$', then a proper value $v^r$ is found in order to let all negative undesirable outputs be positive. That is, $\bar{y}^b{}_{rj} = -y^b_{rj} + v_r > 0$. This is achieved by allowing $v_r = \max_j \{y^b_{rj}\} + 1$.

As a result of the preceding considerations, a model of the water business was arrived at in which the utility sought to minimise Total Operating Cost given the observed values for the production of two outputs: (1) Total Potable Water Supplied and (2) Complaints per 1,000 connections. The variables and associated definitions are detailed in Table 6.2.

Table 6.2: Water input and output variable definitions and sources

| Variable | NSW Definition | Vic Definition |
|---|---|---|
| Total Potable Water Supplied | The aggregate of residential, commercial, industrial, rural, institutional, bulk sales, public parks and water losses. Water losses was defined as the sum of apparent losses (unbilled unmetered, unauthorised consumption and under-registration of customer meters) real losses (leakage). | The sum of residential, commercial and industrial consumption, bulk water sales, environmental flows. and other consumption. |
| Water Service and Quality Complaints (Complaints Index) | Water quality and service complaints (any expression of customer dissatisfaction with the service provided and each complaint reported to an LWU employee, whether in person, by telephone, fax, email or letter). | Water quality complaints: Any complaint regarding discolouration, taste, odour, turbidity, "white" water, stained washing, illness etc.<br>Reliability complaints: Complaints relating to water service interruption, service adequacy, water restrictions, pressure etc. |
| Total Operating Cost | Total operation, maintenance and administration costs. | Operating costs should include water resource access charge or resource rent tax, purchase of raw or treated water, charges for bulk treatment, salaries and wages, overheads on salaries and wages, materials/chemical/energy, contracts, accommodation and all other operating costs that would normally be reported. |

Source: Department of Energy, Utilities and Sustainability (2005) and VicWater (2005).

## 6.4 Descriptive statistics of water inputs and outputs

In order to gain an appreciation of the nuances and scope of these data, descriptive statistics were assembled and reviewed. A précis of the findings is provided here. Descriptive statistics relating to each input and output for each of the four years are presented in Table 6.3.

Table 6.3: Descriptive statistics: water input and outputs

| Year | Input/ Output | Variable | Description | Mean | Median | Standard Deviation | Kurtosis | Skewness | Minimum | Maximum |
|---|---|---|---|---|---|---|---|---|---|---|
| 2001 | Input | $x_1$ | Total Operating Cost | 2,807,560 | 1,168,486 | 3,701,298 | 4.45 | 2.10 | 27,071 | 17,476,632 |
| | Output | $y_1$ | Complaints Index | 128 | 138 | 28 | 8.06 | −2.58 | 1 | 153 |
| | | $y_2$ | Total Potable Water | 5,536 | 2,340 | 9,070 | 20.24 | 3.85 | 30 | 64,412 |
| 2002 | Input | $x_1$ | Total Operating Cost | 2,945,821 | 1,118,130 | 3,868,044 | 3.62 | 1.97 | 32,284 | 17,784,021 |
| | Output | $y_1$ | Complaints Index | 89 | 96 | 24 | 1.81 | −1.41 | 1 | 114 |
| | | $y_2$ | Total Potable Water | 5,865 | 2,420 | 11,038 | 34.23 | 5.13 | 30 | 87,561 |
| 2003 | Input | $x_1$ | Total Operating Cost | 3,255,669 | 1,440,939 | 4,333,530 | 3.91 | 2.04 | 40,611 | 20,275,458 |
| | Output | $y_1$ | Complaints Index | 122 | 128 | 22 | 9.16 | −2.36 | 1 | 143 |
| | | $y_2$ | Total Potable Water | 5,838 | 2,540 | 10,862 | 35.37 | 5.17 | 30 | 87,111 |
| 2004 | Input | $x_1$ | Total Operating Cost | 3,341,285 | 1,259,742 | 4,490,364 | 3.74 | 2.01 | 42,640 | 20,936,520 |
| | Output | $y_1$ | Complaints Index | 96 | 104 | 23 | 3.43 | −1.73 | 1 | 117 |
| | | $y_2$ | Total Potable Water | 5,484 | 2,240 | 10,391 | 38.35 | 5.42 | 30 | 84,785 |
| Number of utilities: | 90 | of which: | Small = 26<br>Medium = 12<br>Large = 21<br>Very Large = 31 | | | | | | | |

A number of interesting patterns emerged from these data. First, despite the fact that Total Operating Cost has been inflated to reflect 2004 nominal cost, mean operating expense increased each year. This suggests that either the inflation factor was far from adequate or there were real increases in operating expense. Second, the quite large standard deviation of Total Operating Cost indicates relatively large variation within this variable, which reflects the underlying diversity in the sector. It is also evident that the distribution of this variable is not normal, indicated by the skewness and kurtosis coefficients. In this light, a median of the distribution is reported, which, when compared with the mean, suggests that the larger utilities dominate the distribution. Saal and Parker (2001) also encountered estimating difficulties as a result of bias due to large utilities in the sample. Steps are taken in later sections to guard against similar complications. Since DEA does not require implicit normality assumptions, this feature of the data further supports the choice of DEA over a parametric model.

Third, while Total Operating Costs on average grew through the period, Total Potable Water Supplied grew sharply in 2002 but on average declined thereafter. Eventually it fell below 2001 levels in 2004, regardless of whether this was measured in terms of the mean or the median. This had interesting implications for the average operating costs in the sector, which grew from approximately \$507 per megalitre of water supplied in 2001 to \$609 in 2004.

Fourth, average complaints rose substantially in 2002 (indicated by a fall in the mean of the complaints index), then fell in 2003 before rising again in 2004. This may have been related to the impact of the drought; however, the drought was more prevalent in 2003 than in either 2002 or 2004. Perhaps this points to a lag effect, meaning that the impact of shifting soils on water mains and the like are reflected in poor service reliability or poor water quality only after a prolonged dry period.

More prosaically, since the data transformation process outlined in Section 6.3.1 is susceptible to outliers, the observed variation may have been partly a result of the data modification. This follows from the utility with the largest sum of complaints setting the base line for the adjustment of the data. As a result, even though there may have been a reduction in mean *observed* complaints, the existence of one particular outlier tended to ratchet the average of the adjusted variable toward the outlier. While the *rank* of utilities remained unchanged, the power of absolute differences tended to be muted. It seems plausible that this variable was moving between the years as a result of this technical quirk, rather than any underlying cause of economic consequence. Finally, demand reduction measures appear to have been successful during 2004, where a six per cent decline in average Total Potable Water consumed was observed when compared with the previous year.

### 6.4.1 Descriptive statistics by state

In an effort to determine whether there were any notable differences between water utilities in NSW and Victoria, the dataset was split into NSW and Victorian partitions. Descriptive statistics were generated pertaining to each and the results are reported in tables 6.4 and 6.5, respectively.

Table 6.4: Descriptive statistics: water input and outputs – NSW utilities

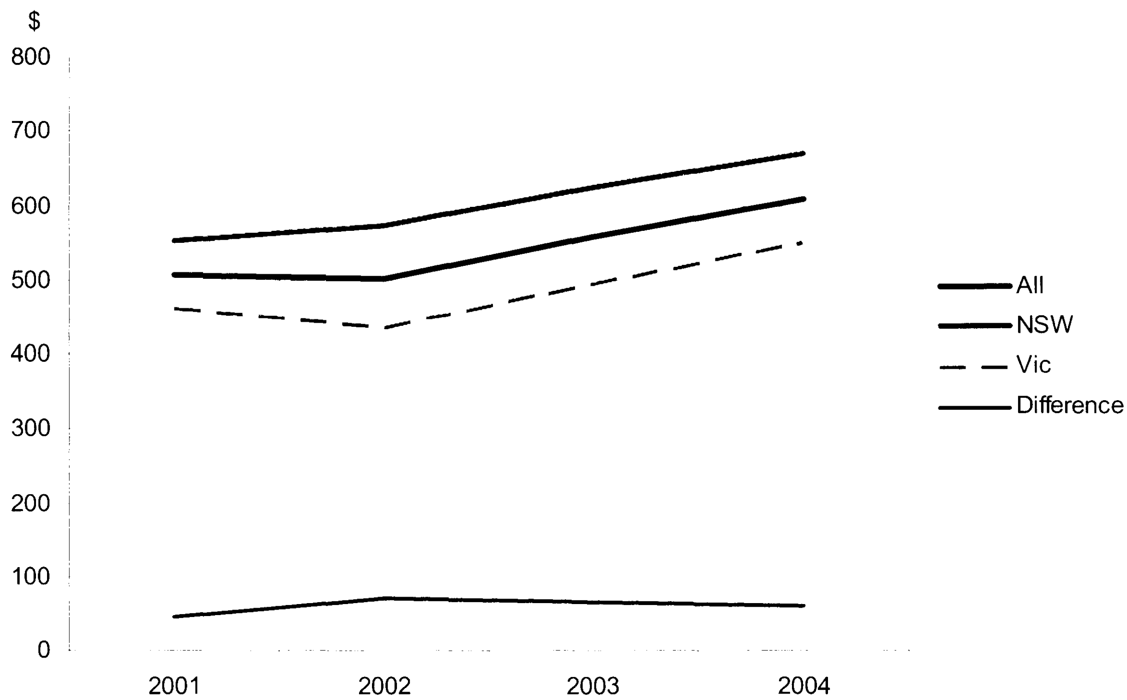
| Year | Input/Output | Variable | Description | Mean | Median | Standard Deviation | Kurtosis | Skewness | Minimum | Maximum |
|---|---|---|---|---|---|---|---|---|---|---|
| 2001 | Input | $x_1$ | Total Operating Cost | 1,822,846 | 844,688 | 2,284,447 | 7.52 | 2.43 | 27,071 | 12,692,401 |
| | Outputs | $y_1$ | Complaints Index | 125 | 135 | 30 | 6.79 | –2.39 | 1 | 153 |
| | | $y_2$ | Total Potable Water | 3,293 | 1,585 | 4,106 | 3.42 | 1.90 | 30 | 18,200 |
| 2002 | Input | $x_1$ | Total Operating Cost | 1,937,745 | 846,414 | 2,479,167 | 6.00 | 2.31 | 32,284 | 12,719,700 |
| | Outputs | $y_1$ | Complaints Index | 88 | 96 | 25 | 1.75 | –1.41 | 1 | 114 |
| | | $y_2$ | Total Potable Water | 3,384 | 1,710 | 4,191 | 3.06 | 1.85 | 30 | 18,300 |
| 2003 | Input | $x_1$ | Total Operating Cost | 2,092,021 | 984,369 | 2,628,615 | 5.88 | 2.26 | 40,611 | 13,598,716 |
| | Output | $y_1$ | Complaints Index | 122 | 127 | 23 | 9.55 | –2.47 | 1 | 143 |
| | | $y_2$ | Total Potable Water | 3,354 | 1,755 | 4,224 | 3.67 | 1.97 | 30 | 18,300 |
| 2004 | Input | $x_1$ | Total Operating Cost | 2,137,453 | 946,461 | 2,750,674 | 6.48 | 2.34 | 42,640 | 14,681,627 |
| | Output | $y_1$ | Complaints Index | 94 | 102 | 24 | 2.98 | –1.64 | 1 | 117 |
| | | $y_2$ | Total Potable Water | 3,188 | 1,745 | 4,050 | 3.25 | 1.92 | 30 | 16,900 |
| Number of utilities: | 76 | of which: | Small = 26<br>Medium = 12<br>Large = 19<br>Very Large = 19 | | | | | | | |

Table 6.5: Descriptive statistics: water input and outputs – Victorian utilities

| Year | Input/Output | Variable | Description | Mean | Median | Standard Deviation | Kurtosis | Skewness | Minimum | Maximum |
|---|---|---|---|---|---|---|---|---|---|---|
| 2001 | Input | $x_1$ | Total Operating Cost | 8,153,149 | 8,510,493 | 5,219,149 | –0.64 | 0.36 | 1,308,535 | 17,476,632 |
| | Outputs | $y_1$ | Complaints Index | 145 | 145 | 6 | –0.20 | –0.63 | 132 | 153 |
| | | $y_2$ | Total Potable Water | 17,715 | 14,579 | 16,637 | 4.17 | 1.81 | 2,240 | 64,412 |
| 2002 | Input | $x_1$ | Total Operating Cost | 8,418,238 | 8,741,253 | 5,364,636 | –0.87 | 0.24 | 1,001,875 | 17,784,021 |
| | Outputs | $y_1$ | Complaints Index | 96 | 107 | 20 | 0.50 | –1.18 | 49 | 113 |
| | | $y_2$ | Total Potable Water | 19,331 | 12,798 | 22,394 | 6.92 | 2.43 | 2,014 | 87,561 |
| 2003 | Input | $x_1$ | Total Operating Cost | 9,572,617 | 9,824,997 | 6,149,353 | –1.05 | 0.20 | 1,310,868 | 20,275,458 |
| | Output | $y_1$ | Complaints Index | 127 | 139 | 18 | –0.99 | –0.85 | 91 | 142 |
| | | $y_2$ | Total Potable Water | 19,325 | 14,831 | 21,743 | 7.90 | 2.56 | 2,166 | 87,111 |
| 2004 | Input | $x_1$ | Total Operating Cost | 9,876,374 | 10,413,690 | 6,318,658 | –1.08 | 0.15 | 1,251,540 | 20,936,520 |
| | Output | $y_1$ | Complaints Index | 106 | 114 | 14 | 1.77 | –1.59 | 71 | 116 |
| | | $y_2$ | Total Potable Water | 17,946 | 11,224 | 21,131 | 8.55 | 2.71 | 2,104 | 84,785 |
| Number of utilities: | 14 | of which: | Small = 0<br>Medium = 0<br>Large = 2<br>Very Large = 12 | | | | | | | |

As one might expect, the general pattern observed in Table 6.3 carried through to the analysis of the states in isolation. That is, Total Operating Cost increased while Total Potable Water decreased, and the Complaints Index followed much the same pattern as that outlined in Table 6.3. However, when expressed in terms of operating cost per megalitre of water, it becomes apparent that Victorian utilities were at a considerable advantage. To illustrate this advantage, the average total operating cost per megalitre of water produced over the period is charted in Figure 6.1.

Figure 6.1: Average total operating cost per megalitre of water produced: 2001–2004




Although utilities in both states faced generally increasing average costs, a reasonably consistent differential of between $46 and $70 per megalitre in favour of Victorian utilities is evident. This is an interesting feature of the data as it would suggest that Victorian utilities are *prima facie* likely to be relatively more efficient than their NSW counterparts.

### 6.4.2 Descriptive statistics – large utilities only

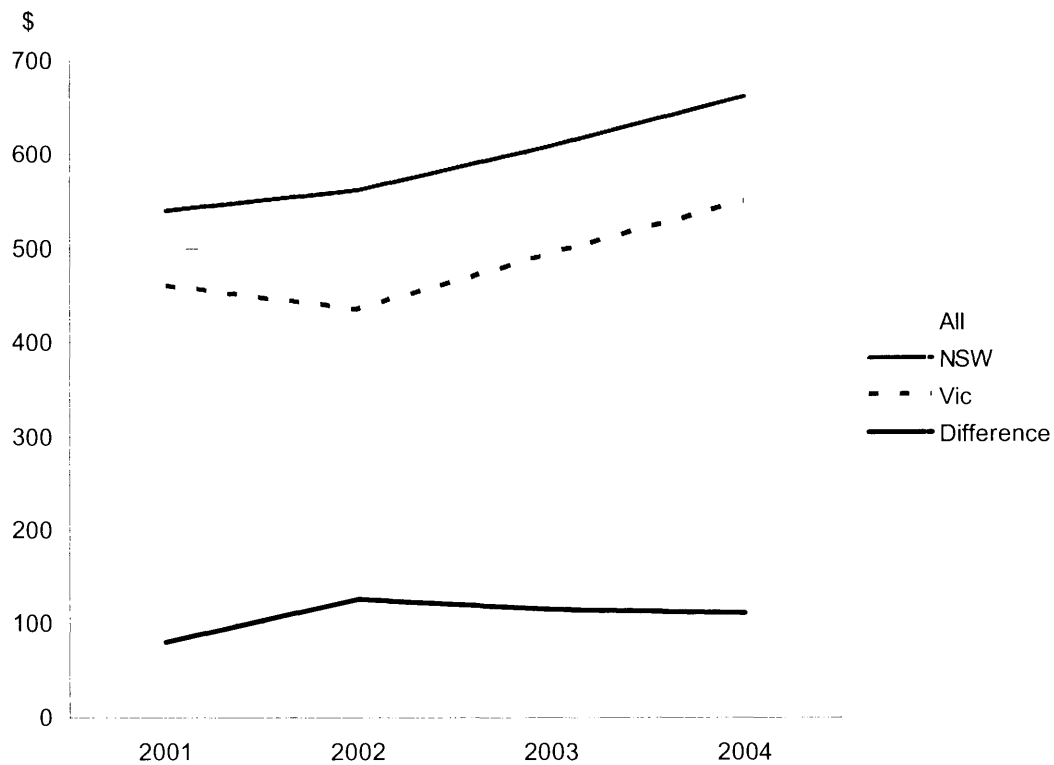
In an effort to determine whether the presence of smaller utilities in NSW was skewing the average cost of producing a megalitre of water, the dataset was truncated such that it included only those utilities, from both states, that serviced in excess of 3,000 connections. The descriptive statistics for this sample are contained in Table 6.6.

Table 6.6: Descriptive statistics: water input and outputs – all large utilities

| Year | Input/Output | Variable | Description | Mean | Median | Standard Deviation | Kurtosis | Skewness | Minimum | Maximum |
|---|---|---|---|---|---|---|---|---|---|---|
| 2001 | Input | $x_1$ | Total Operating Cost | 4,561,622 | 3,154,063 | 4,052,699 | 2.10 | 1.57 | 702,461 | 17,476,632 |
| | Outputs | $y_1$ | Complaints Index | 131 | 138 | 26 | 10.79 | –2.85 | 1 | 153 |
| | | $y_2$ | Total Potable Water | 9,147 | 5,610 | 10,582 | 14.26 | 3.28 | 1,410 | 64,412 |
| 2002 | Input | $x_1$ | Total Operating Cost | 4,789,358 | 3,279,270 | 4,224,969 | 1.38 | 1.41 | 791,488 | 17,784,021 |
| | Outputs | $y_1$ | Complaints Index | 89 | 96 | 24 | 1.16 | –1.35 | 14 | 113 |
| | | $y_2$ | Total Potable Water | 9,699 | 5,210 | 13,304 | 23.30 | 4.32 | 1,470 | 87,561 |
| 2003 | Input | $x_1$ | Total Operating Cost | 5,288,760 | 3,514,837 | 4,765,318 | 1.54 | 1.47 | 896,124 | 20,275,458 |
| | Output | $y_1$ | Complaints Index | 121 | 125 | 19 | –0.45 | –0.72 | 73 | 142 |
| | | $y_2$ | Total Potable Water | 9,650 | 5,347 | 13,062 | 24.43 | 4.39 | 1,730 | 87,111 |
| 2004 | Input | $x_1$ | Total Operating Cost | 5,455,686 | 4,044,671 | 4,932,479 | 1.39 | 1.44 | 904,166 | 20,936,520 |
| | Output | $y_1$ | Complaints Index | 96 | 104 | 22 | 1.91 | –1.45 | 22 | 116 |
| | | $y_2$ | Total Potable Water | 9,062 | 5,060 | 12,545 | 26.38 | 4.59 | 1,700 | 84,785 |
| Number of utilities: | 52 | of which: | Small = 0<br>Medium = 0<br>Large = 21<br>Very Large = 31 | | | | | | | |

The now familiar pattern of increasing operating costs, decreasing potable water supplied, and fluctuating complaints was evident in this sample. This sequence suggests the pooling of data to include both very large and very small utilities had, on the face of it, not substantially distorted the data. Figure 6.2 plots the average cost of producing a megalitre of water for this subset of utilities through the period, and shows that the same division between the states exists when only the larger utilities are included. However, in this instance the difference between Victorian and NSW utilities covers the range $80–$125 per megalitre.

Figure 6.2: Average cost of producing a megalitre of water (large utilities): 2001–2004



## 6.5 Synopsis of descriptive statistics relating to inputs and outputs

A number of useful themes emerge from the analysis of the data. First, the distributions of the three data series are far from normal, being in the most part relatively widely dispersed, as indicated by the triumvirate of large standard deviations, relatively divergent means and medians, and generally negative kurtosis scores. Furthermore, the distributions are generally skewed, and mostly toward the larger utilities. This is all to be expected, given the diverse characteristics of individual utilities in Victoria and NSW, although this is no doubt more pronounced in the case of NSW. Second, real costs for both sectors (water and wastewater) of the industry appear to have increased during the period, in terms of both total and average costs. Third, Victorian utilities appear to have a distinct cost advantage over those in NSW, and this is evident in both the pooled and truncated datasets.

Given this, should analysis of a pooled dataset be abandoned? There are two arguments against this desertion. First, the primary motivation for analysing relative efficiency in water and wastewater provision in regional NSW and Victoria was to investigate the effect of the differing governance structures that exist in each state with respect to relative technical efficiency. If each state were to be analysed in isolation, this would serve to constrain the focus of the research and largely compromise the usefulness of any findings. A second, and related, argument involves the inherent advantage of the analytical technique to be employed. DEA does not require assumptions to be made regarding the distribution of data or the characteristics of error terms. Thus, the particular features of this dataset were less likely to limit the extent to which conclusions could be drawn from the results, as would be the case if a parametric approach such as SFA had been chosen.

Notwithstanding the abovementioned caveats, there does appear to be a size-related differential worthy of investigation. To this end, an analysis was conducted over two datasets for each function. The first included all utilities, while the second was truncated to include only those utilities that service over 3,000 properties.

In terms of the differences between the states, Victorian utilities, when taken as a group, appear to be relatively more technically efficient, at least in terms of operating cost per megalitre of water produced and wastewater treated. However, this was not the only output in the model. A further advantage of DEA is that it allows an analysis of cost minimisation given multiple outputs. It may well be that utilities in NSW are decidedly more efficient at minimising costs when producing both outputs, a possibility not entertained in the preceding analysis.

## 6.6 Explaining differences in the technical and scale efficiency of water utilities

As outlined in Section 3.6.1 of Chapter 3, there are essentially two alternative approaches to incorporating extraneous information into a DEA analysis. The first method is to include information as quasi inputs or outputs to be maximised or minimised in the DEA equation. Section 3.6.1 outlined the limitations this path imposed, including the considerable disadvantage of making *a priori* assertions regarding the directional influence of the variable to be included.

The second technique is sometimes referred to as a 'two-stage' DEA analysis, since it is an investigation of DEA relative efficiency scores via a separate regression-based procedure. The main advantage of this approach has already been alluded to in this chapter: the ability to incorporate multiple variables without loss of explanatory power. Other advantages relate to the use of traditional statistical tests and the allowance for inclusion of variables without the necessity for assumptions regarding the direction of influence to be formed.

This analysis employed the second approach through the specification of a Tobit regression model in which the DEA scores generated from the evaluation of equations 5.1 and 5.2 were regressed against a set of explanatory variables. These are described in detail in sections 6.5 and 6.6. There were two main reasons for adopting this method. First, both the empirical literature and discussions with industry practitioners led to the proposition that a relatively large number of variables may determine relative efficiency. Second, it was particularly important to determine whether a statistically significant relationship exists and, if so, whether that relationship is negatively or positively associated.

## 6.7 Specification of the explanatory variables

The following sections begin by outlining the explanatory variables included in the second stage analysis. A set of descriptive statistics were also generated to chronicle the essential features of the data. Explanatory variables were grouped into four main categories. The first contained variables to allow for returns to scale, scope and density in the water sector. The second included variables that measure differentials in treatment and pumping expenses. The third category of variables captured effects related to the climate, such as temperature and rainfall. Finally, variables were included to measure institutional differences and changes in relative efficiency through time.

Table 6.7 reports the particulars of the suite of variables for potential inclusion in the Tobit model. As with the input and output data, information relating to NSW utilities was sourced from the DEUS (2005a), while that for Victorian utilities was supplied by VicWater (2005). The exception to this was the climate data, which were supplied by the Bureau of Meteorology on request by the author.

Table 6.7: Explanatory variables – water provision

| **Variable** | **Code** | **Definition** | ***a priori* expectation** |
|---|---|---|---|
| | | *Scope, scale and density* | |
| Residential consumption | $z_2$ | Proportion of Total Potable Water consumed by residential consumers | – |
| Water Losses | $z_3$ | Percentage of Total Potable Water attributed to 'Water Losses' | + |
| Production Density | $z_4$ | Total Potable Water (KL)/number of connections | + |
| Change in production density | $z_5$ | Percentage change in per connection consumption from previous period | ~ |
| Customer density | $z_6$ | Number of properties per km of water main | ~ |
| Small utility | n/a | Utility had < 1,501 connections | n/a |
| Medium utility | $z_7$ | Utility had between 1,501 and 3,000 connections | – |
| Large utility | $z_8$ | Utility had between 3,001 and 10,000 connections | – |
| Very large utility | $z_9$ | Utility had > 10,000 connections | – |

Table 6.7 (continued)

| Variable | Code | Definition | *a priori* expectation |
|---|---|---|---|
| | | *Treatment, pumping and infrastructure expenses* | |
| Groundwater | $z_{10}$ | > 50 per cent of water sourced from groundwater | + |
| Reticulator | $z_{11}$ | Primary function of utility was to reticulate treated water supplied from bulk supplier | + |
| Unfiltered supply | $z_{12}$ | > 50 per cent of water supplied was not subject to filtration process | + |
| Dams | $z_{13}$ | Utility was responsible for maintenance of at least one bulk water storage (typically a dam) | – |
| | | *Climate* | |
| Temperature | $z_{14}$ | Average of mean monthly maximum temperature during November to March (inclusive) | + |
| Rain days | $z_{15}$ | Total number of days where rainfall was recorded between November and March (inclusive) | – |
| Rainfall | $z_{16}$ | Total rainfall recorded between November and March (inclusive) | – |
| Rainfall intensity | $z_{17}$ | Aggregate rainfall (mms) during November to March (inclusive)/ aggregate number of days with rain during November to March | – |
| | | *Institutional* | |
| RUWA | $z_{18}$ | Utility was a Regional Urban Water Authority, located in Vic. | ~ |
| | | *Period* | |
| 2002 | $z_{19}$ | Year specific dummy variable: 2002 | – |
| 2003 | $z_{20}$ | Year specific dummy variable: 2003 | – |
| 2004 | $z_{21}$ | Year specific dummy variable: 2004 | – |

### 6.7.1 Returns to scale, economies of scope and economies of density

Although scale economies should be captured by the use of a variable returns to scale specification of the DEA model (eq. 5.1), this set of variables ( $z_{7.}z_8$ and $z_9$ ) could capture scale effects that were not fully accounted for by that model. In the DEA model, scale was in effect measured by the quantity of water supplied, rather than a spatial indicator such as the kilometres of water mains or size of service area. Furthermore, matters related to increased regulatory burden placed on larger utilities could be detected. Regulators may consider that larger utilities are better able to absorb the costs of regulation and/or they should act as a role model of sorts for smaller utilities. Of course, when the DEA model was specified under the constant returns to scale assumption, the dummy variables were likely to play a very important role. Given these conditions, a generally negative trend was expected.

As noted in Chapter 4, Garcia and Thomas (2001) investigated the potential for returns from water networks upon variable cost in a panel of French water utilities. They distinguished between economies of scope, scale, customer density and production density. Although the variable returns to scale specification of the DEA model employed in this study should account for relatively lower operating costs arising from increasing returns to scale, the potential for returns to scope and density had not been controlled. As a result it was important that a number of variables were included in the second stage analysis in order to account for those potential effects.

Control for a specific form of scope economies was attempted through the inclusion of the Water Losses ( $z_3$ ) variable. Garcia and Thomas (2001) found economies of scope in the production of so-called desired and non-desired water. That is, water utilities found it advantageous to tolerate a level of water loss in the distribution network because the additional costs associated with pumping and treatment were relatively less than the cost of repairs, primarily labour and material expenses. This relied crucially upon the fact that French water utilities did not purchase raw water.

The aim of including a variable that measures the quantity of water consumed per connection was to control for economies of production density ( $z_4$ ). Garcia and

Thomas (2001: 13) defined this as a decline in average variable costs as the demand per customer increases, having held constant network size and the number of customers. There was a wide degree of variability in potable water consumption per connection among the utilities in the dataset. Interestingly, of the five utilities that, on average, had a per connection consumption in excess of 1,000kl/year, three were from irrigation districts and a fourth was located adjacent to an irrigation district.

Garcia and Thomas (2001:13) also suggested that water supply networks may display economies of customer density. This is defined as a decline in average variable costs as the number of *customers* increases (as opposed to the quantity of water consumed increasing), while leaving both network size and demand per customer (or in other words, production density) constant. Control was attempted through the use of a variable that measures the number of connections per kilometre of water main ( $z_6$ ).

The findings of Garcia and Thomas (2001) guided the *a priori* expectations of each parameter. The authors found evidence of scope economies, but constant returns to both production and customer density. However, other studies investigating network effects found strong evidence for returns to network density. For instance, Mizutani and Urakami (2001) summarised the findings of 15 papers, including their own, and reported that only two found evidence of decreasing returns to density. Furthermore, Aubert and Reynaud (2005) found evidence of returns to production density of statistical and economic significance.

The above considerations led to the following *a priori* expectations. There was a tentative expectation of finding a positive association between relative technical efficiency and Water Losses ( $z_3$ ). Likewise, considering the literature, a positive coefficient for Production Density ( $z_4$ ) was cautiously expected. Since the existence of returns to customer density ( $z_6$ ) is not well studied, no *a priori* expectations were held for the sign of the coefficient.

It is important to note a number of caveats regarding the quality of the underlying data used to construct the abovementioned variables. First, data pertaining to the kilometres of water mains were available in Victoria only from 2003 onwards. Accordingly it was assumed that network size did not decline between 2001 and 2004 and therefore the values available for 2003 acted as substitutes for the missing data relating to 2001 and 2002.

A more general concern relates to the confidence surrounding the accuracy of this measure. While utilities regularly inspect the condition of sewerage networks to guard against spills and the like, relatively less attention is given to water mains. This stems from the fact that potable water leakage typically does not pose a public health threat. The result of this is that water utilities cannot claim to know the length of their water networks with a high degree of precision, particularly where a network is relatively old.

The number of connections to the network is generally not well reported, particularly in NSW (DEUS, 2005a). This lack of data stems from utilities being more interested in the number of assessments (essentially a measure of the number of customers billed) since this drives revenue. Finally, the proportion of water 'lost' was found to be generally under-reported in NSW (DEUS, 2005a). As a result a default value of 10 per cent of total potable water supplied was imposed by the data collecting agency for a number of utilities.

In Chapter 4 it was shown that industrial potable water consumption had been included as an exogenous variable in numerous studies. Consequently, a variable was included to record the proportion of Total Potable Water consumed by residential consumers ( $z_2$ ), for at least two reasons. First, a utility providing a majority of its total potable water to non-residential customers seems likely to produce a higher quantity of water in total, relative to a utility of comparable size. Whether this results in an increase in relative technical efficiency is a matter for empirical investigation. However, on theoretical grounds, if the slope of the average cost curve is negative over some relevant portion of output, as the literature on scale economies in water production would seem to suggest (see, for instance, Garcia and Thomas, 2001; Mizutani and Urakami, 2001), operating cost per megalitre of water consumed should also decline as output increases[18]. On a practical note, the benefits of billing and servicing one large customer versus numerous smaller customers should also be noted. Industrial consumers are typically not subject to restrictions on water use, since water restriction regulations apply only to outdoor use. Furthermore, industrial users have a more predictable pattern of use, implying less variation in utility costs related to meeting peaks in demand.

It follows that the efficiency score associated with utilities supplying relatively higher proportions of potable water to industrial customers would, *ceteris paribus*, increase. Furthermore, since proportionately less of the water is being supplied to residential customers, one might expect a relative decline in complaints, lending further support to the expectation of a higher technical efficiency score. Alternatively, non-residential consumers (the majority of which are presumably

[18] A countervailing influence may be the quality of water required by industrial customers. A food manufacturer may demand potable water of an exceptional quality, while a textile mill may not.

industrial) may require water supplied at a higher quality or pressure, via pipes of larger diameter, introducing relatively higher costs. The *a priori* expectation was therefore uncertain. However, on balance, it seemed reasonable to tentatively expect a negative coefficient. That is, a higher proportion of water consumed by residential consumers would be associated with a lower relative efficiency score.

### 6.7.2 Treatment, pumping and infrastructure expenses

As outlined in Chapter 2, urban water supply systems are complex, and are distinguished to a considerable extent by the characteristics of the area they are designed to service. For example, most systems are designed to take advantage of gravity as a means of providing cheap and failsafe transportation. However, the topography of an area can necessitate pumps to provide the energy to move water, since it is a relatively heavy and bulky commodity to transport (1,000 litres of water weighs one tonne). Even variations within the one class of topography are important. For example, a town situated in a steep valley may require relatively little pumping provided the water reservoir is located on high ground. However, if a town is distributed along either side of the valley, pumping costs may be considerable (Twort et al., 2000).

The source of the raw supply can also be significant. Surface waters can vary substantially in terms of quality and reliability, with some requiring extensive treatment and others requiring almost none. Furthermore, rainfall or streamflow reliability may necessitate the construction and maintenance of a relatively large storage, while other towns may be blessed with an extremely reliable water source.

Clearly, whether a water utility is in a location characterised by favourable external conditions is largely beyond the control of managers. Thus, the following variables were incorporated to take into account the possible influence of each variable.

When used as a source of raw water, groundwater ($z_{10}$) typically requires vertical pumping from the given aquifer, generally leading to higher energy expenses; however, a characteristic of groundwater is its relative physical and biological purity due to the natural purification that takes place as the water seeps through the soil. The only treatment usually required is for hardness and salinity (Jones and French, 1999: 131). This typically leads to relatively lower treatment expenses than those required for surface water. Furthermore, the multiple contaminants and impurities in surface water typically require a multi-step treatment process, which can substantially increase treatment expenses. Moreover, confined aquifers sometimes have the distinct advantage of flowing to the surface under natural pressure, negating considerable pumping expenses. Utilities that rely on groundwater as a source are generally able to avoid these costs. A further benefit of groundwater is that, providing the size of the aquifer and its recharge rate have been carefully estimated and consumption of the source is conservative, the resource can be considered 100 per cent reliable, unlike surface water.

On balance of these considerations, therefore, it might have been expected that this variable ($z_{10}$) would have a positive coefficient. Furthermore, some evidence in the literature points toward benefits in terms of relative technical efficiency for those utilities reliant on groundwater (see, for instance, Bjattavarcha, 1995b; Woodbury and Dollery, 2004).

Utilities are typically responsible for at least the treatment and reticulation of the potable water they supply, although a small number (all located in NSW) are responsible only for the reticulation of treated water. Generally, a positive coefficient was expected on this variable ( $z_{11}$ ), due to the avoidance of treatment expenses; however, it was equally likely that treatment costs would be partially recovered by the bulk water supplier. Furthermore, reticulation could still result in considerable operating expense due to unfavourable topography or low network density.

Certain water utilities have access to raw water supplies of such quality that filtration is not required. As filtration is a considerable contributor to treatment expenses, this variable ( $z_{12}$ ) was expected to have a positive coefficient.

Utilities that are responsible for the maintenance and operation of a dam or dams or other significant headworks infrastructure are likely to incur significantly higher operating costs than those not saddled with this burden. A dummy variable ( $z_{13}$ ) was included to account for the impact on relative efficiency; a negative coefficient was expected.

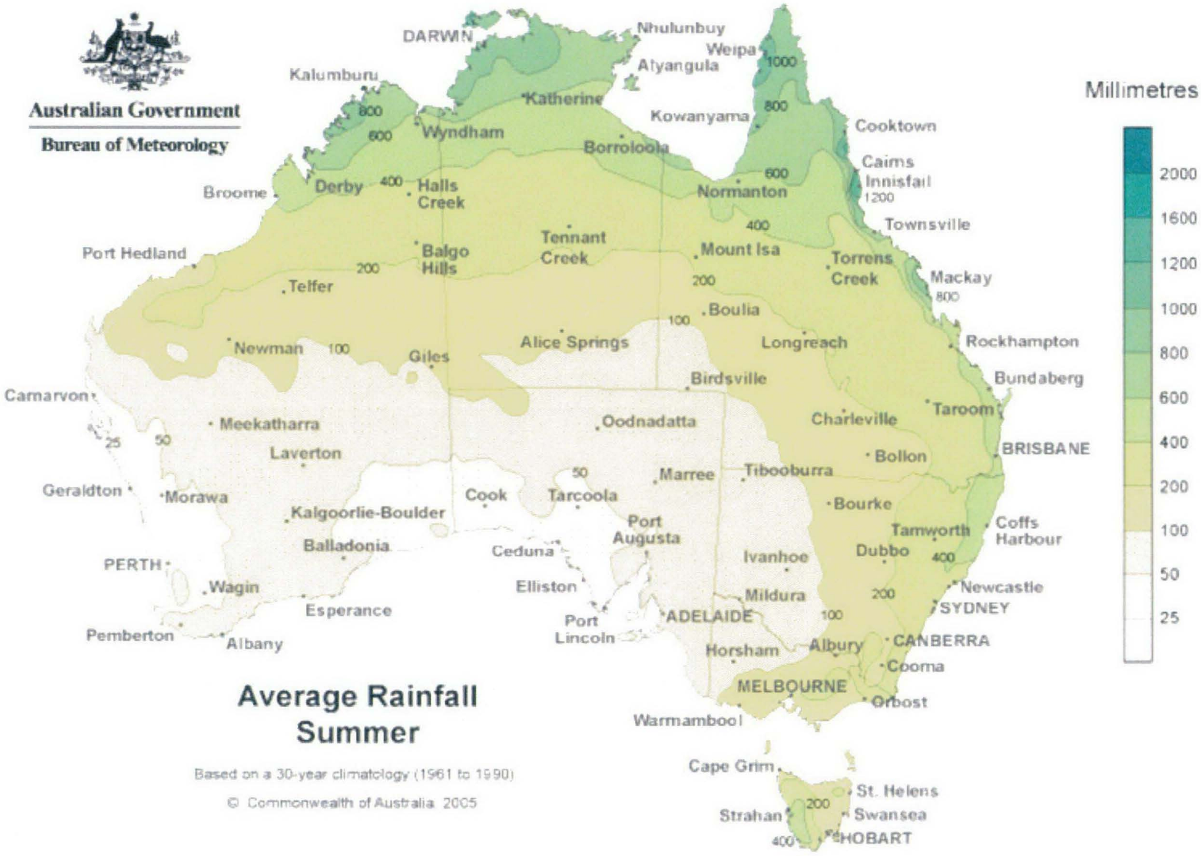
### 6.7.3 Climatic effects

The vagaries of climate impact upon the quantity of water produced more intensely during the so-called irrigation season, covering the months November through to March (C.Heiner, pers. comm., 27 April, 2007). This relates mainly to the tendency for residents to irrigate lawns and fill pools during those months, rather than in winter. The climate-related data employed in this analysis were therefore restricted to the irrigation period for each year. Two dimensions are important in this context: temperature and rainfall.

A variable was included to measure average maximum temperature ( $z_{14}$ ) so that the effect of generally drier conditions on relative efficiency was taken into account. These conditions might be expected to appear through increased per capita consumption, particularly by residential consumers, as they water lawns more often to replenish water lost through higher rates of evapotranspiration. Indeed, the majority of higher temperature districts are located west of the Great Dividing Range, an area associated with lower rainfall (Figure 6.3). However, this might not always be the case. For example, the north-eastern corner of NSW, lying in a sub-tropical temperature zone, is renowned for relatively high rainfall. Nevertheless, the average maximum temperature variable ( $z_{14}$ ) was included with the expectation of a positive coefficient.

Industry representatives also advised identifying rainfall events in which 10 mm or more of rain was recorded, since residential consumers are more likely to have adjust outdoor watering patterns after such an event. In contrast, days with falls of only around 5 mm are unlikely to have any discernable effect on outdoor watering behaviour (C. Heiner, pers. comm., 27 April, 2007; D. Mcgregor, pers. comm., 6 May, 2007). Unfortunately, data limitations prevented implementation of this strategy.

Figure 6.3: Average summer rainfall




Source: Bureau of Meteorology

In an effort to introduce some measure of rainfall intensity, ($z_{17}$), a variable to measure the average rainfall *per rainday* was included. The variable obviously provided only a crude approximation since it gave no indication of whether a combination of both heavy and light rainfall events occurred on the one day, or whether one day with extreme rainfall was followed by several days of lower rainfall. As a result, it was not immediately apparent whether a significant relationship would be found to exist between rainfall intensity ($z_{17}$) and relative technical efficiency. Given the uncertain *a priori* expectations surrounding this variable, the two constituent elements of the rainfall intensity ratio (total number of raindays ( $z_{15}$) and total rainfall during the period ( $z_{16}$)) were to be retained should the rainfall intensity variable prove insignificant.

Also included was a variable to measure the *change* in production density ( $z_5$ ) from the previous year. During the period in question, and particularly in 2003 and 2004, utilities came under increasing pressure from regulators to encourage water conservation (VicWater, 2005). This burden was particularly high in Victoria, although NSW utilities included these water conservation measures (under the guise of so-called 'drought management planning') as part of the equation to determine so-called 'best practice' (DEUS, 2005b). The emphasis on water conservation was a result of concerns surrounding dwindling water storages, despite the fact that residential consumption has typically accounted for only 11 per cent of total water consumption in Australia (NWC, 2006). Although one might arguably support this policy directive on environmental or ecological grounds, the effect on relative efficiency is likely to be negative. The extent to which this is the case may be determined by observing the change in average cost at the margin. A countervailing influence may be that residents increase complaints due to the imposition of water restrictions, or as a result of observing violation of water restrictions. Therefore, a negative sign is tentatively expected on the coefficient to measure changes in production density ( $z_5$ ).

### 6.7.4 Institutional effects

The dummy variable to identify Victorian utilities ( $z_{18}$ ) was included to measure any difference in relative technical efficiency for Victorian utilities as a group when compared with LWUs in NSW. Although analysis of the descriptive statistics relating to the inputs and outputs to be utilised in estimation of the DEA models suggested that Victorian utilities are likely to be relatively more efficient, this variable ( $z_{18}$ ) was included in order to examine this question after having controlled for the other important variables, like relative size and access to groundwater, for instance.

### 6.7.5 Other effects

Three dummy variables were included ( $z_{19}, z_{20}$ and $z_{21}$ ) for each time period to control for changes in relative technical efficiency through the four years of analysis. It should be specifically noted that the aim was not to draw conclusions regarding changes in productivity. As was outlined in Chapter 3, observing only changes in relative technical efficiency for a firm between two periods does not constitute a measure of productivity because allowance for shifts in the production frontier of the industry have not been made. Rather, the purpose of including dummy variables to represent different time periods is to ensure that changes in relative efficiency *partially* attributable to productivity change are not erroneously reflected in other variables included in the model. Given the increase in the average of cost of supplying a megalitre of potable water noted in Section 5.3.2, a generally negative coefficient was expected on each of the time related dummy variables.

## 6.8 Descriptive statistics for water explanatory variables

Table 6.8 provides descriptive statistics for the explanatory variables included to explain variation in relative technical efficiency.

Table 6.8: Descriptive statistics: water explanatory variables

| Year | Variable | Description | Mean | Median | Standard Deviation | Kurtosis | Skewness | Min. | Max. | Variable | Description | Number |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ***Continuous variables*** | | | | | | | | | ***Dummy variables*** | | |
| 2001 | $z_2$ | Residential consumption | 62.76 | 61.52 | 16.17 | 0.10 | 0.04 | 18.02 | 100.00 | n/a | Small utility | 26 |
| | $z_3$ | Water Losses | 14.21 | 10.14 | 6.09 | 2.23 | 1.55 | 6.67 | 37.92 | $z_7$ | Medium utility | 12 |
| | $z_4$ | Production Density | 499.62 | 466.04 | 215.89 | 2.32 | 1.45 | 166.67 | 1,239.47 | $z_8$ | Large utility | 21 |
| | $z_5$ | Change in prod. density | 1.77 | 2.12 | 19.72 | 3.23 | –0.54 | –69.13 | 63.90 | $z_9$ | Very large utility | 31 |
| | $z_6$ | Customer density | 26.81 | 26.44 | 10.96 | 1.36 | 0.65 | 2.73 | 66.17 | $z_{10}$ | Groundwater | 13 |
| | $z_{14}$ | Temperature | 27.99 | 28.25 | 2.86 | –0.70 | –0.33 | 20.60 | 33.76 | $z_{11}$ | Reticulator | 4 |
| | $z_{15}$ | Rain days | 45.92 | 40.50 | 15.57 | –0.59 | 0.50 | 16.00 | 81.00 | $z_{12}$ | Unfiltered supply | 15 |
| | $z_{16}$ | Rainfall | 419.53 | 336.60 | 268.67 | 1.25 | 1.28 | 63.40 | 1,364.20 | $z_{13}$ | Dams | 37 |
| | $z_{17}$ | Rainfall intensity | 8.59 | 8.12 | 3.08 | –0.42 | 0.45 | 3.16 | 16.84 | $z_{18}$ | RUWA | 14 |
| 2002 | $z_2$ | Residential consumption | 62.35 | 60.10 | 15.82 | 0.33 | –0.15 | 12.23 | 93.38 | n/a | Small utility | 27 |
| | $z_3$ | Water Losses | 14.18 | 10.30 | 6.80 | 4.74 | 1.98 | 6.49 | 45.71 | $z_7$ | Medium utility | 11 |
| | $z_4$ | Production Density | 515.53 | 457.47 | 245.24 | 3.70 | 1.66 | 157.90 | 1,548.87 | $z_8$ | Large utility | 21 |
| | $z_5$ | Change in prod. density | 2.57 | 2.65 | 13.59 | –0.06 | 0.05 | –33.26 | 33.17 | $z_9$ | Very large utility | 31 |
| | $z_6$ | Customer density | 26.63 | 25.51 | 11.11 | 1.55 | 0.73 | 2.26 | 66.98 | $z_{10}$ | Groundwater | 13 |

Table 6.8 (continued)

| Year | Variable | Description | Mean | Median | Standard Deviation | Kurtosis | Skewness | Min. | Max. | Variable | Description | Number |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ***Continuous variables*** | | | | | | | | | ***Dummy variables*** | | |
| | $z_{14}$ | Temperature | 27.01 | 27.92 | 3.23 | –0.21 | –0.63 | 18.18 | 33.60 | $z_{11}$ | Reticulator | 4 |
| | $z_{15}$ | Rain days | 42.00 | 42.00 | 16.82 | –1.02 | 0.23 | 12.00 | 76.00 | $z_{12}$ | Unfiltered supply | 14 |
| | $z_{16}$ | Rainfall | 336.20 | 315.35 | 174.90 | 0.88 | 0.88 | 42.20 | 864.20 | $z_{13}$ | Dams | 45 |
| | $z_{17}$ | Rainfall intensity | 8.03 | 8.24 | 2.63 | –0.46 | –0.05 | 2.55 | 13.76 | $z_{18}$ | RUWA | 14 |
| 2003 | $z_2$ | Residential consumption | 61.75 | 62.21 | 15.99 | 0.61 | –0.23 | 13.96 | 92.96 | n/a | Small utility | 26 |
| | $z_3$ | Water Losses | 12.52 | 10.12 | 4.72 | 6.39 | 2.29 | 4.88 | 34.48 | $z_7$ | Medium utility | 12 |
| | $z_4$ | Production Density | 513.10 | 428.71 | 267.27 | 1.72 | 1.33 | 157.90 | 1,516.29 | $z_8$ | Large utility | 21 |
| | $z_5$ | Change in prod. density | –1.47 | –1.99 | 15.92 | 0.43 | 0.35 | –34.89 | 43.24 | $z_9$ | Very large utility | 31 |
| | $z_6$ | Customer density | 26.35 | 26.15 | 10.76 | 2.19 | 0.78 | 2.32 | 68.27 | $z_{10}$ | Groundwater | 13 |
| | $z_{14}$ | Temperature | 28.68 | 29.42 | 3.24 | –0.17 | –0.56 | 19.22 | 35.56 | $z_{11}$ | Reticulator | 4 |
| | $z_{15}$ | Rain days | 35.26 | 33.00 | 16.66 | –1.09 | 0.38 | 7.00 | 66.00 | $z_{12}$ | Unfiltered supply | 14 |
| | $z_{16}$ | Rainfall | 268.76 | 228.50 | 165.25 | 0.33 | 1.02 | 58.80 | 735.80 | $z_{13}$ | Dams | 47 |
| | $z_{17}$ | Rainfall intensity | 7.65 | 7.38 | 2.78 | 1.72 | 0.95 | 2.61 | 18.63 | $z_{18}$ | RUWA | 14 |

Table 6.8 (continued)

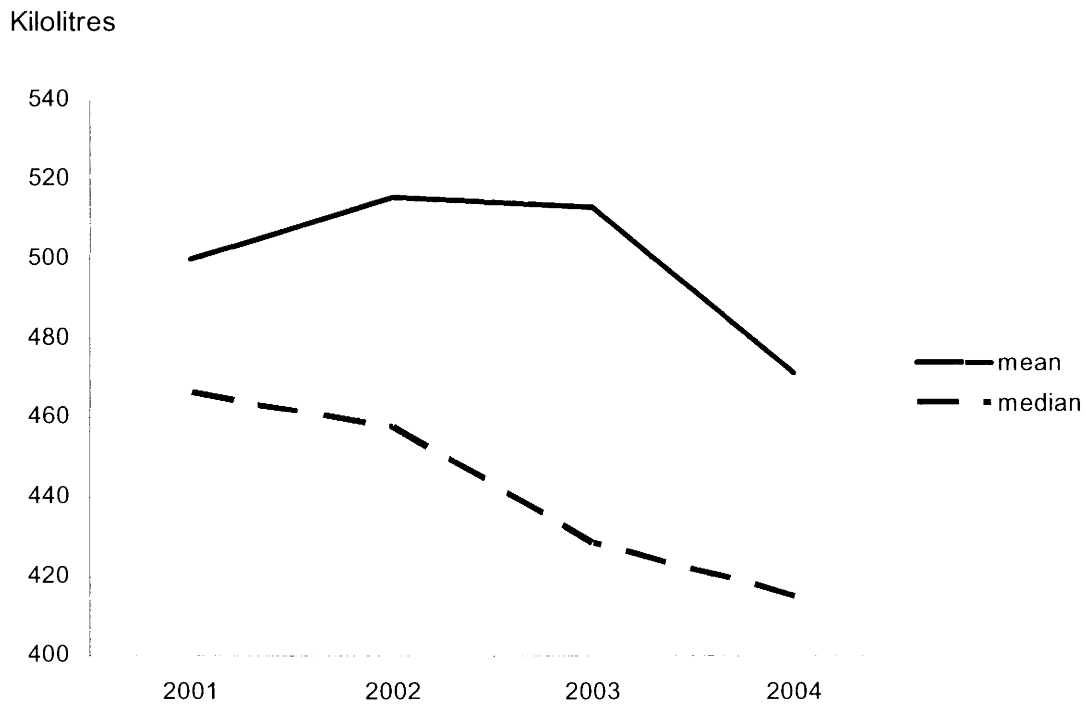
| Year | Variable | Description | Mean | Median | Standard Deviation | Kurtosis | Skewness | Min. | Max. | Variable | Description | Number |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ***Continuous variables*** | | | | | | | | | ***Dummy variables*** | | |
| 2004 | $z_2$ | Residential consumption | 62.19 | 60.89 | 16.64 | 0.14 | −0.10 | 13.68 | 92.96 | n/a | Small utility | 26 |
| | $z_3$ | Water Losses | 12.97 | 10.20 | 5.32 | 13.38 | 2.83 | 5.17 | 44.77 | $z_7$ | Medium utility | 12 |
| | $z_4$ | Production Density | 471.38 | 415.00 | 240.68 | 3.85 | 1.71 | 157.90 | 1,517.92 | $z_8$ | Large utility | 21 |
| | $z_5$ | Change in prod. density | −6.15 | −5.49 | 13.07 | 0.14 | −0.30 | −44.50 | 22.22 | $z_9$ | Very large utility | 31 |
| | $z_6$ | Customer density | 27.01 | 27.28 | 11.24 | 2.17 | 0.81 | 2.32 | 69.97 | $z_{10}$ | Groundwater | 13 |
| | $z_{14}$ | Temperature | 28.48 | 29.26 | 3.22 | −0.28 | −0.61 | 19.56 | 34.04 | $z_{11}$ | Reticulator | 4 |
| | $z_{15}$ | Rain days | 39.96 | 40.00 | 13.60 | −0.44 | 0.34 | 13.00 | 71.00 | $z_{12}$ | Unfiltered supply | 14 |
| | $z_{16}$ | Rainfall | 337.78 | 263.60 | 212.76 | 2.66 | 1.28 | 74.40 | 1,260.20 | $z_{13}$ | Dams | 46 |
| | $z_{17}$ | Rainfall intensity | 8.05 | 7.50 | 3.27 | 0.24 | 0.75 | 3.00 | 18.81 | $z_{18}$ | RUWA | 14 |

### 6.8.1 Returns to scale, economies of scope and economies of density

A number of interesting patterns emerged from the descriptive statistics outlined above. First, the percentage of water consumed by residential customers ( $z_2$ ) was reasonably stable at around 60 per cent of all water consumed. The decline in water losses was also only slight through the period.

As outlined in Figure 6.4, production density ( $z_4$ ) increased between 2001 and 2002 before declining sharply between 2003 and 2004. The mean and median of this variable show an interesting difference: the median is well below the mean, suggesting that the majority of water utilities were successful in convincing their customers to reduce average water consumption. However, the mean is dragged up by those utilities that did not succeed in lowering consumption.

Figure 6.4: Production density: 2001–2004



Customer density ( $z_6$ ) was very stable through the period at around 26–27 properties per kilometre of water main. Again, taking the average of the entire sample had the effect of masking some of the differences between the mean and median utilities.

### 6.8.2 Treatment and pumping expenses

Apart from slight growth in the number of utilities responsible for maintaining headworks ( $z_{13}$ ) and a slight decline in utilities supplying unfiltered water ( $z_{12}$ ), there was no change during the period in the variables relating to raw water source ( $z_{10}$ ) and delivery characteristics ( $z_{11}$ ). All of the utilities relying on groundwater ( $z_{10}$ ) were located in NSW, as were utilities responsible only for reticulation ( $z_{11}$ ).

### 6.8.3 Climatic effects

There is clear evidence in the data of the drought taking hold during 2003. Both average total rainfall ( $z_{16}$ ) and rain days ( $z_{15}$ ) declined over the period 2001–2003 before recovering somewhat in 2004, although to a level still below that reported in 2002.

## 6.9 Descriptive statistics for water explanatory variables by state

Following the analytical method employed to analyse descriptive statistics relating to inputs and outputs, the descriptive statistics are presented for the explanatory variables in tables 6.9 (NSW) and 6.10 (Victoria). A number of pertinent differences are noted below.

Table 6.9: Descriptive statistics: water explanatory variables – NSW utilities

| Year | Variable | Description | Mean | Median | Standard Deviation | Kurtosis | Skewness | Min. | Max. | Variable | Description | Number |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ***Continuous variables*** | | | | | | | | | ***Dummy variables*** | | |
| 2001 | $z_2$ | Residential consumption | 64.94 | 63.36 | 15.55 | –0.16 | 0.15 | 24.35 | 100.00 | n/a | Small utility | 26 |
| | $z_3$ | Water Losses | 13.79 | 10.04 | 6.02 | 2.98 | 1.77 | 9.66 | 37.92 | $z_7$ | Medium utility | 12 |
| | $z_4$ | Production Density | 496.54 | 462.45 | 212.69 | 2.34 | 1.45 | 166.67 | 1,239.47 | $z_8$ | Large utility | 19 |
| | $z_5$ | Change in prod. density | 4.42 | 3.97 | 18.20 | 4.28 | –0.26 | –69.13 | 63.90 | $z_9$ | Very large utility | 19 |
| | $z_6$ | Customer density | 26.75 | 25.22 | 11.73 | 0.96 | 0.65 | 2.73 | 66.17 | $z_{10}$ | Groundwater | 13 |
| | $z_{14}$ | Temperature | 28.32 | 28.96 | 2.66 | –0.76 | –0.33 | 22.13 | 33.76 | $z_{11}$ | Reticulator | 4 |
| | $z_{15}$ | Rain days | 48.05 | 43.00 | 15.53 | –0.82 | 0.41 | 18.00 | 81.00 | $z_{12}$ | Unfiltered supply | 9 |
| | $z_{16}$ | Rainfall | 462.26 | 354.15 | 270.01 | 0.90 | 1.16 | 141.20 | 1,364.20 | $z_{13}$ | Dams | 25 |
| | $z_{17}$ | Rainfall intensity | 9.16 | 8.63 | 2.94 | –0.41 | 0.40 | 3.41 | 16.84 | $z_{18}$ | RUWA | 0 |
| 2002 | $z_2$ | Residential consumption | 64.11 | 61.94 | 15.25 | –0.34 | 0.04 | 27.81 | 93.38 | n/a | Small utility | 27 |
| | $z_3$ | Water Losses | 13.97 | 10.06 | 6.82 | 6.06 | 2.28 | 9.83 | 45.71 | $z_7$ | Medium utility | 11 |
| | $z_4$ | Production Density | 515.63 | 469.05 | 226.57 | 1.70 | 1.29 | 157.90 | 1,270.91 | $z_8$ | Large utility | 19 |
| | $z_5$ | Change in prod. density | 3.97 | 4.77 | 13.12 | 0.19 | –0.15 | –33.26 | 33.17 | $z_9$ | Very large utility | 19 |

Table 6.9 (continued)

| Year | Variable | Description | Mean | Median | Standard Deviation | Kurtosis | Skewness | Min. | Max. | Variable | Description | Number |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ***Continuous variables*** | | | | | | | | | ***Dummy variables*** | | |
| | $z_6$ | Customer density | 26.34 | 24.83 | 11.84 | 1.26 | 0.79 | 2.26 | 66.98 | $z_{10}$ | Groundwater | 13 |
| | $z_{14}$ | Temperature | 27.73 | 28.26 | 2.65 | –0.43 | –0.45 | 21.22 | 33.60 | $z_{11}$ | Reticulator | 4 |
| | $z_{15}$ | Rain days | 41.61 | 41.00 | 16.41 | –1.07 | 0.23 | 15.00 | 76.00 | $z_{12}$ | Unfiltered supply | 8 |
| | $z_{16}$ | Rainfall | 362.37 | 346.70 | 173.30 | 0.79 | 0.85 | 91.20 | 864.20 | $z_{13}$ | Dams | 33 |
| | $z_{17}$ | Rainfall intensity | 8.69 | 8.52 | 2.18 | –0.24 | 0.24 | 4.56 | 13.76 | $z_{18}$ | RUWA | 0 |
| 2003 | $z_2$ | Residential consumption | 63.39 | 63.31 | 15.76 | 0.23 | –0.13 | 15.48 | 92.96 | n/a | Small utility | 26 |
| | $z_3$ | Water Losses | 12.45 | 10.04 | 4.22 | 4.03 | 2.04 | 9.60 | 28.96 | $z_7$ | Medium utility | 12 |
| | $z_4$ | Production Density | 512.51 | 428.71 | 257.20 | 0.22 | 1.01 | 157.90 | 1,223.21 | $z_8$ | Large utility | 19 |
| | $z_5$ | Change in prod. density | –2.12 | –2.97 | 16.68 | 0.33 | 0.47 | –34.89 | 43.24 | $z_9$ | Very large utility | 19 |
| | $z_6$ | Customer density | 25.96 | 24.52 | 11.42 | 1.98 | 0.86 | 2.32 | 68.27 | $z_{10}$ | Groundwater | 13 |
| | $z_{14}$ | Temperature | 29.30 | 30.23 | 2.74 | –0.99 | –0.24 | 23.32 | 35.56 | $z_{11}$ | Reticulator | 4 |
| | $z_{15}$ | Rain days | 35.53 | 33.50 | 16.81 | –1.15 | 0.34 | 7.00 | 66.00 | $z_{12}$ | Unfiltered supply | 8 |
| | $z_{16}$ | Rainfall | 289.21 | 254.00 | 169.87 | –0.04 | 0.84 | 58.80 | 735.80 | $z_{13}$ | Dams | 35 |
| | $z_{17}$ | Rainfall intensity | 8.11 | 7.90 | 2.67 | 2.14 | 1.08 | 3.05 | 18.63 | $z_{18}$ | RUWA | 0 |

Table 6.9 (continued)

| Year | Variable | Description | Mean | Median | Standard Deviation | Kurtosis | Skewness | Min. | Max. | Variable | Description | Number |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ***Continuous variables*** | | | | | | | | | ***Dummy variables*** | | |
| 2004 | $z_2$ | Residential consumption | 63.92 | 63.12 | 16.39 | -0.39 | 0.02 | 20.20 | 92.96 | n/a | Small utility | 26 |
| | $z_3$ | Water Losses | 12.95 | 10.13 | 5.48 | 14.35 | 3.12 | 6.71 | 44.77 | $z_7$ | Medium utility | 12 |
| | $z_4$ | Production Density | 469.76 | 415.00 | 223.00 | 1.14 | 1.22 | 157.90 | 1,200.00 | $z_8$ | Large utility | 19 |
| | $z_5$ | Change in prod. density | -5.84 | -5.04 | 13.76 | -0.06 | -0.30 | -44.50 | 22.22 | $z_9$ | Very large utility | 19 |
| | $z_6$ | Customer density | 26.67 | 26.90 | 11.96 | 1.90 | 0.87 | 2.32 | 69.97 | $z_{10}$ | Groundwater | 13 |
| | $z_{14}$ | Temperature | 29.14 | 29.82 | 2.67 | -0.94 | -0.36 | 23.16 | 34.04 | $z_{11}$ | Reticulator | 4 |
| | $z_{15}$ | Rain days | 40.92 | 41.00 | 13.85 | -0.52 | 0.32 | 13.00 | 71.00 | $z_{12}$ | Unfiltered supply | 8 |
| | $z_{16}$ | Rainfall | 369.54 | 327.90 | 215.71 | 2.45 | 1.13 | 81.20 | 1,260.20 | $z_{13}$ | Dams | 34 |
| | $z_{17}$ | Rainfall intensity | 8.63 | 7.90 | 3.19 | 0.22 | 0.65 | 3.52 | 18.81 | $z_{18}$ | RUWA | 0 |

Table 6.10: Descriptive statistics: water explanatory variables – Victorian utilities

| Year | Variable | Description | Mean | Median | Standard Deviation | Kurtosis | Skewness | Min. | Max. | Variable | Description | Number |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ***Continuous variables*** | | | | | | | | | ***Dummy variables*** | | |
| 2001 | $z_2$ | Residential consumption | 50.93 | 50.18 | 14.73 | 0.42 | –0.62 | 18.02 | 71.69 | n/a | Small utility | 0 |
| | $z_3$ | Water Losses | 16.50 | 16.80 | 6.15 | 1.65 | 0.80 | 6.67 | 31.45 | $z_7$ | Medium utility | 0 |
| | $z_4$ | Production Density | 516.34 | 501.00 | 240.30 | 3.57 | 1.54 | 197.08 | 1,171.13 | $z_8$ | Large utility | 2 |
| | $z_5$ | Change in prod. density | –12.64 | –1.83 | 22.07 | 0.12 | –1.09 | –58.43 | 15.90 | $z_9$ | Very large utility | 12 |
| | $z_6$ | Customer density | 27.17 | 27.30 | 5.35 | –0.17 | –0.23 | 16.75 | 36.36 | $z_{10}$ | Groundwater | 0 |
| | $z_{14}$ | Temperature | 26.20 | 25.11 | 3.30 | –0.67 | 0.21 | 20.60 | 32.24 | $z_{11}$ | Reticulator | 0 |
| | $z_{15}$ | Rain days | 34.36 | 33.50 | 9.86 | 0.24 | 0.03 | 16.00 | 54.00 | $z_{12}$ | Unfiltered supply | 6 |
| | $z_{16}$ | Rainfall | 187.56 | 185.50 | 70.31 | 0.49 | 0.26 | 63.40 | 338.00 | $z_{13}$ | Dams | 12 |
| | $z_{17}$ | Rainfall intensity | 5.51 | 4.90 | 1.71 | –0.51 | 0.84 | 3.16 | 8.80 | $z_{18}$ | RUWA | 14 |
| 2002 | $z_2$ | Residential consumption | 52.75 | 53.74 | 15.93 | 2.37 | –1.06 | 12.23 | 75.30 | n/a | Small utility | 0 |
| | $z_3$ | Water Losses | 15.34 | 14.19 | 6.78 | –1.00 | 0.38 | 6.49 | 26.76 | $z_7$ | Medium utility | 0 |
| | $z_4$ | Production Density | 514.99 | 404.04 | 339.99 | 6.88 | 2.36 | 168.85 | 1,548.87 | $z_8$ | Large utility | 2 |
| | $z_5$ | Change in prod. density | –5.04 | –6.49 | 14.02 | 3.18 | 1.45 | –23.94 | 32.26 | $z_9$ | Very large utility | 12 |

Table 6.10 (continued)

| Year | Variable | Description | Mean | Median | Standard Deviation | Kurtosis | Skewness | Min. | Max. | Variable | Description | Number |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ***Continuous variables*** | | | | | | | | | ***Dummy variables*** | | |
| | $z_6$ | Customer density | 28.24 | 29.26 | 5.69 | −0.24 | −0.48 | 16.92 | 37.10 | $z_{10}$ | Groundwater | 0 |
| | $z_{14}$ | Temperature | 23.11 | 21.85 | 3.37 | −1.07 | 0.40 | 18.18 | 29.04 | $z_{11}$ | Reticulator | 0 |
| | $z_{15}$ | Rain days | 44.14 | 44.50 | 19.47 | −0.93 | 0.17 | 12.00 | 76.00 | $z_{12}$ | Unfiltered supply | 6 |
| | $z_{16}$ | Rainfall | 194.14 | 206.10 | 102.06 | 0.27 | 0.47 | 42.20 | 418.50 | $z_{13}$ | Dams | 12 |
| | $z_{17}$ | Rainfall intensity | 4.47 | 4.18 | 1.94 | 5.74 | 2.13 | 2.55 | 10.21 | $z_{18}$ | RUWA | 14 |
| 2003 | $z_2$ | Residential consumption | 52.86 | 54.19 | 14.77 | 2.81 | −1.44 | 13.96 | 69.71 | n/a | Small utility | 0 |
| | $z_3$ | Water Losses | 12.93 | 11.17 | 7.03 | 7.29 | 2.39 | 4.88 | 34.48 | $z_7$ | Medium utility | 0 |
| | $z_4$ | Production Density | 516.26 | 440.23 | 327.71 | 7.05 | 2.40 | 172.25 | 1,516.29 | $z_8$ | Large utility | 2 |
| | $z_5$ | Change in prod. density | 2.04 | 4.39 | 10.75 | 3.65 | −0.83 | −25.67 | 23.54 | $z_9$ | Very large utility | 12 |
| | $z_6$ | Customer density | 28.52 | 29.46 | 5.85 | −0.16 | −0.40 | 16.98 | 37.86 | $z_{10}$ | Groundwater | 0 |
| | $z_{14}$ | Temperature | 25.32 | 24.71 | 3.75 | −1.12 | 0.07 | 19.22 | 31.00 | $z_{11}$ | Reticulator | 0 |
| | $z_{15}$ | Rain days | 33.79 | 32.50 | 16.32 | −0.33 | 0.68 | 12.00 | 65.00 | $z_{12}$ | Unfiltered supply | 6 |
| | $z_{16}$ | Rainfall | 157.71 | 125.00 | 68.93 | 0.51 | 1.31 | 78.40 | 306.80 | $z_{13}$ | Dams | 12 |
| | $z_{17}$ | Rainfall intensity | 5.13 | 4.82 | 1.91 | 3.15 | 1.51 | 2.61 | 10.23 | $z_{18}$ | RUWA | 14 |

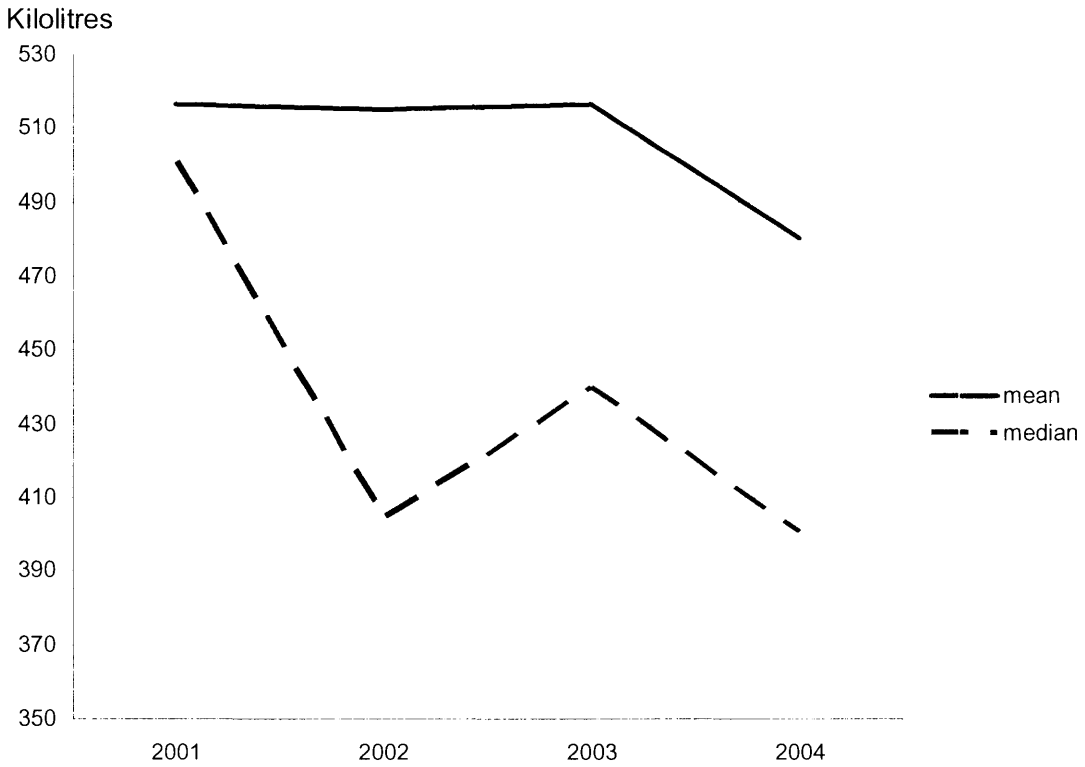
Table 6.10 (continued)

| Year | Variable | Description | Mean | Median | Standard Deviation | Kurtosis | Skewness | Min. | Max. | Variable | Description | Number |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ***Continuous variables*** | | | | | | | | | ***Dummy variables*** | | |
| 2004 | $z_2$ | Residential consumption | 52.80 | 52.69 | 15.24 | 2.45 | -1.43 | 13.68 | 69.94 | n/a | Small utility | 0 |
| | $z_3$ | Water Losses | 13.09 | 13.23 | 4.53 | -0.79 | -0.31 | 5.17 | 19.58 | $z_7$ | Medium utility | 0 |
| | $z_4$ | Production Density | 480.17 | 401.01 | 331.00 | 8.19 | 2.63 | 161.26 | 1,517.92 | $z_8$ | Large utility | 2 |
| | $z_5$ | Change in prod. density | -7.82 | -6.42 | 8.53 | 1.51 | -1.19 | -28.30 | 3.81 | $z_9$ | Very large utility | 12 |
| | $z_6$ | Customer density | 28.81 | 29.38 | 6.00 | -0.21 | -0.35 | 17.08 | 37.83 | $z_{10}$ | Groundwater | 0 |
| | $z_{14}$ | Temperature | 24.92 | 24.13 | 3.68 | -1.12 | 0.31 | 19.56 | 31.32 | $z_{11}$ | Reticulator | 0 |
| | $z_{15}$ | Rain days | 34.71 | 38.00 | 11.14 | -1.07 | -0.06 | 17.00 | 52.00 | $z_{12}$ | Unfiltered supply | 6 |
| | $z_{16}$ | Rainfall | 165.42 | 160.50 | 59.60 | 1.07 | 0.89 | 74.40 | 304.40 | $z_{13}$ | Dams | 12 |
| | $z_{17}$ | Rainfall intensity | 4.89 | 4.61 | 1.31 | -0.27 | 0.74 | 3.00 | 7.42 | $z_{18}$ | RUWA | 14 |

### 6.9.1 Returns to scale, economies of scope and economies of density

Turning first to NSW, the percentage of potable water consumed by residential customers ( $z_2$ ) was slightly higher when compared with the full sample. However, the sequence of change during the period was both stable and similar to that observed in Table 6.8. This pattern contrasts with Victorian utilities, whose residential consumers were responsible for, on average, 10 per cent less consumption of total potable water supplied. Likewise in NSW, production density ( $z_4$ ) followed a similar structure to that of the entire sample. However, when Victoria was analysed in isolation, production density ( $z_4$ ) revealed an interesting structural bifurcation. This revelation is best illustrated by charting the mean and median of production density (Figure 6.5).

Figure 6.5: Production density – Victorian utilities: 2001–2004



It is clear that the majority of Victorian utilities were subject to a decline in production density ( $z_4$ ) during the period, indicated by the median being lower than the mean. This decline can be explained by a unique characteristic of a Victorian utility, Gippsland Water, which supplies water to a number of energy generation plants and was, as a result, responsible for inflating the mean. Thus, the median is a better representation of changes in production density across the industry in Victoria.

In relation to the percentage *change* in production density ( $z_5$ ), generally higher changes were observed in production density ( $z_5$ ) during 2002 for NSW utilities, yet this was reversed by a greater fall in 2003 than the average for the full sample. This pattern was not repeated in 2004, suggesting that Victorian utilities experienced relatively larger changes in production density ( $z_5$ ) during that year. Average customer density ( $z_6$ ) in NSW was steady at around 26 properties per kilometre of water main, which closely followed the average for the full sample. A similar pattern was evident in Victoria although customer density ( $z_6$ ) was, on average, slightly higher.

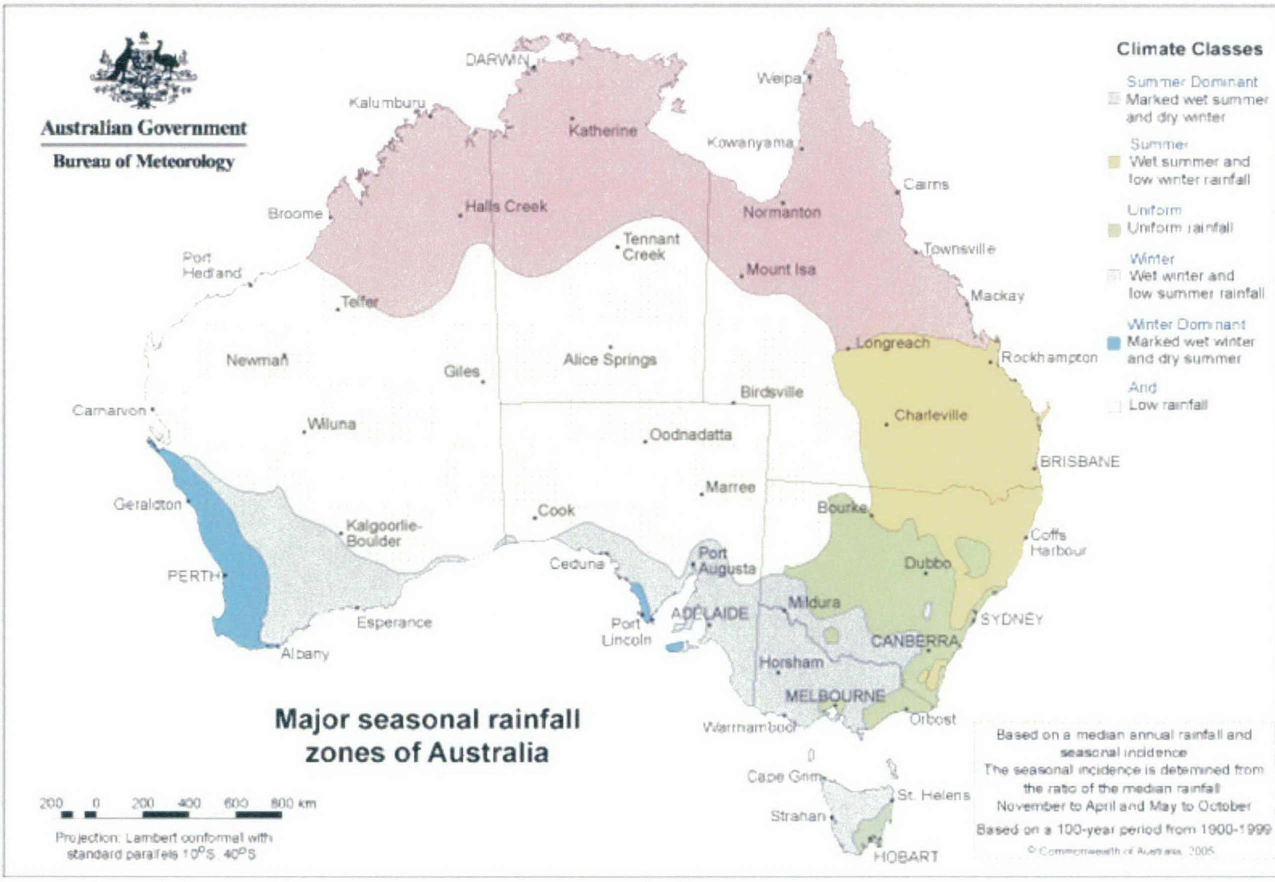
### 6.9.2 Treatment and pumping expenses

NSW utilities were entirely responsible the growth in the number of authorities with headworks responsibilities ( $z_{13}$ ). Whether this variation becomes an important determinant of relative efficiency is a matter for empirical investigation. All but one of the utilities reliant upon groundwater ( $z_{10}$ ) for the majority of their raw water were located in NSW. However, a disproportionate number of utilities able to supply unfiltered water ( $z_{12}$ ) were located in Victoria.

### 6.9.3 Climatic effects

The average maximum temperature ( $z_{14}$ ) for utilities in NSW closely followed that observed for the entire sample. However, NSW utilities as a group experienced generally higher rain days ( $z_{15}$ ) and higher rainfall ( $z_{16}$ ), although the pattern of change during the period was similar to that observed across the entire sample. The same cannot be said for Victorian utilities which, as a group, experienced around half the rainfall ( $z_{16}$ ) of utilities located in NSW during the months November–March each year. This reflected the seasonal rainfall patterns observed by the Bureau of Meteorology in Australia, illustrated in Figure 6.6.

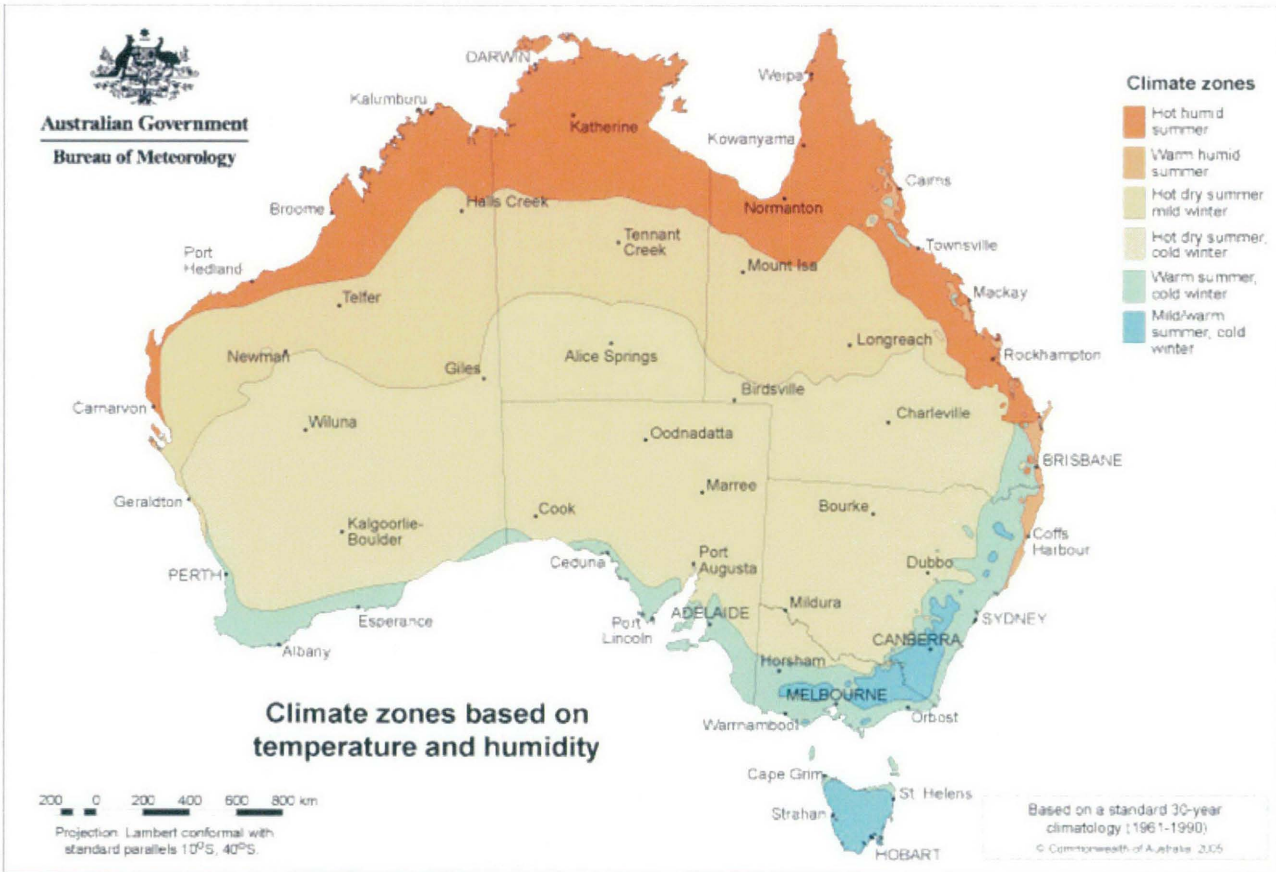
Figure 6.6: Major seasonal rainfall zones of Australia




Source: Bureau of Meteorology

Victorian utilities were also located in slightly cooler climates, on average, as illustrated in the distribution of climate zones (Figure 6.7).

Figure 6.7: Climate zones based on temperature and humidity




Source: Bureau of Meteorology

## 6.10 Descriptive statistics for water explanatory variables – large utilities only

Finally, the database was truncated in order to include only those utilities that supplied in excess of 3,000 connections, in order to investigate the possible existence of size related distortions in the data. The relevant descriptive statistics are reported in Table 6.11.

Table 6.11: Descriptive statistics: water explanatory variables – large utilities

| Year | Variable | Description | Mean | Median | Standard Deviation | Kurtosis | Skewness | Min. | Max. | Variable | Description | Number |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ***Continuous variables*** | | | | | | | | | ***Dummy variables*** | | |
| 2001 | $z_2$ | Residential consumption | 58.67 | 60.78 | 15.51 | 0.46 | –0.08 | 18.02 | 93.38 | $z_{10}$ | Groundwater | 5 |
| | $z_3$ | Water Losses | 13.76 | 11.20 | 5.17 | 1.59 | 1.37 | 6.67 | 31.45 | $z_{11}$ | Reticulator | 3 |
| | $z_4$ | Production Density | 523.38 | 484.38 | 233.73 | 1.87 | 1.40 | 197.08 | 1,239.47 | $z_{12}$ | Unfiltered supply | 12 |
| | $z_5$ | Change in prod. density | 6.91 | 2.07 | 42.18 | 22.59 | 4.12 | –58.43 | 250.42 | $z_{13}$ | Dams | 25 |
| | $z_6$ | Customer density | 30.16 | 29.58 | 11.44 | 1.01 | 0.73 | 9.61 | 66.17 | $z_{18}$ | RUWA | 14 |
| | $z_{14}$ | Temperature | 27.58 | 27.98 | 3.46 | 5.75 | –1.72 | 12.52 | 32.24 | $z_8$ | Large utility | 21 |
| | $z_{15}$ | Rain days | 46.46 | 41.50 | 16.82 | –0.69 | 0.58 | 16.00 | 81.00 | $z_9$ | Very large utility | 31 |
| | $z_{16}$ | Rainfall | 429.06 | 298.20 | 310.30 | 0.81 | 1.27 | 63.40 | 1,364.20 | | | |
| | $z_{17}$ | Rainfall intensity | 8.43 | 7.65 | 3.38 | –0.35 | 0.65 | 3.16 | 16.84 | | | |
| 2002 | $z_2$ | Residential consumption | 58.89 | 58.88 | 14.66 | 1.48 | –0.36 | 12.23 | 93.38 | $z_{10}$ | Groundwater | 5 |
| | $z_3$ | Water Losses | 13.25 | 10.30 | 5.62 | 2.19 | 1.66 | 6.49 | 32.24 | $z_{11}$ | Reticulator | 3 |
| | $z_4$ | Production Density | 535.47 | 495.81 | 274.00 | 3.47 | 1.71 | 168.85 | 1,548.87 | $z_{12}$ | Unfiltered supply | 12 |
| | $z_5$ | Change in prod. density | 0.98 | 2.65 | 12.82 | 0.91 | –0.15 | –33.26 | 32.99 | $z_{13}$ | Dams | 30 |

Table 6.11 (continued)

| Year | Variable | Description | Mean | Median | Standard Deviation | Kurtosis | Skewness | Min. | Max. | Variable | Description | Number |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ***Continuous variables*** | | | | | | | | | ***Dummy variables*** | | |
| | $z_6$ | Customer density | 30.17 | 29.65 | 11.60 | 1.18 | 0.79 | 9.71 | 66.98 | $z_{18}$ | RUWA | 14 |
| | $z_{14}$ | Temperature | 26.29 | 27.26 | 4.04 | 3.14 | −1.45 | 10.58 | 32.08 | $z_8$ | Large utility | 21 |
| | $z_{15}$ | Rain days | 44.79 | 46.50 | 18.23 | −1.23 | 0.03 | 12.00 | 76.00 | $z_9$ | Very large utility | 31 |
| | $z_{16}$ | Rainfall | 343.21 | 291.45 | 204.37 | 0.27 | 0.88 | 42.20 | 864.20 | | | |
| | $z_{17}$ | Rainfall intensity | 7.60 | 7.42 | 2.98 | −0.90 | 0.15 | 2.55 | 13.76 | | | |
| 2003 | $z_2$ | Residential consumption | 58.60 | 58.11 | 13.49 | 2.14 | −0.33 | 13.96 | 92.96 | $z_{10}$ | Groundwater | 5 |
| | $z_3$ | Water Losses | 12.48 | 10.35 | 4.78 | 8.10 | 2.39 | 4.88 | 34.48 | $z_{11}$ | Reticulator | 3 |
| | $z_4$ | Production Density | 540.99 | 468.74 | 289.83 | 1.82 | 1.41 | 172.25 | 1,516.29 | $z_{12}$ | Unfiltered supply | 12 |
| | $z_5$ | Change in prod. density | 0.39 | −0.23 | 13.61 | 1.61 | 0.41 | −28.66 | 41.60 | $z_{13}$ | Dams | 32 |
| | $z_6$ | Customer density | 29.76 | 29.94 | 11.21 | 2.02 | 0.90 | 9.72 | 68.27 | $z_{18}$ | RUWA | 14 |
| | $z_{14}$ | Temperature | 27.81 | 28.57 | 3.97 | 3.41 | −1.43 | 12.24 | 33.08 | $z_8$ | Large utility | 21 |
| | $z_{15}$ | Rain days | 37.42 | 35.00 | 17.03 | −1.24 | 0.23 | 12.00 | 66.00 | $z_9$ | Very large utility | 31 |
| | $z_{16}$ | Rainfall | 281.35 | 222.70 | 190.03 | −0.22 | 0.95 | 58.80 | 735.80 | | | |
| | $z_{17}$ | Rainfall intensity | 7.23 | 7.05 | 2.64 | −0.04 | 0.59 | 2.61 | 13.38 | | | |

Table 6.11 (continued)

| Year | Variable | Description | Mean | Median | Standard Deviation | Kurtosis | Skewness | Min. | Max. | Variable | Description | Number |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ***Continuous variables*** | | | | | | | | | ***Dummy variables*** | | |
| 2004 | $z_2$ | Residential consumption | 57.77 | 57.59 | 13.76 | 2.19 | -0.15 | 13.68 | 92.96 | $z_{10}$ | Groundwater | 5 |
| | $z_3$ | Water Losses | 12.57 | 10.20 | 4.28 | -0.08 | 0.86 | 5.17 | 22.92 | $z_{11}$ | Reticulator | 3 |
| | $z_4$ | Production Density | 488.77 | 432.69 | 265.48 | 4.28 | 1.93 | 161.26 | 1,517.92 | $z_{12}$ | Unfiltered supply | 12 |
| | $z_5$ | Change in prod. density | -7.86 | -5.78 | 13.02 | 0.46 | -0.62 | -44.50 | 18.87 | $z_{13}$ | Dams | 31 |
| | $z_6$ | Customer density | 30.77 | 30.84 | 11.54 | 2.18 | 0.96 | 9.81 | 69.97 | $z_{18}$ | RUWA | 14 |
| | $z_{14}$ | Temperature | 27.47 | 27.94 | 4.38 | 2.69 | -1.34 | 12.16 | 35.44 | $z_8$ | Large utility | 21 |
| | $z_{15}$ | Rain days | 41.10 | 40.50 | 14.48 | -0.81 | 0.26 | 17.00 | 71.00 | $z_9$ | Very large utility | 31 |
| | $z_{16}$ | Rainfall | 338.77 | 251.50 | 241.69 | 2.82 | 1.49 | 74.40 | 1,260.20 | | | |
| | $z_{17}$ | Rainfall intensity | 7.63 | 7.16 | 3.27 | 1.38 | 1.01 | 3.00 | 18.81 | | | |

The proportion of potable water consumed by residential customers ( $z_2$ ) was lower for this subset of utilities and declined during the period in question. This observation suggests that larger utilities tended to supply industrial customers, while the decline during the period might be interpreted as indicating a reluctance on the part of industrial consumers to cut consumption. Restrictions policies are generally more punitive for residential customers. For instance, commercial industrial users of water are treated equivalent to indoor use in most jurisdictions.

There was also a noticeable increase in production density ( $z_4$ ), in terms of both the mean and median. This rise may also indicate higher consumption by industrial customers. The percentage change in production density ( $z_5$ ) might suggest that the larger utilities were less successful in their attempts to convince residents and industrial customers to reduce per connection consumption. Customer density ( $z_6$ ) for this group was on average four properties higher per kilometre of water main, indicating that larger utilities tended to have denser networks.

Just over one third of utilities reliant upon groundwater ( $z_{10}$ ) were in the largest categories, while three of the four utilities that carried out only reticulation functions ( $z_{11}$ ) were also in this group. Almost the opposite was found for utilities able to rely on an unfiltered supply ( $z_{12}$ ). Finally, around two thirds of utilities responsible for dams ( $z_{13}$ ) were in the large or very large category. No difference was detected in climate variables ( $z_{14}$, $z_{15}$, $z_{16}$ and $z_{17}$ ) between the full sample and this truncated sample.

NSW utilities in the large categories were also analysed in order to investigate the possible existence of location specific distortions in the data, and the results are contained in Table 6.12.

Table 6.12: Descriptive statistics: water explanatory variables – NSW large utilities

| Year | Variable | Description | Mean | Median | Standard Deviation | Kurtosis | Skewness | Min. | Max. | Variable | Description | Number |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ***Continuous variables*** | | | | | | | | | ***Dummy variables*** | | |
| 2001 | $z_2$ | Residential consumption | 61.53 | 61.52 | 14.97 | 0.34 | 0.06 | 24.35 | 93.38 | $z_{10}$ | Groundwater | 5 |
| | $z_3$ | Water Losses | 12.75 | 10.01 | 4.43 | 1.77 | 1.68 | 9.97 | 25.39 | $z_{11}$ | Reticulator | 3 |
| | $z_4$ | Production Density | 525.98 | 484.38 | 234.49 | 1.81 | 1.42 | 272.73 | 1,239.47 | $z_{12}$ | Unfiltered supply | 6 |
| | $z_5$ | Change in prod. density | 4.46 | 3.33 | 14.75 | 6.88 | 1.27 | –26.12 | 63.90 | $z_{13}$ | Dams | 13 |
| | $z_6$ | Customer density | 31.27 | 32.25 | 12.88 | 0.21 | 0.50 | 9.61 | 66.17 | $z_{18}$ | RUWA | 0 |
| | $z_{14}$ | Temperature | 28.09 | 28.37 | 3.42 | 10.81 | –2.58 | 12.52 | 32.14 | $z_8$ | Large utility | 19 |
| | $z_{15}$ | Rain days | 50.92 | 43.00 | 16.73 | –1.24 | 0.38 | 29.00 | 81.00 | $z_9$ | Very large utility | 19 |
| | $z_{16}$ | Rainfall | 518.03 | 430.40 | 317.46 | 0.02 | 0.96 | 141.20 | 1,364.20 | | | |
| | $z_{17}$ | Rainfall intensity | 9.51 | 8.40 | 3.20 | –0.59 | 0.50 | 3.82 | 16.84 | | | |
| 2002 | $z_2$ | Residential consumption | 61.15 | 60.50 | 13.70 | 0.61 | 0.09 | 27.81 | 93.38 | $z_{10}$ | Groundwater | 5 |
| | $z_3$ | Water Losses | 12.48 | 10.00 | 5.02 | 6.76 | 2.59 | 9.98 | 32.24 | $z_{11}$ | Reticulator | 3 |
| | $z_4$ | Production Density | 543.02 | 498.02 | 250.31 | 1.50 | 1.34 | 277.45 | 1,270.91 | $z_{12}$ | Unfiltered supply | 6 |
| | $z_5$ | Change in prod. density | 3.20 | 4.82 | 11.77 | 2.60 | –0.79 | –33.26 | 32.99 | $z_{13}$ | Dams | 18 |

Table 6.12 (continued)

| Year | Variable | Description | Mean | Median | Standard Deviation | Kurtosis | Skewness | Min. | Max. | Variable | Description | Number |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ***Continuous variables*** | | | | | | | | | ***Dummy variables*** | | |
| | $z_6$ | Customer density | 30.88 | 30.64 | 13.12 | 0.35 | 0.64 | 9.71 | 66.98 | $z_{18}$ | RUWA | 0 |
| | $z_{14}$ | Temperature | 27.46 | 28.26 | 3.65 | 11.79 | –2.82 | 10.58 | 32.08 | $z_8$ | Large utility | 19 |
| | $z_{15}$ | Rain days | 45.03 | 46.50 | 18.03 | –1.33 | –0.02 | 15.00 | 76.00 | $z_9$ | Very large utility | 19 |
| | $z_{16}$ | Rainfall | 398.14 | 373.70 | 205.93 | –0.18 | 0.67 | 103.40 | 864.20 | | | |
| | $z_{17}$ | Rainfall intensity | 8.75 | 8.38 | 2.41 | –0.72 | 0.22 | 4.65 | 13.76 | | | |
| 2003 | $z_2$ | Residential consumption | 60.72 | 60.58 | 12.53 | 0.94 | 0.38 | 30.60 | 92.96 | $z_{10}$ | Groundwater | 5 |
| | $z_3$ | Water Losses | 12.31 | 10.01 | 3.74 | 1.35 | 1.61 | 9.97 | 21.99 | $z_{11}$ | Reticulator | 3 |
| | $z_4$ | Production Density | 550.10 | 477.57 | 278.82 | 0.07 | 1.01 | 229.77 | 1,223.21 | $z_{12}$ | Unfiltered supply | 6 |
| | $z_5$ | Change in prod. density | –0.22 | –1.57 | 14.61 | 1.52 | 0.64 | –28.66 | 41.60 | $z_{13}$ | Dams | 20 |
| | $z_6$ | Customer density | 30.22 | 31.74 | 12.67 | 1.16 | 0.79 | 9.72 | 68.27 | $z_{18}$ | RUWA | 0 |
| | $z_{14}$ | Temperature | 28.73 | 29.26 | 3.69 | 9.86 | –2.43 | 12.24 | 33.08 | $z_8$ | Large utility | 19 |
| | $z_{15}$ | Rain days | 38.76 | 35.00 | 17.30 | –1.36 | 0.10 | 12.00 | 66.00 | $z_9$ | Very large utility | 19 |
| | $z_{16}$ | Rainfall | 326.90 | 290.60 | 200.48 | –0.88 | 0.55 | 58.80 | 735.80 | | | |
| | $z_{17}$ | Rainfall intensity | 8.00 | 7.69 | 2.45 | 0.09 | 0.60 | 3.05 | 13.38 | | | |

Table 6.12 (continued)

| Year | Variable | Description | Mean | Median | Standard Deviation | Kurtosis | Skewness | Min. | Max. | Variable | Description | Number |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ***Continuous variables*** | | | | | | | | | ***Dummy variables*** | | |
| 2004 | $z_2$ | Residential consumption | 59.60 | 57.90 | 12.91 | 1.20 | 0.66 | 28.41 | 92.96 | $z_{10}$ | Groundwater | 5 |
| | $z_3$ | Water Losses | 12.37 | 10.04 | 4.24 | 0.66 | 1.35 | 6.71 | 22.92 | $z_{11}$ | Reticulator | 3 |
| | $z_4$ | Production Density | 491.94 | 437.07 | 242.10 | 1.63 | 1.45 | 246.21 | 1,200.00 | $z_{12}$ | Unfiltered supply | 6 |
| | $z_5$ | Change in prod. density | -7.87 | -5.49 | 14.42 | 0.05 | -0.56 | -44.50 | 18.87 | $z_{13}$ | Dams | 19 |
| | $z_6$ | Customer density | 31.49 | 32.43 | 13.00 | 1.26 | 0.81 | 9.81 | 69.97 | $z_{18}$ | RUWA | 0 |
| | $z_{14}$ | Temperature | 28.10 | 28.90 | 4.19 | 6.86 | -2.30 | 12.16 | 32.42 | $z_8$ | Large utility | 19 |
| | $z_{15}$ | Rain days | 43.95 | 43.50 | 14.52 | -0.95 | 0.13 | 20.00 | 71.00 | $z_9$ | Very large utility | 19 |
| | $z_{16}$ | Rainfall | 403.37 | 368.10 | 251.69 | 2.11 | 1.18 | 81.20 | 1,260.20 | | | |
| | $z_{17}$ | Rainfall intensity | 8.57 | 7.87 | 3.26 | 1.27 | 0.83 | 3.52 | 18.81 | | | |

When compared with Table 6.9, which isolated all NSW water utilities regardless of size, those in the large categories supplied around two to three per cent more of their potable water to industrial consumers ( $z_2$ ). Following a similar pattern noted in the analysis of all large utilities, the proportion of water supplied to industrial customers ( $z_2$ ) also increased throughout the period. Production density ( $z_4$ ) was consistently higher for this subset of utilities, and followed a similar pattern to that observed in the panel of all larger utilities. That is, there was a sharp decline in production density ( $z_4$ ) from 2003 to 2004 and this was also reflected in the percentage change in production density ( $z_5$ ). Customer density ( $z_6$ ) was around five properties per kilometre of water main higher for larger NSW councils.

Finally, in terms of climate data, large utilities in NSW experienced slightly more rain days ( $z_{15}$ ), and generally higher rainfall ( $z_{16}$ ). This is most likely a result of the tendency for larger utilities to be located along the more heavily populated eastern seaboard, as opposed to the relatively drier western slopes, plains and inland.

## 6.11 Synopsis of the data pertaining to explanatory variables

The above analysis allows the following general conclusions. First, larger utilities, regardless of location, tend to be characterised by both higher customer density and production density. It is also clear that larger utilities supply relatively more of their potable water to industrial consumers. While there appears to be no discernible difference in climate measures between small and large utilities, there is a noticeable difference between NSW and Victoria in terms of temperature, rain days and rainfall.

## 6.12 Concluding remarks

The purpose of this chapter was two-fold. First, the potential inputs and outputs to be included in the DEA model outlined in Chapter 5 were described, and the rationale underpinning the chosen variables was presented. In order to provide a backdrop for the analysis that is to follow in Chapter 8, a number of descriptive statistics were presented and analysed. Of most importance, Victorian utilities appear to have a relative cost advantage over their counterparts in NSW. However, a general pattern of increasing average costs during the period and decreasing water consumption was noted.

Second, in order to incorporate a number of exogenous influences on the relative efficiency of water utilities, a set of potential explanatory variables were specified. Analysis of the descriptive statistics relating to each also led to a number of tentative conclusions being drawn, the most important of which were reviewed in the preceding section, and will not be repeated here.

The following chapter mirrors the analysis reported here. However, the context will be the wastewater utilities in regional NSW and Victoria.

# Chapter 7. The Measurement of Relative Technical Efficiency in Wastewater Utilities

## 7.1 Introduction

Chapter 6 described the suite of inputs, outputs and explanatory variables employed in the analysis of relative efficiency in the provision of urban water services. Chapter 7 repeats that process in the context of urban wastewater utilities. First, it outlines the logical framework for the inputs, outputs and explanatory variables used in the DEA model and Tobit regression equations relating to the wastewater sectors. A synopsis of the descriptive statistics pertaining to each of those variables is then presented.

Chapter 7 consists of three main sections. Section 7.2 discusses the input and output variables to be included in the DEA model, and presents the descriptive statistics in order to provide an overview of the data. Section 7.3 describes the model employed for analysing variances in the relative efficiency scores generated by the DEA models. Section 7.4 specifies the variables of the analysis and the related descriptive statistics, and a summary is contained in Section 7.5.

## 7.2 Specification of inputs and outputs

The underlying model employed to analyse relative efficiency in the wastewater sector of regional NSW and Victoria was outlined in Chapter 5, and the selection of inputs and outputs was identical to that pertaining to the water sector, discussed in

Chapter 6, with the exception of outputs and inputs that relate to wastewater. For the sake of brevity, the rationale for that particular model is not repeated here. Section 6.2 of Chapter 6 discusses the limitations in the data that led to a model containing one input and two outputs. In order to estimate relative efficiency in the wastewater sector the input was Total Operating Cost of the wastewater 'business' and the two outputs were: (1) Total Wastewater Treated and (2) a Complaints Index to be maximised. The definitions and sources of these variables are contained in Table 7.1.

Table 7.1: Definitions of wastewater input and output variables

| Variable | NSW Definition | Victorian Definition |
|---|---|---|
| Total Sewage Collected | Total volume, expressed in megalitres, transported through sewerage network. | Total volume of wastewater collected by the business, measured as treatment plant inflow. |
| Wastewater Service and Quality Complaints (Complaints Index) | Wastewater odour and/or service complaints (any expression of customer dissatisfaction reported to an LWU employee, whether in person, by telephone, fax, email or letter). | Any complaints relating to wastewater service interruption or service adequacy and any complaint regarding odours discharging from wastewater service business assets including odours discharging into houses. |
| Total Operating Cost | Total operation, maintenance and administration costs. | Operating costs should include charges for transfer of wastewater, salaries and wages, overheads on salaries and wages, materials/chemical/energy, contracts, accommodation and all other operating costs that would normally be reported. |

Source: DEUS (2005a) and VIWA (2005)

The utilities included in this dataset are presented in Appendix 1, along with the reason for the exclusion of those utilities not included in the analysis. The framework for presenting the descriptive statistics for the wastewater model follows the identical approach to that employed for describing the statistics relating to water utilities, discussed in the previous chapter. It begins by analysing the data for each year when all 114 utilities are included in the sample. The results are reported in Table 7.2.

Table 7.2: Descriptive statistics: wastewater input and outputs

| Year | Input/Output | Variable | Description | Mean | Median | Standard Deviation | Kurtosis | Skewness | Minimum | Maximum |
|---|---|---|---|---|---|---|---|---|---|---|
| 2001 | Input | $x_1$ | Total Operating Cost | 1,974,926 | 586,668 | 3,001,847 | 6.58 | 2.45 | 52,225 | 16,076,846 |
| | Outputs | $y_1$ | Complaints Index | 133 | 141 | 26 | 5.75 | -1.98 | 0 | 159 |
| | | $y_2$ | Total Sewage Treated | 2,417 | 778 | 4,244 | 19.94 | 3.85 | 20 | 31,248 |
| 2002 | Input | $x_1$ | Total Operating Cost | 2,117,220 | 592,565 | 3,227,756 | 5.71 | 2.36 | 59,531 | 16,513,349 |
| | Outputs | $y_1$ | Complaints Index | 133 | 141 | 25 | 6.60 | -2.02 | 0 | 159 |
| | | $y_2$ | Total Sewage Treated | 2,373 | 789 | 4,100 | 15.78 | 3.49 | 20 | 28,384 |
| 2003 | Input | $x_1$ | Total Operating Cost | 2,218,532 | 581,243 | 3,385,251 | 5.65 | 2.35 | 62,312 | 16,753,053 |
| | Output | $y_1$ | Complaints Index | 76 | 83 | 24 | 0.90 | -1.13 | 0 | 103 |
| | | $y_2$ | Total Sewage Treated | 2,303 | 643 | 3,903 | 11.62 | 3.04 | 20 | 25,084 |
| 2004 | Input | $x_1$ | Total Operating Cost | 2,242,693 | 649,279 | 3,336,943 | 4.58 | 2.19 | 49,063 | 15,721,706 |
| | Output | $y_1$ | Complaints Index | 93 | 102 | 27 | 1.83 | -1.46 | 0 | 120 |
| | | $y_2$ | Total Sewage Treated | 2,332 | 689 | 4,060 | 17.71 | 3.60 | 11 | 29,201 |
| Number of utilities: | 114 | of which: | Small = 42<br>Medium = 16<br>Large = 28<br>Very Large = 28 | | | | | | | |

Many of the familiar patterns in the data pertaining to the water operations were replicated in the wastewater dataset. First, both the mean and median of Total Operating Cost grew during the period, despite nominal costs being inflated to reflect 2004 dollar costs in each year. The Complaints Index followed a slightly different pattern in that the mean and median of actual complaints increased noticeably in 2003 (indicated by a decline in the complaints index) before regaining some ground in 2004. The caveat regarding the influence of the data transformation process on this variable, expressed in Section 6.3.2 of Chapter 6, is equally valid when interpreting this variable in the wastewater context. Finally, Total Wastewater Collected, when measured by both mean and median, was lower in 2004 than in 2001. This may reflect the reduction in potable water consumption during the period, although the extent to which this line of logic extends is limited. Since water restrictions typically do not apply to indoor use, the reductions would derive not from regulation but the success or otherwise of education campaigns designed to change indoor water consumption behaviour.

### 7.2.1 Descriptive statistics by state

By partitioning the dataset along state lines, the potential of distortion through pooling utilities from NSW and Victoria into the one dataset can be investigated. The results are contained in tables 7.3 and 7.4.

Table 7.3: Descriptive statistics: wastewater input and outputs – NSW utilities

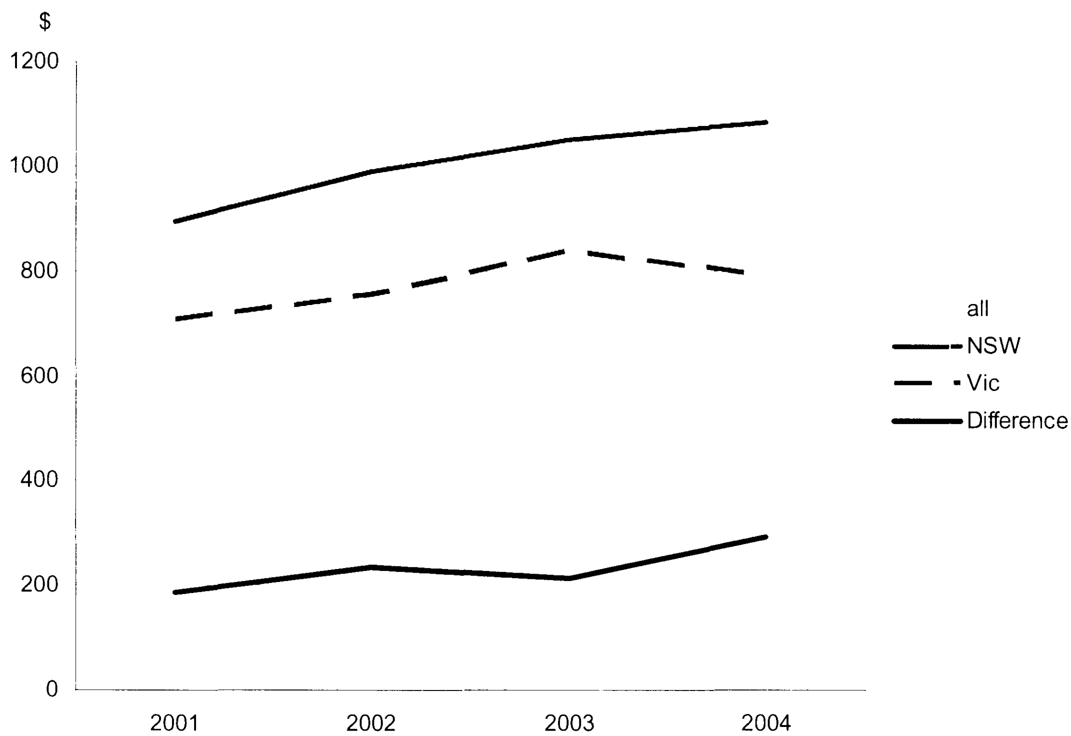
| Year | Input/Output | Variable | Description | Mean | Median | Standard Deviation | Kurtosis | Skewness | Minimum | Maximum |
|---|---|---|---|---|---|---|---|---|---|---|
| 2001 | Input | $x_1$ | Total Operating Cost | 1,453,425 | 399,937 | 2,402,982 | 10.43 | 3.01 | 52,225 | 13,962,075 |
| | Outputs | $y_1$ | Complaints Index | 130 | 139 | 27 | 5.39 | -1.91 | 0 | 159 |
| | | $y_2$ | Total Sewage Treated | 1,627 | 620 | 2,675 | 13.38 | 3.32 | 20 | 15,540 |
| 2002 | Input | $x_1$ | Total Operating Cost | 1,566,870 | 415,356 | 2,625,216 | 9.40 | 2.94 | 59,531 | 14,086,588 |
| | Outputs | $y_1$ | Complaints Index | 131 | 139 | 25 | 6.40 | -1.98 | 0 | 159 |
| | | $y_2$ | Total Sewage Treated | 1,583 | 566 | 2,648 | 14.20 | 3.40 | 20 | 15,700 |
| 2003 | Input | $x_1$ | Total Operating Cost | 1,641,287 | 442,685 | 2,787,269 | 10.36 | 3.04 | 62,312 | 15,141,971 |
| | Output | $y_1$ | Complaints Index | 73 | 79 | 24 | 0.73 | -1.06 | 0 | 103 |
| | | $y_2$ | Total Sewage Treated | 1,564 | 455 | 2,713 | 11.23 | 3.13 | 20 | 15,000 |
| 2004 | Input | $x_1$ | Total Operating Cost | 1,671,144 | 474,883 | 2,788,260 | 9.56 | 2.92 | 49,063 | 15,721,706 |
| | Output | $y_1$ | Complaints Index | 89 | 98 | 27 | 1.52 | -1.38 | 0 | 120 |
| | | $y_2$ | Total Sewage Treated | 1,542 | 506 | 2,555 | 10.47 | 2.99 | 11 | 15,210 |
| Number of utilities: | 100 | of which: | Small = 42<br>Medium = 16<br>Large = 25<br>Very Large = 17 | | | | | | | |

Table 7.4: Descriptive statistics: wastewater input and outputs – Victorian utilities

| Year | Input/Output | Variable | Description | Mean | Median | Standard Deviation | Kurtosis | Skewness | Minimum | Maximum |
|---|---|---|---|---|---|---|---|---|---|---|
| 2001 | Input | $x_1$ | Total Operating Cost | 5,699,936 | 5,138,657 | 4,161,532 | 1.71 | 1.21 | 963,083 | 16,076,846 |
| | Outputs | $y_1$ | Complaints Index | 153 | 157 | 9 | 3.92 | -1.94 | 128 | 159 |
| | | $y_2$ | Total Sewage Treated | 8,059 | 6,187 | 7,937 | 5.43 | 2.13 | 987 | 31,248 |
| 2002 | Input | $x_1$ | Total Operating Cost | 6,048,289 | 5,787,707 | 4,370,894 | 1.11 | 1.09 | 1,096,949 | 16,513,349 |
| | Outputs | $y_1$ | Complaints Index | 153 | 157 | 9 | 3.81 | -1.92 | 128 | 159 |
| | | $y_2$ | Total Sewage Treated | 8,022 | 5,514 | 7,319 | 3.93 | 1.81 | 1,054 | 28,384 |
| 2003 | Input | $x_1$ | Total Operating Cost | 6,341,711 | 5,973,702 | 4,424,788 | 0.89 | 0.98 | 1,161,799 | 16,753,053 |
| | Output | $y_1$ | Complaints Index | 95 | 100 | 12 | 5.97 | -2.30 | 59 | 103 |
| | | $y_2$ | Total Sewage Treated | 7,580 | 5,822 | 6,494 | 3.18 | 1.62 | 1,017 | 25,084 |
| 2004 | Input | $x_1$ | Total Operating Cost | 6,325,182 | 5,682,420 | 4,138,101 | -0.44 | 0.68 | 1,361,700 | 14,730,840 |
| | Output | $y_1$ | Complaints Index | 116 | 119 | 7 | 0.09 | -1.32 | 102 | 120 |
| | | $y_2$ | Total Sewage Treated | 7,979 | 5,990 | 7,377 | 4.92 | 2.01 | 1,234 | 29,201 |
| Number of utilities: | 14 | of which: | Small = 0<br>Medium = 0<br>Large = 2<br>Very Large = 12 | | | | | | | |

In the case of NSW utilities, the movement in Total Operating Cost mimics that of the pooled data base, as does the change in the Complaints Index and Total Wastewater Treated. However, the Victorian subset shows a decline in Total Operating Cost between 2003 and 2004, particularly when measured by the median. When the average cost of treating a megalitre of wastewater is plotted over the period (Figure 7.1), the difference between NSW and Victorian utilities becomes apparent.

Figure 7.1: Average cost of treating a megalitre of sewage: 2001–2004




While average treatment expenses increase for the pooled dataset, this appears to be driven by the utilities in NSW, since Victorian utilities experienced a decrease in average costs in 2004 compared with 2003. Furthermore, the differential between NSW and Victorian utilities exhibits an upward trend through the period. Also apparent from Figure 7.1 is the generally higher cost associated with treating wastewater compared with treating water to a potable standard (Figure 6.1 in Chapter 6).

### 7.2.2 Descriptive statistics – large utilities only

The inclusion of both very large and very small utilities from NSW had the potential to distort the relative performance of those utilities in NSW that were of a similar size to those in Victoria. To control for this, the dataset was truncated such that it included only those utilities that serviced more than 3,000 connections. The associated set of descriptive statistics are reported in Table 7.5.

Table 7.5: Descriptive statistics: wastewater input and outputs – all large utilities

| Year | Input/Output | Variable | Description | Mean | Median | Standard Deviation | Kurtosis | Skewness | Minimum | Maximum |
|---|---|---|---|---|---|---|---|---|---|---|
| 2001 | Input | $x_1$ | Total Operating Cost | 3,738,612 | 2,587,483 | 3,501,319 | 2.73 | 1.66 | 396,441 | 16,076,846 |
| | Outputs | $y_1$ | Complaints Index | 135 | 147 | 28 | 9.50 | -2.53 | 0 | 159 |
| | | $y_2$ | Total Sewage Treated | 4,556 | 2,905 | 5,270 | 11.57 | 2.94 | 415 | 31,248 |
| 2002 | Input | $x_1$ | Total Operating Cost | 4,017,957 | 2,943,465 | 3,761,066 | 1.99 | 1.54 | 384,043 | 16,513,349 |
| | Outputs | $y_1$ | Complaints Index | 134 | 146 | 28 | 8.57 | -2.45 | 0 | 159 |
| | | $y_2$ | Total Sewage Treated | 4,504 | 3,071 | 5,039 | 8.78 | 2.61 | 415 | 28,384 |
| 2003 | Input | $x_1$ | Total Operating Cost | 4,218,759 | 3,008,399 | 3,937,731 | 1.97 | 1.53 | 419,557 | 16,753,053 |
| | Output | $y_1$ | Complaints Index | 76 | 85 | 26 | 1.59 | -1.41 | 0 | 103 |
| | | $y_2$ | Total Sewage Treated | 4,402 | 2,960 | 4,737 | 6.00 | 2.18 | 246 | 25,084 |
| 2004 | Input | $x_1$ | Total Operating Cost | 4,255,662 | 2,994,589 | 3,838,192 | 1.24 | 1.37 | 467,551 | 15,721,706 |
| | Output | $y_1$ | Complaints Index | 93 | 103 | 28 | 2.11 | -1.55 | 0 | 120 |
| | | $y_2$ | Total Sewage Treated | 4,444 | 2,830 | 4,989 | 10.39 | 2.74 | 415 | 29,201 |
| Number of utilities: | 56 | of which: | Small = 0<br>Medium = 0<br>Large = 28<br>Very Large = 28 | | | | | | | |

It would appear from these results that the smaller utilities in NSW were indeed skewing the mean and median of Total Operating Cost, since although both displayed a generally increasing trend, the mean of Total Operating Cost marginally increased in 2004, while the median actually decreased.

This conjecture received additional support when this truncated dataset was further partitioned into two groups, one containing only NSW utilities (Table 7.6) and the other only Victorian utilities (Table 7.7). For both states Total Operating Cost, when measured by the median, declined in 2004.

Table 7.6: Descriptive statistics: wastewater input and outputs – NSW large utilities

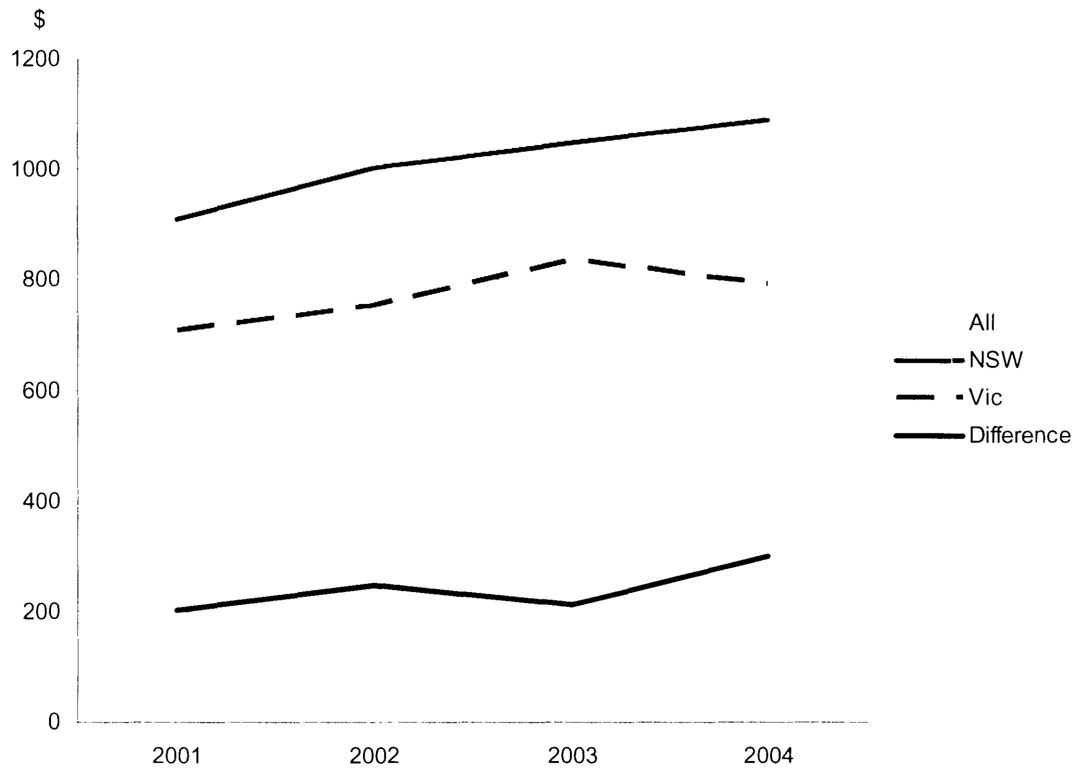
| Year | Input/Output | Variable | Description | Mean | Median | Standard Deviation | Kurtosis | Skewness | Minimum | Maximum |
|---|---|---|---|---|---|---|---|---|---|---|
| 2001 | Input | $x_1$ | Total Operating Cost | 3,084,837 | 2,381,032 | 3,033,603 | 4.00 | 1.95 | 396,441 | 13,962,075 |
| | Outputs | $y_1$ | Complaints Index | 130 | 137 | 29 | 8.19 | -2.34 | 0 | 158 |
| | | $y_2$ | Total Sewage Treated | 3,388 | 2,495 | 3,420 | 5.89 | 2.26 | 415 | 15,540 |
| 2002 | Input | $x_1$ | Total Operating Cost | 3,341,180 | 2,437,120 | 3,322,867 | 3.11 | 1.84 | 384,043 | 14,086,588 |
| | Outputs | $y_1$ | Complaints Index | 128 | 136 | 30 | 7.35 | -2.28 | 0 | 156 |
| | | $y_2$ | Total Sewage Treated | 3,331 | 2,290 | 3,382 | 6.49 | 2.36 | 415 | 15,700 |
| 2003 | Input | $x_1$ | Total Operating Cost | 3,511,108 | 2,581,752 | 3,541,262 | 3.75 | 1.94 | 419,557 | 15,141,971 |
| | Output | $y_1$ | Complaints Index | 70 | 75 | 26 | 1.00 | -1.27 | 0 | 99 |
| | | $y_2$ | Total Sewage Treated | 3,343 | 1,860 | 3,482 | 4.22 | 2.01 | 246 | 15,000 |
| 2004 | Input | $x_1$ | Total Operating Cost | 3,565,822 | 2,499,141 | 3,518,890 | 3.36 | 1.84 | 467,551 | 15,721,706 |
| | Output | $y_1$ | Complaints Index | 86 | 93 | 28 | 1.39 | -1.37 | 0 | 118 |
| | | $y_2$ | Total Sewage Treated | 3,265 | 1,825 | 3,231 | 4.07 | 1.93 | 415 | 15,210 |
| Number of utilities: | 42 | of which: | Small = 0<br>Medium = 0<br>Large = 24<br>Very Large = 18 | | | | | | | |

Table 7.7: Descriptive statistics: wastewater input and outputs – Victorian large utilities

| Year | Input/Output | Variable | Description | Mean | Median | Standard Deviation | Kurtosis | Skewness | Minimum | Maximum |
|---|---|---|---|---|---|---|---|---|---|---|
| 2001 | Input | $x_1$ | Total Operating Cost | 5,699,936 | 5,138,657 | 4,161,532 | 1.71 | 1.21 | 963,083 | 16,076,846 |
| | Outputs | $y_1$ | Complaints Index | 153 | 157 | 9 | 3.92 | -1.94 | 128 | 159 |
| | | $y_2$ | Total Sewage Treated | 8,059 | 6,187 | 7,937 | 5.43 | 2.13 | 987 | 31,248 |
| 2002 | Input | $x_1$ | Total Operating Cost | 6,048,289 | 5,787,707 | 4,370,894 | 1.11 | 1.09 | 1,096,949 | 16,513,349 |
| | Outputs | $y_1$ | Complaints Index | 153 | 157 | 9 | 3.81 | -1.92 | 128 | 159 |
| | | $y_2$ | Total Sewage Treated | 8,022 | 5,514 | 7,319 | 3.93 | 1.81 | 1,054 | 28,384 |
| 2003 | Input | $x_1$ | Total Operating Cost | 6,341,711 | 5,973,702 | 4,424,788 | 0.89 | 0.98 | 1,161,799 | 16,753,053 |
| | Output | $y_1$ | Complaints Index | 95 | 100 | 12 | 5.97 | -2.30 | 59 | 103 |
| | | $y_2$ | Total Sewage Treated | 7,580 | 5,822 | 6,494 | 3.18 | 1.62 | 1,017 | 25,084 |
| 2004 | Input | $x_1$ | Total Operating Cost | 6,325,182 | 5,682,420 | 4,138,101 | -0.44 | 0.68 | 1,361,700 | 14,730,840 |
| | Output | $y_1$ | Complaints Index | 116 | 119 | 7 | 0.09 | -1.32 | 102 | 120 |
| | | $y_2$ | Total Sewage Treated | 7,979 | 5,990 | 7,377 | 4.92 | 2.01 | 1,234 | 29,201 |
| Number of utilities: | 14 | of which: | Small = 0<br>Medium = 0<br>Large = 2<br>Very Large = 12 | | | | | | | |

When expressed in terms of the average cost of treating a megalitre of wastewater, a more familiar pattern emerged, as illustrated in Figure 7.2.

Figure 7.2: Average cost of treating a megalitre of sewage (large NSW utilities): 2001–2004




In a pattern reminiscent of the water operations of larger utilities, NSW utilities were above the average, Victorian utilities were below, and the difference between the two states followed a general positive trend over the period.

## 7.3 Explaining technical and scale efficiency in wastewater utilities

As established in Chapter 4, in contrast to the analysis of relative efficiency in the provision of urban water services, there is a relative paucity of literature on wastewater services. A possible reason is that demand for the treatment of wastewater is largely derived from the consumption of potable water and the preferences of the environmental regulator. However, the efficient treatment of wastewater is no less important than the provision of urban water. It is a matter of crucial importance to public health that sewage is safely and efficiently treated to an acceptable standard, and returned to the environment in a manner that does not generate considerable externalities. Unfortunately, the relative lack of attention to this process has led to a dearth of economic studies to use as a basis for considering variation in the relative technical efficiency of wastewater utilities. Thus, this section of the research was informed by a mixture of engineering considerations, insights from the literature pertaining to urban water systems and advice from industry practitioners. The variables included in the model are outlined in Table 7.8. All data for NSW utilities were sourced from DEUS (2005a), and all data for Victorian RUWAs were supplied from VicWater (2005).

The rationale for the potential inclusion of each variable is outlined below, along with *a priori* expectations; the variables are grouped along similar lines to those employed when summarising the explanatory variables relating to the water businesses in the previous chapter.

Table 7.8: Wastewater explanatory variables – definitions and *a priori* expectations

| **Variable** | **Code** | **Description** | ***a priori* expectation** |
|---|---|---|---|
| | | *Returns to Scale, Economies of Customer and Production Density* | |
| Residential Consumption | $z_2$ | Proportion of connections classified as residential | – |
| Production Density | $z_3$ | Kl of wastewater treated per connection | + |
| Customer Density | $z_4$ | Number of connections per km of main | + |
| Percentage Change in Production Density | $z_5$ | Percentage change in wastewater treated per connection from previous year | + |
| Small utility | $z_{13}$ | Utility serviced up to 1,500 connections | n/a |
| Medium utility | $z_{14}$ | Utility serviced between 1,501 and 3,000 connections | – |
| Large utility | $z_{15}$ | Utility serviced between 3,001 and 10,000 connections | – |
| Very large utility | $z_{16}$ | Utility serviced more than 10,001 connections | – |
| | | *Treatment and pumping expenses* | |
| Sewer main chokes and breaks | $z_6$ | Number of chokes and main breaks per 100km of main | ~ |
| Secondary treatment | $z_7$ | Dummy to reflect majority of wastewater treated to a secondary standard | n/a |
| Tertiary treatment | $z_8$ | Dummy to reflect majority of wastewater treated to a tertiary standard | – |
| Land discharge | $z_9$ | Dummy variable to indicate discharge of treated effluent to land | – |
| Ocean discharge | $z_{10}$ | Dummy variable to indicate discharge of treated effluent to an ocean outfall | + |
| River discharge | $z_{11}$ | Dummy variable to indicate discharge of treated effluent to a river | – |
| | | *Other effects* | |
| RUWA | $z_{12}$ | Dummy variable to identify utility as a Regional Urban Water Authority | + |
| | | *Period* | |
| 2001 | $z_2$ | Year specific dummy variable: 2001 | n/a |
| 2002 | $z_{17}$ | Year specific dummy variable: 2002 | – |
| 2003 | $z_{18}$ | Year specific dummy variable: 2003 | – |
| 2004 | $z_{19}$ | Year specific dummy variable: 2004 | – |

### 7.3.1 Returns to scale, economies of customer and production density

Two sources of evidence indicate the potential for economies arising from customer and production density: that relating to water systems, and that regarding the efficiency, in an engineering sense, of decentralised wastewater networks. In the first instance, similar returns might be expected from production and customer density as those found in water systems, since they are both networks that transport a similar product. However, wastewater systems are typically designed as a branching system similar to that of a tree, where smaller pipes lead into a larger trunk network. This is in contrast to typical water systems that tend to be pressurised loops (Jones and French, 1999). Thus, the addition of customers to a given network might be expected to lead to decreasing returns due to the need for augmentation of trunk lines. This is confirmed to an extent by engineering studies that suggest there are decreasing returns in the network, yet considerable returns to scale at the treatment plant (Mays and Tung, 1992). As a result, measures of customer ( $z_4$ ) and production density ( $z_3$ ) were included; however, there was uncertainty about the expected sign due to the countervailing effects.

Rather than recording the proportion of sewage collected from residential customers, data limitations particular to NSW utilities forced the use of residential connections ( $z_2$ ) to the sewerage network. While it would have been preferable to include the actual quantity of tradewaste passing through the treatment plant, the proxy was expected to detect the presence of any significant relationship between relative operational efficiency and a substantial proportion of tradewaste. There was a reluctance to expect a particular sign, since the extent to which tradewaste must be treated at the treatment plant tends to vary with the particular type of industry and the level to which the waste is treated prior to being released into the sewerage network (VicWater, 2005). It is also influenced by the licensing requirements imposed by the environmental regulator. That is, not all wastewater needs to be treated to the same extent before being returned to the environment.

Lloyd (1993: 69) conveyed the additional burden felt by wastewater authorities from treating tradewaste by invoking an example from the now defunct Shepparton Water Board:

> *Although the Board services a population of approximately 33,000, it estimates that the water and wastewater requirements of major food processing industries within its boundaries are such that it actually services the equivalent residential population of 650,000 or 20 times the actual population.*

Although it is now common practice for wastewater utilities to levy a tradewaste charge, and for specialised connections to the sewerage network to be made at the expense of the industrial customer, disproportionate tradewaste might still be expected to result in lower relative efficiency.

A variable was again included to measure the *change* in production density ($z_5$) from the previous period, since this could reveal consequences for the efficiency of wastewater businesses from water conservation measures. A negative sign on the coefficient was tentatively expected, with the caveat that water conservation primarily impacts on outdoor domestic use, runoff from which seldom returns to the sewer network.

Dummy variables were included to reflect utility size ($z_{14}, z_{15}$ and $z_{16}$), following the same stratification as was applied to the water utilities. Although the specification of the variable returns to scale DEA model should have taken into account scale effects, dummy variables were included to control for the uncertainty associated with the measure of scale employed – the quantity of wastewater treated – rather than a physical measure of network size. An attempt was also made to measure the effect of any increase in regulatory burden imposed on larger utilities. Of course, in analysing the results from the constant returns to scale DEA model, this set of dummy variables will likely be of crucial importance.

### 7.3.2 Treatment and pumping expenses

The major expense arising from operating a wastewater system is that relating to treatment. Accordingly, a range of variables was included to account for differences in the extent to which utilities are required to treat their wastewater. The degree to which sewage is treated depends in part on where the resulting effluent is to be discharged. For instance, a utility that discharges effluent into a river that is both of considerable environmental value and is the source of raw water for a town downstream is required to 'produce' effluent of a quality close to that of the receiving environment. In contrast, effluent that is to be discharged from an ocean outfall might only require rudimentary treatment.

A dummy variable ($z_8$) was included for those utilities that treat to the highest standard (tertiary treatment), and dummy variables accounted for varying discharge points (land ($z_9$), ocean ($z_{10}$) and river ($z_{11}$)). Since some utilities discharge to multiple points, some were assigned dummies for more than one discharge location. It is generally expected that those utilities treating to a tertiary standard will incur greater costs, resulting in a lower relative efficiency score. Consequently, it was expected that those discharging to the ocean would have the lowest treatment expenses, resulting in a positive coefficient, and those discharging to land and river would have higher treatment costs, resulting in negative signs for these variables. However, the magnitude of the coefficient was expected to be higher for those discharging to rivers.

Breaks and chokes in sewer mains are a driver of operation expenses since they must be repaired quickly to minimise spills of raw sewage (Jones and French, 1999). To account for this expense, a variable ( $z_6$ ) was included that measures the number of breaks and chokes per 100km of sewerage main. It was included as an explanatory variable because the majority of breaks and chokes are arguably, and to a limited degree, beyond the direct control of managers. Such incidents usually increase during times of drought as soils shift and put pressure on pipes, and as a result of storm events which cause sewer chokes following the ingress of stormwater. Thus, a degree of uncertainty surrounds the expected sign on this coefficient.

### 7.3.3 Climatic effects

Variables to reflect rainfall were not included due to data limitations. Ideally, a variable would have been included to measure large intense rainfall events, since these tend to result in much higher quantities of stormwater being diverted to treatment plants. This rise is as a result of ingress and illegal connections to the sewerage network. Unfortunately the data were not available, and so climate variables were excluded from this analysis.

### 7.3.4 Institutional effects

A dummy variable for Victorian utilities ( $z_{12}$ ) was included to determine whether, as a group, Victorian wastewater providers were more or less relatively efficient than those in NSW. Based on analysis of the descriptive statistics presented in Table 7.9, a positive coefficient was expected. Finally, dummy variables were included to measure changes in relative efficiency during the period of analysis ( $z_{17}, z_{18}$ and $z_{19}$ ).

## 7.4 Descriptive statistics of wastewater explanatory variables

An identical approach was followed to that used when analysing the explanatory variables relating to the water business, described in the previous chapter. It began by analysing the full panel to include all NSW and Victorian utilities. The descriptive statistics are reported in Table 7.9.

Table 7.9: Descriptive statistics: wastewater explanatory variables

| Year | Variable | Description | Mean | Median | Standard Deviation | Kurtosis | Skewness | Min. | Max. |
|---|---|---|---|---|---|---|---|---|---|
| | ***Continuous variables*** | | | | | | | | |
| 2001 | $z_2$ | Residential Consumption | 90.14 | 90.65 | 3.22 | 4.48 | -1.33 | 75.29 | 96.61 |
| | $z_3$ | Production Density | 276.19 | 266.37 | 125.60 | 16.00 | 2.87 | 88.24 | 1,100.00 |
| | $z_4$ | Customer Density | 35.06 | 35.27 | 10.00 | 5.34 | 1.11 | 13.06 | 86.33 |
| | $z_5$ | Percentage Change in Production Density | 0.04 | 0.00 | 0.33 | 13.79 | 3.15 | -0.76 | 1.75 |
| | $z_6$ | Sewer main chokes and breaks | 59.22 | 33.17 | 79.60 | 17.01 | 3.49 | 0.00 | 576.65 |
| | ***Dummy variables*** | | | | | | | | |
| | **Variable** | **Description** | **Number** | **Variable** | **Description** | **Number** | | | |
| | $z_7$ | Secondary treatment | 106 | $z_{12}$ | RUWA | 14 | | | |
| | $z_8$ | Tertiary treatment | 8 | $z_{13}$ | Small utility | 42 | | | |
| | $z_9$ | Land discharge | 44 | $z_{14}$ | Medium utility | 16 | | | |
| | $z_{10}$ | Ocean discharge | 13 | $z_{15}$ | Large utility | 28 | | | |
| | $z_{11}$ | River discharge | 84 | $z_{16}$ | Very large utility | 28 | | | |

Table 7.9 (continued)

| Year | Variable | Description | Mean | Median | Standard Deviation | Kurtosis | Skewness | Min. | Max. |
|---|---|---|---|---|---|---|---|---|---|
| | ***Continuous variables*** | | | | | | | | |
| 2002 | $z_2$ | Residential Consumption | 90.14 | 90.65 | 3.22 | 4.48 | -1.33 | 75.29 | 96.61 |
| | $z_3$ | Production Density | 276.19 | 266.37 | 125.60 | 16.00 | 2.87 | 88.24 | 1,100.00 |
| | $z_4$ | Customer Density | 35.06 | 35.27 | 10.00 | 5.34 | 1.11 | 13.06 | 86.33 |
| | $z_5$ | Percentage Change in Production Density | 0.04 | 0.00 | 0.33 | 13.79 | 3.15 | -0.76 | 1.75 |
| | $z_6$ | Sewer main chokes and breaks | 59.22 | 33.17 | 79.60 | 17.01 | 3.49 | 0.00 | 576.65 |
| | ***Dummy variables*** | | | | | | | | |
| | **Variable** | **Description** | **Number** | **Variable** | **Description** | **Number** | | | |
| | $z_7$ | Secondary treatment | 106 | $z_{12}$ | RUWA | 14 | | | |
| | $z_8$ | Tertiary treatment | 8 | $z_{13}$ | Small utility | 42 | | | |
| | $z_9$ | Land discharge | 44 | $z_{14}$ | Medium utility | 16 | | | |
| | $z_{10}$ | Ocean discharge | 13 | $z_{15}$ | Large utility | 28 | | | |
| | $z_{11}$ | River discharge | 84 | $z_{16}$ | Very large utility | 28 | | | |

Table 7.9 (continued)

| Year | Variable | Description | Mean | Median | Standard Deviation | Kurtosis | Skewness | Min. | Max. |
|---|---|---|---|---|---|---|---|---|---|
| | ***Continuous variables*** | | | | | | | | |
| 2003 | $z_2$ | Residential Consumption | 90.14 | 90.65 | 3.22 | 4.48 | -1.33 | 75.29 | 96.61 |
| | $z_3$ | Production Density | 276.19 | 266.37 | 125.60 | 16.00 | 2.87 | 88.24 | 1,100.00 |
| | $z_4$ | Customer Density | 35.06 | 35.27 | 10.00 | 5.34 | 1.11 | 13.06 | 86.33 |
| | $z_5$ | Percentage Change in Production Density | 0.04 | 0.00 | 0.33 | 13.79 | 3.15 | -0.76 | 1.75 |
| | $z_6$ | Sewer main chokes and breaks | 59.22 | 33.17 | 79.60 | 17.01 | 3.49 | 0.00 | 576.65 |
| | ***Dummy variables*** | | | | | | | | |
| | **Variable** | **Description** | **Number** | **Variable** | **Description** | **Number** | | | |
| | $z_7$ | Secondary treatment | 106 | $z_{12}$ | RUWA | 14 | | | |
| | $z_8$ | Tertiary treatment | 8 | $z_{13}$ | Small utility | 42 | | | |
| | $z_9$ | Land discharge | 44 | $z_{14}$ | Medium utility | 16 | | | |
| | $z_{10}$ | Ocean discharge | 13 | $z_{15}$ | Large utility | 28 | | | |
| | $z_{11}$ | River discharge | 84 | $z_{16}$ | Very large utility | 28 | | | |

Table 7.9 (continued)

| Year | Variable | Description | Mean | Median | Standard Deviation | Kurtosis | Skewness | Min. | Max. |
|---|---|---|---|---|---|---|---|---|---|
| | ***Continuous variables*** | | | | | | | | |
| 2004 | $z_2$ | Residential Consumption | 90.14 | 90.65 | 3.22 | 4.48 | -1.33 | 75.29 | 96.61 |
| | $z_3$ | Production Density | 276.19 | 266.37 | 125.60 | 16.00 | 2.87 | 88.24 | 1,100.00 |
| | $z_4$ | Customer Density | 35.06 | 35.27 | 10.00 | 5.34 | 1.11 | 13.06 | 86.33 |
| | $z_5$ | Percentage Change in Production Density | 0.04 | 0.00 | 0.33 | 13.79 | 3.15 | -0.76 | 1.75 |
| | $z_6$ | Sewer main chokes and breaks | 59.22 | 33.17 | 79.60 | 17.01 | 3.49 | 0.00 | 576.65 |

| | ***Dummy variables*** | | | | | |
|---|---|---|---|---|---|---|
| | **Variable** | **Description** | **Number** | **Variable** | **Description** | **Number** |
| | $z_7$ | Secondary treatment | 106 | $z_{12}$ | RUWA | 14 |
| | $z_8$ | Tertiary treatment | 8 | $z_{13}$ | Small utility | 42 |
| | $z_9$ | Land discharge | 44 | $z_{14}$ | Medium utility | 16 |
| | $z_{10}$ | Ocean discharge | 13 | $z_{15}$ | Large utility | 28 |
| | $z_{11}$ | River discharge | 84 | $z_{16}$ | Very large utility | 28 |

A number of patterns emerge from the data during the period. First, the proportion of residential connections ( $z_2$ ) and customer density ( $z_4$ ) remained relatively constant and stable over the four years. Second, the average change in production density ( $z_5$ ) declined during 2002 and 2003 before sharply increasing in 2004. Average production density ( $z_3$ ) followed a generally downward trend during the period, and was on average around 50 to 60 per cent lower than the corresponding figure for the potable water sector. This is in line with expectations that the quantity of sewage treated would be less than the quantity of water supplied due to some proportion of potable water being used outdoors.

In an unexpected finding, the number of chokes and breaks to a sewer mains ( $z_6$ ) remained steady at around 58 per 100 km throughout the period. An increase might have been expected in either 2003 or 2004 due to the shifting of soil associated with the drought. It could also be related to the tendency for NSW wastewater utilities to report relatively fewer of the breaks in the sewer network. Furthermore, detection of breaks in sewer pipes may be relatively more difficult in this case since, unlike potable water mains, sewerage pipes are not pressurised.

In terms of variables to take into account treatment and disposal characteristics, seven per cent of utilities treated to a tertiary standard ( $z_8$ ), while the most common location for the discharge of effluent was a river ( $z_{11}$ ) followed by disposal to the land ( $z_9$ ). The least common disposal point was an ocean outfall ( $z_{10}$ ), a result that was expected since the majority of utilities were located away from the coast. The smallest size category ( $z_{13}$ ) dominated the sample.

### 7.4.1 Descriptive statistics by state

Tables 7.10 and 7.11 provide the descriptive statistics for wastewater explanatory variables for NSW and Victorian utilities, respectively.

Table 7.10: Descriptive statistics: wastewater explanatory variables – NSW utilities

| Year | Variable | Description | Mean | Median | Standard Deviation | Kurtosis | Skewness | Min. | Max. |
|---|---|---|---|---|---|---|---|---|---|
| | ***Continuous variables*** | | | | | | | | |
| 2001 | $z_2$ | Residential Consumption | 90.12 | 90.78 | 3.21 | 5.23 | -1.63 | 75.29 | 95.92 |
| | $z_3$ | Production Density | 275.09 | 267.02 | 125.33 | 18.25 | 3.08 | 88.24 | 1,100.00 |
| | $z_4$ | Customer Density | 34.77 | 34.31 | 10.51 | 4.95 | 1.16 | 13.06 | 86.33 |
| | $z_5$ | Percentage Change in Production Density | 0.04 | 0.00 | 0.35 | 12.28 | 3.03 | -0.76 | 1.75 |
| | $z_6$ | Sewer main chokes and breaks | 63.24 | 34.10 | 83.66 | 15.16 | 3.31 | 0.00 | 576.65 |
| | ***Dummy variables*** | | | | | | | | |
| | **Variable** | **Description** | **Number** | **Variable** | **Description** | **Number** | | | |
| | $z_7$ | Secondary treatment | 95 | $z_{12}$ | RUWA | 0 | | | |
| | $z_8$ | Tertiary treatment | 5 | $z_{13}$ | Small utility | 42 | | | |
| | $z_9$ | Land discharge | 44 | $z_{14}$ | Medium utility | 16 | | | |
| | $z_{10}$ | Ocean discharge | 8 | $z_{15}$ | Large utility | 25 | | | |
| | $z_{11}$ | River discharge | 73 | $z_{16}$ | Very large utility | 17 | | | |

Table 7.10 (continued)

| Year | Variable | Description | Mean | Median | Standard Deviation | Kurtosis | Skewness | Min. | Max. |
|---|---|---|---|---|---|---|---|---|---|
| | ***Continuous variables*** | | | | | | | | |
| 2002 | $z_2$ | Residential Consumption | 90.27 | 90.60 | 3.11 | 5.47 | -1.57 | 75.29 | 95.61 |
| | $z_3$ | Production Density | 251.57 | 248.89 | 89.25 | 4.52 | 1.25 | 86.27 | 663.08 |
| | $z_4$ | Customer Density | 34.34 | 34.99 | 10.81 | 4.82 | 0.84 | 3.36 | 86.18 |
| | $z_5$ | Percentage Change in Production Density | -0.03 | -0.01 | 0.22 | 10.29 | 0.97 | -0.75 | 1.14 |
| | $z_6$ | Sewer main chokes and breaks | 62.13 | 35.75 | 81.98 | 17.02 | 3.56 | 0.00 | 576.65 |
| | ***Dummy variables*** | | | | | | | | |
| | **Variable** | **Description** | **Number** | **Variable** | **Description** | **Number** | | | |
| | $z_7$ | Secondary treatment | 95 | $z_{12}$ | RUWA | 0 | | | |
| | $z_8$ | Tertiary treatment | 5 | $z_{13}$ | Small utility | 42 | | | |
| | $z_9$ | Land discharge | 44 | $z_{14}$ | Medium utility | 16 | | | |
| | $z_{10}$ | Ocean discharge | 8 | $z_{15}$ | Large utility | 24 | | | |
| | $z_{11}$ | River discharge | 73 | $z_{16}$ | Very large utility | 18 | | | |

Table 7.10 (continued)

| Year | Variable | Description | Mean | Median | Standard Deviation | Kurtosis | Skewness | Min. | Max. |
|---|---|---|---|---|---|---|---|---|---|
| | ***Continuous variables*** | | | | | | | | |
| 2003 | $z_2$ | Residential Consumption | 89.97 | 90.52 | 3.53 | 2.80 | -1.15 | 75.29 | 96.28 |
| | $z_3$ | Production Density | 225.97 | 227.78 | 77.22 | 5,963.30 | 0.70 | 0.34 | 56.79 |
| | $z_4$ | Customer Density | 34.50 | 34.84 | 8.47 | -0.05 | -0.09 | 13.15 | 54.76 |
| | $z_5$ | Percentage Change in Production Density | -0.07 | -0.04 | 0.18 | 7.05 | -1.49 | -0.88 | 0.54 |
| | $z_6$ | Sewer main chokes and breaks | 61.78 | 43.50 | 59.51 | 5.43 | 2.09 | 4.57 | 335.66 |
| | ***Dummy variables*** | | | | | | | | |
| | **Variable** | **Description** | **Number** | **Variable** | **Description** | **Number** | | | |
| | $z_7$ | Secondary treatment | 95 | $z_{12}$ | RUWA | 0 | | | |
| | $z_8$ | Tertiary treatment | 5 | $z_{13}$ | Small utility | 42 | | | |
| | $z_9$ | Land discharge | 44 | $z_{14}$ | Medium utility | 16 | | | |
| | $z_{10}$ | Ocean discharge | 8 | $z_{15}$ | Large utility | 24 | | | |
| | $z_{11}$ | River discharge | 73 | $z_{16}$ | Very large utility | 18 | | | |

Table 7.10 (continued)

| Year | Variable | Description | Mean | Median | Standard Deviation | Kurtosis | Skewness | Min. | Max. |
|---|---|---|---|---|---|---|---|---|---|
| | ***Continuous variables*** | | | | | | | | |
| 2004 | $z_2$ | Residential Consumption | 89.97 | 90.23 | 3.45 | 1.26 | -0.81 | 78.45 | 96.28 |
| | $z_3$ | Production Density | 229.87 | 224.81 | 71.46 | 0.63 | 0.38 | 50.58 | 448.28 |
| | $z_4$ | Customer Density | 34.90 | 34.29 | 12.49 | 15.14 | 2.57 | 11.92 | 113.77 |
| | $z_5$ | Percentage Change in Production Density | 0.09 | 0.02 | 0.44 | 50.15 | 6.25 | -0.45 | 3.76 |
| | $z_6$ | Sewer main chokes and breaks | 62.36 | 38.29 | 77.13 | 23.57 | 4.02 | 1.39 | 598.80 |
| | ***Dummy variables*** | | | | | | | | |
| | **Variable** | **Description** | **Number** | **Variable** | **Description** | **Number** | | | |
| | $z_7$ | Secondary treatment | 95 | $z_{12}$ | RUWA | 0 | | | |
| | $z_8$ | Tertiary treatment | 5 | $z_{13}$ | Small utility | 42 | | | |
| | $z_9$ | Land discharge | 44 | $z_{14}$ | Medium utility | 17 | | | |
| | $z_{10}$ | Ocean discharge | 8 | $z_{15}$ | Large utility | 23 | | | |
| | $z_{11}$ | River discharge | 73 | $z_{16}$ | Very large utility | 18 | | | |

Table 7.11: Descriptive statistics: wastewater explanatory variables – Victorian utilities

| Year | Variable | Description | Mean | Median | Standard Deviation | Kurtosis | Skewness | Min. | Max. |
|---|---|---|---|---|---|---|---|---|---|
| | ***Continuous variables*** | | | | | | | | |
| 2001 | $z_2$ | Residential Consumption | 90.27 | 89.92 | 3.40 | -0.16 | 0.63 | 85.01 | 96.61 |
| | $z_3$ | Production Density | 284.05 | 258.71 | 132.00 | 3.94 | 1.65 | 103.54 | 648.58 |
| | $z_4$ | Customer Density | 37.13 | 36.10 | 4.76 | -0.16 | -0.08 | 27.62 | 44.59 |
| | $z_5$ | Percentage Change in Production Density | 0.05 | 0.05 | 0.12 | 2.60 | -0.77 | -0.25 | 0.27 |
| | $z_6$ | Sewer main chokes and breaks | 30.48 | 26.49 | 27.60 | 2.31 | 1.44 | 0.00 | 101.45 |
| | ***Dummy variables*** | | | | | | | | |
| | **Variable** | **Description** | **Number** | **Variable** | **Description** | **Number** | | | |
| | $z_7$ | Secondary treatment | 11 | $z_{12}$ | RUWA | 14 | | | |
| | $z_8$ | Tertiary treatment | 3 | $z_{13}$ | Small utility | 0 | | | |
| | $z_9$ | Land discharge | 0 | $z_{14}$ | Medium utility | 0 | | | |
| | $z_{10}$ | Ocean discharge | 5 | $z_{15}$ | Large utility | 3 | | | |
| | $z_{11}$ | River discharge | 11 | $z_{16}$ | Very large utility | 11 | | | |

Table 7.11 (continued)

| Year | Variable | Description | Mean | Median | Standard Deviation | Kurtosis | Skewness | Min. | Max. |
|---|---|---|---|---|---|---|---|---|---|
| | ***Continuous variables*** | | | | | | | | |
| 2002 | $z_2$ | Residential Consumption | 89.89 | 89.96 | 2.97 | 0.84 | 0.64 | 85.06 | 96.67 |
| | $z_3$ | Production Density | 281.84 | 260.66 | 112.34 | 3.51 | 1.37 | 105.54 | 584.03 |
| | $z_4$ | Customer Density | 37.76 | 36.55 | 5.00 | -0.32 | -0.03 | 28.04 | 45.37 |
| | $z_5$ | Percentage Change in Production Density | 0.03 | 0.04 | 0.10 | 0.69 | -0.34 | -0.18 | 0.20 |
| | $z_6$ | Sewer main chokes and breaks | 31.38 | 22.71 | 29.49 | 2.40 | 1.75 | 4.71 | 103.75 |
| | ***Dummy variables*** | | | | | | | | |
| | **Variable** | **Description** | **Number** | **Variable** | **Description** | **Number** | | | |
| | $z_7$ | Secondary treatment | 11 | $z_{12}$ | RUWA | 14 | | | |
| | $z_8$ | Tertiary treatment | 3 | $z_{13}$ | Small utility | 0 | | | |
| | $z_9$ | Land discharge | 0 | $z_{14}$ | Medium utility | 0 | | | |
| | $z_{10}$ | Ocean discharge | 5 | $z_{15}$ | Large utility | 3 | | | |
| | $z_{11}$ | River discharge | 11 | $z_{16}$ | Very large utility | 11 | | | |

Table 7.11 (continued)

| Year | Variable | Description | Mean | Median | Standard Deviation | Kurtosis | Skewness | Min. | Max. |
|---|---|---|---|---|---|---|---|---|---|
| | ***Continuous variables*** | | | | | | | | |
| 2003 | $z_2$ | Residential Consumption | 90.00 | 90.16 | 2.94 | 0.80 | 0.65 | 85.22 | 96.69 |
| | $z_3$ | Production Density | 263.59 | 242.82 | 98.54 | 2.23 | 0.94 | 94.89 | 510.17 |
| | $z_4$ | Customer Density | 38.86 | 37.35 | 5.38 | -0.20 | 0.06 | 28.50 | 47.62 |
| | $z_5$ | Percentage Change in Production Density | -0.03 | -0.04 | 0.06 | 3.75 | 1.45 | -0.12 | 0.12 |
| | $z_6$ | Sewer main chokes and breaks | 32.82 | 26.85 | 29.76 | 7.67 | 2.53 | 3.73 | 125.00 |
| | ***Dummy variables*** | | | | | | | | |
| | **Variable** | **Description** | **Number** | **Variable** | **Description** | **Number** | | | |
| | $z_7$ | Secondary treatment | 11 | $z_{12}$ | RUWA | 14 | | | |
| | $z_8$ | Tertiary treatment | 3 | $z_{13}$ | Small utility | 0 | | | |
| | $z_9$ | Land discharge | 0 | $z_{14}$ | Medium utility | 0 | | | |
| | $z_{10}$ | Ocean discharge | 5 | $z_{15}$ | Large utility | 2 | | | |
| | $z_{11}$ | River discharge | 11 | $z_{16}$ | Very large utility | 12 | | | |

Table 7.11 (continued)

| Year | Variable | Description | Mean | Median | Standard Deviation | Kurtosis | Skewness | Min. | Max. |
|---|---|---|---|---|---|---|---|---|---|
| | ***Continuous variables*** | | | | | | | | |
| 2004 | $z_2$ | Residential Consumption | 89.57 | 89.16 | 2.88 | 3.92 | 1.47 | 85.18 | 97.47 |
| | $z_3$ | Production Density | 272.10 | 237.73 | 118.16 | 5.01 | 1.83 | 108.02 | 610.87 |
| | $z_4$ | Customer Density | 38.19 | 38.12 | 4.54 | 0.47 | 0.03 | 28.99 | 45.96 |
| | $z_5$ | Percentage Change in Production Density | 0.05 | 0.02 | 0.08 | 0.02 | 1.14 | -0.04 | 0.21 |
| | $z_6$ | Sewer main chokes and breaks | 36.56 | 29.37 | 27.56 | 1.30 | 1.26 | 2.79 | 102.05 |
| | ***Dummy variables*** | | | | | | | | |
| | **Variable** | **Description** | **Number** | **Variable** | **Description** | **Number** | | | |
| | $z_7$ | Secondary treatment | 10 | $z_{12}$ | RUWA | 14 | | | |
| | $z_8$ | Tertiary treatment | 4 | $z_{13}$ | Small utility | 0 | | | |
| | $z_9$ | Land discharge | 0 | $z_{14}$ | Medium utility | 0 | | | |
| | $z_{10}$ | Ocean discharge | 5 | $z_{15}$ | Large utility | 2 | | | |
| | $z_{11}$ | River discharge | 11 | $z_{16}$ | Very large utility | 12 | | | |

Turning to an analysis of the states in isolation, only a small number of variations were detected. The most important of these related to the Victorian utilities. Production density ( $z_3$ ) in Victoria followed a similar trend to the pooled database; however, it was of a higher magnitude. Around 21 per cent of Victorian utilities treated sewage to a tertiary standard ( $z_8$ ), as opposed to only five per cent in NSW. With respect to disposal, all of the Victorian utilities disposed of the majority of effluent either into a river ( $z_{11}$ ) or via an ocean outfall ( $z_{10}$ ). This may reflect the relative abundance of suitable rivers in Victoria, compared with NSW. Also of note was that most of the utilities in Victoria serviced in excess of 10,000 connections ( $z_{16}$ ).

### 7.4.2 Descriptive statistics – large utilities only

Tables 7.12 and 7.13 give the descriptive statistics for the wastewater explanatory variables for large utilities, both overall (7.12) and for NSW (7.13).

Table 7.12: Descriptive statistics: wastewater explanatory variables – large utilities

| Year | Variable | Description | Mean | Median | Standard Deviation | Kurtosis | Skewness | Min. | Max. |
|---|---|---|---|---|---|---|---|---|---|
| | ***Continuous variables*** | | | | | | | | |
| 2001 | $z_2$ | Residential Consumption | 90.90 | 91.28 | 3.34 | 7.65 | -1.84 | 75.29 | 96.61 |
| | $z_3$ | Production Density | 276.85 | 272.74 | 84.37 | 6.04 | 1.52 | 103.54 | 648.58 |
| | $z_4$ | Customer Density | 38.83 | 38.02 | 9.86 | 9.73 | 1.81 | 13.69 | 86.33 |
| | $z_5$ | Percentage Change in Production Density | 0.01 | 0.01 | 0.12 | 1.98 | -0.60 | -0.38 | 0.28 |
| | $z_6$ | Sewer main chokes and breaks | 60.32 | 32.83 | 88.50 | 21.34 | 4.09 | 0.00 | 576.65 |
| | ***Dummy variables*** | | | | | | | | |
| | **Variable** | **Description** | **Number** | **Variable** | **Description** | **Number** | | | |
| | $z_7$ | Secondary treatment | 49 | $z_{12}$ | RUWA | 14 | | | |
| | $z_8$ | Tertiary treatment | 7 | $z_{13}$ | Small utility | 0 | | | |
| | $z_9$ | Land discharge | 15 | $z_{14}$ | Medium utility | 0 | | | |
| | $z_{10}$ | Ocean discharge | 13 | $z_{15}$ | Large utility | 28 | | | |
| | $z_{11}$ | River discharge | 47 | $z_{16}$ | Very large utility | 28 | | | |

Table 7.12 (continued)

| Year | Variable | Description | Mean | Median | Standard Deviation | Kurtosis | Skewness | Min. | Max. |
|---|---|---|---|---|---|---|---|---|---|
| | ***Continuous variables*** | | | | | | | | |
| 2002 | $z_2$ | Residential Consumption | 91.00 | 91.42 | 3.23 | 9.15 | -2.12 | 75.29 | 96.67 |
| | $z_3$ | Production Density | 269.15 | 266.19 | 67.40 | 8.14 | 1.53 | 105.54 | 584.03 |
| | $z_4$ | Customer Density | 38.58 | 37.21 | 9.93 | 9.55 | 1.75 | 13.64 | 86.18 |
| | $z_5$ | Percentage Change in Production Density | 0.01 | 0.00 | 0.11 | 0.82 | 0.25 | -0.24 | 0.33 |
| | $z_6$ | Sewer main chokes and breaks | 60.45 | 33.83 | 89.25 | 21.46 | 4.20 | 3.66 | 576.65 |
| | ***Dummy variables*** | | | | | | | | |
| | **Variable** | **Description** | **Number** | **Variable** | **Description** | **Number** | | | |
| | $z_7$ | Secondary treatment | 49 | $z_{12}$ | RUWA | 14 | | | |
| | $z_8$ | Tertiary treatment | 7 | $z_{13}$ | Small utility | 0 | | | |
| | $z_9$ | Land discharge | 15 | $z_{14}$ | Medium utility | 0 | | | |
| | $z_{10}$ | Ocean discharge | 13 | $z_{15}$ | Large utility | 27 | | | |
| | $z_{11}$ | River discharge | 48 | $z_{16}$ | Very large utility | 29 | | | |

Table 7.12 (continued)

| Year | Variable | Description | Mean | Median | Standard Deviation | Kurtosis | Skewness | Min. | Max. |
|---|---|---|---|---|---|---|---|---|---|
| | ***Continuous variables*** | | | | | | | | |
| 2003 | $z_2$ | Residential Consumption | 91.20 | 91.60 | 3.32 | 8.56 | -1.98 | 75.29 | 96.69 |
| | $z_3$ | Production Density | 252.53 | 241.64 | 74.19 | 2.75 | 0.75 | 68.34 | 510.17 |
| | $z_4$ | Customer Density | 38.06 | 37.35 | 6.58 | 2.50 | -0.66 | 13.63 | 53.88 |
| | $z_5$ | Percentage Change in Production Density | -0.04 | -0.04 | 0.16 | 8.83 | -0.58 | -0.75 | 0.54 |
| | $z_6$ | Sewer main chokes and breaks | 52.80 | 35.06 | 52.72 | 4.93 | 2.12 | 3.73 | 266.35 |
| | ***Dummy variables*** | | | | | | | | |
| | **Variable** | **Description** | **Number** | **Variable** | **Description** | **Number** | | | |
| | $z_7$ | Secondary treatment | 49 | $z_{12}$ | RUWA | 14 | | | |
| | $z_8$ | Tertiary treatment | 7 | $z_{13}$ | Small utility | 0 | | | |
| | $z_9$ | Land discharge | 15 | $z_{14}$ | Medium utility | 0 | | | |
| | $z_{10}$ | Ocean discharge | 13 | $z_{15}$ | Large utility | 26 | | | |
| | $z_{11}$ | River discharge | 48 | $z_{16}$ | Very large utility | 30 | | | |

Table 7.12 (continued)

| Year | Variable | Description | Mean | Median | Standard Deviation | Kurtosis | Skewness | Min. | Max. |
|---|---|---|---|---|---|---|---|---|---|
| | ***Continuous variables*** | | | | | | | | |
| 2004 | $z_2$ | Residential Consumption | 91.05 | 91.26 | 3.07 | 4.09 | -1.11 | 78.45 | 97.47 |
| | $z_3$ | Production Density | 254.96 | 237.25 | 79.15 | 6.45 | 1.73 | 108.02 | 610.87 |
| | $z_4$ | Customer Density | 38.05 | 37.14 | 6.81 | 2.37 | -0.55 | 13.19 | 54.99 |
| | $z_5$ | Percentage Change in Production Density | 0.08 | 0.01 | 0.51 | 50.41 | 6.92 | -0.35 | 3.76 |
| | $z_6$ | Sewer main chokes and breaks | 55.17 | 40.84 | 47.94 | 1.27 | 1.37 | 2.79 | 187.10 |
| | ***Dummy variables*** | | | | | | | | |
| | **Variable** | **Description** | **Number** | **Variable** | **Description** | **Number** | | | |
| | $z_7$ | Secondary treatment | 48 | $z_{12}$ | RUWA | 14 | | | |
| | $z_8$ | Tertiary treatment | 8 | $z_{13}$ | Small utility | 0 | | | |
| | $z_9$ | Land discharge | 15 | $z_{14}$ | Medium utility | 0 | | | |
| | $z_{10}$ | Ocean discharge | 13 | $z_{15}$ | Large utility | 26 | | | |
| | $z_{11}$ | River discharge | 48 | $z_{16}$ | Very large utility | 30 | | | |

Table 7.13: Descriptive statistics: wastewater explanatory variables – large utilities in NSW

| Year | Variable | Description | Mean | Median | Standard Deviation | Kurtosis | Skewness | Min. | Max. |
|---|---|---|---|---|---|---|---|---|---|
| | ***Continuous variables*** | | | | | | | | |
| 2001 | $z_2$ | Residential Consumption | 91.74 | 3.33 | 11.83 | -2.70 | 75.29 | 95.92 | 95.92 |
| | $z_3$ | Production Density | 273.39 | 63.26 | 1.11 | 0.24 | 129.69 | 460.00 | 460.00 |
| | $z_4$ | Customer Density | 38.54 | 11.04 | 7.77 | 1.62 | 13.69 | 86.33 | 86.33 |
| | $z_5$ | Percentage Change in Production Density | 0.01 | 0.12 | 2.41 | -0.61 | -0.38 | 0.28 | 0.28 |
| | $z_6$ | Sewer main chokes and breaks | 37.79 | 99.30 | 16.61 | 3.64 | 0.00 | 576.65 | 576.65 |
| | ***Dummy variables*** | | | | | | | | |
| | **Variable** | **Description** | **Number** | **Variable** | **Description** | **Number** | | | |
| | $z_7$ | Secondary treatment | 38 | $z_{12}$ | RUWA | 0 | | | |
| | $z_8$ | Tertiary treatment | 4 | $z_{13}$ | Small utility | 0 | | | |
| | $z_9$ | Land discharge | 15 | $z_{14}$ | Medium utility | 0 | | | |
| | $z_{10}$ | Ocean discharge | 8 | $z_{15}$ | Large utility | 25 | | | |
| | $z_{11}$ | River discharge | 36 | $z_{16}$ | Very large utility | 17 | | | |

Table 7.13 (continued)

| Year | Variable | Description | Mean | Median | Standard Deviation | Kurtosis | Skewness | Min. | Max. |
|---|---|---|---|---|---|---|---|---|---|
| | ***Continuous variables*** | | | | | | | | |
| 2002 | $z_2$ | Residential Consumption | 91.95 | 3.26 | 13.93 | -3.00 | 75.29 | 95.61 | 95.61 |
| | $z_3$ | Production Density | 266.80 | 44.93 | 1.15 | -0.57 | 125.76 | 356.20 | 356.20 |
| | $z_4$ | Customer Density | 37.56 | 11.14 | 7.74 | 1.62 | 13.64 | 86.18 | 86.18 |
| | $z_5$ | Percentage Change in Production Density | 0.00 | 0.11 | 1.27 | 0.44 | -0.24 | 0.33 | 0.33 |
| | $z_6$ | Sewer main chokes and breaks | 37.76 | 100.12 | 16.74 | 3.76 | 3.66 | 576.65 | 576.65 |
| | ***Dummy variables*** | | | | | | | | |
| | **Variable** | **Description** | **Number** | **Variable** | **Description** | **Number** | | | |
| | $z_7$ | Secondary treatment | 38 | $z_{12}$ | RUWA | 14 | | | |
| | $z_8$ | Tertiary treatment | 4 | $z_{13}$ | Small utility | 0 | | | |
| | $z_9$ | Land discharge | 15 | $z_{14}$ | Medium utility | 0 | | | |
| | $z_{10}$ | Ocean discharge | 8 | $z_{15}$ | Large utility | 24 | | | |
| | $z_{11}$ | River discharge | 37 | $z_{16}$ | Very large utility | 18 | | | |

Table 7.13 (continued)

| Year | Variable | Description | Mean | Median | Standard Deviation | Kurtosis | Skewness | Min. | Max. |
|---|---|---|---|---|---|---|---|---|---|
| | ***Continuous variables*** | | | | | | | | |
| 2003 | $z_2$ | Residential Consumption | 92.24 | 3.37 | 12.79 | -2.78 | 75.29 | 96.28 | 96.28 |
| | $z_3$ | Production Density | 241.64 | 65.19 | 2.51 | 0.36 | 68.34 | 446.55 | 446.55 |
| | $z_4$ | Customer Density | 37.53 | 6.97 | 2.58 | -0.71 | 13.63 | 53.88 | 53.88 |
| | $z_5$ | Percentage Change in Production Density | -0.04 | 0.18 | 6.60 | -0.51 | -0.75 | 0.54 | 0.54 |
| | $z_6$ | Sewer main chokes and breaks | 43.50 | 57.14 | 3.75 | 1.90 | 4.57 | 266.35 | 266.35 |
| | ***Dummy variables*** | | | | | | | | |
| | **Variable** | **Description** | **Number** | **Variable** | **Description** | **Number** | | | |
| | $z_7$ | Secondary treatment | 38 | $z_{12}$ | RUWA | 0 | | | |
| | $z_8$ | Tertiary treatment | 4 | $z_{13}$ | Small utility | 0 | | | |
| | $z_9$ | Land discharge | 15 | $z_{14}$ | Medium utility | 0 | | | |
| | $z_{10}$ | Ocean discharge | 8 | $z_{15}$ | Large utility | 24 | | | |
| | $z_{11}$ | River discharge | 37 | $z_{16}$ | Very large utility | 18 | | | |

Table 7.13 (continued)

| Year | Variable | Description | Mean | Median | Standard Deviation | Kurtosis | Skewness | Min. | Max. |
|---|---|---|---|---|---|---|---|---|---|
| | ***Continuous variables*** | | | | | | | | |
| 2004 | $z_2$ | Residential Consumption | 92.09 | 3.00 | 7.86 | -2.01 | 78.45 | 96.28 | 96.28 |
| | $z_3$ | Production Density | 237.07 | 61.99 | 0.55 | 0.57 | 125.76 | 431.67 | 431.67 |
| | $z_4$ | Customer Density | 36.86 | 7.46 | 1.97 | -0.56 | 13.19 | 54.99 | 54.99 |
| | $z_5$ | Percentage Change in Production Density | 0.00 | 0.59 | 38.38 | 6.07 | -0.35 | 3.76 | 3.76 |
| | $z_6$ | Sewer main chokes and breaks | 45.94 | 51.81 | 0.49 | 1.16 | 6.01 | 187.10 | 187.10 |
| | ***Dummy variables*** | | | | | | | | |
| | **Variable** | **Description** | **Number** | **Variable** | **Description** | **Number** | | | |
| | $z_7$ | Secondary treatment | 38 | $z_{12}$ | RUWA | 0 | | | |
| | $z_8$ | Tertiary treatment | 4 | $z_{13}$ | Small utility | 0 | | | |
| | $z_9$ | Land discharge | 15 | $z_{14}$ | Medium utility | 0 | | | |
| | $z_{10}$ | Ocean discharge | 8 | $z_{15}$ | Large utility | 24 | | | |
| | $z_{11}$ | River discharge | 37 | $z_{16}$ | Very large utility | 18 | | | |

In general, there was very little difference in the pattern of variable change between all utilities in the panel and the truncated dataset of large utilities servicing more than 3,000 connections. However, there were a number of notable exceptions. First, production density ( $z_3$ ) fell through the period at a much slower rate than that observed for the entire panel. Again, this may reflect a higher proportion of industrial users who are unable or unwilling to reduce sewage quantities. Second, customer density ( $z_4$ ) was slightly higher, at around three more properties per 100km of sewer main, for larger utilities. Finally, seven of the eight utilities that treated sewer to a tertiary standard ( $z_8$ ) were large or very large. When looking at only the NSW councils in this truncated dataset, customer density ( $z_4$ ) was higher than that for the sample of all NSW councils; these larger utilities also had around eight more chokes and breaks per 100km of sewer mains ( $z_6$ ), an outcome possibly related to more accurate reporting by larger utilities.

## 7.5 Concluding remarks

The purpose of this chapter was two-fold. First, the potential inputs and outputs to be included in the DEA model outlined in Chapter 5 were described, and the rationale underpinning the chosen variables was presented. In order to provide a backdrop for the analysis that is to follow in Chapter 9, a number of descriptive statistics were presented and analysed. Very similar patterns in the variables to those observed when analysing water utilities were repeated with respect to wastewater utilities. Victorian utilities appear to have a relative cost advantage over their counterparts in NSW, and the combination of generally increasing costs coupled with decreasing wastewater treated was repeated.

Given the relative dearth of empirical studies relating to the relative efficiency of wastewater utilities, it proved difficult to be guided by the literature in selecting exogenous variables with the potential to explain variation in relative efficiency. However, after having sought guidance from engineering considerations, and studies relating to networks in general, a set of potential explanatory variables were specified.

Analysis of the descriptive statistics relating to each also led to a number of tentative conclusions being drawn. Victorian utilities treated a greater proportion of sewage to a tertiary standard (21 per cent) compared with only five per cent in NSW. With respect to size differences, all Victorian utilities were in the two largest size groups, while utilities in the two largest size groups suffered a lower decline in production density during the period.

# Chapter 8. Relative Technical Efficiency and Productivity in the Urban Water Sector: the Case of Regional NSW and Victoria

## 8.1 Introduction

Up to this point, attention has been given to the foundation blocks of the subject of this chapter: the results of an analysis of the relative technical efficiency and productivity of urban water utilities in regional NSW and Victoria. The main focus of the research effort reported here is the relative technical efficiency (measured in a number of ways) of the water utilities in question, and an examination of the exogenous determinants of relative efficiency. However, as was foreshadowed in Chapter 5, the results reported in the second section of this chapter are manipulated in order to measure the productivity of the sector.

The findings reviewed here, however, carry an important caveat. The results reported in sections 8.2.1–8.2.3 should be interpreted in the light of the various efficiency scores being relative. An example is when one compares relative efficiency scores through time; this section reports a general increase in mean relative overall efficiency throughout the period, as well as a decline in relative pure technical efficiency. These results should not be interpreted as a general increase and/or decrease in performance. Within each of the four years, each utility is benchmarked against the best performing utility in that period, and that period only. It is perfectly plausible for average relative efficiency to have increased between 2001 and 2002 simply because the utilities forming the frontier suffered a decline in performance relative to all other utilities in the sample. The analysis of the results in the following sections must be considered with that vital caveat in mind.

The chapter consists of eight sections. Three relative technical efficiency scores are reported and analysed in Section 8.2: overall, pure technical and scale efficiency. Section 8.3 is used to lay some preliminary groundwork with respect to the so-called 'second stage' analysis of the various relative efficiency scores. The following three sections discuss whether the suite of exogenous variables reviewed in Chapter 6 are statistically related to each of the three relative efficiency measures. Overall technical efficiency is examined in Section 8.4, pure technical efficiency is modelled in Section 8.5, and the results of the model to examine relative scale efficiency are contained in Section 8.6. Finally, the productivity of the urban water sector in regional NSW and Victoria is examined in Section 8.7. The chapter ends with a synopsis of the results in Section 8.8.

## 8.2 Technical efficiency in urban water provision in NSW and Victoria

This section reports the various relative efficiency scores generated following the evaluation of equations 5.1 and 5.2 with respect to the operations of selected water utilities in NSW and Victoria. The utilities included in this analysis and the chosen input and outputs were outlined in Chapter 6. Efficiency indices by each utility for each year are outlined in Appendix 2a. Of the Victorian utilities, Barwon was excluded since it is twice as large as the next biggest utility.

### 8.2.1 All utilities

In Chapter 3 it was established that relative overall technical efficiency can be decomposed into two elements: relative pure technical efficiency and relative scale efficiency. Equation 5.1 was used to generate estimates of overall technical efficiency, while estimates of pure technical efficiency stemmed from the evaluation of equation 5.2. Relative scale efficiency scores were calculated by taking the ratio of relative overall and pure technical efficiency scores, since overall technical efficiency is equal to the product of pure technical and scale efficiency (Coelli et al., 1998).

***2001–2004***

Table 8.1 provides descriptive statistics following analysis of the 2001 dataset. The mean overall technical efficiency score of 0.245 suggests that the average water utility could have potentially reduced input consumption by 75.5 per cent while holding output produced constant. Although the average Victorian utility was found to have slightly higher overall technical efficiency, the mean was rather deceptive; the highest relative efficiency score obtained in this group was 0.399. This result indicated that none of the 15 Victorian utilities was located on the efficient frontier. The two utilities forming the frontier, Murrumbidgee and Severn, were both located in NSW, yet comparison of the mean and median for both states suggests water authorities in both states exhibited considerable overall relative technical inefficiency.

Table 8.1: Relative technical efficiency scores – 2001

| | Overall Technical Efficiency | | | Pure Technical Efficiency | | | Scale Technical Efficiency | | |
|---|---|---|---|---|---|---|---|---|---|
| **Statistic** | *All* | *NSW* | *Vic* | *All* | *NSW* | *Vic* | *All* | *NSW* | *Vic* |
| No. of obs. | 90 | 76 | 14 | 90 | 76 | 14 | 90 | 76 | 14 |
| Min. | 0.106 | 0.106 | 0.124 | 0.108 | 0.108 | 0.303 | 0.113 | 0.113 | 0.299 |
| Max. | 1.000 | 1.000 | 0.399 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 0.468 |
| Freq. of max. | 2 | 2 | 1 | 12 | 10 | 2 | 2 | 2 | 1 |
| Median | 0.197 | 0.199 | 0.189 | 0.410 | 0.399 | 0.504 | 0.457 | 0.477 | 0.409 |
| Mean | 0.245 | 0.250 | 0.216 | 0.492 | 0.480 | 0.556 | 0.545 | 0.572 | 0.399 |
| St.Dev. | 0.161 | 0.171 | 0.082 | 0.266 | 0.269 | 0.239 | 0.214 | 0.222 | 0.043 |

When the assumption of variable returns to scale was imposed, the average pure technical efficiency score doubled. There was also an increase in the number of utilities forming the frontier, from two to 12. This suggests the assumption of scale effects as a contributing factor to the determination of relative efficiency was plausible.

The higher average pure technical efficiency score for the Victorian group indicates that managers of those water authorities were relatively more successful than their NSW counterparts in managing inputs at their disposal. Further evidence to support this claim can be found through an examination of the overall distribution of pure technical and scale efficiency for the two states.

In the case of Victorian utilities, the lower average overall technical efficiency score appears to have resulted from operating at a larger than optimal scale. The average utility in Victoria was around 17 per cent less scale efficient than those in NSW. However, the significance of that result is tempered somewhat by the relative dispersion of scale efficiency scores among NSW utilities. This indicates that, while some NSW utilities were operating at close to optimal scale, others were far from this point.

The measure of scale efficiency calculated in this model relied upon the proxy chosen for scale: Total Operating Cost. Clearly this was far from ideal since operating costs can vary without any change in scale[19]. In order to aid the interpretation of relative scale efficiency, the correlation between Total Operating Cost and the number of connections serviced by a utility was estimated. The lowest correlation between the two was 0.96, while the highest was 0.98. Thus, results relating to scale efficiency can be interpreted with a reasonable degree of confidence.

Notwithstanding, the scale efficiency results are still a cause for concern for two related reasons. First, 83 of the 90 firms were found to be operating with decreasing returns to scale. Second, the two utilities forming the overall technical efficiency frontier were both in the smallest size group, suggesting relative measures of overall and scale efficiency should be treated with a degree of scepticism. This is particularly true in the current context. In the face of evidence for scale economies in urban water provision, presented in Chapter 4, the findings presented in Table 8.1 would appear to be evidence of model mis-specification rather than diseconomies of scale in the Australian water industry. Further support for this argument is found in Section 8.2.2, where the scale effect was not evident when analysing only large utilities.

The results relating to 2002, reported in Table 8.2, once again indicate scope for efficiency gains across all three measures. A point of difference noted between the

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[19] A physical measure of scale (kilometres of main) was included in an earlier iteration of the research. However, following consultation with industry participants, it was excluded since relative *operational* efficiency was unlikely to be a function of this variable.

states in 2001, relatively higher technical efficiency for Victorian utilities, was not evident in 2002. Similarly, the relative scale efficiency of NSW authorities in 2001 could not be verified in 2002. However, the caveat regarding scale efficiency scores expressed with respect to the analysis of the 2001 results applies equally in this instance.

Table 8.2: Relative technical efficiency scores – 2002

| | **Overall Technical Efficiency** | | | **Pure Technical Efficiency** | | | **Scale Technical Efficiency** | | |
|---|---|---|---|---|---|---|---|---|---|
| **Statistic** | *All* | *NSW* | *Vic* | *All* | *NSW* | *Vic* | *All* | *NSW* | *Vic* |
| No. of obs. | 90 | 76 | 14 | 90 | 76 | 14 | 90 | 76 | 14 |
| Min. | 0.107 | 0.108 | 0.107 | 0.108 | 0.108 | 0.184 | 0.141 | 0.141 | 0.437 |
| Max. | 1.000 | 1.000 | 0.564 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 0.608 |
| Freq. of max. | 2 | 2 | 1 | 6 | 5 | 1 | 2 | 2 | 1 |
| Median | 0.177 | 0.177 | 0.177 | 0.353 | 0.354 | 0.338 | 0.564 | 0.564 | 0.560 |
| Mean | 0.233 | 0.236 | 0.219 | 0.412 | 0.414 | 0.401 | 0.596 | 0.605 | 0.547 |
| St.Dev. | 0.158 | 0.164 | 0.122 | 0.235 | 0.238 | 0.216 | 0.167 | 0.179 | 0.045 |

Measured solely on the basis of observable best practice, average overall technical efficiency appeared to increase in 2003 (Table 8.3). As will be established in Section 8.7, this was as a result of the efficient frontier contracting, rather than a movement closer to the frontier by a majority of utilities. The contraction can largely be explained by the more than doubling in 2003 in average cost of producing a megalitre of water experienced by Murrumbidgee, one of the utilities forming the overall technical efficiency frontier in 2002 and 2003.

Table 8.3: Relative technical efficiency scores – 2003

| | Overall Technical Efficiency | | | Pure Technical Efficiency | | | Scale Technical Efficiency | | |
|---|---|---|---|---|---|---|---|---|---|
| **Statistic** | *All* | *NSW* | *Vic* | *All* | *NSW* | *Vic* | *All* | *NSW* | *Vic* |
| No. of obs. | 90 | 76 | 14 | 90 | 76 | 14 | 90 | 76 | 14 |
| Min. | 0.162 | 0.162 | 0.196 | 0.176 | 0.176 | 0.200 | 0.162 | 0.162 | 0.432 |
| Max. | 1.000 | 1.000 | 0.987 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 0.989 |
| Freq. of max. | 2 | 2 | 1 | 9 | 7 | 2 | 2 | 2 | 1 |
| Median | 0.309 | 0.306 | 0.316 | 0.332 | 0.332 | 0.330 | 0.988 | 0.988 | 0.987 |
| Mean | 0.364 | 0.364 | 0.365 | 0.418 | 0.419 | 0.416 | 0.925 | 0.924 | 0.930 |
| St.Dev. | 0.193 | 0.193 | 0.195 | 0.246 | 0.245 | 0.254 | 0.163 | 0.166 | 0.142 |

There was little difference in pure technical efficiency between the two states in 2003; however, average scale efficiency increased substantially. Again, this would appear to the 'reining in' of some extremely well performing utilities (in relative terms) that also happened to be 'small' by the scale measure employed here.

Table 8.4: Relative technical efficiency scores – 2004

| | Overall Technical Efficiency | | | Pure Technical Efficiency | | | Scale Technical Efficiency | | |
|---|---|---|---|---|---|---|---|---|---|
| **Statistic** | *All* | *NSW* | *Vic* | *All* | *NSW* | *Vic* | *All* | *NSW* | *Vic* |
| No. of obs. | 90 | 76 | 14 | 90 | 76 | 14 | 90 | 76 | 14 |
| Min. | 0.142 | 0.147 | 0.142 | 0.142 | 0.160 | 0.142 | 0.184 | 0.184 | 0.898 |
| Max. | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |
| Freq. of max. | 3 | 2 | 1 | 8 | 7 | 1 | 3 | 2 | 1 |
| Median | 0.320 | 0.317 | 0.330 | 0.350 | 0.352 | 0.342 | 0.990 | 0.989 | 0.992 |
| Mean | 0.377 | 0.381 | 0.355 | 0.422 | 0.432 | 0.365 | 0.938 | 0.931 | 0.973 |
| St.Dev. | 0.190 | 0.187 | 0.204 | 0.234 | 0.238 | 0.205 | 0.144 | 0.156 | 0.035 |

The 2004 results reported in Table 8.4 are similar to those returned in 2003 with one notable difference: a Victorian utility was located on the overall technical efficiency frontier. While Gippsland Water had formed part of the pure technical efficiency frontier (the variable returns to scale specification) in 2002 and 2003, up to this point Gippsland had not been located on the overall technically efficient frontier.

***Summary of results relating to all utilities***

With the exception of relative scale efficiency, evidence suggests the urban water sector in regional NSW and Victoria suffered from significant relative inefficiency during the period. In addition, there appears to be no convincing evidence that Victorian utilities were relatively more efficient than their counterparts in NSW. Based on the results of this investigation, little benefit seems to have been gained from the substantial reform of the water sector in Victoria during the 1990s. The only exception to the observed low level of relative efficiency was the substantial improvement in scale efficiency in 2003, which appeared to carry through to 2004.

However, it would appear that the larger utilities have been unfairly compared with smaller utilities, resulting in relatively lower efficiency scores. This tentative conclusion stems from the observation that two utilities from the smallest size category formed the overall technical efficiency frontier in all but one of the years included in the sample. In order to investigate this further, the analysis of all utilities outlined in this section was repeated across the sample consisting of only those utilities in the two largest size categories, described in the following section.

### 8.2.2 Large utilities

As outlined in Section 6.4.2, a truncated dataset was constructed over the period containing only those utilities that served more than 3,000 connections. Following the analytical framework of Section 8.2.1, overall, pure and scale technical efficiency scores were evaluated for each of the 52 utilities in question. The full set of efficiency indices by each utility for each year are outlined in Appendix 2a. Once again, Barwon Water was excluded due to size.

***2001–2004***

The first point of difference between the results from this analysis and that of all utilities, discussed above (Section 8.2.1), was the general increase in relative efficiency across all three model specifications. The average overall relative technical efficiency score, relative to the observed best-practice utility, was double that observed when all utilities were included in the sample. The average relative pure technical efficiency was also higher.

The most substantial improvement between the two set of results was in terms of relative scale efficiency. Again, caution should be exercised when interpreting this measure. However, when compared with the results reported in Table 8.1, it appears that the larger utilities were being unfairly compared with smaller water authorities, with a resulting relatively high degree of scale inefficiency. A comparison of the average scale efficiency score of RUWAs and LWUs suggests the latter were operating closer to the optimal scale. When the results reported in Table 8.5 are taken on face value, NSW utilities were on average 11.5 per cent more scale efficient.

Table 8.5: Relative technical efficiency scores (large utilities) – 2001

| | **Overall Technical Efficiency** | | | **Pure Technical Efficiency** | | | **Scale Technical Efficiency** | | |
|---|---|---|---|---|---|---|---|---|---|
| **Statistic** | *All* | *NSW* | *Vic* | *All* | *NSW* | *Vic* | *All* | *NSW* | *Vic* |
| No. of obs. | 52 | 38 | 14 | 52 | 38 | 14 | 52 | 38 | 14 |
| Min. | 0.249 | 0.271 | 0.249 | 0.301 | 0.301 | 0.303 | 0.587 | 0.789 | 0.587 |
| Max. | 1.000 | 1.000 | 0.804 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 0.997 |
| Freq. of max. | 2 | 2 | 1 | 6 | 3 | 3 | 2 | 2 | 1 |
| Median | 0.433 | 0.433 | 0.428 | 0.477 | 0.477 | 0.559 | 0.887 | 0.905 | 0.823 |
| Mean | 0.482 | 0.491 | 0.458 | 0.555 | 0.537 | 0.603 | 0.878 | 0.909 | 0.794 |
| St.Dev. | 0.190 | 0.198 | 0.165 | 0.220 | 0.198 | 0.263 | 0.092 | 0.061 | 0.109 |

The results relating to 2002 are reported in Table 8.6, and show similar patterns to those for 2001, with two key differences. First, Victorian utilities improved their scale efficiency from 2001 to be approximately equal, on average, with NSW utilities in 2002. Furthermore, scale efficiency for all utilities was higher, suggesting a movement towards achieving optimal scale across the sector.

Table 8.6: Relative technical efficiency scores (large utilities) – 2002

| | **Overall Technical Efficiency** | | | **Pure Technical Efficiency** | | | **Scale Technical Efficiency** | | |
|---|---|---|---|---|---|---|---|---|---|
| **Statistic** | *All* | *NSW* | *Vic* | *All* | *NSW* | *Vic* | *All* | *NSW* | *Vic* |
| No. of obs. | 52 | 38 | 14 | 52 | 38 | 14 | 52 | 38 | 14 |
| Min. | 0.193 | 0.225 | 0.193 | 0.198 | 0.233 | 0.198 | 0.456 | 0.578 | 0.456 |
| Max. | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |
| Freq. of max. | 3 | 2 | 1 | 5 | 3 | 2 | 3 | 2 | 1 |
| Median | 0.413 | 0.401 | 0.435 | 0.431 | 0.430 | 0.436 | 0.989 | 0.985 | 0.992 |
| Mean | 0.459 | 0.462 | 0.450 | 0.495 | 0.495 | 0.497 | 0.934 | 0.934 | 0.936 |
| St.Dev. | 0.216 | 0.209 | 0.234 | 0.226 | 0.209 | 0.268 | 0.117 | 0.104 | 0.147 |

Second, the average relative pure technical efficiency score in 2002 was lower, particularly with respect to Victorian utilities. This appears to have been driven by Gippsland Water, one of the five utilities forming the pure technical efficiency frontier. Gippsland Water benefited from a 30 per cent decline in the average cost of producing water between 2001 and 2002. The reasons for this are not clear. As outlined in Table 8.7, this was in stark contrast to the majority of RUWAs, which experienced either an increase in costs or only marginal decline. The result of this was that most Victorian utilities were deemed relatively more inefficient in purely technical efficiency terms, because they were being compared with the vastly improved Gippsland Water.

Table 8.7: Percentage change in average cost of producing water between 2001 and 2002 – Victorian utilities

| RUWA | % change in $/ML |
|---|---|
| Central Highlands | 11.75 |
| Coliban | −7.06 |
| Gippsland | −29.76 |
| Goulburn Valley | 1.18 |
| North East | −3.72 |
| Western | 8.82 |
| East Gippsland | 12.40 |
| Glenelg | 6.18 |
| Grampians | 38.29 |
| Lower Murray | 7.08 |
| Portland Coast | 23.03 |
| South Gippsland | 12.90 |
| South West | 4.20 |
| Westernport | −14.84 |

There was very little difference in relative efficiency scores between 2003 and 2004, as reported in tables 8.8 and 8.9. The descriptive statistics suggest that there was still considerable scope for improvement in performance, in both overall efficiency and pure technical efficiency. Indeed, average relative overall technical inefficiency could be attributed almost entirely to pure technical inefficiency. Put differently, the managers of the utilities included in this dataset had only their own managerial inefficiency to blame for not performing as well as the best-practice water authorities.

Table 8.8: Relative technical efficiency scores (large utilities) – 2003

| | **Overall Technical Efficiency** | | | **Pure Technical Efficiency** | | | **Scale Technical Efficiency** | | |
|---|---|---|---|---|---|---|---|---|---|
| **Statistic** | *All* | *NSW* | *Vic* | *All* | *NSW* | *Vic* | *All* | *NSW* | *Vic* |
| No. of obs. | 52 | 38 | 14 | 52 | 38 | 14 | 52 | 38 | 14 |
| Min. | 0.204 | 0.211 | 0.204 | 0.208 | 0.220 | 0.208 | 0.449 | 0.639 | 0.449 |
| Max. | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |
| Freq. of max. | 3 | 2 | 1 | 5 | 2 | 3 | 3 | 2 | 1 |
| Median | 0.387 | 0.387 | 0.399 | 0.440 | 0.445 | 0.414 | 0.981 | 0.970 | 0.993 |
| Mean | 0.461 | 0.471 | 0.433 | 0.503 | 0.503 | 0.504 | 0.931 | 0.938 | 0.910 |
| St.Dev. | 0.216 | 0.216 | 0.211 | 0.239 | 0.223 | 0.278 | 0.113 | 0.083 | 0.167 |

Table 8.9: Relative technical efficiency scores (large utilities) – 2004

| | **Overall Technical Efficiency** | | | **Pure Technical Efficiency** | | | **Scale Technical Efficiency** | | |
|---|---|---|---|---|---|---|---|---|---|
| **Statistic** | *All* | *NSW* | *Vic* | *All* | *NSW* | *Vic* | *All* | *NSW* | *Vic* |
| No. of obs. | 52 | 38 | 14 | 52 | 38 | 14 | 52 | 38 | 14 |
| Min. | 0.153 | 0.187 | 0.153 | 0.155 | 0.224 | 0.155 | 0.430 | 0.592 | 0.430 |
| Max. | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |
| Freq. of max. | 3 | 2 | 1 | 7 | 3 | 4 | 3 | 2 | 1 |
| Median | 0.424 | 0.424 | 0.407 | 0.460 | 0.460 | 0.426 | 0.950 | 0.949 | 0.974 |
| Mean | 0.456 | 0.466 | 0.427 | 0.517 | 0.513 | 0.527 | 0.902 | 0.911 | 0.877 |
| St.Dev. | 0.217 | 0.213 | 0.225 | 0.253 | 0.225 | 0.315 | 0.128 | 0.102 | 0.177 |

*Summary of results relating to large water utilities*

Three characteristics encapsulate the results from this analysis of relative efficiency in larger urban water utilities. First, by truncating the dataset to include only utilities from the two largest size categories, scale efficiency measures appear to have stabilised. This was an expected outcome. Second, regardless of the absence of relatively smaller utilities, evidence suggests that the average utility could have potentially employed fewer resources to produce a given output. In other words, managers of relatively larger utilities were just as likely to waste inputs as were their counterparts at the smaller utilities. Finally, as was the case when examining the entire sample, little evidence was found to suggest Victorian utilities were any more relatively efficient than those in NSW.

## 8.3 Explaining technical efficiency in urban water provision in NSW and Victoria

The analysis of urban water utilities in Section 8.2 revealed that while a number of water authorities were very efficient relative to their peers, the remainder of the industry was consuming, on average, excess resources to produce given outputs. However, since the DEA model utilised for the analysis was deterministic, a valid critique of the results could be made on the grounds that the analytical model had not sufficiently accounted for both the diversity within the sector and the effect of exogenous variables in the production process.

The primary aim of the analysis presented in this section was to address these two weaknesses of the model. Particular attention is given to determining whether institutional structure was associated with relative efficiency. Through the estimation of a Tobit regression, in which the observed relative efficiency scores obtained in Section 8.2 were regressed against a broad set of explanatory variables, any advantage or disadvantage accrued to Victorian water authorities could be detected, after having controlled for the influence of other factors. That is, the hypothesis of interest was whether, *ceteris paribus*, Victorian RUWAs were any more or less relatively efficient.

### 8.3.1 Justification for Tobit Regression Analysis

The Tobit regression analysis technique for examining determinants of relative efficiency scores was introduced briefly in chapters 3 and 5. The specification of the independent variables to be included in the Tobit regression analysis was outlined in Chapter 6. However, the justification for choosing the Tobit technique over the alternatives has not yet been explicitly argued. The aims of this section are to present the arguments for a Tobit regression analysis, and to draw attention to a number of general caveats relating to the technique itself and the results generated by the model.

The Tobit technique is but one of a number of competing methodologies that researchers have applied when examining exogenous influences on relative efficiency scores. A number of these were reviewed in Section 3.6 of Chapter 3. In this study, the Tobit technique was preferred over the alternative, SFA, primarily as a result of a series of disappointing results generated when a variant of the Fried et al. (2002) model was investigated in an early iteration of this research. Although a number of difficulties were encountered, two were particularly detrimental to the plausibility of results obtained.

First, the imposed linearity of the estimated feasible slack frontier had the unfortunate consequence of attributing almost all variation in relative efficiency scores to statistical noise. Had this been a true reflection of the industry, the result may well have been acceptable. However, it was clear that model mis-specification, attributable to the assumption of linearity rather than genuine noise, was more likely to have been the primary source. Subsequent communication with the authors of the Fried et al. (2002) study has revealed that even they have abandoned further use of the model due to the restriction imposed by the assumption of linearity (R. Villano, pers. comm., 24 July, 2007).

The second reason for preferring a Tobit specification stemmed from the extensive reporting of the technique in the literature. Although Roff (2007) recently established that the technique is a mis-specification in the context of explaining variations in DEA scores, the technique was found to return results similar to those generated by correctly specified models. Since the computational expense of the statistically correct models outlined by Roff (2007) was substantial, Tobit was retained as the analytical model.

### 8.3.2 Outline of the analytical approach

The analysis aimed to determine the extent to which variations in relative technical efficiency could be attributed to a number of explanatory variables. Separate models were estimated for each of the three types of relative technical efficiency: overall, pure technical and scale efficiency. The suite of explanatory variables considered for inclusion in each of the models was reviewed in Chapter 6.

Following the analytical framework established in sections 8.2.1 and 8.2.2, Tobit regression equations were estimated for two datasets; the first included all utilities and the second contained only utilities from the two largest size groups. The criterion of parsimony underpinned the formulation of the various models. When selecting the optimal group of explanatory variables for inclusion in each of the various Tobit equations, a technique known as 'testing down' was used. Having begun with a general model in which all explanatory variables were included strictly for the purposes of establishing a baseline for comparative purposes, variables were progressively excluded with reference to a number of test statistics. The most important of these was the omitted variable test. However, a number of diagnostic tests – including $R^2$, adjusted $R^2$, log likelihood ratio tests, Wald tests for the significance of the final model and a joint omitted variable test for the joint significance of the excluded variables – aided in the construction of the various models.

The 'testing down' procedure has received a level of acceptance from applied econometricians, since it is likely to result in less bias in coefficient estimates than the alternative method of 'testing up' (Kennedy, 2003). Finally, heteroskedasticity in the residuals of all models and a degree of autocorrelation were assumed. The presence of heteroskedasticity was compensated for by estimating all models with robust covariances, following the Huber/White option for robust standard errors. However, since the econometric software used in this portion of the analysis did not allow for correction of autocorrelation in the residuals in Tobit models, the standard correction procedures for the presence of autocorrelation typically followed in Ordinary Least Squares estimation could not be used. As a result, the likely effects of autocorrelation remained. However, since the panel covers only four years, it is reasonable to assume the estimation efficiency has not been seriously compromised by the violation.

Of far more importance is the presence of multicollinearity, which was investigated among the independent variables. The relevant statistics are reported in tables 8.10 and 8.11. To detect multicollinearities between variables and identify the variables responsible, linear regressions were estimated on each of the variables as a function of the others. The $R^2$ of each model is one indicator of the presence and degree of multicollinearity between the variables. An $R^2$ of 1 suggests a linear relationship between the dependent variable of the model and the explanatory variables, often referred to as perfect multicollinearity, the presence of which renders regression analysis impossible.

The extent to which the existence of multicollinearity is likely to affect the model can be approximated by calculating the Variance Inflation Factor (VIF), given by $(1-R^2)^{-1}$ (Kennedy, 2003). A rule of thumb for interpreting VIF scores is that a VIF factor >10 indicates serious multicollinearity (Kennedy, 2003).

Table 8.10: Multicollinearity statistics for water explanatory variables – all utilities

| Variable | $R^2$ | VIF |
|---|---|---|
| $z_2$ | 0.386 | 1.629 |
| $z_3$ | 0.217 | 1.277 |
| $z_4$ | 0.580 | 2.380 |
| $z_5$ | 0.156 | 1.185 |
| $z_6$ | 0.346 | 1.529 |
| $z_8$ | 0.338 | 1.512 |
| $z_9$ | 0.610 | 2.567 |
| $z_{10}$ | 0.140 | 1.163 |

Table 8.10 (continued)

| Variable | $R^2$ | VIF |
|---|---|---|
| $Z_{11}$ | 0.139 | 1.161 |
| $Z_{12}$ | 0.296 | 1.420 |
| $Z_{13}$ | 0.252 | 1.337 |
| $Z_{14}$ | 0.609 | 2.557 |
| $Z_{15}$ | 0.904 | 10.471 |
| $Z_{16}$ | 0.947 | 18.793 |
| $Z_{17}$ | 0.873 | 7.873 |
| $Z_{18}$ | 0.568 | 2.315 |
| $Z_{19}$ | 0.386 | 1.630 |
| $Z_{20}$ | 0.425 | 1.738 |
| $Z_{21}$ | 0.394 | 1.651 |

Table 8.11: Multicollinearity statistics for water explanatory variables – large utilities

| Variable | $R^2$ | VIF |
|---|---|---|
| $Z_2$ | 0.491 | 1.964 |
| $Z_3$ | 0.298 | 1.425 |
| $Z_4$ | 0.628 | 2.689 |
| $Z_5$ | 0.092 | 1.102 |
| $Z_6$ | 0.460 | 1.852 |
| $Z_9$ | 0.462 | 1.858 |
| $Z_{10}$ | 0.220 | 1.283 |
| $Z_{11}$ | 0.210 | 1.266 |
| $Z_{12}$ | 0.400 | 1.667 |
| $Z_{13}$ | 0.363 | 1.570 |
| $Z_{14}$ | 0.425 | 1.741 |
| $Z_{15}$ | 0.898 | 9.842 |
| $Z_{16}$ | 0.957 | 23.084 |
| $Z_{17}$ | 0.903 | 10.337 |
| $Z_{18}$ | 0.526 | 2.108 |
| $Z_{19}$ | 0.387 | 1.632 |
| $Z_{20}$ | 0.414 | 1.706 |
| $Z_{21}$ | 0.414 | 1.707 |

The results suggest that there is little evidence of serious multicollinearity between the variables, with one exception. Rainfall ($z_{15}$, $z_{16}$) and rainfall intensity ($z_{16}, z_{17}$) are highly correlated. As a result the two pairs of variables were excluded from all final models. The other result of note is that production density was reasonably correlated (maximum score 0.56) with each of the climate variables.

Given the presence of a balanced panel of data over the four years 2001–2004, a natural temptation was to employ a panel estimation technique. However, this was rejected, based upon the relation of DEA scores generated in each year. Since each year was considered in isolation, the relative efficiency scores calculated from each year were unique to the observed best-practice utilities from each year. As a result tracking utility and/or time specific changes in relative efficiency between years would have, at best, carried little economic value and, at worst, given a misleading indication of the importance of such observations. For this reason the four years of data were analysed as a pooled cross-section. The results of the Tobit regression analysis are therefore reflective of *average* influences of the explanatory variables included in the various specifications of the model over the four years.

Coefficients generated from a Tobit regression cannot be interpreted as marginal effects (Greene, 2002); rather, they represent average effects. However, a rule of thumb reported by Greene (2002) when seeking to determine marginal effects is to multiply the coefficient by the probability that the true value of the observation is included within the censoring band. Since, in this case, all observations are 'true' in that sense, the estimated parameters approximate the true marginal effect. However, it is important to note that this does not apply to the interpretation of coefficients on dummy variables.

## 8.4 Explaining overall technical efficiency in urban water provision in NSW and Victoria

This section provides the results of the estimation of a Tobit regression equation to explain variance in overall relative technical efficiency scores. First, the analysis of the dataset including all utilities is reviewed, then results from the analysis of utilities from the two largest size categories are reported. In general, three tables relating to the analysis of each dataset are provided. The first gives results from the final model produced by the testing procedure outlined in Section 8.3.2. This is followed by a table reporting test statistics on the variables excluded from that model. The so-called redundant variable test was for whether a subset of variables in an equation all have zero coefficients and might thus be deleted from the equation. The null hypothesis was therefore that the coefficients on the variables are jointly zero. Therefore, if a p-value higher than 0.05 was generated, it was concluded that there was insufficient evidence to reject the null hypothesis that the joint significance of the variables is zero. If this was this case, the variables could be correctly deleted from the equation with confidence.

The third table reports a Wald test for the joint significance of the variables included in the final model. The null hypothesis of this test was that all coefficients are equal to zero. A p-value of the test statistic less than 0.05 indicates that the final specification of the model was reasonable, at a 95 per cent confidence interval.

### 8.4.1 All utilities

The results of the redundant variable test were used as a basis for the following model and generated the results reported in Table 8.12 overleaf.

Relative overall technical efficiency was associated with the majority of variables in the model, indicated by the statistical significance of the coefficients. Based on the results in Table 8.12, a number of tentative conclusions may be drawn. First, returns to both production density and customer density were found. Although the economic significance of each can be questioned, the positive relationship between overall technical efficiency and production density is of particular importance in the current policy context. Water conservation measures, particularly those that result in a decline in per connection consumption of potable water, are likely to have deleterious effects on overall technical efficiency. Thus, it would appear unreasonable of policy makers to expect urban water authorities to improve operational performance while simultaneously directing consumers to reduce average consumption. The positive coefficient on customer density confirms the common assumption that denser networks require relatively fewer resources.

The inclusion of dummy variables to control for time periods appears to have been justified, since the coefficient on each of the dummy variables was statistically significant for all but one of the years, 2002. It was important to take account of this in the model in a statistical sense. Had this step not been taken, other variables correlated with time may have varied, resulting in biased estimates.

Table 8.12: Explaining overall technical efficiency of all water utilities

| Variable | Description | Coefficient | Std. error | z-stat. | Prob. |
|---|---|---|---|---|---|
| $\alpha$ | Constant | 0.3372 | 0.1000 | 3.374 | 0.001 |
| $z_4$ | Prod. density | 0.0005 | 0.0000 | 10.142 | 0.000 |
| $z_6$ | Customer density | 0.0024 | 0.0007 | 3.289 | 0.001 |
| $z_7$ | Medium utility | –0.1243 | 0.0209 | –5.939 | 0.000 |
| $z_8$ | Large utility | –0.1266 | 0.0223 | –5.677 | 0.000 |
| $z_9$ | Very large utility | –0.0962 | 0.0242 | –3.980 | 0.000 |
| $z_{10}$ | Groundwater | 0.1665 | 0.0295 | 5.653 | 0.000 |
| $z_{11}$ | Reticulator | –0.0547 | 0.0176 | –3.108 | 0.002 |
| $z_{12}$ | Unfiltered supply | 0.0434 | 0.0222 | 1.958 | 0.050 |
| $z_{13}$ | Dams | –0.0417 | 0.0148 | –2.815 | 0.005 |
| $z_{14}$ | Temperature | –0.0115 | 0.0035 | –3.330 | 0.001 |
| $z_{17}$ | Rainfall intensity | 0.0008 | 0.0030 | 0.278 | 0.781 |
| $z_{18}$ | RUWA | –0.0202 | 0.0221 | –0.914 | 0.361 |
| $z_{19}$ | 2002 | –0.0258 | 0.0195 | –1.321 | 0.187 |
| $z_{20}$ | 2003 | 0.1288 | 0.0190 | 6.795 | 0.000 |
| $z_{21}$ | 2004 | 0.1568 | 0.0201 | 7.792 | 0.000 |
| ***Error Distribution*** | | | | | |
| $e$ | | 0.127 | 0.011 | 11.644 | 0.000 |
| ***Diagnostic Statistics*** | | | | | |
| R-squared | | 0.574 | Mean dependent var | | 0.305 |
| Adjusted R-squared | | 0.554 | S.D. dependent var | | 0.189 |
| S.E. of regression | | 0.126 | Akaike info criterion | | –1.086 |
| Sum squared resid | | 5.453 | Schwarz criterion | | –0.902 |
| Log likelihood | | 212.394 | Hannan-Quinn criter. | | –1.013 |
| Avg. log likelihood | | 0.590 | | | |
| Left censored obs | | 0 | Right censored obs | | 9 |
| Uncensored obs | | 351 | Total obs | | 360 |
| ***Redundant variables test*** | | | | | |
| Redundant variables: Z2 Z3 Z5 Z15 Z16 | | | | | |
| F-statistic | | 2.478 | Probability | | 0.032 |
| Log likelihood ratio | | 12.093 | Probability | | 0.033 |
| ***Wald test of joint significance of variables*** | | | | | |
| Wald test: all coefficients = 0 | | | | | |
| Test Statistic | | | Value | df | Probability |
| F-statistic | | | 254.616 | (16, 343) | 0.000 |
| Chi-square | | | 4073.858 | 16 | 0.000 |

The expectation of a positive correlation between average maximum temperature and relative efficiency failed to eventuate. Indeed, a one degree increase in maximum average temperature was found to result in a one per cent *decline* in relative efficiency. A possible explanation for this result may be that the relatively warmer areas of both states were also relatively poorly populated. Beyond this assertion, no other possible explanation is advanced, and the matter is left as an area for further investigation.

The size dummy variables were found to be statistically significant. This result was expected, since the constant returns to scale specification of DEA had not explicitly accounted for scale effects. While a statistical significance was anticipated, the negative coefficient on each of the variables was surprising. This suggested that, with respect to overall technical efficiency, those utilities servicing fewer than 1,500 connections were more efficient than all other classes. Furthermore, if one accepts relative efficiency scores as reasonable proxies for average cost, the sector was characterised by an inverted U-shaped cost curve. While this was an unexpected result, it did provide implicit support for a variable returns to scale specification of the DEA model, since it would control for the effect of scale on relative efficiency scores.

Of particular interest were the results relating to relative treatment levels and sources of raw water. Those utilities with access to groundwater for the majority of their raw water source were found to be, on average, 16 per cent more relatively efficient in terms of overall efficiency. Since all but one of the utilities relying on groundwater were located in NSW, this result suggested that an important source of overall relative efficiency for some NSW LWUs was their source of water. Woodbury and Dollery (2004) found a similar relationship between groundwater reliance and relative technical efficiency. This result suggests that groundwater aquifers should be carefully managed for two reasons. First, groundwater represents a reasonably secure source of water for a number of rural towns in NSW, since it is less susceptible to variation during drought when compared with surface water sources. Second, groundwater aquifers are a source of relative overall technical efficiency for those LWUs that rely upon groundwater. A final consideration may relate to the relatively unregulated nature of groundwater aquifers, as highlighted by Cullen (2006).

Those water utilities responsible only for reticulation were found, on average, to be around five per cent less overall technically efficient. An opposite sign was expected, since those authorities responsible for only reticulation were expected to incur lower expenses. However, the result may reflect high operating costs due to other factors not included in the model. In particular, difficult terrain and higher wage costs per unit of water produced were not controlled for in the specification, nor the necessity of purchasing water from a regulated supplier.

As expected, those utilities reliant upon a supply not requiring filtration were relatively more efficient. Evidence was also found to suggest that those utilities burdened with the responsibility of maintaining headworks were, on average, four per cent less efficient than those not maintaining this infrastructure.

Finally, utilities located in Victoria were found to be marginally less efficient. However, since the coefficient on the dummy variable was not of statistical significance, there was no evidence to suggest any advantage in terms of overall technical efficiency accruing from institutional structure.

### 8.4.2 Large utilities

This section presents the analysis of utilities from the two largest size categories.

Table 8.13: Explaining overall technical efficiency of large water utilities

| Variable | Description | Coefficient | Std. error | z-stat. | Prob. |
|---|---|---|---|---|---|
| $\alpha$ | Constant | 0.1549 | 0.0855 | 1.811 | 0.070 |
| $z_2$ | Residential consumption | 0.0020 | 0.0009 | 2.232 | 0.026 |
| $z_4$ | Production density | 0.0005 | 0.0001 | 7.376 | 0.000 |
| $z_9$ | Very large utility | –0.0483 | 0.0190 | –2.540 | 0.011 |
| $z_{10}$ | Groundwater | 0.1236 | 0.0439 | 2.819 | 0.005 |
| $z_{11}$ | Reticulator | –0.0640 | 0.0225 | –2.843 | 0.005 |
| $z_{12}$ | Unfiltered supply | –0.0684 | 0.0243 | –2.821 | 0.005 |
| $z_{13}$ | Dams | –0.0625 | 0.0233 | –2.685 | 0.007 |
| $z_{18}$ | RUWA | 0.0541 | 0.0257 | 2.107 | 0.035 |
| ***Error Distribution*** | | | | | |
| $e$ | | 0.137 | 0.009 | 15.411 | 0.000 |
| ***Diagnostic Statistics*** | | | | | |
| R-squared | | 0.576 | Mean dependent var | | 0.464 |
| Adjusted R-squared | | 0.557 | S.D. dependent var | | 0.211 |
| S.E. of regression | | 0.140 | Akaike info criterion | | –1.042 |
| Sum squared resid | | 3.899 | Schwarz criterion | | –0.882 |
| Log likelihood | | 118.404 | Hannan-Quinn criter. | | –0.977 |
| Avg. log likelihood | | 0.569 | | | |
| Left censored obs | | 0 | Right censored obs | | 0 |
| Uncensored obs | | 208 | Total obs | | 208 |
| ***Redundant variables test*** | | | | | |
| Redundant variables: Z3 Z5 Z6 Z14 Z15 Z16 Z17 Z19 Z20 Z21 | | | | | |
| F-statistic | | 0.486 | Probability | | 0.898 |
| Log likelihood ratio | | 5.352 | Probability | | 0.866 |
| ***Wald test of joint significance of variables*** | | | | | |
| Wald test: all coefficients = 0 | | | | | |
| Test Statistic | | | Value | df | Probability |
| F-statistic | | | 448.091 | (9, 198) | 0.000 |
| Chi-square | | | 4032.819 | 9 | 0.000 |

A relatively smaller set of variables were found to have a statistically significant relationship with overall relative efficiency. Of particular note, evidence of an association between climate measures and the relative overall efficiency of this group of larger utilities did not eventuate. On reflection this was a plausible result, since the utilities in this dataset were typically located in regions with relatively minimal variance in rainfall and temperature.

For this set of utilities, the percentage of water consumed by residential customers was found to be significant, a result that was in direct contrast with that found in the 'all-inclusive' dataset. However, the coefficient was positive; the opposite to the *a priori* expectation for this variable. This may be explained by the tendency for a greater proportion of the water supply of larger utilities being for industrial use. Industrial consumers tend not to be homogenous since the relative quality of the water required is a function of the purpose for which the water is used. An industry representative (D. McGregor, pers. comm., 6 May, 2007) stated that it was customary for some industrial customers to regularly monitor the quality of water arriving at the factory, and if water quality was found to be poor, the customer would seek rectification.

It seems reasonable, therefore, to argue that this variable may reflect the tendency for those utilities supplying a relatively large proportion of their water to industrial customers to invest more heavily in water treatment in order to meet the standards required by industrial customers. However, it is important to note the indirect nature of this argument. It would seem the proposition is worthy of further investigation in later studies, since the consequences of relative efficiency may well be of significance.

This subset of utilities provided evidence for returns to production density; however, the economic significance of this variable was once again questionable. As an example, based on the results of this study, a large urban water utility would experience a decline in relative efficiency of two and a half per cent from a cut in per connection consumption of 50 kilolitres per year. Nevertheless, cumulative reductions in per connection consumption are likely to result in a decline in relative efficiency. Perhaps not surprisingly, customer density was found to be insignificant for this subset. This might have been a result of relatively limited variation in customer densities between the utilities in this group.

Somewhat unexpectedly, the dummy variable to identify very large utilities (>10,000 connections) returned a negative coefficient. This implied decreasing returns to scale in water provision, at least for utilities of this size, assuming overall relative efficiency was a reasonable proxy for average cost. Furthermore, as reported in Section 8.2.3, all of the Victorian utilities were identified as operating in the decreasing returns to scale region in the first stage DEA model. This result contradicts the substantial evidence in the literature for increasing returns to scale in the urban water sector (see Chapter 4 for a review); however, given that the model is not a direct test of the shape and slope of the long-run average cost curve for the industry, it would be heroic in the extreme to conclude that this result disproves the body of evidence alluded to above. On balance, it would be imprudent to draw any firm conclusion from this particular finding.

An alternative explanation may be the relatively higher regulatory burden imposed on the largest utilities by regulators. This might take the form of implied expectations that services delivered by these water providers will be of an exceptional standard, or that far more rigorous reporting requirements are imposed. Thus, the relative inefficiency may be found in the administrative aspects of the utilities operations, rather than the physical relationship between inputs consumed in the direct production process and the resultant output of potable water consumed. In other words, the result may simply reflect additional costs incurred as a result of regulatory impost, rather than defiance of the well established law of increasing returns to scale in large network industries (Friedman, 2002).

The dummy variable reflecting reliance on groundwater as a source of raw water supply was found to be positive and statistically significant for this group of utilities. Furthermore, the magnitude of the coefficient suggests economic significance. This result is particularly relevant because it suggests the benefits of sourcing raw water supplies from groundwater are relatively large regardless of the size of the utility. This is also confirms that the variable was not acting as a surrogate for variation in relative size not accounted for by the size-related dummy variables.

The results relating to the dummy variables identifying reticulators and those utilities responsible for headworks were similar to those reported for the full sample of utilities. That is, reticulators were found to be less relatively efficient on average, as were utilities responsible for maintenance of a dam or headworks.

However, in this subset of larger authorities, utilities reliant on water not requiring filtration were found to be less efficient on average. Further investigation revealed that all but one of the utilities reliant upon unfiltered supply was from the very large category, suggesting that this variable was in fact measuring differences in size not detected by the dummy variable included for that purpose. To test that assertion, the dummy variable for unfiltered supply was excluded from the equation in order to conduct an omitted variable test. It was then possible to reject the null hypothesis that the co-efficient related to this variable was equal to zero at the one per cent level using a log likelihood ratio, and at the two per cent level under an F-test. This result suggests that those able to supply unfiltered potable water are relatively less efficient than other utilities in this subset. Why this is the case is a matter for further study. No correlated defining characteristic is apparent. For example, some of the utilities are located in relatively high population growth areas on the coast (Coffs Harbour and North Coast Water), while others are located inland, in areas experiencing relative population decline (Mudgee, Grampians and Central Highlands).

Of most relevance to the central research question of this thesis, Victorian utilities were found to be on average five per cent more efficient (by this measure), after having controlled for all other variables included in the model. Consequently, it can be concluded that RUWAs are relatively more efficient than their similarly-sized NSW counterparts.

### 8.4.3 Summary of results explaining relative overall technical efficiency

Two variables are of significance to relative overall efficiency. First, utilities reliant upon groundwater benefited in terms of relative overall efficiency, regardless of utility size. Second, there was evidence to suggest that returns to production density were present in this industry. Finally, although Victorian utilities were found to be significantly more relatively efficient than those in NSW, this was only the case when measured solely against NSW utilities of a similar size.

## 8.5 Explaining pure technical efficiency in urban water provision in NSW and Victoria

This section discusses the determinants of pure technical efficiency or. in other words, relative technical efficiency after having controlled for scale effects in the DEA model. Following the same process as that employed in the analysis of overall relative technical efficiency, this section reports results of the analysis of two datasets: all utilities, and only those utilities from the two largest size categories.

### 8.5.1 All utilities

Table 8.14 shows the results of the model to analyse the determinants of pure technical efficiency. The variables included were selected according to the results of a redundant variable test.

Returns to production density were apparent, even after having controlled for scale effects. This result was anticipated, given the nature of the variable. It measured water consumption per connection, and as such had already been standardised for the size effects. The finding that pure technical efficiency was determined in part by production density has a number of related policy implications. First, a variable over which utility managers have only indirect influence has been shown to nevertheless determine pure technical efficiency.

Table 8.14: Explaining pure technical efficiency of all water utilities

| Variable | Description | Coefficient | Std. error | z-stat. | Prob. |
|---|---|---|---|---|---|
| $\alpha$ | Constant | 0.7438 | 0.1363 | 5.459 | 0.000 |
| $z_4$ | Production density | 0.0004 | 0.0000 | 9.542 | 0.000 |
| $z_6$ | Customer density | 0.0020 | 0.0011 | 1.865 | 0.062 |
| $z_7$ | Medium utility | –0.0802 | 0.0430 | –1.867 | 0.062 |
| $z_8$ | Large utility | –0.1380 | 0.0274 | –5.040 | 0.000 |
| $z_9$ | Very large utility | –0.0681 | 0.0310 | –2.196 | 0.028 |
| $z_{10}$ | Groundwater | 0.1695 | 0.0343 | 4.946 | 0.000 |
| $z_{11}$ | Reticulator | –0.1289 | 0.0350 | –3.677 | 0.000 |
| $z_{13}$ | Dams | –0.0849 | 0.0247 | –3.434 | 0.001 |
| $z_{14}$ | Temperature | –0.0125 | 0.0041 | –3.025 | 0.003 |
| $z_{15}$ | Rain days | –0.0021 | 0.0007 | –3.057 | 0.002 |
| $z_{19}$ | 2002 | –0.1005 | 0.0302 | –3.334 | 0.001 |
| $z_{20}$ | 2003 | –0.0835 | 0.0317 | –2.633 | 0.009 |
| $z_{21}$ | 2004 | –0.0563 | 0.0305 | –1.845 | 0.065 |
| ***Error Distribution*** | | | | | |
| $e$ | | 0.192 | 0.011 | 18.194 | 0.000 |
| ***Diagnostic Statistics*** | | | | | |
| R-squared | | 0.402 | Mean dependent var | | 0.436 |
| Adjusted R-squared | | 0.378 | S.D. dependent var | | 0.248 |
| S.E. of regression | | 0.196 | Akaike info criterion | | –0.379 |
| Sum squared resid | | 13.246 | Schwarz criterion | | –0.217 |
| Log likelihood | | 83.293 | Hannan-Quinn criter. | | –0.315 |
| Avg. log likelihood | | 0.231 | | | |
| Left censored obs | | 0 | Right censored obs | | 0 |
| Uncensored obs | | 360 | Total obs | | 360 |
| ***Redundant variables test*** | | | | | |
| Redundant variables: Z2 Z3 Z5 Z12 Z16 Z17 Z18 | | | | | |
| F-statistic | | 1.689 | Probability | | 0.111 |
| Log likelihood ratio | | 11.865 | Probability | | 0.105 |
| ***Wald test of joint significance of variables*** | | | | | |
| Wald test: all coefficients = 0 | | | | | |
| Test Statistic | | | Value | df | Probability |
| F-statistic | | | 241.616 | (14, 345) | 0.000 |
| Chi-square | | | 3382.623 | 14 | 0.000 |

Second, although utility managers can influence to some extent the average consumption of customers through the implementation of water restrictions and campaigns designed to encourage water use conservation or through 'pressure reduction' technologies, the decision regarding consumption is primarily one for consumers. The implication for managers is that active pursuit of a policy to encourage water use conservation is likely to contribute to a reduction in relative pure efficiency of the utility in question. This result adds further weight to the argument that governments cannot reasonably expect water utilities to simultaneously improve relative efficiency and encourage water use conservation.

Third, customer density also influences pure technical efficiency. Since the determinant of this measure is typically outside the control of water utility managers[20], it was important to account for this factor when analysing the determinants of pure technical efficiency.

Fourth, the sign, magnitude and statistical significance of the coefficients for each of the dummy variables included to capture scale effects are cause for alarm. Had the variable returns to scale DEA model been correctly specified, one might have anticipated coefficients of statistical insignificance. The results clearly indicate this is not the case.

In an effort to determine why relative size was found to be a significant influence on pure technical efficiency, the utilities forming the fully efficient frontier were examined in greater detail. Utilities such as Corowa, Murrumbidgee, Culcairn, Gunning and Nundle were found to be peers for the majority of water authorities in this dataset. This suggests a mis-specification of the DEA model, and/or Tobit equation.

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[20] Although planning is typically a function of local government in NSW, planning decisions are typically implemented by a group separate to that responsible for water utilities.

Apart from Corowa, all the utilities in question were from the smallest size group, suggesting those in the largest size category were being unfairly judged against those from the smallest size category. Utilities responsible for water provision to fewer than 1,500 connections could safely be classified as providers of relatively limited services when compared with those servicing more than 10,000 connections. Since both the variable returns to scale DEA model and the Tobit equation – constructed to analyse the variation on the relative efficiency scores generated by that model – failed to account for those service intensity differences, this result is most likely to have stemmed from model misspecification. Furthermore, even if larger utilities were actually less technically efficient by this measure of relative efficiency, the policy implication of such a result is meaningless. It would be impractical to break up utilities responsible for servicing over 10,000 connections such that they autonomously serviced less than 1,500 properties.

Fifth, groundwater was found to be a highly significant and economically important determinant of pure technical efficiency, providing further confirmation that the management of groundwater resources is critical to both overall and pure technical efficiency. This is an important finding, since it suggests that much of the managerial skill ascribed to NSW councils in this specification of the DEA model is, rather, simply having access to a groundwater resource, a factor that is clearly outside the control of management[21].

Utilities with only reticulation responsibilities were, on average, relatively less efficient in terms of pure technical efficiency. This result may simply reflect the difficulty these utilities face in attracting highly skilled staff. Average maximum

[21] Utility managers reliant on groundwater may argue that they take an active role in protecting the aquifer, however this would appear to be a function of the relevant catchment level authority.

temperature was negatively correlated with relative pure technical efficiency; a result similar to that found in the analysis of overall technical efficiency. This association is difficult to explain, and is left for further investigation in later studies. The remaining coefficients returned signs as expected.

The dummy variable included to measure variance in pure technical efficiency as a result of institutional structure was found to be statistically insignificant. Based on that result, when compared with utilities in NSW and across all size classes, Victorian utilities gained no detectible advantage in terms of relative pure technical efficiency from the regulatory structure in place in that state.

### 8.5.2 Large utilities

This section presents the analysis of utilities from the two largest size categories.

The results outlined in Table 8.15 generally reflect those reported in the previous section. There was evidence of both returns to production density and benefits from supplying a relatively higher proportion of potable water to residential consumers. Utilities with only reticulation functions and those able to rely on a supply of water not requiring filtration were found to be relatively inefficient by this measure. The importance of access to groundwater as a source of relative efficiency was confirmed. Finally, those utilities with dams or headworks were found to be relatively purely technically inefficient.

Table 8.15: Explaining pure technical efficiency of large water utilities

| Variable | Description | Coefficient | Std. error | z-stat. | Prob. |
|---|---|---|---|---|---|
| $\alpha$ | Constant | 0.2024 | 0.0924 | 2.190 | 0.029 |
| $z_2$ | Residential consumption | 0.0024 | 0.0010 | 2.440 | 0.015 |
| $z_4$ | Production density | 0.0005 | 0.0001 | 6.900 | 0.000 |
| $z_9$ | Very large utility | –0.0611 | 0.0207 | –2.957 | 0.003 |
| $z_{10}$ | Groundwater | 0.1184 | 0.0427 | 2.771 | 0.006 |
| $z_{11}$ | Reticulator | –0.1009 | 0.0265 | –3.801 | 0.000 |
| $z_{12}$ | Unfiltered supply | –0.1071 | 0.0319 | –3.359 | 0.001 |
| $z_{13}$ | Dams | –0.0940 | 0.0240 | –3.921 | 0.000 |
| $z_{18}$ | RUWA | 0.1303 | 0.0339 | 3.845 | 0.000 |
| ***Error Distribution*** | | | | | |
| $e$ | | 0.158 | 0.011 | 14.595 | 0.000 |
| ***Diagnostic Statistics*** | | | | | |
| R-squared | | 0.553 | Mean dependent var | | 0.305 |
| Adjusted R-squared | | 0.533 | S.D. dependent var | | 0.189 |
| S.E. of regression | | 0.162 | Akaike info criterion | | –1.086 |
| Sum squared resid | | 5.170 | Schwarz criterion | | –0.902 |
| Log likelihood | | 89.115 | Hannan-Quinn criter. | | –1.013 |
| Avg. log likelihood | | 0.428 | | | |
| Left censored obs | | 0 | Right censored obs | | 0 |
| Uncensored obs | | 208 | Total obs | | 208 |
| ***Redundant variables test*** | | | | | |
| Redundant variables: Z3 Z5 Z6 Z14 Z15 Z16 Z17 Z19 Z20 Z21 | | | | | |
| F-statistic | | 0.917 | Probability | | 0.518 |
| Log likelihood ratio | | 9.734 | Probability | | 0.464 |
| ***Wald test of joint significance of variables*** | | | | | |
| Wald test: all coefficients = 0 | | | | | |
| Test Statistic | | | Value | df | Probability |
| F-statistic | | | 407.063 | (9, 198) | 0.000 |
| Chi-square | | | 3663.564 | 9 | 0.000 |

Victorian water utilities were relatively more efficient in terms of pure technical efficiency than NSW utilities of a similar size. Specifically, Victorian utilities were, on average, around 13 per cent more efficient. This result contrasts with that reported in Section 8.2.2, in which Victorian utilities were found to be, on average, relatively *less* efficient by this measure. This suggests that the managers of Victorian utilities may have had grounds to complain that the first stage DEA model did not adequately reflect the operating environment or other exogenous influences.

## 8.6 Explaining scale efficiency in urban water provision in NSW and Victoria

This section discusses variation in scale efficiency among utilities. As with overall technical and pure technical efficiency, discussed above, two datasets were examined: all utilities and those from the two largest size categories. To the author's knowledge, this kind of analysis has not previously been attempted, and certainly not in the context of urban water provision in Australia.

Unfortunately, results suggest that the analysis was not particularly illuminating. Each of the two estimated models had generally low $R^2$ scores and a relatively low number of significant variables. Thus, although the results do shed some light on factors associated with variation in scale efficiency, they are of limited value and should be interpreted with caution.

### 8.6.1 All utilities

Table 8.16 shows the results of the model to analyse the determinants of scale technical efficiency. The variables included were selected according to the results of a redundant variable test.

Table 8.16: Explaining scale efficiency of all water utilities

| Variable | Description | Coefficient | Std. error | z-stat. | Prob. |
|---|---|---|---|---|---|
| $\alpha$ | Constant | 0.5719 | 0.0319 | 17.921 | 0.000 |
| $z_7$ | Medium utility | –0.0392 | 0.0465 | –0.842 | 0.400 |
| $z_8$ | Large utility | –0.0226 | 0.0240 | –0.941 | 0.347 |
| $z_9$ | Very large utility | –0.0310 | 0.0243 | –1.278 | 0.201 |
| $z_{18}$ | RUWA | –0.0356 | 0.0152 | –2.342 | 0.019 |
| $z_{19}$ | 2002 | 0.0505 | 0.0277 | 1.820 | 0.069 |
| $z_{20}$ | 2003 | 0.3800 | 0.0278 | 13.661 | 0.000 |
| $z_{21}$ | 2004 | 0.3924 | 0.0269 | 14.604 | 0.000 |
| ***Error Distribution*** | | | | | |
| $e$ | | 0.173 | 0.011 | 15.581 | 0.000 |
| ***Diagnostic Statistics*** | | | | | |
| R-squared | | 0.528 | Mean dependent var | | 0.436 |
| Adjusted R-squared | | 0.518 | S.D. dependent var | | 0.248 |
| S.E. of regression | | 0.175 | Akaike info criterion | | –0.379 |
| Sum squared resid | | 10.721 | Schwarz criterion | | –0.217 |
| Log likelihood | | 121.496 | Hannan-Quinn criter. | | –0.315 |
| Avg. log likelihood | | 0.337 | | | |
| Left censored obs | | 0 | Right censored obs | | 0 |
| Uncensored obs | | 360 | Total obs | | 360 |
| ***Redundant variables test*** | | | | | |
| Redundant variables: Z2 Z3 Z4 Z5 Z6 Z10 Z11 Z12 Z13 Z14 Z15 Z16 Z17 | | | | | |
| F-statistic | | 1.221 | Probability | | 0.262 |
| Log likelihood ratio | | 16.262 | Probability | | 0.235 |
| ***Wald test of joint significance of variables*** | | | | | |
| Wald Test: all coefficients = 0 | | | | | |
| Test Statistic | | | Value | df | Probability |
| F-statistic | | | 3194.182 | (8, 351) | 0.000 |
| Chi-square | | | 25553.45 | 8 | 0.000 |

The results reported in Table 8.16 relate to the analysis of the dataset that included all utilities. Very few of the explanatory variables were statistically significant. Furthermore, the dummy variables included to account for size effects were individually insignificant. However, a test for the joint significance (at the five per cent level) of the three variables established that as a group they were of statistical significance. This result simply indicates, somewhat tautologically, that the relative size of a utility was weakly associated with relative scale efficiency. The only other result of interest was that RUWAs were found to be on average three and a half per cent less scale efficient than NSW utilities. As was argued in Section 8.4.2, this result should be interpreted with caution. The three dummy variables to measure changes in scale efficiency through time confirm that the dramatic increase in scale efficiency observed between 2002 and 2003 was of statistical significance. However, this result carries little economic meaning due to the relative nature of the efficiency scores.

### 8.6.2 Large utilities

This section presents the analysis of utilities from the two largest size categories.

Similarly disappointing results were found when analysing the dataset including only those utilities for the two largest size categories. One exception was the significant and positive coefficient on the dummy variable to take account of scale effects. This result suggests increasing returns to scale if one accepts relative scale efficiency scores as a reasonable proxy for a decline in average costs. Another perspective on this outcome is that the group of authorities in the largest size category are operating at a scale relatively closer to the minimum efficient scale. In general, however, it is clear that scale efficiency is determined by variables other than those included in the two models estimated.

Table 8.17: Explaining scale efficiency of large water utilities

| Variable | Description | Coefficient | Std. error | z-stat. | Prob. |
|---|---|---|---|---|---|
| $\alpha$ | Constant | 0.8704 | 0.0170 | 51.272 | 0.000 |
| $z_9$ | Very large utility | 0.0386 | 0.0158 | 2.451 | 0.014 |
| $z_{18}$ | RUWA | –0.0574 | 0.0221 | –2.593 | 0.010 |
| $z_{19}$ | 2002 | 0.0561 | 0.0203 | 2.760 | 0.006 |
| $z_{20}$ | 2003 | 0.0526 | 0.0199 | 2.647 | 0.008 |
| $z_{21}$ | 2004 | 0.0238 | 0.0211 | 1.130 | 0.258 |
| ***Error Distribution*** | | | | | |
| $e$ | | 0.110 | 0.009 | 11.985 | 0.000 |
| ***Diagnostic Statistics*** | | | | | |
| R-squared | | 0.090 | Mean dependent var | | 0.911 |
| Adjusted R-squared | | 0.063 | S.D. dependent var | | 0.116 |
| S.E. of regression | | 0.112 | Akaike info criterion | | –1.507 |
| Sum squared resid | | 2.525 | Schwarz criterion | | –1.395 |
| Log likelihood | | 163.778 | Hannan-Quinn criter. | | –1.462 |
| Avg. log likelihood | | 0.787 | | | |
| Left censored obs | | 0 | Right censored obs | | |
| Uncensored obs | | 208 | Total obs | | 208 |
| ***Redundant variables test*** | | | | | |
| Redundant variables: Z2 Z3 Z4 Z5 Z6 Z10 Z11 Z12 Z13 Z14 Z15 Z16 Z17 | | | | | |
| F-statistic | | 1.511 | Probability | | 0.116 |
| Log likelihood ratio | | 20.211 | Probability | | 0.090 |
| ***Wald test of joint significance of variables*** | | | | | |
| Wald test: all coefficients = 0 | | | | | |
| Test Statistic | | | Value | df | Probability |
| F-statistic | | | 16.891 | (6, 188) | 0.000 |
| Chi-square | | | 101.345 | 6 | 0.000 |

## 8.7 Productivity in urban water provision in regional NSW and Victoria

As well as determining relative efficiency rankings with respect to a best practice frontier, DEA models have been usefully employed to measure productivity improvements and declines. The theoretical underpinnings of using DEA relative efficiency as a basis for measuring changes in productivity were reviewed in Section 3.7 of Chapter 3.

This section examines the productivity of water utilities over the period 2001–2004. Following a similar analytical framework to that employed when examining relative efficiency, two datasets were analysed: all utilities across the four years in question, and only those utilities from the two largest size groups.

A common method of reporting productivity changes for an industry or sector is to calculate the geometric mean of the average (itself a geometric mean) productivity index for each period. It is also conventional to report changes related to total factor productivity as well as the two components of total factor productivity: overall efficiency change and so-called technical change. In essence, efficiency change refers to variation in the relative efficiency score with respect to the best practice frontier, while technical change reflects movements in the best practice frontier. Efficiency change might be thought of as changes in the capacity of managers to make the most efficient use of a given set of resources, while technical change implies changes in the productive capacity of the industry, measured with respect to the best practice firm/s.

### 8.7.1 All utilities

Table 8.18: Average productivity changes over period 2001–2004

| | Total Factor Productivity | Efficiency Change | Technical Change |
|---|---|---|---|
| Ave. All Utilities: 2001–2004 | 0.925 (–7.8%) | 1.166 (15.4%) | 0.793 (–23.2%) |
| Ave. NSW Utilities: 2001–2004 | 0.180 (–7.9%) | 1.168 (15.5%) | 0.089 (–23.4%) |
| Ave. Vic. Utilities: 2001–2004 | 0.924 (–7.5%) | 1.158 (14.7%) | 0.792 (–22.2%) |
| Ave. All Utilities: 2002 | 0.922 (–8.1%) | 0.952 (–4.9%) | 0.968 (–3.2%) |
| Ave. All Utilities: 2003 | 0.940 (–6.2%) | 1.599 (46.9%) | 0.588 (–53.1%) |
| Ave. All Utilities: 2004 | 0.914 (–9.1%) | 1.043 (4.2%) | 0.876 (–13.3%) |

In terms of Total Factor Productivity (TFP), the water sectors of NSW and Victoria when analysed as a group suffered an average decline in productivity each year of 7.8 per cent over the period 2001–2004. The results relating to NSW and Victorian utilities, considered separately, suggest that there was little difference in any of the three measures of productivity change between the utilities in each state.

Calculations of both efficiency and technical change are reported in Table 8.18. Again, the results suggest little difference in terms of productivity between the utilities in each state; however, as an industry, overall technical efficiency grew during the period, while the productive capacity of the sector declined. In fact, the decline in TFP was entirely due to negative technical change. Furthermore, when the productivity of the entire industry was examined in terms of productivity change from year to year, an interesting pattern emerged. The productive capacity of the sector (measured by technical change) fell by 53 per cent – a rather implausible decrease – between 2002 and 2003. While the actual magnitude of this result could be challenged, it is clear that the efficiency frontier declined significantly during the period. Of equal interest was the ability of managers to cope with this situation. Overall efficiency grew by around 47 per cent, suggesting that even though drought or other factors reduced the productive capacity of the industry, managers almost offset this through greater technical efficiency.

The results outlined above point to the following tentative conclusions. First, productivity universally declined across the industry during the period. It is tempting to assign this to the effect of drought, since by consequence of model design, productivity was essentially measuring change in total cost per litre of water consumed. The effect of drought may have been to decrease the quantity of water consumed, while simultaneously delivering an increase in the cost associated with delivering water for consumption. The analysis of descriptive statistics in Chapter 5 lends support to this proposition; indeed, Coelli and Walding (2005) reached similar conclusions in their study of the productivity of major water utilities in Australia.

Second, to the extent that water restrictions were responsible for the decline in productivity (a conclusion also supported by Coelli and Walding, 2005), governments would do well to recognise from these results that policies with an outcome of reduced water consumption per connection are more than likely to result in declines in productivity. This may be an unavoidable result in the face of severely restricted supply[22]. Nevertheless, a decline in the performance of water utilities should be anticipated and allowances made when reviewing the relative efficiency of utilities operating under such conditions. Finally, institutional structure appears not to have conferred any meaningful advantage in terms of the three productivity

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[22] The costs of water restrictions have only recently received the attention of policy makers. For a comprehensive assessment of the welfare consequences of water restrictions, changes in the technical efficiency of utilities warrant consideration.

measures reported in Table 8.18. This finding suggests that institutional structure bears no influence on efforts to manage the impact of drought in the urban water sector.

### 8.7.2 Large utilities

Table 8.19 reports the results relating to productivity changes when only those utilities from the two largest size categories were included in the dataset.

Table 8.19: Average productivity changes over period 2001–2004

| | Total Factor Productivity | Efficiency Change | Technical Change |
|---|---|---|---|
| Ave All Utilities: 2001–2004 | 0.905 (–10%) | 0.969 (–3.1%) | 0.933 (–6.9%) |
| Ave NSW Utilities: 2001–2004 | 0.901 (–10.4%) | 0.975 (–2.6%) | 0.924 (–7.9%) |
| Ave Vic Utilities: 2001–2004 | 0.916 (–8.8%) | 0.955 (–4.6%) | 0.958 (–4.3%) |
| Ave All Utilities: 2002 | 0.867 (–14.3%) | 0.927 (–7.6%) | 0.935 (–6.7%) |
| Ave All Utilities: 2003 | 0.995 (–0.5%) | 1.003 (0.3%) | 0.992 (–0.8%) |
| Ave All Utilities: 2004 | 0.859 (–15.2%) | 0.98 (–2.0%) | 0.877 (–13.1%) |

The TFP of this group of utilities fell by an average of 10 per cent each year through the period. This was slightly higher than that observed for the entire sample. Utilities in the two states had slightly different TFPs, although this would appear to be of little economic significance. A more striking result was the decline in both efficiency change and technical change. While the productive capacity of the industry declined over the period, the overall technical efficiency in the sector also fell. However, just under 70 per cent of the decline in TFP was attributable to declines in the productive capacity of the sector.

A second point of difference between this set of utilities and the full set was the relative stability of the frontier in 2003. It appears that the shift in productive capacity noted for the sample of all utilities was due largely to the presence of the smaller utilities. This follows from the observation that the efficiency frontier generated in the analysis of this subset of utilities did not recede nearly to the extent observed for the full sample.

### 8.7.3 Synopsis of results

The results for TFP and the two components of TFP were relatively more stable when only the utilities from the two largest groups were analysed. Regardless, TFP declined for both datasets, indicating that the effect of the drought had a noticeable impact upon the productivity of the water sector during the period. Furthermore, institutional design appeared not to be associated with any relative advantage in managing the set of circumstances that caused the decline in productivity.

## 8.8 Concluding remarks

A number of broad themes can be gleaned from the results presented in this chapter. First, there appears to be little difference between utilities located in NSW and Victoria in terms of the various measures of relative technical efficiency examined, when calculated with reference to the DEA model alone. However, when those results are examined through regression against a number of exogenous variables, Victorian utilities have a relative advantage in terms of overall technical efficiency (around five per cent) and pure technical efficiency (around 13 per cent) when compared with utilities in NSW of similar size.

Second, evidence was found to suggest returns to production density in urban water networks, in both NSW and Victoria and regardless of utility size. Third, once again regardless of utility size, the relationship between use of groundwater as a source of raw water and relative overall and pure technical efficiency was positive and economically significant. Fourth, those utilities from the largest two size groups that supplied a relatively higher proportion of water to industrial consumers were found to suffer a decline in relative technical efficiency as a result.

Finally, the total factor productivity of the sector showed a consistent decline over the period of analysis. Moreover, no evidence suggested institutional structure delivered any benefit in terms of productivity. Ramifications of these results for policy makers are discussed in Chapter 10.

# Chapter 9. Relative Technical Efficiency and Productivity in the Urban Wastewater Sector: the Case of Regional NSW and Victoria

## 9.1 Introduction

Chapter 8 reported the results from the analysis of urban water utilities in regional NSW and Victoria. Chapter 9 presents the results of a similar analysis pertaining to the wastewater operations of those utilities. In Chapter 4 it was noted that there is a paucity of empirical evidence with respect to Victorian Wastewater Utilities. The work reported here, therefore, constitutes a new contribution to the literature.

A similar analytical framework was employed as for that employed in the analysis of the water utilities (Chapter 8). Section 8.3 of Chapter 8 described the methodology followed to arrive at the empirical models presented in this chapter. The caveat regarding the interpretation of relative efficiency scores through time also applies to the results for wastewater operations reported here.

The chapter consists of six main sections. Three relative technical efficiency scores are reported and analysed in Section 9.2: overall, pure technical and scale efficiency. Section 9.3 examines whether the suite of exogenous variables reviewed in Chapter 7 are statistically related to each of the three relative efficiency measures. The productivity of the urban wastewater sector in regional NSW and Victoria is examined in Section 9.4, while a synopsis of the results is given in Section 9.5.

## 9.2 Technical efficiency in urban wastewater provision in NSW and Victoria

This section presents the various relative efficiency scores generated following the evaluation of equations 5.1 and 5.2 with respect to the operations of selected wastewater utilities in NSW and Victoria. The utilities included for this analysis, as well as the input and output variables chosen, were outlined in Chapter 7. Efficiency indices by each utility for each year are outlined in Appendix 3. Barwon, the largest utility in Victoria, was omitted for reasons explained in Chapter 8.

Following the analytical framework employed in the analysis of technical efficiency in urban water provision, two datasets were employed: one containing all 114 utilities, and the other consisting of only the 56 utilities with over 3,000 connections.

### 9.2.1 All utilities

Very similar patterns in the relationship between overall pure and scale efficiency exist in each of the years of the analysis. As a result, the general themes that emerge over the period, rather than a year-by-year analysis, are discussed. The results for each year are reported in Table 9.1.

Table 9.1: Descriptive statistics of relative technical efficiency scores – all wastewater utilities

| *2001* | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | **Overall Technical Efficiency** | | | **Pure Technical Efficiency** | | | **Scale Technical Efficiency** | | |
| **Statistic** | *All* | *NSW* | *Vic* | *All* | *NSW* | *Vic* | *All* | *NSW* | *Vic* |
| No. of obs. | 114 | 100 | 14 | 114 | 100 | 14 | 114 | 100 | 14 |
| Min. | 0.137 | 0.137 | 0.204 | 0.185 | 0.185 | 0.338 | 0.193 | 0.193 | 0.406 |
| Max. | 1.000 | 1.000 | 0.436 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 0.603 |
| Freq. of max. | 3 | 3 | 1 | 11 | 9 | 2 | 3 | 3 | 1 |
| Median | 0.285 | 0.288 | 0.261 | 0.435 | 0.395 | 0.553 | 0.804 | 0.831 | 0.441 |
| Mean | 0.339 | 0.346 | 0.288 | 0.479 | 0.459 | 0.624 | 0.745 | 0.784 | 0.474 |
| St.Dev. | 0.176 | 0.184 | 0.074 | 0.232 | 0.230 | 0.198 | 0.209 | 0.193 | 0.056 |
| *2002* | | | | | | | | | |
| | **Overall Technical Efficiency** | | | **Pure Technical Efficiency** | | | **Scale Technical Efficiency** | | |
| **Statistic** | *All* | *NSW* | *Vic* | *All* | *NSW* | *Vic* | *All* | *NSW* | *Vic* |
| No. of obs. | 114 | 100 | 14 | 114 | 100 | 14 | 114 | 100 | 14 |
| Min. | 0.126 | 0.126 | 0.187 | 0.171 | 0.171 | 0.454 | 0.269 | 0.269 | 0.331 |
| Max. | 1.000 | 1.000 | 0.384 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 0.441 |
| Freq. of max. | 3 | 3 | 1 | 10 | 8 | 2 | 3 | 3 | 1 |
| Median | 0.276 | 0.279 | 0.264 | 0.451 | 0.424 | 0.690 | 0.678 | 0.783 | 0.386 |
| Mean | 0.325 | 0.332 | 0.273 | 0.509 | 0.481 | 0.711 | 0.682 | 0.724 | 0.387 |
| St.Dev. | 0.171 | 0.180 | 0.055 | 0.230 | 0.224 | 0.157 | 0.238 | 0.225 | 0.029 |
| *2003* | | | | | | | | | |
| | **Overall Technical Efficiency** | | | **Pure Technical Efficiency** | | | **Scale Technical Efficiency** | | |
| **Statistic** | *All* | *NSW* | *Vic* | *All* | *NSW* | *Vic* | *All* | *NSW* | *Vic* |
| No. of obs. | 114 | 100 | 14 | 114 | 100 | 14 | 114 | 100 | 14 |
| Min. | 0.109 | 0.109 | 0.262 | 0.113 | 0.113 | 0.477 | 0.327 | 0.407 | 0.327 |
| Max. | 1.000 | 1.000 | 0.504 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 0.564 |
| Freq. of max. | 2 | 2 | 1 | 8 | 6 | 2 | 2 | 2 | 1 |
| Median | 0.342 | 0.335 | 0.358 | 0.518 | 0.465 | 0.707 | 0.723 | 0.751 | 0.533 |
| Mean | 0.369 | 0.368 | 0.375 | 0.539 | 0.511 | 0.738 | 0.716 | 0.744 | 0.517 |
| St.Dev. | 0.155 | 0.163 | 0.071 | 0.227 | 0.220 | 0.165 | 0.160 | 0.150 | 0.056 |
| *2004* | | | | | | | | | |
| | **Overall Technical Efficiency** | | | **Pure Technical Efficiency** | | | **Scale Technical Efficiency** | | |
| **Statistic** | *All* | *NSW* | *Vic* | *All* | *NSW* | *Vic* | *All* | *NSW* | *Vic* |
| No. of obs. | 114 | 100 | 14 | 114 | 100 | 14 | 114 | 100 | 14 |
| Min. | 0.184 | 0.184 | 0.321 | 0.204 | 0.204 | 0.397 | 0.443 | 0.565 | 0.443 |
| Max. | 1.000 | 1.000 | 0.834 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 0.838 |
| Freq. of max. | 1 | 1 | 1 | 6 | 3 | 3 | 1 | 1 | 1 |
| Median | 0.402 | 0.396 | 0.445 | 0.472 | 0.459 | 0.579 | 0.858 | 0.862 | 0.819 |
| Mean | 0.442 | 0.437 | 0.484 | 0.526 | 0.506 | 0.664 | 0.857 | 0.871 | 0.756 |
| St.Dev. | 0.167 | 0.171 | 0.129 | 0.213 | 0.205 | 0.212 | 0.088 | 0.068 | 0.133 |

Overall technical efficiency results suggest that there was considerable scope for improvement in the use of inputs to 'produce' wastewater services. Specifically, the 'average' utility had potential to reduce input use by between 67.5 per cent in 2002 and 55.8 per cent in 2004. Furthermore, there was little evidence to suggest a consistent trend in higher relative overall technical efficiency as a result of institutional structure. In 2001 and 2002, wastewater utilities located in NSW were, on average, 5.8 and 5.9 per cent relatively more overall technically efficient, respectively. However, in the following two years Victorian utilities held an advantage – in terms of this efficiency measure – of 0.7 and 4.7 per cent.

Although there is little evidence that institutional structure confers any advantage in terms of relative overall technical efficiency, the results relating to the *components* of relative overall technical efficiency suggest otherwise. The results relating to relative pure technical and scale efficiency indicate that NSW wastewater utilities were operating at a scale relatively closer to the optimum, yet they performed relatively more poorly in terms of managing a given set of resources. In direct contrast, it would appear that the average Victorian authority was operating during the period at a scale relatively further from the optimum, although the negative effect of this on overall technical efficiency was negated by the substantially higher ability of managers in the Victorian sector (indicated by higher pure technical efficiency scores) to utilise inputs in the provision of wastewater services. As a result, overall technical efficiency scores masked considerable diversity between utilities in NSW and Victoria.

### 9.2.2 Large utilities

The results relating to the dataset containing only those utilities with more than 3,000 connections are reported in Table 9.2.

There was evidence of a slight improvement in the average overall technical efficiency of this subset of large wastewater utilities relative to that observed for all utilities. The overall technical efficiency score for this group was around 0.16 higher, averaged across the period. However, the results also suggest there was still considerable scope for relatively more efficient use of inputs by this group of utilities. In the year in which average overall technical efficiency for utilities in both states was at its highest (2004), the 'average' utility could have reduced input use by 44.3 percent while leaving output unchanged.

In contrast to the results reviewed below in Section 9.3.1, a consistent pattern of higher relative overall technical efficiency for Victorian utilities from 2002 onward was evident from this group of utilities. This finding suggests that Victorian wastewater utilities were at an advantage during the period, and this may have been due to institutional structure.

The sample of larger utilities showed a similar pattern for pure technical and scale efficiency scores as that observed for all utilities. Victorian utilities were substantially more efficient in terms of relative pure technical efficiency, although this was offset by relative scale inefficiency. Utilities in NSW were on average less efficient with respect to pure technical efficiency while simultaneously operating at a scale relatively closer to the optimum. However, in this instance Victorian utilities overcompensated for their collective relative scale inefficiency through a proportionately higher increase in pure technical efficiency.

Table 9.2: Descriptive statistics of relative technical efficiency scores – large wastewater utilities

| | **Overall Technical Efficiency** | | | **Pure Technical Efficiency** | | | **Scale Technical Efficiency** | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | ***2001*** | | | | | |
| **Statistic** | *All* | *NSW* | *Vic* | *All* | *NSW* | *Vic* | *All* | *NSW* | *Vic* |
| No. of obs. | 56 | 42 | 14 | 56 | 42 | 14 | 56 | 42 | 14 |
| Min. | 0.232 | 0.232 | 0.350 | 0.241 | 0.241 | 0.351 | 0.436 | 0.684 | 0.436 |
| Max. | 1.000 | 1.000 | 0.734 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 0.999 |
| Freq. of max. | 2 | 2 | 1 | 6 | 2 | 4 | 2 | 2 | 1 |
| Median | 0.459 | 0.459 | 0.463 | 0.516 | 0.491 | 0.680 | 0.947 | 0.966 | 0.742 |
| Mean | 0.487 | 0.483 | 0.501 | 0.569 | 0.526 | 0.698 | 0.879 | 0.918 | 0.760 |
| St.Dev. | 0.159 | 0.170 | 0.119 | 0.201 | 0.172 | 0.227 | 0.136 | 0.093 | 0.172 |
| | | | | ***2002*** | | | | | |
| | **Overall Technical Efficiency** | | | **Pure Technical Efficiency** | | | **Scale Technical Efficiency** | | |
| **Statistic** | *All* | *NSW* | *Vic* | *All* | *NSW* | *Vic* | *All* | *NSW* | *Vic* |
| No. of obs. | 56 | 42 | 14 | 56 | 42 | 14 | 56 | 42 | 14 |
| Min. | 0.268 | 0.268 | 0.396 | 0.316 | 0.316 | 0.454 | 0.460 | 0.827 | 0.460 |
| Max. | 1.000 | 1.000 | 0.814 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 0.935 |
| Freq. of max. | 2 | 2 | 1 | 6 | 2 | 4 | 2 | 2 | 1 |
| Median | 0.511 | 0.489 | 0.560 | 0.546 | 0.498 | 0.823 | 0.959 | 0.995 | 0.800 |
| Mean | 0.535 | 0.520 | 0.580 | 0.607 | 0.544 | 0.796 | 0.904 | 0.955 | 0.752 |
| St.Dev. | 0.158 | 0.167 | 0.116 | 0.204 | 0.168 | 0.184 | 0.124 | 0.059 | 0.143 |
| | | | | ***2003*** | | | | | |
| | **Overall Technical Efficiency** | | | **Pure Technical Efficiency** | | | **Scale Technical Efficiency** | | |
| **Statistic** | *All* | *NSW* | *Vic* | *All* | *NSW* | *Vic* | *All* | *NSW* | *Vic* |
| No. of obs. | 56 | 42 | 14 | 56 | 42 | 14 | 56 | 42 | 14 |
| Min. | 0.156 | 0.156 | 0.397 | 0.316 | 0.316 | 0.517 | 0.283 | 0.283 | 0.484 |
| Max. | 1.000 | 1.000 | 0.737 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 0.810 |
| Freq. of max. | 2 | 2 | 1 | 9 | 4 | 5 | 2 | 2 | 1 |
| Median | 0.507 | 0.491 | 0.541 | 0.633 | 0.546 | 0.842 | 0.808 | 0.854 | 0.723 |
| Mean | 0.527 | 0.515 | 0.563 | 0.664 | 0.610 | 0.828 | 0.808 | 0.846 | 0.694 |
| St.Dev. | 0.167 | 0.184 | 0.095 | 0.209 | 0.194 | 0.162 | 0.142 | 0.133 | 0.103 |
| | | | | ***2004*** | | | | | |
| | **Overall Technical Efficiency** | | | **Pure Technical Efficiency** | | | **Scale Technical Efficiency** | | |
| **Statistic** | *All* | *NSW* | *Vic* | *All* | *NSW* | *Vic* | *All* | *NSW* | *Vic* |
| No. of obs. | 56 | 42 | 14 | 56 | 42 | 14 | 56 | 42 | 14 |
| Min. | 0.220 | 0.220 | 0.407 | 0.263 | 0.263 | 0.495 | 0.517 | 0.517 | 0.535 |
| Max. | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |
| Freq. of max. | 3 | 2 | 1 | 6 | 2 | 4 | 3 | 2 | 1 |
| Median | 0.535 | 0.509 | 0.549 | 0.581 | 0.559 | 0.767 | 0.961 | 0.966 | 0.850 |
| Mean | 0.557 | 0.542 | 0.602 | 0.629 | 0.579 | 0.777 | 0.902 | 0.936 | 0.801 |
| St.Dev. | 0.179 | 0.186 | 0.146 | 0.206 | 0.187 | 0.190 | 0.137 | 0.095 | 0.185 |

Some tentative policy conclusions can be drawn from this confluence of results. First, the ability of Victorian wastewater authority managers to be relatively frugal with inputs appears to have been to their distinct advantage. However, the average scale of operations was a handicap in their efforts to attain higher levels of overall technical efficiency. Based on this evidence, one might argue that the reform process of the 1990s in Victoria delivered some net benefits in terms of overall technical efficiency, yet these benefits were muted by creating utilities that were larger than optimum. Had relatively smaller RUWAs been formed during the reform phase of the 1990s, Victorian utilities may have recorded even higher overall technical efficiency scores in terms of wastewater functions.

### 9.2.3 Summary of results

At least two themes emerged from this analysis of wastewater utilities in NSW and Victoria. First, considerable scope for improvements in relative technical efficiency across the sector seemed evident. Second, Victorian utilities were generally relatively more efficient overall, but particularly so in terms of pure technical efficiency, while utilities located in NSW were relatively more scale efficient. This curious finding suggests that the managers of Victorian utilities may have been hindered in their efforts to increase relative overall efficiency as a result of being forced to operate on a scale beyond the optimum. Since utility size was not a variable over which management had any control, one might conclude that this constitutes evidence of a policy failing resulting from the reform process carried out in the Victorian regional urban water and wastewater sector during the 1990s.

The results of the analysis outlined in this section suggest that Victorian utilities were outperforming their counterparts in NSW during the period. However, wastewater utility managers in NSW may argue that the DEA model that formed the basis of this analysis did not accounted for several factors that might determine relative efficiency. The following section discusses factors that were not included in the DEA model.

## 9.3 Explaining technical efficiency in urban wastewater provision in regional NSW and Victoria

A similar procedure was followed to that employed in the investigation of the water sector (Chapter 8). Section 8.3.2 in Chapter 8 provides a detailed outline of the approach that generated the results reported in Section 8.4. In Section 8.3.2 concerns were expressed regarding possible effects on estimation from the presence of multicollinearity. This section reports the results of analysis of the multicollinearity tests for the variables to be employed in the analysis of relative efficiency scores for wastewater utilities.

Table 9.3: Multicollinearity statistics Wastewater explanatory variables – all utilities

| Variable | $R^2$ | VIF |
|---|---|---|
| $z_2$ | 0.244 | 1.323 |
| $z_3$ | 0.178 | 1.217 |
| $z_4$ | 0.262 | 1.356 |
| $z_5$ | 0.115 | 1.130 |
| $z_6$ | 0.101 | 1.112 |
| $z_8$ | 0.117 | 1.132 |
| $z_9$ | 0.405 | 1.681 |
| $z_{10}$ | 0.358 | 1.557 |
| $z_{11}$ | 0.388 | 1.635 |
| $z_{12}$ | 0.364 | 1.571 |

Table 9.3 (continued)

| Variable | $R^2$ | VIF |
|---|---|---|
| $z_{14}$ | 0.270 | 1.370 |
| $z_{15}$ | 0.365 | 1.575 |
| $z_{16}$ | 0.631 | 2.712 |
| $z_{17}$ | 0.340 | 1.516 |
| $z_{18}$ | 0.359 | 1.560 |
| $z_{19}$ | 0.358 | 1.559 |

Table 9.4: Multicollinearity statistics Wastewater explanatory variables -- large utilities

| Variable | $R^2$ | VIF |
|---|---|---|
| $z_2$ | 0.391 | 1.641 |
| $z_3$ | 0.244 | 1.324 |
| $z_4$ | 0.070 | 1.075 |
| $z_5$ | 0.080 | 1.087 |
| $z_6$ | 0.083 | 1.090 |
| $z_8$ | 0.108 | 1.122 |
| $z_9$ | 0.188 | 1.231 |
| $z_{10}$ | 0.352 | 1.543 |
| $z_{11}$ | 0.125 | 1.142 |
| $z_{12}$ | 0.356 | 1.554 |
| $z_{16}$ | 0.383 | 1.620 |
| $z_{17}$ | 0.335 | 1.504 |
| $z_{18}$ | 0.347 | 1.531 |
| $z_{19}$ | 0.354 | 1.547 |

Following the 'rule of thumb' advanced by Kennedy (2003), since none of the variables returned a VIF of greater than 10, detrimental multicollinearity between the variables appears not be present. In theory at least, this should lead to more efficient estimates of the coefficients in the Tobit regression analysis of the DEA scores.

### 9.3.1 Explaining overall technical efficiency in urban wastewater provision in NSW and Victoria

The process followed in order to arrive at the various Tobit regression equations presented in the sections to follow mirrored that outlined in Section 8.3.2 of Chapter 8. That is, three tables relating to the analysis of each dataset are reported. The first sets out the results from the final model arrived as a result of the testing procedure outlined in Section 8.3.2. This is followed by a table reporting test statistics on the variables excluded from that model. The so-called redundant variable test was for whether a subset of variables in an equation all had zero coefficients and might, thus, be deleted from the equation. The null hypothesis was therefore that the coefficients on the variables are jointly zero. Therefore, if a p-value higher than 0.05 was generated, it was concluded that there was insufficient evidence to reject the null hypothesis that the joint significance of the variables is zero. If this was the case, the variables could be correctly deleted from the equation with confidence.

The third table reports a Wald test for the joint significance of the variables included in the final model. The null hypothesis of this test was that all coefficients are equal to zero. A p-value of the test statistic of less than 0.05 would indicate that the final specification of the model was reasonable, at a 95 per cent confidence interval.

*All utilities*

The results of the redundant variable test were used as a basis for the following model and generated the results reported in Table 9.5.

Table 9.5: Explaining overall technical efficiency of all wastewater utilities

| Variable | Description | Coefficient | Std. error | z-stat. | Prob. |
|---|---|---|---|---|---|
| $\alpha$ | Constant | 0.2560 | 0.0322 | 7.943710 | 0.0000 |
| $z_3$ | Residential connections | 0.0007 | 0.0000 | 8.893790 | 0.0000 |
| $z_6$ | Sewer main chokes | –0.0002 | 0.0000 | –2.089191 | 0.0367 |
| $z_{10}$ | Ocean discharge | –0.0722 | 0.0144 | –5.015728 | 0.0000 |
| $z_{11}$ | River discharge | –0.0433 | 0.0162 | –2.674446 | 0.0075 |
| $z_{14}$ | Medium utility | –0.0684 | 0.0200 | –3.417790 | 0.0006 |
| $z_{15}$ | Large utility | –0.1119 | 0.0188 | –5.956852 | 0.0000 |
| $z_{16}$ | Very large utility | –0.0843 | 0.0190 | –4.443246 | 0.0000 |
| $z_{17}$ | 2002 | –0.0000 | 0.0192 | –0.003891 | 0.9969 |
| $z_{18}$ | 2003 | 0.0613 | 0.019565 | 3.131300 | 0.0017 |
| $z_{19}$ | 2004 | 0.1315 | 0.020239 | 6.499257 | 0.0000 |
| ***Error Distribution*** | | | | | |
| $e$ | | 0.143828 | 0.008457 | 17.00727 | 0.000 |
| ***Diagnostic Statistics*** | | | | | |
| R-squared | | 0.311 | Mean dependent var | | 0.369 |
| Adjusted R-squared | | 0.294 | S.D. dependent var | | 0.173 |
| S.E. of regression | | 0.146 | Akaike info criterion | | –0.988 |
| Sum squared resid | | 9.427 | Schwarz criterion | | –0.879 |
| Log likelihood | | 237.209 | Hannan-Quinn criter. | | –0.945 |
| Avg. log likelihood | | 0.520 | | | |
| Left censored obs | | 0 | Right censored obs | | 0 |
| Uncensored obs | | 456 | Total obs | | 456 |
| ***Redundant variables test*** | | | | | |
| Redundant variables: Z2 Z4 Z5 Z8 Z9 Z12 | | | | | |
| F-statistic | | 0.848 | Probability | | 0.533 |
| Log likelihood ratio | | 5.162 | Probability | | 0.523 |
| ***Wald test of joint significance of variables*** | | | | | |
| Wald test: all coefficients = 0 | | | | | |
| Test Statistic | | | Value | df | Probability |
| F-statistic | | | 187.356 | (9, 444) | 0.000 |
| Chi-square | | | 1686.206 | 9 | 0.000 |

The diagnostic statistics relating to the specification of the model outlined above suggest the results have limited worth. Nevertheless, the results may be instructive in terms of informing future research efforts.

There appeared to be some evidence of returns to production density; however, the relatively small magnitude of the coefficient suggested that the economic significance of this relationship was negligible. As an example, in order to generate a 10 per cent increase in relative overall efficiency, the average utility would have needed to treat an additional 143 kilolitres of sewerage per connection. This would have represented a 57 per cent increase on the average volume of sewerage treated by the average utility over the period, holding the size of the network constant.

The finding with respect to the influence of discharge location was unexpected. As noted in Chapter 7, those utilities burdened with discharging effluent to rivers were expected to suffer a decline in relative efficiency as a result. However, the results outlined in Table 9.5 suggest the opposite. That is, those utilities discharging to ocean outfalls are relatively inefficient in an overall technical sense when compared with those releasing treated effluent to rivers or land. It is difficult to conceive why this result may reflect actual operating conditions at the time. As has already been noted, the explanatory power of this particular model appears limited, and this curious result may primarily be a result of omitted variable bias. Finally, Victorian utilities appear to have been slightly more technically efficient by this measure. However, the coefficient on the dummy variable of interest was significant at only the 10 per cent level.

### *Large utilities*

The results relating to the relative efficiency of those utilities serving more than 3,000 connections are reported in Table 9.6.

Table 9.6: Explaining overall technical efficiency of large wastewater utilities

| Variable | Description | Coefficient | Std. error | z-stat. | Prob. |
|---|---|---|---|---|---|
| $\alpha$ | Constant | –0.8377 | 0.2937 | –2.852 | 0.004 |
| $z_2$ | Residential connections | 0.0125 | 0.0030 | 4.166 | 0.000 |
| $z_3$ | Production density | 0.0007 | 0.0001 | 4.725 | 0.000 |
| $z_8$ | Tertiary treatment | –0.0766 | 0.0192 | –3.978 | 0.000 |
| $z_{10}$ | Ocean discharge | –0.0531 | 0.0261 | –2.033 | 0.042 |
| $z_{12}$ | RUWA | 0.0726 | 0.0178 | 4.078 | 0.000 |
| $z_{17}$ | 2002 | 0.0519 | 0.0280 | 1.853 | 0.064 |
| $z_{18}$ | 2003 | 0.0532 | 0.0294 | 1.813 | 0.070 |
| $z_{19}$ | 2004 | 0.0846 | 0.0294 | 2.882 | 0.004 |
| ***Error Distribution*** | | | | | |
| $e$ | | 0.153 | 0.010 | 16.145 | 0.000 |
| ***Diagnostic Statistics*** | | | | | |
| R-squared | | 0.165 | Mean dependent var | | 0.527 |
| Adjusted R-squared | | 0.130 | S.D. dependent var | | 0.168 |
| S.E. of regression | | 0.157 | Akaike info criterion | | –0.822 |
| Sum squared resid | | 5.275 | Schwarz criterion | | –0.669 |
| Log likelihood | | 102.023 | Hannan-Quinn criter. | | –0.760 |
| Avg. log likelihood | | 0.455 | | | |
| Left censored obs | | 0 | Right censored obs | | 0 |
| Uncensored obs | | 224 | Total obs | | 224 |
| ***Redundant variables test*** | | | | | |
| Redundant variables: Z4 Z5 Z6 Z9 Z11 Z16 | | | | | |
| F-statistic | | 1.000 | Probability | | 0.426 |
| Log likelihood ratio | | 6.358 | Probability | | 0.384 |
| ***Wald test of joint significance of variables*** | | | | | |
| Wald test: all coefficients = 0 | | | | | |
| Test Statistic | | | Value | df | Probability |
| F-statistic | | | 407.658 | (9, 214) | 0.000 |
| Chi-square | | | 3668.918 | 9 | 0.000 |

When the analysis was confined to only those utilities from the large and very large size groups, the explanatory power of the model decreased (indicated by an $R^2$ of 0.165), suggesting the model to explain variance in the relative overall technical efficiency of wastewater utilities in this group is of limited worth. With that caveat in mind, the following results are noted.

First, there is evidence of returns to production density and also evidence that a higher proportion of residential connections is positively related to gains in relative overall technical efficiency. The first result confirms the findings of other authors such as Garcia and Thomas (2001). The second is probably reflective of the additional burden carried by wastewater utilities responsible for treating sewage from industrial customers.

Second, a negative sign was found to exist for the ocean outfall dummy variable and the tertiary treatment variable. This finding echoed the results from the analysis of the full dataset. This finding is equally perplexing, and especially so since both coefficients are significantly different from zero in this case.

Finally, Victorian utilities were, as a group, around seven per cent relatively more efficient than those in NSW. This result broadly confirms the findings of the DEA model estimations outlined in Section 9.2.2. Discussion of the policy implications of this result is left to Chapter 10.

### 9.3.2 Explaining pure technical efficiency in urban wastewater provision in NSW and Victoria

This section presents the results of an analysis of the determinants of relative technical efficiency in regional urban Wastewater utilities in NSW and Victoria. Results relating to the full sample of utilities are reported first, followed by those pertaining to the subset of larger utilities.

***All utilities***

When applied to the determination of factors influencing variation in pure technical efficiency, the model showed improved performance, as reported in Table 9.7. This is indicated by the higher $R^2$ scored and the greater number of significant variables.

Table 9.7: Explaining pure technical efficiency of all wastewater utilities

| Variable | Description | Coefficient | Std. error | z-stat. | Prob. |
|---|---|---|---|---|---|
| $\alpha$ | Constant | 0.3069 | 0.0529 | 5.802 | 0.000 |
| $z_3$ | Production density | 0.0008 | 0.0001 | 7.725 | 0.000 |
| $z_4$ | Customer density | 0.0017 | 0.0010 | 1.689 | 0.091 |
| $z_6$ | Sewer main chokes | –0.0005 | 0.0001 | –3.971 | 0.000 |
| $z_{10}$ | Ocean discharge | –0.1016 | 0.0242 | –4.195 | 0.000 |
| $z_{11}$ | River discharge | –0.1058 | 0.0212 | –4.995 | 0.000 |
| $z_{12}$ | RUWA | 0.1402 | 0.0236 | 5.949 | 0.000 |
| $z_{14}$ | Medium utility | –0.0568 | 0.0299 | –1.900 | 0.057 |
| $z_{15}$ | Large utility | –0.0644 | 0.0258 | –2.491 | 0.013 |
| $z_{16}$ | Very large utility | 0.0466 | 0.0310 | 1.505 | 0.132 |
| $z_{17}$ | 2002 | 0.0463 | 0.0255 | 1.811 | 0.070 |
| $z_{18}$ | 2003 | 0.0948 | 0.0255 | 3.718 | 0.000 |
| $z_{19}$ | 2004 | 0.0780 | 0.0255 | 3.053 | 0.002 |
| ***Error Distribution*** | | | | | |
| $e$ | | 0.187 | 0.008 | 0.000 | 0.000 |
| ***Diagnostic Statistics*** | | | | | |
| R-squared | | 0.322 | Mean dependent var | | 0.513 |
| Adjusted R-squared | | 0.302 | S.D. dependent var | | 0.227 |
| S.E. of regression | | 0.189 | Akaike info criterion | | –0.455 |
| Sum squared resid | | 15.867 | Schwarz criterion | | –0.328 |
| Log likelihood | | 117.688 | Hannan-Quinn criter. | | –0.405 |
| Avg. log likelihood | | 0.258 | | | |
| Left censored obs | | 0 | Right censored obs | | 0 |
| Uncensored obs | | 456 | Total obs | | 456 |
| ***Redundant variables test*** | | | | | |
| Redundant variables: Z2 Z5 Z8 Z9 | | | | | |
| F-statistic | | 1.065 | Probability | | 0.373 |
| Log likelihood ratio | | 3.580 | Probability | | 0.466 |
| ***Wald test of joint significance of variables*** | | | | | |
| Wald test: all coefficients = 0 | | | | | |
| Test Statistic | | | Value | df | Probability |
| F-statistic | | | 346.278 | (13, 442) | 0.000 |
| Chi-square | | | 4501.617 | 13 | 0.000 |

There is evidence to suggest both returns to production density and customer density. This finding is interesting in that it is not in keeping with previous evidence that there are decreasing returns to customer density (see, for instance, Mays and Tung, 1992). However, this may be explained by some unique characteristics of Victorian and NSW wastewater networks not found in typical wastewater networks. In another result related to the nature of the network, higher numbers of sewer main chokes and breaks were statistically associated with lower pure technical efficiency. However, the magnitude of the influence draws into question the economic significance of this finding.

Utilities discharging to either a river or an ocean outfall were found to be hampered to an approximately equal degree. This result is odd in that many in the industry suggest that discharging to a river, and in particular an environmentally sensitive river, is the most costly in terms of treatment, while discharging to an ocean outfall incurs the least cost.

The dummy variables included to measure size indicate that while the smallest utilities were around 10 per cent more efficient than those in the medium and large categories, those in the very large category were around four per cent more efficient than those in the smallest category. Since the majority of utilities in the largest category are located in Victoria, this regression was re-estimated excluding the dummy variable representing RUWAs. The coefficient on the dummy variable for very large utilities increased from 0.0466 to 0.102 (at a 99 per cent confidence level), suggesting that the largest firms were, on average, 10 per cent more efficient than the smallest in the sample.

Finally, Victorian utilities were found, as a group, to be around 14 per cent more efficient in terms of pure technical efficiency. When the equation was estimated excluding the dummy variables for size, the coefficient on the dummy for Victorian utilities increased to 0.17 (at the 99 per cent confidence level). Considered together, the results add weight to the argument that Victorian wastewater utility managers are considerably better at managing resources than those in NSW.

***Large utilities***

The results relating to the analysis of the determinants of pure technical efficiency in large regional urban wastewater utilities in Victorian and NSW are reported in Table 9.8.

In general, many of the coefficients found to be of significance in the full sample were also significant in this context. In particular, evidence supports both returns to production and increased relative pure technical efficiency from servicing a relatively higher proportion of residential connections. A similar pattern was also detected in terms of relative treatment expenses; however, in this case those discharging to a river environment were disadvantaged in terms of efficiency relatively more heavily.

The result of most interest, however, relates to the dummy variable identifying Victorian utilities. Noting that the dummy variable for size was found to be insignificant in this specification, Victorian utilities were, on average, 22 per cent more purely technically efficient. This has obvious policy implications, discussion of which is deferred to Chapter 10

Table 9.8: Explaining pure technical efficiency of large wastewater utilities

| Variable | Description | Coefficient | Std. error | z-stat. | Prob. |
|---|---|---|---|---|---|
| $\alpha$ | Constant | –0.7418 | 0.3423 | –2.167 | 0.030 |
| $z_2$ | Residential connections | 0.0141 | 0.0035 | 4.010 | 0.000 |
| $z_3$ | Production density | 0.0004 | 0.0002 | 2.218 | 0.027 |
| $z_8$ | Tertiary treatment | –0.1097 | 0.0286 | –3.834 | 0.000 |
| $z_9$ | Land discharge | –0.0576 | 0.0279 | –2.068 | 0.039 |
| $z_{10}$ | Ocean discharge | –0.0548 | 0.0317 | –1.730 | 0.084 |
| $z_{11}$ | River discharge | –0.0865 | 0.0345 | –2.506 | 0.012 |
| $z_{12}$ | RUWA | 0.2204 | 0.0288 | 7.647 | 0.000 |
| $z_{18}$ | 2003 | 0.0811 | 0.0291 | 2.789 | 0.005 |
| $z_{19}$ | 2004 | 0.0488 | 0.0287 | 1.702 | 0.089 |
| ***Error Distribution*** | | | | | |
| $e$ | | 0.173 | 0.008 | 0.000 | 0.000 |
| ***Diagnostic Statistics*** | | | | | |
| R-squared | | 0.306 | Mean dependent var | | 0.617 |
| Adjusted R-squared | | 0.273 | S.D. dependent var | | 0.208 |
| S.E. of regression | | 0.178 | Akaike info criterion | | –0.573 |
| Sum squared resid | | 6.717 | Schwarz criterion | | –0.405 |
| Log likelihood | | 75.153 | Hannan-Quinn criter. | | –0.505 |
| Avg. log likelihood | | 0.336 | | | |
| Left censored obs | | 0 | Right censored obs | | 0 |
| Uncensored obs | | 224 | Total obs | | 224 |
| ***Redundant variables test*** | | | | | |
| Redundant variables: Z4 Z5 Z6 Z16 Z17 | | | | | |
| F-statistic | | 1.305 | Probability | | 0.263 |
| Log likelihood ratio | | 6.912 | Probability | | 0.227 |
| ***Wald test of joint significance of variables*** | | | | | |
| Wald test: all coefficients = 0 | | | | | |
| Test Statistic | | | Value | df | Probability |
| F-statistic | | | 304.232 | (10, 213) | 0.000 |
| Chi-square | | | 3042.315 | 10 | 0.000 |

### 9.3.3 Explaining scale efficiency in urban wastewater provision in NSW and Victoria

This section discusses the determinants of relative scale efficiency of regional urban wastewater utilities in NSW and Victoria. Again, the analysis was conducted across two datasets partitioned according to relative size.

***All utilities***

Table 9.9 shows the results of the model to analyse the determinants of scale technical efficiency. The variables included were selected according to the results of a redundant variable test.

In contrast to its explanation of scale efficiency in the provision of water, the model applied to wastewater utilities has been of relatively more use. The analysis of the full dataset produced a number of notable results.

First, there was evidence of decreasing returns to customer density. This was intuitively appealing since it indicated that an optimal customer density existed, and this finding was therefore in line with previous evidence on this measure.

Table 9.9: Explaining scale efficiency of all wastewater utilities

| Variable | Description | Coefficient | Std. error | z-stat. | Prob. |
|---|---|---|---|---|---|
| $\alpha$ | Constant | 0.8395 | 0.0332 | 25.321 | 0.000 |
| $z_4$ | Customer density | –0.0016 | 0.0008 | –2.143 | 0.032 |
| $z_6$ | Sewer main chokes | 0.0005 | 0.0001 | 6.423 | 0.000 |
| $z_{11}$ | River discharge | 0.0627 | 0.0165 | 3.806 | 0.000 |
| $z_{12}$ | RUWA | –0.0894 | 0.0176 | –5.067 | 0.000 |
| $z_{14}$ | Medium utility | –0.0508 | 0.0219 | –2.321 | 0.020 |
| $z_{15}$ | Large utility | –0.1401 | 0.0178 | –7.879 | 0.000 |
| $z_{16}$ | Very large utility | –0.2452 | 0.0175 | –14.027 | 0.000 |
| $z_{17}$ | 2002 | –0.0622 | 0.0202 | –3.081 | 0.002 |
| $z_{18}$ | 2003 | –0.0267 | 0.0166 | –1.615 | 0.106 |
| $z_{19}$ | 2004 | 0.1135 | 0.0166 | 6.816 | 0.000 |
| ***Error Distribution*** | | | | | |
| $e$ | | 0.131 | 0.006 | 0.000 | 0.000 |
| ***Diagnostic Statistics*** | | | | | |
| R-squared | | 0.549 | Mean dependent var | | 0.750 |
| Adjusted R-squared | | 0.538 | S.D. dependent var | | 0.194 |
| S.E. of regression | | 0.132 | Akaike info criterion | | –1.172 |
| Sum squared resid | | 7.749 | Schwarz criterion | | –1.064 |
| Log likelihood | | 279.308 | Hannan-Quinn criter. | | –1.130 |
| Avg. log likelihood | | 0.613 | | | |
| Left censored obs | | 0 | Right censored obs | | 0 |
| Uncensored obs | | 456 | Total obs | | 456 |
| ***Redundant variables test*** | | | | | |
| Redundant variables: Z2 Z3 Z5 Z8 Z9 Z10 | | | | | |
| F-statistic | | 0.686 | Probability | | 0.661 |
| Log likelihood ratio | | 4.421 | Probability | | 0.620 |
| ***Wald test of joint significance of variables*** | | | | | |
| Wald test: all coefficients = 0 | | | | | |
| Test Statistic | | | Value | df | Probability |
| F-statistic | | | 1755.560 | (11, 444) | 0.000 |
| Chi-square | | | 19311.16 | 11 | 0.000 |

The dummy variables for size suggest that the larger a utility was, the less scale efficient it became. This was possibly muting to some extent the true scale inefficiency of Victorian wastewater utilities, and so the model was re-estimated excluding the size dummy variables. The result was that the coefficient on the RUWA dummy variable increased from –0.08 to –0.214 (at a confidence level of

99.9 per cent). From this it can be tentatively concluded that either Victorian utilities are too large, or they are being unfairly compared with smaller utilities.

***Large utilities***

The results relating to the analysis of the determinants of scale efficiency in large regional urban wastewater utilities in Victoria and NSW are reported in Table 9.10.

The first result of note in Table 9.10 is that there was no longer any evidence of a relation between relative scale efficiency and customer density. This may be related to the exclusion of the two small size categories. Second, when Victorian utilities were compared with utilities of a similar size in NSW, they were found as a group to be, on average, 14 per cent less scale efficient. Again, this finding has significant policy implications, especially when viewed in conjunction with the results relating to relative pure technical efficiency; these implications are discussed in the following section.

Table 9.10: Explaining scale efficiency of large wastewater utilities

| Variable | Description | Coefficient | Std. error | z-stat. | Prob. |
|---|---|---|---|---|---|
| $\alpha$ | Constant | 0.7164 | 0.0396 | 18.102 | 0.000 |
| $z_3$ | Production density | 0.0004 | 0.0001 | 3.380 | 0.001 |
| $z_9$ | Land discharge | 0.0319 | 0.0159 | 2.001 | 0.045 |
| $z_{11}$ | River discharge | 0.1103 | 0.0258 | 4.276 | 0.000 |
| $z_{12}$ | RUWA | −0.1465 | 0.0197 | −7.440 | 0.000 |
| $z_{17}$ | 2002 | 0.0263 | 0.0181 | 1.448 | 0.148 |
| $z_{18}$ | 2003 | −0.0637 | 0.0218 | −2.915 | 0.004 |
| $z_{19}$ | 2004 | 0.0294 | 0.0208 | 1.414 | 0.157 |
| ***Error Distribution*** | | | | | |
| $e$ | | 0.106 | 0.007 | 14.387 | 0.000 |
| ***Diagnostic Statistics*** | | | | | |
| R-squared | | 0.438 | Mean dependent var | | 0.873 |
| Adjusted R-squared | | 0.417 | S.D. dependent var | | 0.141 |
| S.E. of regression | | 0.108 | Akaike info criterion | | −1.580 |
| Sum squared resid | | 2.486 | Schwarz criterion | | −1.442 |
| Log likelihood | | 185.908 | Hannan-Quinn criter. | | −1.524 |
| Avg. log likelihood | | 0.830 | | | |
| Left censored obs | | 0 | Right censored obs | | 0 |
| Uncensored obs | | 224 | Total obs | | 224 |
| ***Redundant variables test*** | | | | | |
| Redundant variables: Z2 Z4 Z5 Z6 Z8 Z10 Z16 | | | | | |
| F-statistic | | 0.390 | Probability | | 0.907 |
| Log likelihood ratio | | 2.878 | Probability | | 0.896 |
| ***Wald test of joint significance of variables*** | | | | | |
| Wald test: all coefficients = 0 | | | | | |
| Test Statistic | | | Value | df | Probability |
| F-statistic | | | 2618.706 | (8, 215) | 0.000 |
| Chi-square | | | 20949.64 | 8 | 0.000 |

### 9.3.4 Summary of results

The results of the analysis reported here can be summarised as follows. First, Victorian utilities were relatively more efficient in terms of overall efficiency, and particularly in terms of pure technical efficiency. In contrast, RUWAs were operating far from the optimal scale compared with the best performing utilities. Second, there appeared to be some evidence in support of returns to production density, while the evidence on the role of returns to customer density was mixed. Finally, a consistent relationship between the various measures of treatment intensity and discharge location was not detected, despite the lack of collinearity between the variables. This was with one exception: those utilities treating to a tertiary standard were generally found to be less efficient both in terms of overall and pure technical inefficiency.

## 9.4 Productivity in the wastewater sector of NSW and Victoria

In Chapter 3, the theoretical underpinnings relating to the calculation of productivity with reference to DEA relative efficiency scores were outlined. This section reports the results relating to the estimation of productivity change in regional urban wastewater utilities. Again, two datasets are analysed, partitioned according to relative size.

### 9.4.1 All utilities

The results of the analysis of productivity change in regional urban wastewater utilities are reported in tables 9.11 and 9.12. Since the analytical technique followed in this context was identical to that applied to regional urban water utilities, the reader is referred to Section 8.7 of Chapter 8 for a discussion of productivity analysis results.

Table 9.11: Average productivity changes over period 2001–2004

| | Total Factor Productivity | Efficiency Change | Technical Change |
|---|---|---|---|
| Ave All Utilities | 0.914 (–8.9%) | 1.106 (10.1%) | 0.827 (–19%) |
| Ave NSW Utilities | 0.908 (–9.6%) | 1.095 (9.1%) | 0.829 (–18.7%) |
| Ave Vic Utilities | 0.963 (–3.7%) | 1.188 (17.2%) | 0.811 (–21%) |
| Ave All Utilities – 2002 | 0.911 (–9.3%) | 0.962 (–3.9%) | 0.947 (–5.4%) |
| Ave All Utilities – 2003 | 0.811 (–20.9%) | 1.166 (15.4%) | 0.696 (–36.2%) |
| Ave All Utilities – 2004 | 1.035 (3.4%) | 1.207 (18.8%) | 0.858 (–15.3%) |

When productivity was measured in terms of changes in TFP, wastewater utilities in NSW and Victoria suffered an average decline in productivity per year of around nine per cent. A similar decrease was found for water utilities. However, when the average change per year was analysed in terms of the utilities in each state, it would appear that wastewater utilities in NSW suffered a decline in productivity almost twice that felt by Victorian utilities. It is also interesting to note that the decline in TFP was entirely due to a decrease in the productive capacity of the industry, denoted by the decline in technical change. This result was true for both NSW and Victorian utilities. However, the relatively stronger growth in overall efficiency for Victorian utilities resulted in utilities from that state clawing back much of that lost productivity through efficiency improvements.

Whether this result is of economic significance is a matter for debate. It appears from closer inspection of the results that the shift in the frontier occurred mostly between 2002 and 2003. Furthermore, much of this decline can be attributed to the 'coming back to the pack' of a small number of utilities in NSW, the majority of which were from the smallest size class of utilities. Thus, the performance of Victorian utilities may be attributable more to the erroneous inclusion of very small utilities in the dataset rather than to real economic factors. Further evidence for this proposition is apparent from the changes in TFP when only the two largest size classes of utilities were analysed. This point is discussed further in Section 9.4.2.

### 9.4.2 Large utilities

Table 9.12 reports the results relating to productivity changes when only those utilities from the two largest size categories were included in the dataset.

Table 9.12: Average productivity changes over period 2001–2004

| | **Total Factor Productivity** | **Efficiency Change** | **Technical Change** |
|---|---|---|---|
| Ave All Utilities | 0.937 (–6.5%) | 1.044 (4.3%) | 0.897 (–10.8%) |
| Ave NSW Utilities | 0.930 (–7.2%) | 1.038 (3.8%) | 0.896 (–11%) |
| Ave Vic Utilities | 0.959 (–4.2%) | 1.063 (6.1%) | 0.902 (–10.3%) |
| Ave All Utilities – 2002 | 0.936 (–6.6%) | 1.105 (10%) | 0.847 (–16.6%) |
| Ave All Utilities – 2003 | 0.86 (–15.1%) | 0.974 (–2.6%) | 0.883 (–12.4%) |
| Ave All Utilities – 2004 | 1.022 (2.2%) | 1.058 (5.6%) | 0.966 (–3.5%) |

Once utilities in the two smallest size groups were excluded, a noticeable difference in technical change was detected. While TFP still declined over the period, the proportion that was due to a fall in technical change almost halved. However, the change in overall technical efficiency during the period was positive, indicating that managers improved the productivity with which they managed the available resources.

The decline in technical change appears to have been equally severe in NSW and Victoria, suggesting institutional structure delivers little advantage in managing a decline in the productive capacity of the industry. However, managers of Victorian utilities improved technical efficiency by around 60 per cent more than those in NSW. This supports a conclusion that Victorian wastewater utility managers dealt with the consequences of frontier shift relatively better than their counterparts in NSW.

## 9.5 Concluding remarks

While a number of the results presented in this chapter have implications for policy makers, perhaps the most interesting implication relates to the relative pure technical and scale efficiency of wastewater utilities located in Victoria. It would appear from the results presented here that the managers of Victorian wastewater utilities were at a significant advantage in terms of deploying the resources available to them in the delivery of wastewater services; however, this was negated somewhat by relative scale inefficiency. Expressed slightly differently, NSW utilities were of a size relatively closer to the optimum, but they were managed relatively poorly in comparison to their counterparts in Victoria.

This result has a number of policy implications. An examination of these is presented in Chapter 10.

# Chapter 10. Conclusion and Policy Implications

## 10.1 Introduction

The divergent institutional frameworks that govern the provision of urban water and wastewater services in regional NSW and Victoria present an ideal backdrop against which the association between a given regulatory regime and relative technical (in)efficiency and productivity have been measured. Within the limitations of the model employed and the data analysed, three clear themes have emerged. First, access to groundwater has been a significant source of both overall and pure technical efficiency for water utilities located in NSW. Second, evidence suggesting returns to production density in both water and wastewater networks points to costs associated with policies designed to bring about a reduction in per capita water consumption. For utilities providing those services, water restrictions and the like may lead to foregone relative efficiency. Finally, Victorian utilities have had a relative advantage in terms of pure technical efficiency in the provision of both water and wastewater services.

This chapter draws the policy implications from the results of this thesis, while simultaneously highlighting the limitations of the study. Avenues for further research are also identified. The chapter consists of five main sections. In Section 10.2 the significance of this study is established, while in Section 10.3 a number of implications for urban water and wastewater policy are outlined. Implications for the structure of water and wastewater utilities are suggested in Section 10.4. Finally, the limitations of this study and avenues for further research are identified in Section 10.5.

## 10.2 General summary

In Chapter 1, it was argued that while much of the recent attention of policy makers had been trained on the efficiency with which water is consumed, the efficiency with which water is produced had largely appeared to be of secondary importance to policy elites. While this might be understandable in the current circumstances, it was argued that there are still grounds for investigating the role of differing institutional or regulatory structures as a determinant of relative efficiency. It was argued that such a study is justified based on the general welfare-enhancing consequences to society that would result from improved efficiency in the use of resources.

Chapter 2 further explored the divergences in institutional structure for the regulation of regional urban water and wastewater utilities in NSW and Victoria. It was established that the most notable differences were in governance and economic regulation. While NSW LWUs were typically a business unit of local government within that state, RUWAs in Victoria were independent statutory authorities, governed by a state government appointed board, which was indirectly responsible to the relevant state government minister.

The theoretical approaches to the measurement of relative efficiency were reviewed in Chapter 3. Two broad analytical techniques were identified: DEA and SFA. Both represent frameworks for determining the relative efficiency of firms against a production of cost frontier. Chapter 3 also demonstrated the technique by which DEA and/or SFA relative efficiency scores can be utilised in order to measure productivity change.

The body of empirical literature relating to the measurement of relative efficiency in water and/or wastewater utilities was reviewed in Chapter 4. A number of conclusions were drawn, including the observation that there was a paucity of research relating to regional urban water and wastewater sectors in Australia. Furthermore, no study appears to have been undertaken in which all of the 15 RUWAs in Victoria were included for analysis.

Chapter 5 outlined the specification of the DEA model employed in this study. It was argued that DEA was the better of the two approaches in this context, given that little empirical evidence exists to guide assumptions regarding the shape of the production or cost function to be estimated. For this reason, the non-parametric framework was employed. Furthermore, since DEA is a deterministic model, a Tobit regression equation was specified by which the determinants of relative technical efficiency could be investigated.

In view of the fact that relative efficiency techniques are based on the relationship between inputs and outputs in the production process, chapters 6 and 7 outlined the rationale for the choice of these variables to be used in the analysis of water and wastewater utilities, respectively. The choice of exogenous variables to be included in the so-called 'second stage' analysis of DEA scores was also justified. A précis of descriptive statistics aligned to the inputs, outputs and exogenous variables relating to each sector was also presented.

The results of the analysis of water utilities were presented in Chapter 8, while those pertaining to wastewater utilities were outlined in Chapter 9. The two main results to arise from the water sector analysis suggested that groundwater is significantly related to the relative efficiency of water utilities and that when Victorian utilities were compared with utilities of a similar size in NSW, they were around 13% more efficient in terms of pure technical efficiency. The main conclusion to be drawn from the analysis of wastewater utilities suggested that although Victorian utilities held a significant advantage in terms of pure technical efficiency, the effect of this on overall efficiency was muted to a degree by relative scale inefficiency. This result pointed to some countervailing consequences arising from the reforms of the sector carried out by the Kennett government in the 1990s.

## 10.3 Significance of the study

The significance of this thesis can be argued along four main fronts. First, this study represents the first analysis of the economic efficiency of regional urban water and wastewater utilities in NSW and Victoria. Second, to the author's knowledge, this is the first analysis of the contribution differing institutional structure makes to relative (in)efficiency and productivity in the Australian water context. Combined, these two aspects of the study represent genuine contributions to the literature. Furthermore, in the context of the newly established national performance reporting arrangements for water utilities, the thesis establishes a benchmark against which future analysis of urban water and wastewater utilities can be measured.

Third, this study is a relatively more comprehensive analysis of water and wastewater utilities in Australia than has previously been attempted, particularly with respect to regional utilities. In fact, to the author's knowledge, Woodbury and Dollery (2004) conducted the only other analysis of regional utilities. Finally, consistent evidence was found for a number of influences that are strongly related to relative efficiency.

The most important of these were production density and access to groundwater resources. As will be outlined in the following section, it is hoped that these results will greatly assist those charged with formulating policy for this sector.

## 10.4 Implications for Urban Water and Wastewater Policy

The results derived from this thesis suggest a number of distinct implications for urban water and wastewater policy. Each of these is briefly discussed below.

### 10.4.1 Water conservation policies reduce efficiency

The results that indicate there are efficiency advantages from higher levels of production density in both water and wastewater networks are powerful in terms of informing current water policy. They suggest that policies designed to reduce per capita consumption of water within a given network, such as water restrictions, are likely to have a negative impact on the relative technical efficiency of both water and wastewater utilities. It has already been established elsewhere that water restrictions result in welfare losses for consumers of water (Brennan et al., 2007). This study indicates that the policy also has an efficiency aspect. Thus, there are now multiple reasons to suggest that rationing potable water via regulation is a policy with multiple costs attached. It follows that the purported benefits of rationing potable water by regulation should be compared with the costs outlined by Brennan et al. (2007) and the present study.

### 10.4.2 Groundwater is a source of efficiency in regional NSW

This analysis found an economically and statistically significant link between the relative efficiency of water utilities and access to groundwater. The policy implications of the result are limited, since they merely confirm the existence of such a relationship, rather than explaining why that link exists. However, it seems a matter of some importance to further investigate this relationship with a view to determining why relative technical efficiency has been found to be higher in those utilities with access to groundwater. For instance, it might be hypothesised that the protection of groundwater from pollutants provided by the barrier between the surface and the groundwater aquifer may result in reduced costs from the avoidance of some of the treatment related expenses faced by those utilities reliant on surface water. Alternatively, the existence of groundwater may be correlated with another exogenous factor that has not been included in this model. Regardless, activities that prevent LWUs from accessing groundwater have been shown by this thesis to have well established costs attached in the form of foregone efficiency. It follows that current efforts to better understand the nature of groundwater systems (see, for instance, NWC, 2007a) are, as a result of this finding, even more valuable.

### 10.4.3 Higher proportion of industrial consumers reduces efficiency

An unexpected finding from this study was the negative correlation between higher proportions of water supplied to industrial users and relative efficiency. While it is clearly not sensible to suggest water utilities limit the proportion of water supplied to industrial consumers in order to improve relative efficiency, the result should be considered by regulators and policy makers when considering the relative performance of urban water utilities in regional locations. This also points to the need for councils and state governments to re-evaluate the net benefits of attracting industry to their jurisdiction.

### 10.4.4 Drought and water restrictions impact water utilities equally

A final policy implication from this study relates to the role of institutional or regulatory structure in managing the effects of drought. It seems clear from the results relating to the productivity of the water sectors in regional NSW and Victoria that the ability of managers to cope with the consequences of the drought is not related to the state in which the utility is located. Consequently, threats to the security of urban water supply are not likely to be ameliorated through the pursuit of a 'basin-wide' approach to urban water management. In other words, the benefits of a plan such as that proposed by the federal government to take control of rural water management in the Murray–Darling Basin, replicated in the urban water context, appear to have little support from the empirical results presented here.

## 10.5 Implications for the structure of the urban water and wastewater sector

The results also suggest a number of implications for policy related to the structure of the water and wastewater sectors in Australia. Each is considered separately in this section.

One of the main findings from the analysis of water utilities was that RUWAs were around 5% more efficient in terms of relative pure technical efficiency. This suggests that the case for wholesale, wide-reaching structural change in the provision of potable water in NSW is not strong, given that the costs from reform may outweigh the predicted benefits. Perhaps a relatively cost-free option might be incorporated, such as reforming governance arrangements. Water utilities of sufficient size (for example, more than 10,000 connections) could be brought within the regulatory gamut of the IPART (the independent economic regulator in NSW). Separation of ownership may also be considered. Utilities with more than 10,000 connections could be required to separate from local government, following adequate compensation from the state government, to form state government statutory authorities. To mimic the Victorian structure, each authority could be governed by a board, based on relevant expertise, rather than council representation. The board would be responsible to the relevant state government minister, via a license that established the conditions by which the authority would be permitted to operate. However, the transaction costs incurred would need to be carefully estimated, since the benefits associated with reform of this type are likely to be minimal based on this result.

In terms of wastewater, the results of this thesis generally suggest advantages that may accrue from the differentiation of water and wastewater functions when reforming institutional structure. Although it seems impractical to break up Victorian regional water authorities, those responsible for the reform of the urban water and wastewater sector in South East Queensland may find the results informative. In particular, it appears that the optimal scale, measured by relative scale efficiency, of wastewater utilities is substantially smaller than that in water utilities. It may be worthwhile for policy makers to investigate this aspect further to determine whether this result stemmed from model design or genuine production relationships.

The relative scale inefficiency of Victorian wastewater utilities may reflect an underlying disadvantage stemming from the reforms undertaken in the 1990s. As outlined in Chapter 2, most RUWAs were formed around a relatively densely populated regional centre. It seems possible that the requirement of uniform quality standards across each RUWA district was in part responsible for an increase in treatment efficiency. The logic of this hypothesis is as follows. It may be economic for the sewage treatment plant of a relatively large town to provide treatment at a relatively high standard. This is in line with the evidence that there are scale economies in the treatment of wastewater. However, the costs associated with treating wastewater at a sewage treatment plant with a relatively smaller volume of sewage to an equal standard may be substantial. In NSW this may not be a problem because there are fewer examples of LWUs servicing multiple locations of varying size and density.

Another interesting question raised by this thesis related to structure surrounds the finding that RUWAs were on average 20 per cent more purely technically efficient in terms of wastewater, and 13 per cent more efficient in terms of water provision. This was hypothesised to have been a consequence of a number of related factors. First, the composition of the boards of RUWAs was a function of relative expertise, rather than boards being required to provide proportional representation to the local government area each served. Local government water utility managers are likely to have an engineering background, while strategic decisions made by the RUWA boards are less likely to be framed within an engineering paradigm, perhaps thus leading to a lower propensity to 'gold-plate' infrastructure.

Second, management expertise may be relatively more attracted to Victorian utilities due to the prospect of reporting to a board, rather than the general manager of a council. In other words, the relatively more corporate structure may attract professionals comfortable in that environment. The implication of this assumption is that the relatively more skilled employees are attracted and retained by RUWAs, and less so by NSW councils. However, an interesting trade-off appears to be present. While the generally bigger RUWAs are able to attract water and wastewater management expertise, giving rise to technical efficiencies, set against this is the loss of scale efficiency, in so much as the results suggest that RUWAs exceed 'optimal' size. Finally, the proximity of the relevant elected officials (i.e. councillors) in NSW may have resulted in some diversion of attention or resources to projects that did not constitute an efficient use of resources.

## 10.6 Limitations and further research

There are two main and fundamental limitations that should be considered when reflecting on the results of this thesis: a) the quality of the data analysed and b) the robustness of the various models employed in order to estimate relative efficiency and productivity.

As has been alluded to in chapters 6 and 7, the data analysed in this thesis are of questionable quality. While financial data were subject to some verification through the auditing of annual accounts, the physical data relating to variables such as the length of mains or the volume of water consumed were not audited. The results of this thesis therefore are influenced by the accuracy of the manually recorded data collection process, and should be considered in that light. Fortunately, the national performance reporting framework, to apply to all utilities with 10,000 or more connections from 2007, is likely to require all data to be audited and this will benefit subsequent research.

In a related point, the two models employed to generate various technical efficiency scores were limited to the extent that they excluded a number of variables that some may argue are significant in determining relative efficiency. This would suggest that the first stage DEA models were mis-specified to an extent. It follows that the results could be construed as representative of a fictitious industry forced to exist for the sake of estimating relative efficiency scores. Furthermore, the results of the second stage analysis of those relative efficiency scores could also be seen as simply explaining a water and wastewater industry that exists in the DEA models specified in this thesis, and therefore not particularly relevant to the more complex 'real world' in which water and wastewater utilities operate.

Each critique is valid, and the results outlined in this thesis are limited by the extent to which each caveat holds. Thus, while policy makers may be guided to investigate certain aspects of the water and wastewater sectors in regional Australia by the findings presented here, it is hoped that more detailed investigation will be undertaken before making any policy decisions.

There is scope for at least three further lines of enquiry. First, it has been hypothesised that several factors could explain why Victorian water and wastewater utilities are more efficient by some measures; however, at this stage these hypotheses are simply conjectures. The finding of a relative advantage due to regulatory and/or institutional structure points to the need for a study of the causes of that result.

Similarly, it has been established that utilities with access to a groundwater resource have a relative advantage in terms of both pure technical and overall efficiency. The next step would be to investigate why this is the case. If it is related to the relative quality of the resource, empirical evidence to support this would build a case for further protection of groundwater aquifers. However, until the cause for the link between relative efficiency and groundwater is established, knowing which particular aspect of the resource to protect will be difficult.

Finally, this study has been entirely focused on the relative efficiency and productivity of water and wastewater utilities in regional NSW and Victoria. A matter neglected, but of equal relevance, is the extent to which economies of scope are prevalent in the industry. A recent working paper by Kittelsen and Magnussen (2003) suggested a means of testing for scope economies in a DEA framework. This would appear to be a potentially fruitful line of enquiry in this context.

# References


ACIL Tasman (2005) *Institutional Arrangements in the Australian Water Sector: Information Paper*, Prepared for the National Water Commission, ACIL Tasman, Melbourne.

Aigner, D.J. and Chu, S.F. (1968) On estimating the industry production function. *American Economic Review*, 58(4), 826–839.

Aigner, D. Lovell, C.A.K. and Schmidt, P. (1977) Formulation and estimation of stochastic frontier production function models. *Journal of Econometrics*, 6(1), 21–37.

Allen (2006) *Are Councils Sustainable? Final Report: Findings and Recommendations*. Independent Inquiry into Local Government Inquiry (LGI), NSW Local Government and Shires Association, Sydney.

Anwandter, L. and T. J. Ozuna (2002) Can public sector reforms improve the efficiency of public water utilities? *Environment and Development Economics*, 7, 687–700.

Arnell, N.W. (2004) Climate Change and Global Water Resources: SRES Emissions and Socio-economic Scenarios. *Global Environmental Change*, 14, 31–52.

Ashton, J. K. (2000). Total factor productivity growth and technical change in the water and sewerage industry. *The Service Industries Journal,* 20(4), 121.

Aubert, C. and Reynaud, A. (2005) The impact of regulation on cost efficiency: an empirical analysis of Wisconsin water utilities. *Journal of Productivity* Analysis, 23(3): 383–409.

Banker, R.D. and Morey, R.C. (1986) The use of categorical variables in data envelopment analysis. *Management Science*, 32(12), 1613–1627.

Banker, R.D. Charnes, A. and Cooper, W.W. (1984) Some models for estimating technical and scale inefficiencies in data envelopment analysis. *Management Science*, 30(9), 1078–1092.

Bhattacharyya, A., Parker, E. and Raffie, K. (1994) An examination of the effect of ownership on the relative efficiency of public and private water utilities. *Land Economics*, 70, 197–209.

Bhattacharyya, A., Harris, R., Narayanan, R. and Raffie, K. (1995a) Specification and estimation of the effect of ownership on the economic efficiency of the water utilities. *Regional Science and Urban Economics*, 25, 759–784.

Bhattacharyya, A., Harris, R., Narayanan, R. and Kambiz, K. (1995b), Allocative efficiency of rural Nevada water systems: a hedonic shadow cost function approach. *Journal of Regional Science*, 35 (3), 485–502.

Bottasso, A. and Conti, M. (2003) Cost Efficiency in the English and Welsh Water Industry: A Heteroskedastic Stochastic Cost Frontier Approach. *Economics Discussion Papers.* Essex, University of Essex.

Brennan, D., Tapsuwan, S. and Ingram, G. (2007) The welfare costs of urban outdoor water restrictions. *The Australian Journal of Agricultural and Resource Economics*, 51(3), 243–261.

Byrnes, P., Grosskopf, S. and Hayes, K. (1986) Efficiency and ownership: further evidence. *The Review of Economics and Statistics*, 68, 337–341.

Byrnes, J.D., Crase, L. and Dollery, B.E. (2006). Regulation versus pricing in urban water policy: the case of the Australian National Water Initiative. *Australian Journal of Agricultural and Resource Economics,* 50(3), 437–449.

Caves, D.W., Christensen, L.R. and Diewert, W.E. (1982a) Multilateral Comparisons of Output, Input and Productivity Using Superlative Index Numbers. *Economic Journal,* 92, 73-86.

Caves, D.W., Christensen, L.R. and Diewert, W.E. (1982b) The Economic Theory of Index Numbers and the Measurement of Input, Output and Productivity. *Econometrica*, 50, 1393–1414.

Charnes, A. Cooper, W.W. and Rhodes, E. (1978) Measuring the efficiency of decision making units. *European Journal of Operational Research*, 2(6), 429–444.

Charnes, A. Cooper, W.W. and Rhodes, E. (1981) Evaluating program and managerial efficiency: An application of data envelopment analysis to Program Follow Through. *Management Science*, 27(6), 668–697.

CoAG (1992) Council of Australian Governments, viewed 15 February 2005, http://www.coag.gov.au/meetings/071292/index.htm

CoAG (1993) Council of Australian Governments, viewed 15 February 2005, http://www.coag.gov.au/meetings/080693/index.htm#water

CoAG (1994) Council of Australian Governments, *Attachment A – Water Resource Policy.* Viewed 15 February 2005, http://www.coag.gov.au/meetings/250294/attachment_a.htm

CoAG (1995) Council of Australian Governments, viewed 15 February 2005, http://www.coag.gov.au/meetings/110495/index.htm

CoAG (2004) Council of Australian Governments, *Intergovernmental Agreement on A National Water Initiative.* Viewed 15 February 2005, http://www.coag.gov.au/meetings/250604/iga_national_water_initiative.pdf

Coelli, T. and S. Walding (2005) *Performance Measurement in the Australian Water Supply Industry.* St. Lucia Qld., Centre for Efficiency and Productivity Analysis.

Coelli, T., Rao, D.S. and Battese, G. (1998) *An Introduction to Efficiency and Productivity Analysis*. London: Kluwer Academic Publisher.

Coelli, T., Prasada Rao, D.S., O'Donnell, C.J. and Battese, G. (2005) *An Introduction to Efficiency and Productivity Analysis*. Kluwer Academic Publisher.

Connell, D. (2007) *Water Politics in the Murray-Darling Basin*. Annandale: Federation Press.

Cook, W.D., Chai, D., Doyle, J. and Green, R. (1998) Hierarchies and Groups in DEA. *Journal of Productivity Analysis*, 10, 177–198.

Crain, W. M. and A. Zardkoohi (1978) A Test of the Property-Rights Theory of the Firm: Water Utilities in the United States. *Journal of Law and Economics*, 21(2), 395-408.

Crase, L. and Dollery, B. (2006). The inter-sectoral implications of "securing our water future together. *International Journal of Environmental, Cultural, Economic and Social Sustainability*, 1(5), 13–22.

Cubbin, J. and Tzanidakis, G. (1998) Regression versus data envelopment analysis for efficiency measurement: an application to the England and Wales regulated water industry. *Utilities Policy,* 7, 75–85.

Cullen, P. (2006) Flying Blind – The Disconnect Between Groundwater and Policy. 10th Murray-Darling Groundwater Workshop, Canberra. Viewed 8 November 2007, http://www.nwc.gov.au/news/speeches/MDB_Groundwater_250906.pdf

Debreu, G. (1951) The coefficient of resource utilization. *Econometrica*, 19(3), 273–292.

Department of the Environment and Heritage (2001) Australian Natural Resource Atlas: Australia's Water Resources – An Overview. Viewed 5 September 2007, http://audit.deh.gov.au/ANRA/water/maps/national/division.pdf

Department of Environment and Water Resources (2007) Murray-Darling Basin policies and programmes. Viewed 7 November 2007, URL:http://www.environment.gov.au/water/mdb/policies.html

DEUS (2005a) Department of Energy, Utilities and Sustainability, *2003/04 Water Supply and Sewerage Benchmarking Report,* DEUS, Sydney.

DEUS (2005b) Department of Energy, Utilities and Sustainability, *Best-Practice Management of Water Supply and Sewerage: Guidelines,* DEUS, Sydney.

Dollery, B.E. and Marshall, N. (eds.) (1997) *Australian Local Government: Reform and Renewal.* South Melbourne: MacMillan Education Australia.

Dollery, B.E., Crase, L. and Johnson, A. (2006) *Australian Local Government Economics*. Sydney: UNSW Press.

Dwyer, T. (2006) Urban Water Policy: In Need of Economics, *Agenda*, 13(1), 3–16.

Estache, A. and Kouassi, E. (2002) Sector Organization, Governance, and the Inefficiency of African Water Utilities, *Policy Research Working Paper 2890*, The World Bank Institute, Governance, Regulation, and Finance Division, The World Bank.

Estache, A. and Rossi, M.A. (2002) How Different Is the Efficiency of Public and Private Water Companies in Asia? *The World Bank Economic Review*, 16(1), 139–148.

Faria, C.R., Souza, G. and Moreira, T. (2005) Public Versus Private Water Utilities: Empirical Evidence for Brazilian Companies, *Economics Bulletin*, viewed 14 June 2006, http://www.economicsbulletin.uiuc.edu/2005/volume8/EB-05H00001A.pdf

Farrell, M.J. (1957) The measurement of productive efficiency. *Journal of the Royal Statistical Society*, Series A (General) 120(3), 253–289.

Feigenbaum, S. and R. Teeples (1983) Public Versus Private Water Delivery: A Hedonic Cost Approach. *The Review of Economics and Statistics*, 65(4), 672–678.

Ferrier, G.D. and Lovell, C.A.K. (1990) Measuring cost efficiency in banking: Econometric and linear programming evidence. *Journal of Econometrics*, 46(1-2), 229–245.

Forsund, F. R and Sarafoglou, N. (2002), On the Origins of Data Envelopment Analysis. *Journal of Productivity Analysis*, 17, 23–40.

Fox, W. F. and Hofler, R.A. (1986) Using Homothetic Composed Error Frontiers to Measure Water Utility Efficiency. *Southern Economic Journal,* 53(2), 461–477.

Fried, H.O., Lovell, C.A.K., Schmidt, S.S. and Yaisawarng, S. (2002) Accounting for Environmental Effects and Statistical Noise in Data Envelopment Analysis. *Journal of Productivity Analysis,* 17, 157–174.

Friedman, L.S. (2002) *The Microeconomics of Public Policy Analysis.* Oxfordshire: Princeton University Press.

Gabrielsen, A. (1975) *On Estimating Efficient Production Functions*, Working Paper A-85, Chr. Michelsen Institute, Department of Humanities and Social Sciences, Bergen, Norway.

Garcia, S. and Thomas, A. (2001) The Structure of Municipal Water Supply Costs: Application to a Panel of French Local Communities, *Journal of Productivity Analysis*, 16, 5–29.

Garcia-Sanchez (2006) Efficiency Measurement in Spanish Local Government: The Case of Municipal Water Services. *Review of Policy Research,* 23(2), 355–371.

Geoscience Australia (2007) Viewed 2 September 2007, http://www.ga.gov.au/education/facts/landforms/longrive.htm

Greene, W. (1980) Maximum Likelihood Estimation of Econometric Frontier Functions. *Journal of Econometrics*, 13, 27–56.

Greene, W. (1995) Frontier Production Functions, in M. Hashen Pesaran and P. Schmidt (eds) *Handbook of Applied Econometrics: Volume II Microeconomics.* Oxford: Blackwell.

Greene, W. (2002) *LIMDEP Version 8.0: Econometric Modeling Guide, Vol. 2*. New York: Econometric Software Inc.

HLSGW (1999) High Level Steering Group on Water, *Progress in Implementation of the COAG Water Reform Framework*, Report to COAG, Occasional Paper no. 1.

Hoff, A. (2007) Second stage DEA: Comparison of approaches for modelling the DEA score. *European Journal of Operational Research*, 181, 425–435.

Howard, J. (2007) Viewed 4 February 2007, http://www.pm.gov.au/docs/national_plan_water_security.pdf

Hunt, L.C. and Lynk, E.L. (1995) Privatisation and efficiency in the UK water industry: An empirical analysis. *Oxford Bulletin of Economics and Statistics*, 57, 371–388.

IRF (2002) Institute for Rural Futures, *Agriculture and Natural Resource Management in the Murray-Darling Basin: A Policy History and Analysis*, Report to the Murray-Darling Basin Commission, Armidale.

Jones, M. and French, R. (1999) *Local Government Engineering in Australia*. Leichhardt: Federation Press.

Kelly, P. (1994) *The End of Certainty: Power, Politics and Business in Australia*. St Leonards, NSW: Allen and Unwin.

Kennedy, P. (2003), *A Guide to Econometrics*, 5th edition. Cambridge MA: The MIT Press.

Kittelsen, S. and Magnussen, J. (2003) Economies of Scope in Norwegian hospital Production – A DEA analysis, *Health Economics Research Programme*, University of Oslo.

Koopmans, T.C. (1951) Analysis of Production as an Efficient Combination of Activities, in T.C. Koopmans (ed.) *Activity Analysis of Production and Allocation*, 33–97. New York: Wiley.

Kopp, R.J. (1981) The Measurement of Productive Efficiency: A Reconsideration. *Quarterly Journal of Economics*, 96, 477–503.

Kumbhakar, S.C. and Lovell, C.A.K. (2000), *Stochastic Frontier Analysis*. USA: Cambridge University Press.

Lambert, D.K.; Dichev, D. and Raffiee, K. (1993) Ownership and sources of inefficiency in the provision of water services, *Water Resources Research*, 29(6), 1573–1578.

Leibenstein, H. (1966) Allocative efficiency vs. X–efficiency, *American Economic Review*, 56(3), 392–415.

Lloyd, C. (1993) The Delivery of Sewerage and Waste Treatment Services in Australia, in M. Johnson, and S. Rix, S., *Water in Australia: Managing Economic, Environmental and Community Reform*. Leichhardt: Pluto Press Australia.

Lovell, C.A.K. (1993) Production frontiers and productive efficiency, in H.O. Fried, C.A. Lovell and S.S. Schmidt (eds.) *The Measurement of Productive Efficiency: Techniques and Applications*, 3–67. New York: Oxford University Press.

Lynk, E. L. (1993) Privatisation, joint production and the comparative efficiencies of private and public ownership: the UK water industry case. *Fiscal Studies*, 14(2), 98–116.

Mays, L. and Tung, Y. (1992) *Hydrosystems engineering and Management*. New York: McGraw-Hill.

MDBC (2006) Murray–Darling Basin Commission, viewed 2 September 2007, http://www.mdbc.gov.au/__data/page/20/July2006-Drought-update.pdf

MDBC, (2007a) Murray–Darling Basin Commission, viewed 2 September 2007, http://www.mdbc.gov.au/__data/page/1366/Drought_Update7_April07(web)

MDBC (2007b) Murray–Darling Basin Commission, viewed 2 September 2007, http://www.mdbc.gov.au/about/basin_statistics

Meeusen, W. and van den Broeck, J. (1977) Technical efficiency and dimension of the firm: Some results on the use of frontier production functions. *Empirical Economics*, 2(2), 109–122.

Mizutani, F. and Urakami, T. (2001) Indentifying network density and scale economies for Japanese water supply organizations. *Papers in Regional Science*, 80, 211–230.

NIC (2007) NSW Irrigator's Council, *A National Plan for Water Security: No Industry Support for Compulsory Acquisition*, NSW Irrigators' Council Media Release, 31 January, 2007, viewed 21 October 2007, http://www.nswirrigators.org.au/pdf/press_release/Compulsory%20Acquisition.pdf

NLWRA (2002) viewed 4 August 2005, http://audit.ea.gov.au/ANRA/water/water_frame.cfm?region_type=AUS&region_code=AUS&info=resources

North East Water (2005), *Customer Charter,* viewed 6 July 2007, http://www.nerwa.vic.gov.au/customer/charter.htm

NSW Department of Local Government (2006) *Asset Management Planning for NSW Local Government,* Department of Local Government Position Paper, Nowra.

NSW EPA (2003) Environment Protection Authority, *New South Wales State of the Environment Report*, NSW EPA, Sydney.

NWC (2006) National Water Commission, *Australian Water Resources 2005: A baseline assessment of water resources for the National Water Initiative – Level 1 assessment key findings*, National Water Commission, Canberra.

NWC (2007a) National Water Commission, *National Performance Report 2005-06: Major Urban Water Utilities*, Water Services Association of Australia, Melbourne.

NWC (2007b) National Water Commission, *National Performance Report 2005-06: Non Major Urban Water Utilities*, Water Services Association of Australia, Melbourne.

Pahl-Wostl, C. (2002) Towards sustainability in the water sector – The importance of human actors and processes of social learning. *Aquatic Sciences – Research Across Boundaries*, 64(4), 394–411.

Payne, J.T., Wood, A.W., Hamlet, A.F., Palmer, R.N. and Lettenmaier, D.P. (2004) Mitigating the Effects of Climate Change on the Water Resources of the Columbia River Basin, *Climate Change*, 62, (1), 233–256.

Pigram, J.J. (2006) *Australia's Water Resources: From Use to Management.* Collingwood: CSIRO Publishing.

Powell, J. (1989) *Watering the Garden State: Water Land and Community in Victoria, 1834-1988.* Sydney: Allen and Unwin.

QWC (2007) Queensland Water Commission, *Our Water: Urban water supply arrangements in South East Queensland*, Final Report – May 2007, Queensland Water Commission, Brisbane.

Robinson, J. and Cowen, S. (2003) Climate Change and Sustainable Development: Expanding the Options, *Climate Policy*, 3(Supplement 1), 19–40.

Saal, D.S. and Parker, D. (2000) The Impact of Privatization and Regulation on the Water and Sewerage Industry in England and Wales: A Translog Cost Function Model, *Managerial and Decision Economics,* 21, 253–268

Saal, D. S. and Parker, D. (2001) Productivity and Price Performance in the Privatized Water and Sewerage Companies of England and Wales. *Journal of Regulatory Economics,* 20(1), 61.

SECITARC (2002) *The Value of Water: Inquiry into Australia's Management of Urban Water*, Report of the Senate Environment, Communications, Information Technology and the Arts References Committee, The Parliament of the Commonwealth of Australia.

Sheil, C. (2000) Running the Risks: The Rationalisation of Australia's Water. *Australian Journal of Public Administration*, 59 (3), 11–21.

Smith, D.I. (2004) *Water in Australia: Resources and Management*. Melbourne: Oxford University Press.

Smith, A. (2007) Tighter restrictions possible to get water to crisis zone, Sydney Morning Herald, 28 September, 2007.

Teeples, R. and Glyer, D. (1986) *Cost of Water Delivery Systems*, Working Paper Series, Claremont Centre for Economic Policy Studies.

Teeples, R. and Glyer, D. (1987) Cost of Water Delivery Systems: Specification and Ownership Effects. *The Review of Economics and Statistics,* 69(3), 399–408.

Tupper, H.C., and Resende, M. (2004) Efficiency and regulatory issues in the Brazilian water and sewage sector: an empirical study, *Utilities Policy*, 12, 29–40.

Turnbull, M. (2007) Water Bill 2007 – Second Reading Speech. Delivered 8 August to the House of Representatives, Australian Parliament, Canberra. Viewed 7 November 2007, http://www.environment.gov.au/minister/env/2007/pubs/tr08aug07.pdf

Twort, A.C., Ratnayaka, D.D and Brandt, M.J. (2000) *Water Supply*, 5th edition. London: Arnold and IWA Publishing.

Vaile, M., Bracks, S. and Rann, M. (2007) Water Contingency Planning in the Southern Murray-Darling Basin. Viewed 23 March 2007, http://www.ministers.dotars.gov.au/mv/releases/2007/January/002MV_2007.htm

VicWater (2005) *Victorian Water Review 2003-04*, Victorian Water Industry Association Inc., Melbourne.

VicWater (2007) *Victorian Water Review 2005-06*, Victorian Water Industry Association Inc., Melbourne.

Watson (2007) *A National Plan for Water Security: Pluses and Minuses*, viewed 4 August 2007, http://www.agrifood.info/connections/2007/Watson.html

WGCS (2006) Wentworth Group of Concerned Scientists, *Australia's Climate is Changing Australia: The state of Australia's Water*, Wentworth Group of Concerned Scientists, November 2006.

Winsten, C. (1957) Discussion of Mr. Farrell's Paper, *Journal of Royal Statistical Society, Series A, General,* 120, 282–284.

Woodbury, K. (2001) *Efficiency Measurement in NSW Local Government Water and Wastewater Services using Data Envelopment Analysis*, unpublished Honours dissertation, University of New England, Armidale.

Woodbury, K. and Dollery, B. (2004) Efficiency Measurement in Australian Local Government: The Case of New South Wales Municipal Water Services. *Review of Policy Research,* 21(5), 615.

World Bank (2004) *The Institutional Economics of Water: A Cross-Country Analysis of Institutions and Performance*. Edward Elgar.

Worthington, A. (1998) *Economic Efficiency in the Provision of Local Public Goods*, Unpublished doctoral thesis, University of Queensland, June 1998.

WSAA (2003) *WSAAfacts 2003*, Water Services Association of Australia, Melbourne, Australia.

Young, M. and McColl, J. (2007) *The unmentionable option: Is there a place for an across-the-board purchase?* Droplet No.8, viewed 22 July 2007, http://www.myoung.net.au/water/droplets/Over_allocation.doc

Young, M.D., Proctor, W., Ejaz Qureshi, M. and Wittwer, G. (2006) *Without Water: The economics of supplying water to 5 million more Australians*. Water for a Healthy Country Flagship report, CSIRO Land and Water and Monash University

Zhu, J. (2003) *Quantitative Models for Performance Evaluation and Benchmarking: Data Envelopment Analysis with Spreadsheets and DEA Excel Solver*. Massachusetts: Kluwer Academic Publishers.

## Appendix 1a
## Water utilities excluded from database

| Water Utility | *Reason for exclusion from database:* | | | | | |
|---|---|---|---|---|---|---|
| | **Supplier of potable and non-potable water** | **Incoplete complaints data** | **Incomplete residential percentage consumed data** | **Incomplete operating cost data** | **Not primarily a Local Water Utilitiy** | **Only provides wastewater service** |
| Armidale Dumaresq | | X | X | | | |
| Australian Inland Energy & Water | | | | | X | |
| Balranald (Dual Supply) | X | | | | | |
| Bega Valley (Unfiltered) | | X | X | | | |
| Bellingen (Unfiltered) | | X | X | | | |
| Berrigan (Dual Supply) | X | | | | | |
| Bingara | | | | X | | |
| Bland | | | | | | X |
| Blayney | | | | | | X |
| Bourke (Dual Supply) | X | | X | | | |
| Byron (Reticulator) | | X | | | | |
| Central Darling (Dual Supply) | X | | X | | | |
| Cobar (Dual Supply) | X | | | | | |
| Cobar WB (Bulk Supplier) | | X | | | | |
| Coolamon | | | | | | X |
| Cootamundra (Reticulator) | | X | | | | |
| Copmanhurst (Unfiltered) | | X | | | | |
| Dungog (Unfiltered) | | X | | | | |
| Fish River WS (Unfiltered, Bulk Supplier) | | | | | X | |
| Goldenfields (Bulk Supplier) | | | | | X | |
| Goldenfields (Combined) | | | | | X | |
| Goldenfields (Reticulator) | | | | | X | |
| Grafton (Unfiltered) | | | | X | | |
| Hawkesbury | | | | | X | |
| Hay (Dual Supply) | X | X | | | | |
| Holbrook | | | | | | X |
| Hunter Water | | | | | X | |
| Jerilderie (Dual Supply) | X | | | | | |

# Appendix 1a
## Water utilities excluded from database

| Water Utility | *Reason for exclusion from database:* | | | | | |
|---|---|---|---|---|---|---|
| | **Supplier of potable and non-potable water** | **Incoplete complaints data** | **Incomplete residential percentage consumed data** | **Incomplete operating cost data** | **Not primarily a Local Water Utilitiy** | **Only provides wastewater service** |
| Junee | | | | | | X |
| Lockhart | | | | | | X |
| Maclean | | | | | | X |
| MidCoast (Great Lakes - Unfiltered) | | | | X | | |
| MidCoast (Manning - Unfiltered) | | | | X | | |
| Murray | | X | | | | |
| Narrabri (Groundwater) | | X | X | | | |
| Narromine (Groundwater) | | X | X | | | |
| North Coast Water (Unfiltered) | | | | | X | |
| Oberon (Unfiltered, Reticulator) | | X | | | | |
| Pristine Waters (Unfiltered) | | X | | | | |
| Quirindi (Groundwater) | | X | | | | |
| Rous (Bulk Supplier) | | | | | | X |
| Snowy River (Unfiltered) | | X | | | | |
| Sydney Water | | | | | X | |
| Tallaganda (Unfiltered) | | X | | | | |
| Temora | | | | | | X |
| Tumut | | X | | | | |
| Urana | | | | | | X |
| Wagga Wagga | | | | | | X |
| Wakool (Dual Supply) | X | | | | | |
| Walgett (Dual Supply non-potable) | X | X | | | | |
| Warren (Dual Supply) | X | | | | | |
| Weddin | | | | X | | |
| Wentworth (Dual Supply) | X | | | | | |
| Wingecarribee | | X | | | | |
| Yallaroi (Groundwater) | | X | | | | |
| Yarrowlumla (Groundwater) | | | | X | | |
| Young (Reticulator) | | X | | | | |

## Appendix 1b
## Wastewater utilities excluded from database

| Wastewater Utility | Reason for exclusion from database: | | | |
|---|---|---|---|---|
| | Incomplete breaks and chokes data | Incomplete odour complaints data | Incomplete service complaints data | Only provides water service |
| Armidale Dumaresq | X | | X | |
| Australian Inland | | X | | |
| Bega Valley | | X | X | |
| Bellingen | X | X | X | |
| Bingara | X | | | |
| Bogan | X | X | X | |
| Bourke | X | | | |
| Byron | | | X | |
| Central Darling | X | X | | |
| Central Tablelands | | | | X |
| Cobar | X | | | |
| Cobar WB | | | | X |
| Coolamon | | X | X | |
| Coonabarabran | X | | | |
| Coonamble | | | X | |
| Crookwell | X | | | |
| Deniliquin | X | | | |
| Dungog | | | | |
| Fish River WS | | | | X |
| Goldenfields (Bulk) | | | | X |
| Goldenfields (Comb) | | | | X |
| Goldenfields (Retic) | | | | X |
| Goulburn | X | | | |
| Griffith | | | X | |
| Hastings | X | X | X | |
| Hawkesbury | | | | X |
| Hay | X | X | X | |
| Hume | X | | | |
| Hunter Water | | | | X |
| Jerilderie | X | | X | |

## Appendix 1b
## Wastewater utilities excluded from database

| Wastewater Utility | *Reason for exclusion from database:* | | | |
|---|---|---|---|---|
| | **Incomplete breaks and chokes data** | **Incomplete odour complaints data** | **Incomplete service complaints data** | **Only provides water service** |
| Kempsey | X | | | |
| Lachlan | X | | | |
| Lismore | | X | | |
| Lithgow | X | | | |
| Maclean | | | X | |
| Manilla | X | | X | |
| Merriwa | X | | X | |
| MidCoast (Combined) | X | | | |
| Mulwaree | X | | | |
| Murrumbidgee | | | X | |
| Narrabri | X | X | X | |
| Narromine | X | X | X | |
| North Coast Water | | | | X |
| Nundle | | | | X |
| Oberon | | X | X | |
| Parkes | X | | | |
| Pristine Waters | X | | | |
| Riverina | | | | X |
| Rous | | | | X |
| Rylstone | X | X | | |
| Severn | X | | | |
| Snowy River | | | X | |
| Sydney Water | | | | X |
| Tallaganda | | X | X | |
| Uralla | | | X | |
| Urana | X | | | |
| Wakool | X | X | X | |
| Walgett | X | X | X | |
| Warren | X | X | X | |
| Wentworth | X | | | |
| Wingecarribee | | | | |
| Yallaroi | X | X | X | |

# Appendix 2a
# DEA scores for all water utilities: 2001

| Water Utility | Technical efficiency measure: | | | Returns to scale |
|---|---|---|---|---|
| | Pure | Overall | Scale | |
| Albury | 0.638 | 0.269 | 0.422 | Decreasing |
| Ballina (Reticulator) | 0.336 | 0.152 | 0.451 | Decreasing |
| Barraba | 0.219 | 0.206 | 0.942 | Decreasing |
| Bathurst | 0.506 | 0.220 | 0.434 | Decreasing |
| Bogan | 0.435 | 0.174 | 0.401 | Decreasing |
| Bombala | 0.253 | 0.239 | 0.945 | Increasing |
| Boorowa | 0.341 | 0.282 | 0.827 | Decreasing |
| Brewarrina | 0.182 | 0.169 | 0.930 | Decreasing |
| Cabonne | 0.167 | 0.152 | 0.912 | Decreasing |
| Carrathool (Groundwater) | 0.260 | 0.130 | 0.500 | Decreasing |
| Central Highlands | 0.303 | 0.124 | 0.409 | Decreasing |
| Central Tablelands | 0.294 | 0.154 | 0.523 | Decreasing |
| Coffs Harbour (Unfiltered) | 0.349 | 0.156 | 0.447 | Decreasing |
| Coliban | 1.000 | 0.337 | 0.337 | Decreasing |
| Coolah | 0.444 | 0.199 | 0.447 | Decreasing |
| Cooma-Monaro | 0.265 | 0.159 | 0.602 | Decreasing |
| Coonabarabran | 0.158 | 0.140 | 0.885 | Decreasing |
| Corowa | 1.000 | 0.497 | 0.497 | Decreasing |
| Cowra | 0.224 | 0.116 | 0.517 | Decreasing |
| Crookwell | 0.197 | 0.185 | 0.938 | Decreasing |
| Culcairn (Groundwater) | 1.000 | 0.675 | 0.675 | Decreasing |
| Deniliquin | 0.599 | 0.301 | 0.504 | Decreasing |
| Dubbo | 0.450 | 0.192 | 0.426 | Decreasing |
| East Gippsland | 0.345 | 0.153 | 0.444 | Decreasing |
| Eurobodalla (Unfiltered) | 0.301 | 0.134 | 0.446 | Decreasing |
| Forbes | 1.000 | 0.469 | 0.469 | Decreasing |
| Gilgandra (Groundwater) | 0.319 | 0.305 | 0.956 | Increasing |
| Gippsland | 1.000 | 0.399 | 0.399 | Decreasing |
| Glen Innes | 0.254 | 0.142 | 0.558 | Decreasing |
| Glenelg | 0.332 | 0.155 | 0.468 | Decreasing |
| Gloucester | 0.168 | 0.163 | 0.966 | Increasing |
| Gosford | 0.379 | 0.155 | 0.410 | Decreasing |
| Goulburn | 0.328 | 0.150 | 0.458 | Decreasing |
| Goulburn Valley | 0.743 | 0.300 | 0.404 | Decreasing |
| Grampians | 0.361 | 0.149 | 0.412 | Decreasing |
| Griffith | 0.741 | 0.315 | 0.425 | Decreasing |
| Gundagai | 0.669 | 0.265 | 0.396 | Decreasing |
| Gunnedah (Groundwater) | 0.858 | 0.374 | 0.436 | Decreasing |
| Gunning (Groundwater) | 1.000 | 0.785 | 0.785 | Decreasing |
| Guyra | 1.000 | 0.242 | 0.242 | Decreasing |
| Harden (Reticulator) | 0.154 | 0.139 | 0.906 | Decreasing |
| Hastings (Unfiltered) | 0.364 | 0.160 | 0.439 | Decreasing |
| Hume (Unfiltered) | 1.000 | 0.113 | 0.113 | Decreasing |
| Inverell | 0.193 | 0.114 | 0.590 | Decreasing |
| Kempsey (Groundwater) | 0.632 | 0.284 | 0.449 | Decreasing |
| Kyogle | 0.191 | 0.182 | 0.953 | Decreasing |
| Lachlan | 0.371 | 0.166 | 0.447 | Decreasing |
| Leeton | 0.566 | 0.277 | 0.489 | Decreasing |
| Lismore (Reticulator) | 0.318 | 0.145 | 0.456 | Decreasing |
| Lithgow | 0.238 | 0.127 | 0.533 | Decreasing |
| Lower Murray | 0.659 | 0.270 | 0.409 | Decreasing |
| Manilla | 0.833 | 0.216 | 0.259 | Decreasing |
| Merriwa | 0.402 | 0.275 | 0.685 | Decreasing |

# Appendix 2a
## DEA scores for all water utilities: 2001

| Water Utility | *Technical efficiency measure:* | | | Returns to scale |
|---|---|---|---|---|
| | Pure | Overall | Scale | |
| MidCoast (Combined - Unfiltered) | 0.397 | 0.167 | 0.420 | Decreasing |
| Moree Plains (Groundwater) | 0.493 | 0.235 | 0.476 | Decreasing |
| Mudgee (Unfiltered) | 0.276 | 0.151 | 0.549 | Decreasing |
| Mulwaree | 0.309 | 0.254 | 0.821 | Decreasing |
| Murrumbidgee (Groundwater) | 1.000 | 1.000 | 1.000 | Constant |
| Murrurundi (Unfiltered) | 0.422 | 0.401 | 0.950 | Decreasing |
| Muswellbrook | 0.358 | 0.166 | 0.464 | Decreasing |
| Nambucca (Groundwater) | 0.488 | 0.219 | 0.449 | Decreasing |
| Narrandera (Groundwater) | 0.899 | 0.414 | 0.461 | Decreasing |
| North Coast Water (Unfiltered) | 0.464 | 0.221 | 0.477 | Decreasing |
| North East | 0.762 | 0.267 | 0.350 | Decreasing |
| Nundle (Groundwater) | 1.000 | 0.439 | 0.439 | Decreasing |
| Orange | 0.638 | 0.276 | 0.432 | Decreasing |
| Parkes | 0.685 | 0.303 | 0.443 | Decreasing |
| Parry (Groundwater) | 0.663 | 0.218 | 0.329 | Decreasing |
| Portland Coast | 0.550 | 0.212 | 0.386 | Decreasing |
| Queanbeyan (Reticulator) | 0.329 | 0.151 | 0.457 | Decreasing |
| Richmond Valley | 0.418 | 0.200 | 0.478 | Decreasing |
| Riverina (Groundwater) | 0.702 | 0.291 | 0.414 | Decreasing |
| Rylstone | 0.125 | 0.124 | 0.993 | Increasing |
| Scone (Unfiltered) | 0.331 | 0.210 | 0.634 | Decreasing |
| Severn | 1.000 | 1.000 | 1.000 | Constant |
| Shoalhaven | 0.575 | 0.237 | 0.412 | Decreasing |
| Singleton | 0.309 | 0.157 | 0.508 | Decreasing |
| South Gippsland | 0.320 | 0.141 | 0.442 | Decreasing |
| South West | 0.459 | 0.192 | 0.418 | Decreasing |
| Tamworth | 0.527 | 0.224 | 0.425 | Decreasing |
| Tenterfield | 0.108 | 0.106 | 0.989 | Increasing |
| Tumbarumba | 0.680 | 0.364 | 0.536 | Decreasing |
| Tweed | 0.491 | 0.208 | 0.424 | Decreasing |
| Uralla | 1.000 | 0.196 | 0.196 | Decreasing |
| Walcha | 0.269 | 0.167 | 0.622 | Decreasing |
| Wellington | 0.135 | 0.111 | 0.823 | Decreasing |
| Western | 0.335 | 0.138 | 0.412 | Decreasing |
| Westernport | 0.620 | 0.185 | 0.299 | Decreasing |
| Wyong | 0.460 | 0.189 | 0.411 | Decreasing |
| Yass | 0.344 | 0.122 | 0.356 | Decreasing |

# Appendix 2a
## DEA scores for all water utilities: 2002

| Water Utility | *Technical efficiency measure:* | | | Returns to scale |
|---|---|---|---|---|
| | Pure | Overall | Scale | |
| Albury | 0.497 | 0.280 | 0.562 | Decreasing |
| Ballina (Reticulator) | 0.284 | 0.156 | 0.550 | Decreasing |
| Barraba | 0.209 | 0.181 | 0.868 | Increasing |
| Bathurst | 0.301 | 0.174 | 0.579 | Decreasing |
| Bogan | 0.426 | 0.175 | 0.410 | Decreasing |
| Bombala | 0.246 | 0.219 | 0.891 | Increasing |
| Boorowa | 0.365 | 0.271 | 0.743 | Decreasing |
| Brewarrina | 0.447 | 0.177 | 0.396 | Decreasing |
| Cabonne | 0.177 | 0.129 | 0.729 | Decreasing |
| Carrathool (Groundwater) | 0.123 | 0.121 | 0.991 | Increasing |
| Central Highlands | 0.200 | 0.110 | 0.549 | Decreasing |
| Central Tablelands | 0.254 | 0.164 | 0.643 | Decreasing |
| Coffs Harbour (Unfiltered) | 0.246 | 0.136 | 0.552 | Decreasing |
| Coliban | 0.633 | 0.359 | 0.567 | Decreasing |
| Coolah | 0.368 | 0.150 | 0.407 | Decreasing |
| Cooma-Monaro | 0.293 | 0.164 | 0.562 | Decreasing |
| Coonabarabran | 0.296 | 0.151 | 0.511 | Decreasing |
| Corowa | 0.840 | 0.482 | 0.574 | Decreasing |
| Cowra | 0.238 | 0.149 | 0.625 | Decreasing |
| Crookwell | 0.226 | 0.184 | 0.813 | Decreasing |
| Culcairn (Groundwater) | 1.000 | 0.575 | 0.575 | Decreasing |
| Deniliquin | 0.532 | 0.305 | 0.575 | Decreasing |
| Dubbo | 0.407 | 0.217 | 0.533 | Decreasing |
| East Gippsland | 0.223 | 0.135 | 0.608 | Decreasing |
| Eurobodalla (Unfiltered) | 0.194 | 0.118 | 0.607 | Decreasing |
| Forbes | 0.889 | 0.456 | 0.513 | Decreasing |
| Gilgandra (Groundwater) | 0.669 | 0.331 | 0.495 | Decreasing |
| Gippsland | 1.000 | 0.564 | 0.564 | Decreasing |
| Glen Innes | 0.108 | 0.108 | 0.993 | Increasing |
| Glenelg | 0.292 | 0.145 | 0.496 | Decreasing |
| Gloucester | 0.168 | 0.162 | 0.968 | Increasing |
| Gosford | 0.270 | 0.155 | 0.573 | Decreasing |
| Goulburn | 0.343 | 0.179 | 0.521 | Decreasing |
| Goulburn Valley | 0.522 | 0.295 | 0.564 | Decreasing |
| Grampians | 0.184 | 0.107 | 0.579 | Decreasing |
| Griffith | 0.495 | 0.272 | 0.549 | Decreasing |
| Gundagai | 0.443 | 0.221 | 0.499 | Decreasing |
| Gunnedah (Groundwater) | 0.831 | 0.395 | 0.475 | Decreasing |
| Gunning (Groundwater) | 1.000 | 1.000 | 1.000 | Constant |
| Guyra | 0.587 | 0.224 | 0.381 | Decreasing |
| Harden (Reticulator) | 0.142 | 0.141 | 0.991 | Decreasing |
| Hastings (Unfiltered) | 0.224 | 0.133 | 0.595 | Decreasing |
| Hume | 1.000 | 0.141 | 0.141 | Decreasing |
| Inverell | 0.187 | 0.129 | 0.691 | Decreasing |
| Kempsey (Groundwater) | 0.281 | 0.174 | 0.618 | Decreasing |
| Kyogle | 0.162 | 0.141 | 0.871 | Decreasing |
| Lachlan | 0.350 | 0.144 | 0.411 | Decreasing |
| Leeton | 0.502 | 0.252 | 0.502 | Decreasing |
| Lismore (Reticulator) | 0.290 | 0.148 | 0.511 | Decreasing |
| Lithgow | 0.182 | 0.108 | 0.594 | Decreasing |
| Lower Murray | 0.458 | 0.250 | 0.545 | Decreasing |
| Manilla | 0.511 | 0.175 | 0.342 | Decreasing |
| Merriwa | 0.502 | 0.281 | 0.560 | Decreasing |

## Appendix 2a
## DEA scores for all water utilities: 2002

| Water Utility | *Technical efficiency measure:* | | | Returns to scale |
|---|---|---|---|---|
| | Pure | Overall | Scale | |
| MidCoast (Combined - Unfiltered) | 0.264 | 0.153 | 0.580 | Decreasing |
| Moree Plains (Groundwater) | 0.358 | 0.229 | 0.639 | Decreasing |
| Mudgee (Unfiltered) | 0.254 | 0.169 | 0.664 | Decreasing |
| Mulwaree | 0.235 | 0.176 | 0.752 | Decreasing |
| Murrumbidgee (Groundwater) | 1.000 | 1.000 | 1.000 | Constant |
| Murrurundi | 0.222 | 0.172 | 0.776 | Increasing |
| Muswellbrook | 0.325 | 0.178 | 0.548 | Decreasing |
| Nambucca (Groundwater) | 0.432 | 0.199 | 0.461 | Decreasing |
| Narrandera (Groundwater) | 0.797 | 0.360 | 0.452 | Decreasing |
| North Coast Water (Unfiltered) | 0.416 | 0.233 | 0.560 | Decreasing |
| North East | 0.495 | 0.275 | 0.556 | Decreasing |
| Nundle (Groundwater) | 1.000 | 0.291 | 0.291 | Decreasing |
| Orange | 0.393 | 0.221 | 0.563 | Decreasing |
| Parkes | 0.554 | 0.329 | 0.593 | Decreasing |
| Parry (Groundwater) | 0.530 | 0.214 | 0.405 | Decreasing |
| Portland Coast | 0.355 | 0.171 | 0.481 | Decreasing |
| Queanbeyan (Reticulator) | 0.370 | 0.208 | 0.564 | Decreasing |
| Richmond Valley | 0.368 | 0.197 | 0.536 | Decreasing |
| Riverina (Groundwater) | 0.547 | 0.303 | 0.553 | Decreasing |
| Rylstone | 0.282 | 0.116 | 0.411 | Decreasing |
| Scone (Unfiltered) | 0.389 | 0.274 | 0.704 | Decreasing |
| Severn (Unfiltered) | 0.920 | 0.697 | 0.757 | Increasing |
| Shoalhaven | 0.307 | 0.171 | 0.555 | Decreasing |
| Singleton | 0.334 | 0.188 | 0.565 | Decreasing |
| South Gippsland | 0.208 | 0.124 | 0.597 | Decreasing |
| South West | 0.320 | 0.183 | 0.571 | Decreasing |
| Tamworth | 0.380 | 0.206 | 0.542 | Decreasing |
| Tenterfield | 0.132 | 0.131 | 0.994 | Increasing |
| Tumbarumba | 0.731 | 0.426 | 0.583 | Decreasing |
| Tweed | 0.362 | 0.210 | 0.579 | Decreasing |
| Uralla | 0.452 | 0.171 | 0.379 | Decreasing |
| Walcha | 0.236 | 0.162 | 0.688 | Decreasing |
| Wellington | 0.133 | 0.112 | 0.844 | Decreasing |
| Western | 0.230 | 0.126 | 0.548 | Decreasing |
| Westernport | 0.495 | 0.216 | 0.437 | Decreasing |
| Wyong | 0.305 | 0.170 | 0.558 | Decreasing |
| Yass | 0.340 | 0.137 | 0.403 | Decreasing |

## Appendix 2a
## DEA scores for all water utilities: 2003

| Water Utility | *Technical efficiency measure:* | | | Returns to scale |
|---|---|---|---|---|
| | Pure | Overall | Scale | |
| Albury | 0.481 | 0.476 | 0.988 | Decreasing |
| Ballina (Reticulator) | 0.193 | 0.180 | 0.937 | Decreasing |
| Barraba | 0.234 | 0.229 | 0.978 | Increasing |
| Bathurst | 0.307 | 0.304 | 0.989 | Decreasing |
| Bogan | 0.296 | 0.292 | 0.985 | Decreasing |
| Bombala | 0.359 | 0.318 | 0.886 | Decreasing |
| Boorowa | 1.000 | 0.351 | 0.351 | Decreasing |
| Brewarrina | 0.316 | 0.289 | 0.915 | Decreasing |
| Cabonne | 0.180 | 0.175 | 0.970 | Increasing |
| Carrathool (Groundwater) | 0.299 | 0.299 | 0.999 | Decreasing |
| Central Highlands | 0.200 | 0.196 | 0.981 | Decreasing |
| Central Tablelands | 0.278 | 0.275 | 0.991 | Decreasing |
| Coffs Harbour (Unfiltered) | 0.260 | 0.257 | 0.989 | Decreasing |
| Coliban | 0.345 | 0.340 | 0.988 | Decreasing |
| Coolah | 0.208 | 0.202 | 0.972 | Increasing |
| Cooma-Monaro | 0.312 | 0.310 | 0.993 | Decreasing |
| Coonabarabran | 1.000 | 0.186 | 0.186 | Decreasing |
| Corowa | 0.875 | 0.866 | 0.990 | Decreasing |
| Cowra | 0.362 | 0.358 | 0.990 | Decreasing |
| Crookwell | 0.247 | 0.236 | 0.953 | Increasing |
| Culcairn (Groundwater) | 0.817 | 0.777 | 0.952 | Increasing |
| Deniliquin | 0.627 | 0.621 | 0.991 | Decreasing |
| Dubbo | 0.375 | 0.361 | 0.962 | Decreasing |
| East Gippsland | 0.224 | 0.222 | 0.989 | Decreasing |
| Eurobodalla (Unfiltered) | 0.197 | 0.195 | 0.989 | Decreasing |
| Forbes | 0.734 | 0.726 | 0.990 | Decreasing |
| Gilgandra (Groundwater) | 0.687 | 0.684 | 0.997 | Decreasing |
| Gippsland | 1.000 | 0.987 | 0.987 | Decreasing |
| Glen Innes | 0.256 | 0.256 | 0.998 | Increasing |
| Glenelg | 0.339 | 0.315 | 0.929 | Decreasing |
| Gloucester | 0.191 | 0.177 | 0.929 | Increasing |
| Gosford | 0.274 | 0.270 | 0.988 | Decreasing |
| Goulburn | 0.232 | 0.230 | 0.990 | Decreasing |
| Goulburn Valley | 0.466 | 0.460 | 0.987 | Decreasing |
| Grampians | 0.257 | 0.254 | 0.988 | Decreasing |
| Griffith | 0.550 | 0.539 | 0.980 | Decreasing |
| Gundagai | 0.356 | 0.356 | 0.999 | Increasing |
| Gunnedah (Groundwater) | 0.795 | 0.730 | 0.918 | Decreasing |
| Gunning (Groundwater) | 1.000 | 1.000 | 1.000 | Constant |
| Guyra | 0.355 | 0.258 | 0.725 | Decreasing |
| Harden (Reticulator) | 0.198 | 0.197 | 0.998 | Decreasing |
| Hastings (Unfiltered) | 0.190 | 0.188 | 0.989 | Decreasing |
| Hume | 1.000 | 0.162 | 0.162 | Decreasing |
| Inverell | 0.207 | 0.205 | 0.992 | Decreasing |
| Kempsey (Groundwater) | 0.335 | 0.331 | 0.990 | Decreasing |
| Kyogle | 0.222 | 0.215 | 0.967 | Increasing |
| Lachlan | 0.333 | 0.321 | 0.964 | Decreasing |
| Leeton | 0.574 | 0.545 | 0.949 | Decreasing |
| Lismore (Reticulator) | 0.180 | 0.177 | 0.982 | Decreasing |
| Lithgow | 0.225 | 0.223 | 0.992 | Decreasing |
| Lower Murray | 1.000 | 0.432 | 0.432 | Decreasing |
| Manilla | 0.472 | 0.334 | 0.709 | Decreasing |
| Merriwa | 0.517 | 0.515 | 0.997 | Increasing |

## Appendix 2a
## DEA scores for all water utilities: 2003

| Water Utility | *Technical efficiency measure:* | | | Returns to scale |
|---|---|---|---|---|
| | Pure | Overall | Scale | |
| MidCoast (Combined - Unfiltered) | 0.272 | 0.269 | 0.988 | Decreasing |
| Moree Plains (Groundwater) | 0.356 | 0.352 | 0.990 | Decreasing |
| Mudgee (Unfiltered) | 0.289 | 0.287 | 0.992 | Decreasing |
| Mulwaree | 0.221 | 0.208 | 0.943 | Increasing |
| Murrumbidgee (Groundwater) | 1.000 | 1.000 | 1.000 | Constant |
| Murrurundi | 0.269 | 0.262 | 0.975 | Increasing |
| Muswellbrook | 0.299 | 0.297 | 0.992 | Decreasing |
| Nambucca (Groundwater) | 0.332 | 0.330 | 0.993 | Decreasing |
| Narrandera (Groundwater) | 0.662 | 0.658 | 0.993 | Decreasing |
| North Coast Water (Unfiltered) | 0.332 | 0.329 | 0.990 | Decreasing |
| North East | 0.515 | 0.508 | 0.987 | Decreasing |
| Nundle (Groundwater) | 1.000 | 0.539 | 0.539 | Decreasing |
| Orange | 0.372 | 0.368 | 0.989 | Decreasing |
| Parkes | 0.570 | 0.560 | 0.981 | Decreasing |
| Parry (Groundwater) | 0.391 | 0.311 | 0.796 | Decreasing |
| Portland Coast | 0.297 | 0.278 | 0.935 | Decreasing |
| Queanbeyan (Reticulator) | 0.407 | 0.403 | 0.989 | Decreasing |
| Richmond Valley | 0.252 | 0.250 | 0.991 | Decreasing |
| Riverina (Groundwater) | 0.622 | 0.615 | 0.988 | Decreasing |
| Rylstone | 0.201 | 0.200 | 0.992 | Decreasing |
| Scone (Unfiltered) | 0.530 | 0.526 | 0.992 | Decreasing |
| Severn (Unfiltered) | 1.000 | 0.565 | 0.565 | Increasing |
| Shoalhaven | 0.361 | 0.357 | 0.988 | Decreasing |
| Singleton | 0.390 | 0.387 | 0.991 | Decreasing |
| South Gippsland | 0.235 | 0.232 | 0.989 | Decreasing |
| South West | 0.322 | 0.318 | 0.988 | Decreasing |
| Tamworth | 0.346 | 0.342 | 0.988 | Decreasing |
| Tenterfield | 0.176 | 0.171 | 0.968 | Increasing |
| Tumbarumba | 0.544 | 0.472 | 0.868 | Decreasing |
| Tweed | 0.313 | 0.309 | 0.988 | Decreasing |
| Uralla | 0.256 | 0.193 | 0.754 | Decreasing |
| Walcha | 0.216 | 0.207 | 0.960 | Increasing |
| Wellington | 0.225 | 0.224 | 0.995 | Decreasing |
| Western | 0.240 | 0.233 | 0.969 | Decreasing |
| Westernport | 0.384 | 0.332 | 0.866 | Decreasing |
| Wyong | 0.274 | 0.271 | 0.988 | Decreasing |
| Yass | 0.237 | 0.221 | 0.930 | Decreasing |

## Appendix 2a
## DEA scores for all water utilities: 2004

| Water Utility | *Technical efficiency measure:* | | | Returns to scale |
|---|---|---|---|---|
| | Pure | Overall | Scale | |
| Albury | 0.511 | 0.511 | 1.000 | Decreasing |
| Ballina (Reticulator) | 0.213 | 0.205 | 0.962 | Decreasing |
| Barraba | 0.350 | 0.342 | 0.976 | Increasing |
| Bathurst Regional | 0.357 | 0.357 | 0.999 | Decreasing |
| Bogan | 0.402 | 0.348 | 0.865 | Decreasing |
| Bombala | 0.509 | 0.508 | 0.997 | Increasing |
| Boorowa | 0.942 | 0.518 | 0.549 | Decreasing |
| Brewarrina | 0.349 | 0.335 | 0.960 | Decreasing |
| Cabonne | 0.268 | 0.260 | 0.973 | Increasing |
| Carrathool (Groundwater) | 0.328 | 0.301 | 0.919 | Decreasing |
| Central Highlands | 0.180 | 0.178 | 0.991 | Decreasing |
| Central Tablelands | 0.229 | 0.229 | 1.000 | Increasing |
| Coffs Harbour (Unfiltered) | 0.261 | 0.261 | 1.000 | Increasing |
| Coliban | 0.376 | 0.376 | 1.000 | Increasing |
| Coolah | 0.266 | 0.265 | 0.996 | Increasing |
| Cooma-Monaro | 0.304 | 0.302 | 0.995 | Increasing |
| Coonabarabran | 0.354 | 0.292 | 0.823 | Decreasing |
| Corowa | 0.804 | 0.803 | 0.999 | Increasing |
| Cowra | 0.252 | 0.251 | 0.996 | Increasing |
| Crookwell | 0.608 | 0.264 | 0.435 | Decreasing |
| Culcairn (Groundwater) | 0.651 | 0.636 | 0.976 | Increasing |
| Deniliquin | 0.577 | 0.575 | 0.997 | Increasing |
| Dubbo | 0.401 | 0.394 | 0.983 | Decreasing |
| East Gippsland | 0.243 | 0.236 | 0.969 | Decreasing |
| Eurobodalla (Unfiltered) | 0.208 | 0.208 | 0.998 | Increasing |
| Forbes | 0.546 | 0.545 | 0.998 | Increasing |
| Gilgandra (Groundwater) | 0.745 | 0.744 | 0.999 | Increasing |
| Gippsland | 1.000 | 1.000 | 1.000 | Constant |
| Glen Innes | 0.234 | 0.230 | 0.983 | Increasing |
| Glenelg | 0.300 | 0.281 | 0.937 | Decreasing |
| Gloucester | 0.160 | 0.147 | 0.918 | Increasing |
| Gosford | 0.242 | 0.242 | 1.000 | Increasing |
| Goulburn | 0.177 | 0.175 | 0.989 | Increasing |
| Goulburn Valley | 0.481 | 0.481 | 0.999 | Decreasing |
| Grampians | 0.142 | 0.142 | 1.000 | Increasing |
| Griffith | 0.542 | 0.534 | 0.984 | Decreasing |
| Gundagai | 0.490 | 0.417 | 0.850 | Decreasing |
| Gunnedah (Groundwater) | 0.630 | 0.588 | 0.934 | Decreasing |
| Gunning (Groundwater) | 1.000 | 0.809 | 0.809 | Increasing |
| Guyra | 1.000 | 0.435 | 0.435 | Decreasing |
| Harden (Reticulator) | 0.283 | 0.279 | 0.984 | Increasing |
| Hastings (Unfiltered) | 0.187 | 0.186 | 0.996 | Decreasing |
| Hume | 1.000 | 0.184 | 0.184 | Decreasing |
| Inverell | 0.253 | 0.239 | 0.943 | Decreasing |
| Kempsey (Groundwater) | 0.369 | 0.365 | 0.989 | Decreasing |
| Kyogle | 0.244 | 0.237 | 0.972 | Increasing |
| Lachlan | 0.439 | 0.403 | 0.918 | Decreasing |
| Leeton | 0.573 | 0.544 | 0.950 | Decreasing |
| Lismore (Reticulator) | 0.231 | 0.225 | 0.974 | Decreasing |
| Lithgow | 0.233 | 0.233 | 1.000 | Increasing |
| Lower Murray | 0.459 | 0.412 | 0.898 | Decreasing |
| Manilla | 1.000 | 0.313 | 0.313 | Decreasing |
| Merriwa | 0.422 | 0.420 | 0.996 | Increasing |

# Appendix 2a
# DEA scores for all water utilities: 2004

| | | | | |
|---|---|---|---|---|
| MidCoast (Combined - Unfiltered) | 0.262 | 0.261 | 0.998 | Increasing |
| Moree Plains (Groundwater) | 0.254 | 0.252 | 0.992 | Increasing |
| Mudgee (Unfiltered) | 0.279 | 0.277 | 0.991 | Increasing |
| Mulwaree | 0.247 | 0.239 | 0.967 | Increasing |
| Murrumbidgee (Groundwater) | 1.000 | 1.000 | 1.000 | Constant |
| Murrurundi | 0.434 | 0.410 | 0.943 | Increasing |
| Muswellbrook | 0.320 | 0.320 | 1.000 | Increasing |
| Nambucca (Groundwater) | 0.366 | 0.345 | 0.941 | Decreasing |
| Narrandera (Groundwater) | 0.636 | 0.635 | 0.998 | Decreasing |
| North Coast Water (Unfiltered) | 0.377 | 0.376 | 0.998 | Increasing |
| North East | 0.440 | 0.438 | 0.994 | Decreasing |
| Nundle (Groundwater) | 1.000 | 1.000 | 1.000 | Constant |
| Orange | 0.256 | 0.256 | 0.997 | Increasing |
| Parkes | 0.583 | 0.569 | 0.976 | Decreasing |
| Parry (Groundwater) | 0.336 | 0.284 | 0.848 | Decreasing |
| Portland Coast | 0.342 | 0.319 | 0.933 | Decreasing |
| Queanbeyan (Reticulator) | 0.210 | 0.207 | 0.986 | Decreasing |
| Richmond Valley | 0.301 | 0.289 | 0.958 | Decreasing |
| Riverina (Groundwater) | 0.582 | 0.578 | 0.993 | Decreasing |
| Rylstone | 0.270 | 0.244 | 0.904 | Decreasing |
| Scone (Unfiltered) | 0.489 | 0.486 | 0.994 | Increasing |
| Severn (Unfiltered) | 1.000 | 0.827 | 0.827 | Increasing |
| Shoalhaven | 0.394 | 0.392 | 0.995 | Decreasing |
| Singleton | 0.360 | 0.360 | 0.999 | Increasing |
| South Gippsland | 0.228 | 0.227 | 0.998 | Increasing |
| South West | 0.341 | 0.341 | 1.000 | Increasing |
| Tamworth | 0.389 | 0.389 | 0.999 | Increasing |
| Tenterfield | 0.192 | 0.187 | 0.976 | Increasing |
| Tumbarumba | 0.495 | 0.495 | 0.999 | Increasing |
| Tweed | 0.332 | 0.331 | 0.999 | Increasing |
| Uralla | 0.292 | 0.288 | 0.986 | Decreasing |
| Walcha | 0.304 | 0.301 | 0.992 | Increasing |
| Wellington | 0.231 | 0.230 | 0.995 | Increasing |
| Western | 0.188 | 0.186 | 0.985 | Decreasing |
| Westernport | 0.393 | 0.359 | 0.915 | Decreasing |
| Wyong | 0.270 | 0.268 | 0.995 | Decreasing |
| Yass Valley | 0.220 | 0.220 | 1.000 | Increasing |

## Appendix 2b
## DEA scores for large water utilities: 2001

| Water Utility | *Technical efficiency measure:* | | | Returns to scale |
|---|---|---|---|---|
| | Pure | Overall | Scale | |
| Albury | 0.638 | 0.541 | 0.849 | Decreasing |
| Ballina (Reticulator) | 0.336 | 0.305 | 0.909 | Decreasing |
| Bathurst | 0.506 | 0.443 | 0.874 | Decreasing |
| Central Tablelands | 0.392 | 0.309 | 0.789 | Increasing |
| Coffs Harbour (Unfiltered) | 0.349 | 0.314 | 0.899 | Decreasing |
| Cooma-Monaro | 0.732 | 0.700 | 0.957 | Increasing |
| Corowa | 1.000 | 1.000 | 1.000 | Constant |
| Cowra | 0.327 | 0.322 | 0.984 | Increasing |
| Deniliquin | 0.745 | 0.734 | 0.986 | Increasing |
| Dubbo | 0.450 | 0.386 | 0.858 | Decreasing |
| Eurobodalla (Unfiltered) | 0.301 | 0.271 | 0.899 | Decreasing |
| Forbes | 1.000 | 1.000 | 1.000 | Constant |
| Gosford | 0.379 | 0.313 | 0.826 | Decreasing |
| Goulburn | 0.328 | 0.302 | 0.921 | Decreasing |
| Griffith | 0.741 | 0.634 | 0.856 | Decreasing |
| Gunnedah (Groundwater) | 1.000 | 0.906 | 0.906 | Decreasing |
| Hastings (Unfiltered) | 0.364 | 0.322 | 0.884 | Decreasing |
| Inverell | 0.439 | 0.415 | 0.945 | Increasing |
| Kempsey (Groundwater) | 0.632 | 0.572 | 0.904 | Decreasing |
| Leeton | 0.726 | 0.720 | 0.992 | Increasing |
| Lismore (Reticulator) | 0.318 | 0.292 | 0.919 | Decreasing |
| Lithgow | 0.351 | 0.330 | 0.940 | Increasing |
| North Coast Water (Unfiltered) | 0.464 | 0.445 | 0.960 | Decreasing |
| MidCoast (Combined - Unfiltered) | 0.397 | 0.336 | 0.846 | Decreasing |
| Moree Plains (Groundwater) | 0.493 | 0.473 | 0.959 | Decreasing |
| Mudgee (Unfiltered) | 0.461 | 0.383 | 0.831 | Increasing |
| Muswellbrook | 0.491 | 0.489 | 0.996 | Increasing |
| Nambucca (Groundwater) | 0.837 | 0.833 | 0.996 | Increasing |
| Orange | 0.638 | 0.555 | 0.869 | Decreasing |
| Parkes | 0.685 | 0.610 | 0.891 | Decreasing |
| Queanbeyan (Reticulator) | 0.329 | 0.303 | 0.920 | Decreasing |
| Richmond Valley | 0.424 | 0.423 | 0.997 | Increasing |
| Riverina (Groundwater) | 0.702 | 0.585 | 0.834 | Decreasing |
| Shoalhaven | 0.575 | 0.477 | 0.830 | Decreasing |
| Singleton | 0.372 | 0.365 | 0.981 | Increasing |
| Tamworth | 0.527 | 0.452 | 0.856 | Decreasing |
| Tweed | 0.491 | 0.419 | 0.854 | Decreasing |
| Wyong | 0.460 | 0.381 | 0.827 | Decreasing |
| Central Highlands | 0.303 | 0.249 | 0.823 | Decreasing |
| Coliban | 1.000 | 0.678 | 0.678 | Decreasing |
| Gippsland | 1.000 | 0.804 | 0.804 | Decreasing |
| Goulburn Valley | 0.743 | 0.605 | 0.814 | Decreasing |
| North East | 0.792 | 0.538 | 0.679 | Decreasing |
| Western | 0.335 | 0.278 | 0.830 | Decreasing |
| East Gippsland | 0.345 | 0.309 | 0.894 | Decreasing |
| Glenelg | 0.409 | 0.408 | 0.997 | Increasing |
| Grampians | 0.361 | 0.300 | 0.829 | Decreasing |
| Lower Murray | 0.659 | 0.543 | 0.823 | Decreasing |
| Portland Coast | 0.718 | 0.447 | 0.623 | Decreasing |
| South Gippsland | 0.320 | 0.284 | 0.890 | Decreasing |
| South West | 0.459 | 0.387 | 0.842 | Decreasing |
| Westernport | 1.000 | 0.587 | 0.587 | Decreasing |

## Appendix 2b
## DEA scores for large water utilities: 2002

| Water Utility | *Technical efficiency measure:* | | | Returns to scale |
|---|---|---|---|---|
| | Pure | Overall | Scale | |
| Albury | 0.523 | 0.522 | 0.998 | Decreasing |
| Ballina (Reticulator) | 0.322 | 0.319 | 0.991 | Decreasing |
| Bathurst | 0.338 | 0.336 | 0.995 | Increasing |
| Central Tablelands | 0.415 | 0.322 | 0.776 | Increasing |
| Coffs Harbour (Unfiltered) | 0.270 | 0.268 | 0.992 | Decreasing |
| Cooma-Monaro | 0.824 | 0.729 | 0.884 | Increasing |
| Corowa | 1.000 | 1.000 | 1.000 | Constant |
| Cowra | 0.448 | 0.347 | 0.773 | Increasing |
| Deniliquin | 0.833 | 0.717 | 0.861 | Increasing |
| Dubbo | 0.436 | 0.415 | 0.952 | Decreasing |
| Eurobodalla (Unfiltered) | 0.233 | 0.225 | 0.964 | Increasing |
| Forbes | 1.000 | 1.000 | 1.000 | Constant |
| Gosford | 0.282 | 0.276 | 0.979 | Increasing |
| Goulburn | 0.378 | 0.365 | 0.964 | Decreasing |
| Griffith | 0.521 | 0.517 | 0.993 | Decreasing |
| Gunnedah (Groundwater) | 1.000 | 0.993 | 0.993 | Decreasing |
| Hastings (Unfiltered) | 0.256 | 0.252 | 0.983 | Increasing |
| Inverell | 0.482 | 0.279 | 0.578 | Increasing |
| Kempsey (Groundwater) | 0.355 | 0.336 | 0.949 | Increasing |
| Leeton | 0.675 | 0.675 | 1.000 | Decreasing |
| Lismore (Reticulator) | 0.326 | 0.309 | 0.950 | Decreasing |
| Lithgow | 0.378 | 0.315 | 0.834 | Increasing |
| North Coast Water (Unfiltered) | 0.465 | 0.463 | 0.995 | Decreasing |
| MidCoast (Combined - Unfiltered) | 0.283 | 0.274 | 0.968 | Increasing |
| Moree Plains (Groundwater) | 0.553 | 0.415 | 0.751 | Increasing |
| Mudgee (Unfiltered) | 0.518 | 0.324 | 0.626 | Increasing |
| Muswellbrook | 0.557 | 0.509 | 0.914 | Increasing |
| Nambucca (Groundwater) | 0.792 | 0.790 | 0.998 | Decreasing |
| Orange | 0.424 | 0.423 | 0.998 | Decreasing |
| Parkes | 0.631 | 0.623 | 0.987 | Increasing |
| Queanbeyan (Reticulator) | 0.414 | 0.413 | 0.997 | Decreasing |
| Richmond Valley | 0.425 | 0.424 | 0.998 | Decreasing |
| Riverina (Groundwater) | 0.562 | 0.558 | 0.992 | Decreasing |
| Shoalhaven | 0.317 | 0.316 | 0.995 | Decreasing |
| Singleton | 0.468 | 0.413 | 0.883 | Increasing |
| Tamworth | 0.400 | 0.390 | 0.975 | Decreasing |
| Tweed | 0.392 | 0.389 | 0.994 | Increasing |
| Wyong | 0.314 | 0.312 | 0.996 | Decreasing |
| Central Highlands | 0.269 | 0.202 | 0.749 | Decreasing |
| Coliban | 0.643 | 0.640 | 0.995 | Increasing |
| Gippsland | 1.000 | 1.000 | 1.000 | Constant |
| Goulburn Valley | 0.529 | 0.529 | 1.000 | Decreasing |
| North East | 0.505 | 0.500 | 0.991 | Decreasing |
| Western | 0.239 | 0.234 | 0.982 | Decreasing |
| East Gippsland | 0.269 | 0.263 | 0.979 | Increasing |
| Glenelg | 0.426 | 0.426 | 1.000 | Decreasing |
| Grampians | 0.198 | 0.193 | 0.976 | Increasing |
| Lower Murray | 1.000 | 0.456 | 0.456 | Decreasing |
| Portland Coast | 0.446 | 0.444 | 0.995 | Decreasing |
| South Gippsland | 0.242 | 0.239 | 0.986 | Increasing |
| South West | 0.342 | 0.341 | 0.998 | Increasing |
| Westernport | 0.845 | 0.839 | 0.993 | Decreasing |

## Appendix 2b
## DEA scores for large water utilities: 2003

| Water Utility | *Technical efficiency measure:* | | | Returns to scale |
|---|---|---|---|---|
| | **Pure** | **Overall** | **Scale** | |
| Albury | 0.516 | 0.507 | 0.982 | Decreasing |
| Ballina (Reticulator) | 0.245 | 0.244 | 0.998 | Decreasing |
| Bathurst | 0.348 | 0.338 | 0.972 | Decreasing |
| Central Tablelands | 0.463 | 0.352 | 0.760 | Increasing |
| Coffs Harbour (Unfiltered) | 0.293 | 0.288 | 0.982 | Decreasing |
| Cooma-Monaro | 0.819 | 0.751 | 0.916 | Increasing |
| Corowa | 1.000 | 1.000 | 1.000 | Constant |
| Cowra | 0.494 | 0.466 | 0.945 | Increasing |
| Deniliquin | 0.923 | 0.787 | 0.853 | Increasing |
| Dubbo | 0.487 | 0.390 | 0.801 | Decreasing |
| Eurobodalla (Unfiltered) | 0.220 | 0.217 | 0.987 | Increasing |
| Forbes | 0.929 | 0.892 | 0.960 | Increasing |
| Gosford | 0.281 | 0.280 | 0.997 | Increasing |
| Goulburn | 0.305 | 0.274 | 0.900 | Increasing |
| Griffith | 0.613 | 0.589 | 0.960 | Decreasing |
| Gunnedah (Groundwater) | 1.000 | 1.000 | 1.000 | Constant |
| Hastings (Unfiltered) | 0.220 | 0.211 | 0.958 | Decreasing |
| Inverell | 0.428 | 0.315 | 0.735 | Increasing |
| Kempsey (Groundwater) | 0.423 | 0.413 | 0.978 | Decreasing |
| Leeton | 0.789 | 0.780 | 0.989 | Increasing |
| Lismore (Reticulator) | 0.272 | 0.267 | 0.980 | Increasing |
| Lithgow | 0.473 | 0.376 | 0.796 | Increasing |
| North Coast Water (Unfiltered) | 0.387 | 0.385 | 0.993 | Decreasing |
| MidCoast (Combined - Unfiltered) | 0.285 | 0.281 | 0.988 | Increasing |
| Moree Plains (Groundwater) | 0.405 | 0.393 | 0.969 | Increasing |
| Mudgee (Unfiltered) | 0.545 | 0.348 | 0.639 | Increasing |
| Muswellbrook | 0.560 | 0.518 | 0.926 | Increasing |
| Nambucca (Groundwater) | 0.875 | 0.840 | 0.961 | Increasing |
| Orange | 0.421 | 0.408 | 0.969 | Decreasing |
| Parkes | 0.658 | 0.625 | 0.950 | Decreasing |
| Queanbeyan (Reticulator) | 0.468 | 0.453 | 0.967 | Decreasing |
| Richmond Valley | 0.392 | 0.381 | 0.972 | Increasing |
| Riverina (Groundwater) | 0.654 | 0.643 | 0.984 | Decreasing |
| Shoalhaven | 0.383 | 0.376 | 0.982 | Decreasing |
| Singleton | 0.563 | 0.519 | 0.921 | Increasing |
| Tamworth | 0.367 | 0.365 | 0.996 | Decreasing |
| Tweed | 0.333 | 0.332 | 0.996 | Decreasing |
| Wyong | 0.291 | 0.285 | 0.981 | Decreasing |
| Central Highlands | 0.208 | 0.204 | 0.983 | Decreasing |
| Coliban | 0.350 | 0.349 | 0.999 | Increasing |
| Gippsland | 1.000 | 1.000 | 1.000 | Constant |
| Goulburn Valley | 0.476 | 0.473 | 0.994 | Decreasing |
| North East | 0.533 | 0.527 | 0.988 | Decreasing |
| Western | 0.377 | 0.246 | 0.654 | Decreasing |
| East Gippsland | 0.250 | 0.248 | 0.993 | Decreasing |
| Glenelg | 0.550 | 0.546 | 0.993 | Increasing |
| Grampians | 0.265 | 0.263 | 0.994 | Increasing |
| Lower Murray | 1.000 | 0.449 | 0.449 | Decreasing |
| Portland Coast | 0.452 | 0.448 | 0.992 | Increasing |
| South Gippsland | 0.254 | 0.253 | 0.995 | Increasing |
| South West | 0.338 | 0.338 | 0.998 | Decreasing |
| Westernport | 1.000 | 0.715 | 0.715 | Decreasing |

## Appendix 2b
## DEA scores for large water utilities: 2004

| Water Utility | Technical efficiency measure: | | | Returns to scale |
|---|---|---|---|---|
| | Pure | Overall | Scale | |
| Albury | 0.569 | 0.553 | 0.972 | Decreasing |
| Ballina (Reticulator) | 0.293 | 0.261 | 0.894 | Decreasing |
| Bathurst Regional | 0.423 | 0.405 | 0.957 | Decreasing |
| Central Tablelands | 0.461 | 0.412 | 0.894 | Increasing |
| Coffs Harbour (Unfiltered) | 0.313 | 0.300 | 0.960 | Decreasing |
| Cooma-Monaro | 0.754 | 0.545 | 0.722 | Increasing |
| Corowa | 1.000 | 1.000 | 1.000 | Constant |
| Cowra | 0.419 | 0.318 | 0.760 | Increasing |
| Deniliquin | 0.941 | 0.775 | 0.823 | Increasing |
| Dubbo | 0.462 | 0.434 | 0.938 | Decreasing |
| Eurobodalla (Unfiltered) | 0.240 | 0.234 | 0.976 | Increasing |
| Forbes | 1.000 | 0.847 | 0.847 | Increasing |
| Gosford | 0.252 | 0.252 | 0.999 | Increasing |
| Goulburn | 0.290 | 0.187 | 0.645 | Increasing |
| Griffith | 0.639 | 0.598 | 0.935 | Decreasing |
| Gunnedah (Groundwater) | 1.000 | 1.000 | 1.000 | Constant |
| Hastings (Unfiltered) | 0.224 | 0.213 | 0.950 | Decreasing |
| Inverell | 0.512 | 0.497 | 0.971 | Increasing |
| Kempsey (Groundwater) | 0.493 | 0.453 | 0.918 | Decreasing |
| Leeton | 0.847 | 0.806 | 0.951 | Decreasing |
| Lismore (Reticulator) | 0.323 | 0.301 | 0.932 | Decreasing |
| Lithgow | 0.474 | 0.428 | 0.902 | Increasing |
| North Coast Water (Unfiltered) | 0.446 | 0.435 | 0.977 | Increasing |
| MidCoast (Combined - Unfiltered) | 0.279 | 0.269 | 0.963 | Increasing |
| Moree Plains (Groundwater) | 0.459 | 0.298 | 0.649 | Increasing |
| Mudgee (Unfiltered) | 0.571 | 0.338 | 0.592 | Increasing |
| Muswellbrook | 0.534 | 0.502 | 0.940 | Increasing |
| Nambucca (Groundwater) | 0.845 | 0.816 | 0.966 | Increasing |
| Orange | 0.299 | 0.284 | 0.949 | Increasing |
| Parkes | 0.716 | 0.656 | 0.917 | Decreasing |
| Queanbeyan (Reticulator) | 0.282 | 0.257 | 0.913 | Decreasing |
| Richmond Valley | 0.454 | 0.448 | 0.987 | Decreasing |
| Riverina (Groundwater) | 0.630 | 0.610 | 0.969 | Decreasing |
| Shoalhaven | 0.425 | 0.413 | 0.972 | Decreasing |
| Singleton | 0.552 | 0.512 | 0.929 | Increasing |
| Tamworth | 0.426 | 0.420 | 0.986 | Increasing |
| Tweed | 0.359 | 0.354 | 0.987 | Increasing |
| Wyong | 0.293 | 0.284 | 0.971 | Decreasing |
| Central Highlands | 0.221 | 0.187 | 0.848 | Decreasing |
| Coliban | 0.385 | 0.384 | 0.997 | Increasing |
| Gippsland | 1.000 | 1.000 | 1.000 | Constant |
| Goulburn Valley | 0.498 | 0.493 | 0.989 | Decreasing |
| North East | 0.467 | 0.455 | 0.975 | Decreasing |
| Western | 0.223 | 0.202 | 0.905 | Decreasing |
| East Gippsland | 0.316 | 0.283 | 0.897 | Decreasing |
| Glenelg | 0.486 | 0.483 | 0.995 | Increasing |
| Grampians | 0.155 | 0.153 | 0.982 | Decreasing |
| Lower Murray | 1.000 | 0.430 | 0.430 | Decreasing |
| Portland Coast | 1.000 | 0.522 | 0.522 | Decreasing |
| South Gippsland | 0.254 | 0.247 | 0.973 | Increasing |
| South West | 0.367 | 0.366 | 0.996 | Increasing |
| Westernport | 1.000 | 0.773 | 0.773 | Decreasing |

# Appendix 3a
## DEA scores for all wastewater utilities: 2001

| Wastewater Utility | *Technical efficiency measure:* | | | Returns to scale |
|---|---|---|---|---|
| | Pure | Overall | Scale | |
| Albury | 0.390 | 0.237 | 0.607 | Decreasing |
| Armidale Dumaresq | 0.262 | 0.208 | 0.796 | Decreasing |
| Ballina | 0.504 | 0.222 | 0.441 | Decreasing |
| Balranald | 0.682 | 0.681 | 0.999 | Increasing |
| Barraba | 0.278 | 0.265 | 0.951 | Increasing |
| Bathurst | 0.516 | 0.266 | 0.515 | Decreasing |
| Bellingen | 0.240 | 0.204 | 0.852 | Decreasing |
| Berrigan | 0.228 | 0.139 | 0.609 | Decreasing |
| Bingara | 0.695 | 0.598 | 0.860 | Decreasing |
| Bland | 0.230 | 0.206 | 0.894 | Increasing |
| Blayney | 0.280 | 0.230 | 0.821 | Decreasing |
| Bombala | 0.315 | 0.303 | 0.962 | Increasing |
| Boorowa | 0.578 | 0.565 | 0.977 | Increasing |
| Brewarrina | 0.509 | 0.498 | 0.979 | Increasing |
| Byron | 0.354 | 0.154 | 0.436 | Decreasing |
| Cabonne | 0.291 | 0.223 | 0.766 | Decreasing |
| Carrathool | 0.503 | 0.430 | 0.856 | Decreasing |
| Cobar | 0.665 | 0.650 | 0.977 | Decreasing |
| Coffs Harbour | 0.411 | 0.240 | 0.585 | Decreasing |
| Coolah | 0.508 | 0.487 | 0.959 | Increasing |
| Coolamon | 0.449 | 0.426 | 0.950 | Decreasing |
| Cooma-Monaro | 0.185 | 0.178 | 0.965 | Increasing |
| Coonamble | 0.515 | 0.503 | 0.978 | Increasing |
| Cootamundra | 0.560 | 0.554 | 0.988 | Increasing |
| Copmanhurst | 0.232 | 0.213 | 0.921 | Increasing |
| Corowa | 0.248 | 0.248 | 1.000 | Increasing |
| Cowra | 0.496 | 0.363 | 0.731 | Decreasing |
| Culcairn | 0.534 | 0.397 | 0.743 | Decreasing |
| Deniliquin | 0.349 | 0.341 | 0.978 | Decreasing |
| Dubbo | 0.289 | 0.190 | 0.660 | Decreasing |
| Dungog | 1.000 | 1.000 | 1.000 | Constant |
| Eurobodalla | 0.217 | 0.138 | 0.633 | Decreasing |
| Forbes | 0.378 | 0.373 | 0.989 | Increasing |
| Gilgandra | 0.649 | 0.600 | 0.924 | Increasing |
| Glen Innes | 0.806 | 0.592 | 0.734 | Decreasing |
| Gloucester | 0.374 | 0.295 | 0.789 | Decreasing |
| Gosford | 0.541 | 0.250 | 0.461 | Decreasing |
| Goulburn | 0.308 | 0.213 | 0.690 | Decreasing |
| Grafton | 0.488 | 0.298 | 0.611 | Decreasing |
| Griffith | 0.401 | 0.265 | 0.662 | Decreasing |
| Gundagai | 0.345 | 0.286 | 0.829 | Decreasing |
| Gunnedah | 1.000 | 0.490 | 0.490 | Decreasing |
| Gunning | 1.000 | 1.000 | 1.000 | Constant |
| Guyra | 0.605 | 0.514 | 0.851 | Decreasing |

## Appendix 3a
## DEA scores for all wastewater utilities: 2001

| Wastewater Utility | *Technical efficiency measure:* | | | Returns to scale |
|---|---|---|---|---|
| | Pure | Overall | Scale | |
| Harden | 0.251 | 0.247 | 0.983 | Increasing |
| Hastings | 0.610 | 0.290 | 0.475 | Decreasing |
| Holbrook | 0.294 | 0.241 | 0.821 | Increasing |
| Hume | 1.000 | 0.193 | 0.193 | Decreasing |
| Inverell | 0.186 | 0.183 | 0.982 | Increasing |
| Jerilderie | 1.000 | 0.524 | 0.524 | Decreasing |
| Junee | 0.192 | 0.175 | 0.913 | Increasing |
| Kempsey | 0.392 | 0.230 | 0.587 | Decreasing |
| Kyogle | 0.189 | 0.170 | 0.897 | Decreasing |
| Lachlan | 0.476 | 0.449 | 0.942 | Decreasing |
| Leeton | 0.464 | 0.424 | 0.914 | Decreasing |
| Lismore | 0.365 | 0.240 | 0.657 | Decreasing |
| Lockhart | 0.432 | 0.356 | 0.825 | Decreasing |
| Maclean | 0.241 | 0.203 | 0.842 | Decreasing |
| Manilla | 0.266 | 0.233 | 0.876 | Increasing |
| Merriwa | 0.533 | 0.491 | 0.921 | Increasing |
| MidCoast (Combined) | 0.391 | 0.196 | 0.501 | Decreasing |
| Moree Plains | 0.191 | 0.184 | 0.965 | Decreasing |
| Mudgee | 0.347 | 0.284 | 0.819 | Decreasing |
| Murray | 1.000 | 0.366 | 0.366 | Decreasing |
| Murrumbidgee | 1.000 | 0.811 | 0.811 | Decreasing |
| Murrurundi | 1.000 | 1.000 | 1.000 | Constant |
| Muswellbrook | 0.250 | 0.208 | 0.833 | Decreasing |
| Nambucca | 0.439 | 0.243 | 0.555 | Decreasing |
| Narrabri | 0.284 | 0.279 | 0.982 | Increasing |
| Narrandera | 0.301 | 0.293 | 0.972 | Increasing |
| Oberon | 0.526 | 0.295 | 0.560 | Decreasing |
| Orange | 1.000 | 0.594 | 0.594 | Decreasing |
| Parkes | 0.295 | 0.294 | 0.998 | Increasing |
| Parry | 0.525 | 0.372 | 0.708 | Decreasing |
| Queanbeyan | 0.725 | 0.345 | 0.476 | Decreasing |
| Quirindi | 0.348 | 0.344 | 0.987 | Increasing |
| Richmond Valley | 0.450 | 0.253 | 0.563 | Decreasing |
| Rylstone | 0.226 | 0.203 | 0.899 | Increasing |
| Scone | 0.319 | 0.318 | 0.995 | Increasing |
| Shoalhaven | 0.284 | 0.137 | 0.483 | Decreasing |
| Singleton | 0.475 | 0.264 | 0.555 | Decreasing |
| Snowy River | 0.226 | 0.177 | 0.785 | Decreasing |
| Tamworth | 0.334 | 0.208 | 0.623 | Decreasing |
| Temora | 0.398 | 0.387 | 0.972 | Increasing |
| Tenterfield | 0.201 | 0.190 | 0.947 | Increasing |
| Tumbarumba | 0.343 | 0.309 | 0.899 | Decreasing |
| Tumut | 0.276 | 0.276 | 0.999 | Increasing |
| Tweed | 0.655 | 0.305 | 0.467 | Decreasing |

# Appendix 3a
# DEA scores for all wastewater utilities: 2001

| Wastewater Utility | *Technical efficiency measure:* | | | Returns to scale |
|---|---|---|---|---|
| | Pure | Overall | Scale | |
| Uralla | 0.356 | 0.240 | 0.673 | Decreasing |
| Wagga Wagga | 0.795 | 0.477 | 0.599 | Decreasing |
| Urana | 0.846 | 0.732 | 0.865 | Increasing |
| Walcha | 0.402 | 0.368 | 0.917 | Decreasing |
| Weddin | 0.567 | 0.468 | 0.825 | Decreasing |
| Wellington | 0.247 | 0.246 | 0.995 | Increasing |
| Wentworth | 0.616 | 0.361 | 0.585 | Decreasing |
| Wingecarribee | 0.311 | 0.207 | 0.666 | Decreasing |
| Wyong | 0.679 | 0.311 | 0.459 | Decreasing |
| Yarrowlumla | 0.252 | 0.178 | 0.705 | Decreasing |
| Yass | 0.185 | 0.185 | 0.999 | Increasing |
| Young | 0.542 | 0.529 | 0.977 | Increasing |
| Central Highlands | 1.000 | 0.406 | 0.406 | Decreasing |
| Coliban | 0.478 | 0.237 | 0.496 | Decreasing |
| Gippsland | 1.000 | 0.436 | 0.436 | Decreasing |
| Goulburn Valley | 0.842 | 0.373 | 0.443 | Decreasing |
| North East | 0.703 | 0.308 | 0.438 | Decreasing |
| Western | 0.559 | 0.240 | 0.429 | Decreasing |
| East Gippsland | 0.386 | 0.210 | 0.543 | Decreasing |
| Glenelg | 0.546 | 0.269 | 0.492 | Decreasing |
| Grampians | 0.338 | 0.204 | 0.603 | Decreasing |
| Lower Murray | 0.678 | 0.290 | 0.427 | Decreasing |
| Portland Coast | 0.528 | 0.232 | 0.439 | Decreasing |
| South Gippsland | 0.658 | 0.363 | 0.551 | Decreasing |
| South West | 0.508 | 0.253 | 0.499 | Decreasing |
| Westernport | 0.506 | 0.218 | 0.430 | Decreasing |

## Appendix 3a
## DEA scores for all wastewater utilities: 2002

| Wastewater Utility | *Technical efficiency measure:* | | | Returns to scale |
|---|---|---|---|---|
| | Pure | Overall | Scale | |
| Albury | 0.454 | 0.215 | 0.473 | Decreasing |
| Armidale Dumaresq | 0.345 | 0.206 | 0.599 | Decreasing |
| Ballina | 0.484 | 0.192 | 0.397 | Decreasing |
| Balranald | 0.736 | 0.722 | 0.981 | Decreasing |
| Barraba | 0.352 | 0.248 | 0.705 | Increasing |
| Bathurst | 0.582 | 0.253 | 0.435 | Decreasing |
| Bellingen | 0.343 | 0.210 | 0.611 | Decreasing |
| Berrigan | 0.228 | 0.153 | 0.670 | Decreasing |
| Bingara | 0.517 | 0.511 | 0.987 | Decreasing |
| Bland | 0.217 | 0.201 | 0.928 | Increasing |
| Blayney | 0.281 | 0.272 | 0.970 | Decreasing |
| Bombala | 0.424 | 0.398 | 0.940 | Increasing |
| Boorowa | 0.717 | 0.672 | 0.936 | Increasing |
| Brewarrina | 0.411 | 0.400 | 0.972 | Increasing |
| Byron | 0.313 | 0.126 | 0.402 | Decreasing |
| Cabonne | 0.294 | 0.236 | 0.802 | Decreasing |
| Carrathool | 0.521 | 0.426 | 0.817 | Increasing |
| Cobar | 0.397 | 0.245 | 0.616 | Decreasing |
| Coffs Harbour | 0.458 | 0.207 | 0.452 | Decreasing |
| Coolah | 0.465 | 0.438 | 0.941 | Increasing |
| Coolamon | 0.548 | 0.539 | 0.984 | Increasing |
| Cooma-Monaro | 0.171 | 0.165 | 0.962 | Increasing |
| Coonamble | 0.385 | 0.356 | 0.925 | Increasing |
| Cootamundra | 0.598 | 0.554 | 0.925 | Decreasing |
| Copmanhurst | 0.368 | 0.346 | 0.940 | Increasing |
| Corowa | 0.322 | 0.248 | 0.770 | Decreasing |
| Cowra | 0.550 | 0.318 | 0.578 | Decreasing |
| Culcairn | 0.548 | 0.437 | 0.798 | Decreasing |
| Deniliquin | 0.368 | 0.289 | 0.785 | Decreasing |
| Dubbo | 0.393 | 0.197 | 0.501 | Decreasing |
| Dungog | 0.359 | 0.356 | 0.991 | Decreasing |
| Eurobodalla | 0.367 | 0.159 | 0.432 | Decreasing |
| Forbes | 0.817 | 0.370 | 0.453 | Decreasing |
| Gilgandra | 1.000 | 1.000 | 1.000 | Constant |
| Glen Innes | 0.582 | 0.389 | 0.668 | Decreasing |
| Gloucester | 0.274 | 0.273 | 0.997 | Increasing |
| Gosford | 0.615 | 0.242 | 0.394 | Decreasing |
| Goulburn | 0.373 | 0.201 | 0.540 | Decreasing |
| Grafton | 0.536 | 0.254 | 0.473 | Decreasing |
| Griffith | 0.355 | 0.188 | 0.529 | Decreasing |
| Gundagai | 0.285 | 0.281 | 0.988 | Decreasing |
| Gunnedah | 1.000 | 0.490 | 0.490 | Decreasing |
| Gunning | 1.000 | 0.848 | 0.848 | Increasing |
| Guyra | 0.443 | 0.424 | 0.958 | Decreasing |

## Appendix 3a
## DEA scores for all wastewater utilities: 2002

| Wastewater Utility | *Technical efficiency measure:* | | | Returns to scale |
|---|---|---|---|---|
| | Pure | Overall | Scale | |
| Harden | 0.305 | 0.289 | 0.949 | Increasing |
| Hastings | 0.604 | 0.242 | 0.400 | Decreasing |
| Holbrook | 0.331 | 0.251 | 0.757 | Increasing |
| Hume | 1.000 | 0.269 | 0.269 | Decreasing |
| Inverell | 0.204 | 0.201 | 0.982 | Increasing |
| Jerilderie | 1.000 | 0.824 | 0.824 | Decreasing |
| Junee | 0.954 | 0.257 | 0.269 | Decreasing |
| Kempsey | 0.371 | 0.167 | 0.452 | Decreasing |
| Kyogle | 0.178 | 0.177 | 0.995 | Increasing |
| Lachlan | 0.625 | 0.354 | 0.565 | Decreasing |
| Leeton | 0.729 | 0.379 | 0.520 | Decreasing |
| Lismore | 0.484 | 0.240 | 0.496 | Decreasing |
| Lockhart | 0.352 | 0.304 | 0.863 | Increasing |
| Maclean | 0.213 | 0.192 | 0.897 | Decreasing |
| Manilla | 0.249 | 0.195 | 0.780 | Increasing |
| Merriwa | 0.423 | 0.371 | 0.877 | Increasing |
| MidCoast (Combined) | 0.358 | 0.145 | 0.405 | Decreasing |
| Moree Plains | 0.223 | 0.159 | 0.711 | Decreasing |
| Mudgee | 0.562 | 0.306 | 0.544 | Decreasing |
| Murray | 0.531 | 0.325 | 0.612 | Decreasing |
| Murrumbidgee | 1.000 | 1.000 | 1.000 | Constant |
| Murrurundi | 1.000 | 1.000 | 1.000 | Constant |
| Muswellbrook | 0.323 | 0.216 | 0.671 | Decreasing |
| Nambucca | 0.449 | 0.220 | 0.489 | Decreasing |
| Narrabri | 0.307 | 0.258 | 0.842 | Decreasing |
| Narrandera | 0.389 | 0.359 | 0.924 | Increasing |
| Oberon | 0.302 | 0.280 | 0.928 | Decreasing |
| Orange | 1.000 | 0.472 | 0.472 | Decreasing |
| Parkes | 0.522 | 0.373 | 0.715 | Decreasing |
| Parry | 0.761 | 0.420 | 0.551 | Decreasing |
| Queanbeyan | 0.673 | 0.306 | 0.455 | Decreasing |
| Quirindi | 0.399 | 0.392 | 0.983 | Decreasing |
| Richmond Valley | 0.442 | 0.212 | 0.479 | Decreasing |
| Rylstone | 0.212 | 0.171 | 0.809 | Increasing |
| Scone | 0.375 | 0.316 | 0.842 | Decreasing |
| Shoalhaven | 0.338 | 0.139 | 0.413 | Decreasing |
| Singleton | 0.628 | 0.284 | 0.452 | Decreasing |
| Snowy River | 0.226 | 0.155 | 0.686 | Decreasing |
| Tamworth | 0.466 | 0.223 | 0.479 | Decreasing |
| Temora | 0.380 | 0.364 | 0.959 | Increasing |
| Tenterfield | 0.175 | 0.162 | 0.927 | Increasing |
| Tumbarumba | 0.459 | 0.451 | 0.982 | Increasing |
| Tumut | 0.267 | 0.243 | 0.910 | Decreasing |
| Tweed | 0.641 | 0.257 | 0.402 | Decreasing |

## Appendix 3a
## DEA scores for all wastewater utilities: 2002

| Wastewater Utility | *Technical efficiency measure:* | | | Returns to scale |
|---|---|---|---|---|
| | Pure | Overall | Scale | |
| Uralla | 0.311 | 0.278 | 0.893 | Decreasing |
| Wagga Wagga | 0.888 | 0.406 | 0.457 | Decreasing |
| Urana | 0.590 | 0.483 | 0.819 | Increasing |
| Walcha | 0.441 | 0.428 | 0.970 | Decreasing |
| Weddin | 0.447 | 0.444 | 0.995 | Increasing |
| Wellington | 0.255 | 0.254 | 0.995 | Increasing |
| Wentworth | 0.862 | 0.382 | 0.443 | Decreasing |
| Wingecarribee | 0.441 | 0.225 | 0.511 | Decreasing |
| Wyong | 0.720 | 0.281 | 0.391 | Decreasing |
| Yarrowlumla | 0.281 | 0.243 | 0.864 | Decreasing |
| Yass | 0.213 | 0.205 | 0.960 | Increasing |
| Young | 0.413 | 0.403 | 0.977 | Increasing |
| Central Highlands | 1.000 | 0.346 | 0.346 | Decreasing |
| Coliban | 0.655 | 0.264 | 0.402 | Decreasing |
| Gippsland | 1.000 | 0.384 | 0.384 | Decreasing |
| Goulburn Valley | 0.833 | 0.323 | 0.387 | Decreasing |
| North East | 0.735 | 0.281 | 0.382 | Decreasing |
| Western | 0.774 | 0.287 | 0.371 | Decreasing |
| East Gippsland | 0.525 | 0.221 | 0.421 | Decreasing |
| Glenelg | 0.575 | 0.225 | 0.391 | Decreasing |
| Grampians | 0.575 | 0.254 | 0.441 | Decreasing |
| Lower Murray | 0.638 | 0.236 | 0.370 | Decreasing |
| Portland Coast | 0.725 | 0.265 | 0.365 | Decreasing |
| South Gippsland | 0.814 | 0.341 | 0.418 | Decreasing |
| South West | 0.454 | 0.187 | 0.413 | Decreasing |
| Westernport | 0.653 | 0.216 | 0.331 | Decreasing |

## Appendix 3a
## DEA scores for all wastewater utilities: 2003

| Wastewater Utility | *Technical efficiency measure:* | | | Returns to scale |
|---|---|---|---|---|
| | Pure | Overall | Scale | |
| Albury | 0.518 | 0.300 | 0.581 | Decreasing |
| Armidale Dumaresq | 0.380 | 0.273 | 0.719 | Decreasing |
| Ballina | 0.636 | 0.338 | 0.531 | Decreasing |
| Balranald | 1.000 | 1.000 | 1.000 | Constant |
| Barraba | 0.291 | 0.223 | 0.768 | Increasing |
| Bathurst | 0.625 | 0.353 | 0.565 | Decreasing |
| Bellingen | 0.350 | 0.237 | 0.679 | Decreasing |
| Berrigan | 0.286 | 0.187 | 0.653 | Decreasing |
| Bingara | 0.324 | 0.285 | 0.878 | Increasing |
| Bland | 0.280 | 0.256 | 0.913 | Decreasing |
| Blayney | 0.299 | 0.273 | 0.916 | Decreasing |
| Bombala | 0.433 | 0.384 | 0.886 | Increasing |
| Boorowa | 0.748 | 0.466 | 0.623 | Increasing |
| Brewarrina | 0.391 | 0.374 | 0.956 | Increasing |
| Byron | 0.294 | 0.172 | 0.586 | Decreasing |
| Cabonne | 0.251 | 0.215 | 0.859 | Decreasing |
| Carrathool | 0.635 | 0.516 | 0.812 | Increasing |
| Cobar | 0.672 | 0.424 | 0.631 | Decreasing |
| Coffs Harbour | 0.531 | 0.312 | 0.588 | Decreasing |
| Coolah | 0.743 | 0.573 | 0.772 | Decreasing |
| Coolamon | 0.529 | 0.527 | 0.996 | Increasing |
| Cooma-Monaro | 0.231 | 0.182 | 0.787 | Decreasing |
| Coonamble | 0.399 | 0.372 | 0.933 | Decreasing |
| Cootamundra | 0.540 | 0.433 | 0.802 | Decreasing |
| Copmanhurst | 0.359 | 0.278 | 0.774 | Increasing |
| Corowa | 0.416 | 0.320 | 0.769 | Decreasing |
| Cowra | 0.587 | 0.448 | 0.763 | Decreasing |
| Culcairn | 0.488 | 0.403 | 0.826 | Decreasing |
| Deniliquin | 0.538 | 0.399 | 0.741 | Decreasing |
| Dubbo | 0.684 | 0.383 | 0.559 | Decreasing |
| Dungog | 0.403 | 0.368 | 0.913 | Decreasing |
| Eurobodalla | 0.342 | 0.197 | 0.576 | Decreasing |
| Forbes | 0.518 | 0.397 | 0.767 | Decreasing |
| Gilgandra | 0.668 | 0.494 | 0.740 | Decreasing |
| Glen Innes | 0.466 | 0.333 | 0.713 | Decreasing |
| Gloucester | 0.370 | 0.254 | 0.687 | Decreasing |
| Gosford | 0.631 | 0.326 | 0.516 | Decreasing |
| Goulburn | 0.330 | 0.237 | 0.717 | Decreasing |
| Grafton | 0.444 | 0.307 | 0.692 | Decreasing |
| Griffith | 0.464 | 0.307 | 0.661 | Decreasing |
| Gundagai | 0.289 | 0.245 | 0.845 | Increasing |
| Gunnedah | 0.819 | 0.562 | 0.686 | Decreasing |
| Gunning | 0.967 | 0.678 | 0.701 | Increasing |
| Guyra | 0.482 | 0.449 | 0.931 | Increasing |

# Appendix 3a
## DEA scores for all wastewater utilities: 2003

| | | | | |
|---|---|---|---|---|
| Harden | 0.329 | 0.294 | 0.892 | Increasing |
| Hastings | 1.000 | 0.521 | 0.521 | Decreasing |
| Holbrook | 0.356 | 0.188 | 0.527 | Increasing |
| Hume | 0.631 | 0.257 | 0.407 | Decreasing |
| Inverell | 0.403 | 0.306 | 0.760 | Decreasing |
| Jerilderie | 0.654 | 0.616 | 0.941 | Decreasing |
| Junee | 0.274 | 0.271 | 0.990 | Decreasing |
| Kempsey | 0.383 | 0.209 | 0.546 | Decreasing |
| Kyogle | 0.165 | 0.156 | 0.946 | Increasing |
| Lachlan | 0.818 | 0.609 | 0.744 | Decreasing |
| Leeton | 1.000 | 0.542 | 0.542 | Decreasing |
| Lismore | 0.553 | 0.374 | 0.677 | Decreasing |
| Lockhart | 0.392 | 0.355 | 0.906 | Increasing |
| Maclean | 0.346 | 0.259 | 0.749 | Decreasing |
| Manilla | 0.255 | 0.254 | 0.996 | Decreasing |
| Merriwa | 0.569 | 0.453 | 0.796 | Increasing |
| MidCoast (Combined) | 0.464 | 0.247 | 0.532 | Decreasing |
| Moree Plains | 0.318 | 0.235 | 0.738 | Decreasing |
| Mudgee | 0.420 | 0.306 | 0.729 | Decreasing |
| Murray | 0.748 | 0.404 | 0.541 | Decreasing |
| Murrumbidgee | 0.627 | 0.381 | 0.607 | Increasing |
| Murrurundi | 1.000 | 1.000 | 1.000 | Constant |
| Muswellbrook | 0.437 | 0.318 | 0.728 | Decreasing |
| Nambucca | 0.578 | 0.343 | 0.594 | Decreasing |
| Narrabri | 0.113 | 0.109 | 0.968 | Decreasing |
| Narrandera | 0.582 | 0.462 | 0.794 | Decreasing |
| Oberon | 0.264 | 0.210 | 0.794 | Decreasing |
| Orange | 0.932 | 0.543 | 0.583 | Decreasing |
| Parkes | 0.847 | 0.541 | 0.639 | Decreasing |
| Parry | 0.928 | 0.526 | 0.567 | Decreasing |
| Queanbeyan | 0.661 | 0.376 | 0.570 | Decreasing |
| Quirindi | 0.454 | 0.385 | 0.848 | Decreasing |
| Richmond Valley | 0.421 | 0.248 | 0.589 | Decreasing |
| Rylstone | 0.225 | 0.217 | 0.963 | Increasing |
| Scone | 0.519 | 0.393 | 0.756 | Decreasing |
| Shoalhaven | 0.364 | 0.196 | 0.538 | Decreasing |
| Singleton | 0.680 | 0.397 | 0.584 | Decreasing |
| Snowy River | 0.233 | 0.193 | 0.828 | Decreasing |
| Tamworth | 0.466 | 0.281 | 0.603 | Decreasing |
| Temora | 0.651 | 0.522 | 0.801 | Decreasing |
| Tenterfield | 0.193 | 0.183 | 0.951 | Decreasing |
| Tumbarumba | 0.399 | 0.395 | 0.991 | Decreasing |
| Tumut | 0.386 | 0.291 | 0.753 | Decreasing |
| Tweed | 0.781 | 0.408 | 0.522 | Decreasing |

## Appendix 3a
## DEA scores for all wastewater utilities: 2003

| | | | | |
|---|---|---|---|---|
| Uralla | 0.234 | 0.230 | 0.984 | Increasing |
| Wagga Wagga | 1.000 | 0.698 | 0.698 | Decreasing |
| Urana | 1.000 | 0.941 | 0.941 | Decreasing |
| Walcha | 0.336 | 0.322 | 0.958 | Decreasing |
| Weddin | 0.530 | 0.430 | 0.810 | Increasing |
| Wellington | 0.336 | 0.278 | 0.828 | Decreasing |
| Wentworth | 0.749 | 0.420 | 0.560 | Decreasing |
| Wingecarribee | 0.472 | 0.308 | 0.653 | Decreasing |
| Wyong | 0.680 | 0.350 | 0.514 | Decreasing |
| Yarrowlumla | 0.272 | 0.223 | 0.819 | Decreasing |
| Yass | 0.293 | 0.249 | 0.849 | Decreasing |
| Young | 0.736 | 0.562 | 0.764 | Decreasing |
| Central Highlands | 0.935 | 0.472 | 0.504 | Decreasing |
| Coliban | 0.679 | 0.369 | 0.544 | Decreasing |
| Gippsland | 1.000 | 0.504 | 0.504 | Decreasing |
| Goulburn Valley | 0.851 | 0.433 | 0.509 | Decreasing |
| North East | 0.735 | 0.375 | 0.510 | Decreasing |
| Western | 0.742 | 0.375 | 0.505 | Decreasing |
| East Gippsland | 0.477 | 0.262 | 0.550 | Decreasing |
| Glenelg | 0.617 | 0.336 | 0.544 | Decreasing |
| Grampians | 0.614 | 0.346 | 0.564 | Decreasing |
| Lower Murray | 1.000 | 0.327 | 0.327 | Decreasing |
| Portland Coast | 0.620 | 0.342 | 0.551 | Decreasing |
| South Gippsland | 0.895 | 0.494 | 0.552 | Decreasing |
| South West | 0.615 | 0.329 | 0.535 | Decreasing |
| Westernport | 0.550 | 0.292 | 0.531 | Decreasing |

## Appendix 3a
## DEA scores flr all wastewater utilities: 2004

| Wastewater Utility | *Technical efficiency measure:* | | | Returns to scale |
|---|---|---|---|---|
| | Pure | Overall | Scale | |
| Albury | 0.465 | 0.389 | 0.837 | Decreasing |
| Armidale Dumaresq | 0.377 | 0.318 | 0.844 | Decreasing |
| Ballina | 0.462 | 0.387 | 0.837 | Decreasing |
| Balranald | 0.935 | 0.856 | 0.916 | Decreasing |
| Barraba | 0.254 | 0.251 | 0.987 | Increasing |
| Bathurst Valley | 0.565 | 0.474 | 0.839 | Decreasing |
| Bellingen | 0.367 | 0.315 | 0.859 | Decreasing |
| Berrigan | 0.229 | 0.205 | 0.898 | Decreasing |
| Bingara | 0.281 | 0.222 | 0.790 | Increasing |
| Bland | 0.317 | 0.289 | 0.911 | Decreasing |
| Blayney | 0.273 | 0.249 | 0.913 | Decreasing |
| Bombala | 0.592 | 0.569 | 0.961 | Decreasing |
| Boorowa | 0.575 | 0.503 | 0.876 | Increasing |
| Brewarrina | 0.423 | 0.403 | 0.952 | Decreasing |
| Byron | 0.311 | 0.262 | 0.840 | Decreasing |
| Cabonne | 0.392 | 0.354 | 0.903 | Decreasing |
| Carrathool | 0.314 | 0.272 | 0.865 | Increasing |
| Cobar | 0.781 | 0.536 | 0.686 | Decreasing |
| Coffs Harbour | 0.443 | 0.371 | 0.837 | Decreasing |
| Coolah | 0.678 | 0.624 | 0.920 | Decreasing |
| Coolamon | 0.411 | 0.406 | 0.987 | Increasing |
| Cooma-Monaro | 0.210 | 0.184 | 0.875 | Decreasing |
| Coonamble | 0.584 | 0.531 | 0.909 | Decreasing |
| Cootamundra | 0.718 | 0.620 | 0.864 | Decreasing |
| Copmanhurst | 0.360 | 0.318 | 0.883 | Decreasing |
| Corowa | 0.436 | 0.375 | 0.860 | Decreasing |
| Cowra | 0.607 | 0.521 | 0.859 | Decreasing |
| Culcairn | 0.540 | 0.497 | 0.922 | Decreasing |
| Deniliquin | 0.471 | 0.404 | 0.858 | Decreasing |
| Dubbo | 0.278 | 0.234 | 0.840 | Decreasing |
| Dungog | 0.395 | 0.364 | 0.922 | Decreasing |
| Eurobodalla | 0.247 | 0.208 | 0.840 | Decreasing |
| Forbes | 0.447 | 0.385 | 0.860 | Decreasing |
| Gilgandra | 0.785 | 0.705 | 0.898 | Decreasing |
| Glen Innes | 0.787 | 0.681 | 0.865 | Decreasing |
| Gloucester | 0.257 | 0.239 | 0.931 | Decreasing |
| Gosford | 0.488 | 0.407 | 0.835 | Decreasing |
| Goulburn | 0.363 | 0.306 | 0.844 | Decreasing |
| Grafton | 0.407 | 0.344 | 0.845 | Decreasing |
| Griffith | 0.473 | 0.398 | 0.841 | Decreasing |
| Gundagai | 0.268 | 0.248 | 0.926 | Increasing |
| Gunnedah | 0.681 | 0.588 | 0.863 | Decreasing |
| Gunning | 1.000 | 0.673 | 0.673 | Increasing |
| Guyra | 0.312 | 0.300 | 0.962 | Increasing |

## Appendix 3a
## DEA scores flr all wastewater utilities: 2004

| Wastewater Utility | *Technical efficiency measure:* | | | Returns to scale |
|---|---|---|---|---|
| | **Pure** | **Overall** | **Scale** | |
| Harden | 0.405 | 0.384 | 0.948 | Decreasing |
| Hastings | 0.729 | 0.609 | 0.835 | Decreasing |
| Holbrook | 0.391 | 0.385 | 0.984 | Decreasing |
| Hume | 0.285 | 0.266 | 0.932 | Decreasing |
| Inverell | 0.427 | 0.366 | 0.859 | Decreasing |
| Jerilderie | 1.000 | 0.565 | 0.565 | Decreasing |
| Junee | 0.332 | 0.304 | 0.914 | Decreasing |
| Kempsey | 0.341 | 0.277 | 0.813 | Decreasing |
| Kyogle | 0.370 | 0.331 | 0.895 | Decreasing |
| Lachlan | 0.824 | 0.712 | 0.863 | Decreasing |
| Leeton | 0.965 | 0.744 | 0.772 | Decreasing |
| Lismore | 0.539 | 0.452 | 0.839 | Decreasing |
| Lockhart | 0.394 | 0.393 | 0.999 | Decreasing |
| Maclean | 0.355 | 0.304 | 0.854 | Decreasing |
| Manilla | 0.204 | 0.188 | 0.924 | Decreasing |
| Merriwa | 0.463 | 0.417 | 0.902 | Increasing |
| MidCoast (Combined) | 0.346 | 0.289 | 0.836 | Decreasing |
| Moree Plains | 0.473 | 0.400 | 0.846 | Decreasing |
| Mudgee | 0.410 | 0.349 | 0.851 | Decreasing |
| Murray | 0.790 | 0.554 | 0.701 | Decreasing |
| Murrumbidgee | 0.736 | 0.721 | 0.980 | Decreasing |
| Murrurundi | 1.000 | 1.000 | 1.000 | Constant |
| Muswellbrook | 0.499 | 0.423 | 0.848 | Decreasing |
| Nambucca | 0.473 | 0.400 | 0.847 | Decreasing |
| Narrabri | 0.787 | 0.669 | 0.850 | Decreasing |
| Narrandera | 0.536 | 0.466 | 0.870 | Decreasing |
| Oberon | 0.375 | 0.337 | 0.898 | Decreasing |
| Orange | 0.770 | 0.645 | 0.838 | Decreasing |
| Parkes | 0.856 | 0.728 | 0.850 | Decreasing |
| Parry | 0.389 | 0.320 | 0.825 | Decreasing |
| Queanbeyan | 0.504 | 0.423 | 0.839 | Decreasing |
| Quirindi | 0.617 | 0.565 | 0.916 | Decreasing |
| Richmond Valley | 0.455 | 0.384 | 0.844 | Decreasing |
| Rylstone | 0.275 | 0.256 | 0.932 | Decreasing |
| Scone | 0.581 | 0.498 | 0.857 | Decreasing |
| Shoalhaven | 0.291 | 0.244 | 0.836 | Decreasing |
| Singleton | 0.622 | 0.529 | 0.850 | Decreasing |
| Snowy River | 0.303 | 0.267 | 0.881 | Decreasing |
| Tamworth | 0.630 | 0.527 | 0.837 | Decreasing |
| Temora | 0.544 | 0.483 | 0.889 | Decreasing |
| Tenterfield | 0.264 | 0.240 | 0.907 | Decreasing |
| Tumbarumba | 0.668 | 0.610 | 0.913 | Decreasing |
| Tumut | 0.469 | 0.400 | 0.854 | Decreasing |
| Tweed | 0.526 | 0.440 | 0.836 | Decreasing |

## Appendix 3a
## DEA scores flr all wastewater utilities: 2004

| Wastewater Utility | *Technical efficiency measure:* | | | Returns to scale |
|---|---|---|---|---|
| | Pure | Overall | Scale | |
| Uralla | 0.256 | 0.252 | 0.984 | Decreasing |
| Wagga Wagga | 0.954 | 0.798 | 0.837 | Decreasing |
| Urana | 0.804 | 0.744 | 0.925 | Increasing |
| Walcha | 0.549 | 0.520 | 0.947 | Decreasing |
| Weddin | 0.712 | 0.683 | 0.960 | Decreasing |
| Wellington | 0.339 | 0.299 | 0.882 | Decreasing |
| Wentworth | 0.708 | 0.615 | 0.869 | Decreasing |
| Wingecarribee | 0.405 | 0.340 | 0.840 | Decreasing |
| Wyong | 0.441 | 0.368 | 0.835 | Decreasing |
| Yarrowlumla | 0.364 | 0.255 | 0.701 | Decreasing |
| Yass Valley | 0.422 | 0.370 | 0.876 | Decreasing |
| Young | 0.906 | 0.778 | 0.859 | Decreasing |
| Central Highlands | 0.871 | 0.585 | 0.672 | Decreasing |
| Coliban | 0.490 | 0.409 | 0.835 | Decreasing |
| Gippsland | 1.000 | 0.834 | 0.834 | Decreasing |
| Goulburn Valley | 0.677 | 0.564 | 0.833 | Decreasing |
| North East | 0.540 | 0.447 | 0.828 | Decreasing |
| Western | 1.000 | 0.452 | 0.452 | Decreasing |
| East Gippsland | 0.397 | 0.321 | 0.809 | Decreasing |
| Glenelg | 0.515 | 0.411 | 0.797 | Decreasing |
| Grampians | 0.618 | 0.518 | 0.838 | Decreasing |
| Lower Murray | 1.000 | 0.443 | 0.443 | Decreasing |
| Portland Coast | 0.428 | 0.342 | 0.800 | Decreasing |
| South Gippsland | 0.738 | 0.618 | 0.838 | Decreasing |
| South West | 0.530 | 0.444 | 0.837 | Decreasing |
| Westernport | 0.499 | 0.381 | 0.765 | Decreasing |

## Appendix 3b
## DEA scores for large wastewater utilities: 2001

| Wastewater Utility | *Technical efficiency measure:* | | | Returns to scale |
|---|---|---|---|---|
| | Pure | Overall | Scale | |
| Albury | 0.402 | 0.401 | 0.998 | Increasing |
| Armidale Dumaresq | 0.391 | 0.376 | 0.962 | Increasing |
| Ballina | 0.513 | 0.386 | 0.752 | Decreasing |
| Bathurst | 0.516 | 0.462 | 0.896 | Decreasing |
| Byron | 0.399 | 0.273 | 0.684 | Decreasing |
| Coffs Harbour | 0.411 | 0.404 | 0.985 | Decreasing |
| Cooma-Monaro | 0.454 | 0.339 | 0.746 | Increasing |
| Corowa | 0.510 | 0.496 | 0.972 | Increasing |
| Cowra | 0.760 | 0.737 | 0.969 | Increasing |
| Deniliquin | 0.676 | 0.635 | 0.939 | Increasing |
| Dubbo | 0.335 | 0.330 | 0.984 | Increasing |
| Eurobodalla | 0.241 | 0.240 | 0.996 | Increasing |
| Forbes | 0.769 | 0.703 | 0.915 | Increasing |
| Gosford | 0.541 | 0.420 | 0.776 | Decreasing |
| Goulburn | 0.380 | 0.374 | 0.983 | Increasing |
| Grafton | 0.540 | 0.537 | 0.996 | Increasing |
| Griffith | 0.467 | 0.460 | 0.985 | Increasing |
| Gunnedah | 1.000 | 1.000 | 1.000 | Constant |
| Hastings | 0.610 | 0.488 | 0.799 | Decreasing |
| Inverell | 0.472 | 0.368 | 0.781 | Increasing |
| Kempsey | 0.408 | 0.408 | 0.998 | Increasing |
| Lismore | 0.421 | 0.414 | 0.983 | Increasing |
| Maclean | 0.413 | 0.406 | 0.983 | Increasing |
| MidCoast (Combined) | 0.391 | 0.330 | 0.844 | Decreasing |
| Moree Plains | 0.363 | 0.343 | 0.945 | Increasing |
| Mudgee | 0.538 | 0.529 | 0.984 | Increasing |
| Muswellbrook | 0.395 | 0.378 | 0.957 | Increasing |
| Nambucca | 0.458 | 0.457 | 0.998 | Increasing |
| Narrabri | 0.585 | 0.469 | 0.801 | Increasing |
| Orange | 1.000 | 1.000 | 1.000 | Constant |
| Parkes | 0.676 | 0.597 | 0.883 | Increasing |
| Queanbeyan | 0.725 | 0.595 | 0.821 | Decreasing |
| Richmond Valley | 0.460 | 0.460 | 0.999 | Increasing |
| Shoalhaven | 0.284 | 0.232 | 0.817 | Decreasing |
| Singleton | 0.517 | 0.515 | 0.997 | Increasing |
| Snowy River | 0.675 | 0.641 | 0.949 | Increasing |
| Tamworth | 0.357 | 0.356 | 0.995 | Increasing |
| Tumut | 0.551 | 0.521 | 0.946 | Increasing |
| Tweed | 0.655 | 0.514 | 0.785 | Decreasing |
| Wagga Wagga | 0.806 | 0.803 | 0.996 | Increasing |
| Wingecarribee | 0.366 | 0.360 | 0.984 | Increasing |
| Wyong | 0.679 | 0.524 | 0.772 | Decreasing |

## Appendix 3b
## DEA scores for large wastewater utilities: 2001

| Wastewater Utility | *Technical efficiency measure:* | | | Returns to scale |
|---|---|---|---|---|
| | Pure | Overall | Scale | |
| Central Highlands | 1.000 | 0.683 | 0.683 | Decreasing |
| Coliban | 0.478 | 0.400 | 0.836 | Decreasing |
| Gippsland | 1.000 | 0.734 | 0.734 | Decreasing |
| Goulburn Valley | 0.842 | 0.627 | 0.745 | Decreasing |
| North East | 0.703 | 0.518 | 0.738 | Decreasing |
| Western | 0.703 | 0.404 | 0.575 | Decreasing |
| East Gippsland | 0.386 | 0.369 | 0.955 | Decreasing |
| Glenelg | 0.546 | 0.528 | 0.967 | Decreasing |
| Grampians | 0.351 | 0.350 | 0.999 | Increasing |
| Lower Murray | 1.000 | 0.491 | 0.491 | Decreasing |
| Portland Coast | 0.603 | 0.417 | 0.692 | Decreasing |
| South Gippsland | 0.658 | 0.628 | 0.954 | Decreasing |
| South West | 0.508 | 0.427 | 0.842 | Decreasing |
| Westernport | 1.000 | 0.436 | 0.436 | Decreasing |

## Appendix 3b
## DEA scores for large wastewater utilities: 2002

| Wastewater Utility | Technical efficiency measure: | | | Returns to scale |
|---|---|---|---|---|
| | Pure | Overall | Scale | |
| Albury | 0.455 | 0.455 | 1.000 | Increasing |
| Armidale Dumaresq | 0.439 | 0.439 | 0.998 | Increasing |
| Ballina | 0.486 | 0.408 | 0.838 | Decreasing |
| Bathurst | 0.582 | 0.537 | 0.922 | Decreasing |
| Byron | 0.316 | 0.268 | 0.846 | Decreasing |
| Coffs Harbour | 0.458 | 0.439 | 0.958 | Decreasing |
| Cooma-Monaro | 0.403 | 0.352 | 0.874 | Increasing |
| Corowa | 0.521 | 0.518 | 0.994 | Increasing |
| Cowra | 0.659 | 0.658 | 0.999 | Increasing |
| Deniliquin | 0.618 | 0.615 | 0.996 | Increasing |
| Dubbo | 0.417 | 0.417 | 1.000 | Increasing |
| Eurobodalla | 0.367 | 0.336 | 0.916 | Decreasing |
| Forbes | 0.840 | 0.776 | 0.924 | Decreasing |
| Gosford | 0.615 | 0.513 | 0.835 | Decreasing |
| Goulburn | 0.428 | 0.428 | 0.999 | Increasing |
| Grafton | 0.539 | 0.539 | 1.000 | Increasing |
| Griffith | 0.398 | 0.398 | 0.999 | Increasing |
| Gunnedah | 1.000 | 1.000 | 1.000 | Constant |
| Hastings | 0.604 | 0.512 | 0.848 | Decreasing |
| Inverell | 0.442 | 0.429 | 0.971 | Increasing |
| Kempsey | 0.371 | 0.356 | 0.960 | Decreasing |
| Lismore | 0.509 | 0.509 | 1.000 | Increasing |
| Maclean | 0.411 | 0.410 | 0.997 | Increasing |
| MidCoast (Combined) | 0.358 | 0.307 | 0.858 | Decreasing |
| Moree Plains | 0.339 | 0.337 | 0.995 | Increasing |
| Mudgee | 0.651 | 0.651 | 0.999 | Increasing |
| Muswellbrook | 0.462 | 0.460 | 0.998 | Increasing |
| Nambucca | 0.468 | 0.468 | 1.000 | Increasing |
| Narrabri | 0.553 | 0.547 | 0.990 | Increasing |
| Orange | 1.000 | 1.000 | 1.000 | Constant |
| Parkes | 0.799 | 0.798 | 0.998 | Increasing |
| Queanbeyan | 0.673 | 0.648 | 0.963 | Decreasing |
| Richmond Valley | 0.451 | 0.451 | 1.000 | Increasing |
| Shoalhaven | 0.338 | 0.295 | 0.874 | Decreasing |
| Singleton | 0.628 | 0.606 | 0.966 | Decreasing |
| Snowy River | 0.525 | 0.501 | 0.953 | Increasing |
| Tamworth | 0.473 | 0.473 | 1.000 | Increasing |
| Tumut | 0.521 | 0.518 | 0.995 | Increasing |
| Tweed | 0.641 | 0.545 | 0.851 | Decreasing |
| Wagga Wagga | 0.888 | 0.859 | 0.968 | Decreasing |
| Wingecarribee | 0.478 | 0.478 | 0.999 | Increasing |
| Wyong | 0.720 | 0.596 | 0.827 | Decreasing |

## Appendix 3b
## DEA scores for large wastewater utilities: 2002

| Wastewater Utility | *Technical efficiency measure:* | | | Returns to scale |
|---|---|---|---|---|
| | Pure | Overall | Scale | |
| Central Highlands | 1.000 | 0.733 | 0.733 | Decreasing |
| Coliban | 0.655 | 0.558 | 0.852 | Decreasing |
| Gippsland | 1.000 | 0.814 | 0.814 | Decreasing |
| Goulburn Valley | 0.833 | 0.683 | 0.821 | Decreasing |
| North East | 0.758 | 0.595 | 0.786 | Decreasing |
| Western | 0.959 | 0.609 | 0.634 | Decreasing |
| East Gippsland | 0.525 | 0.468 | 0.892 | Decreasing |
| Glenelg | 0.690 | 0.480 | 0.696 | Decreasing |
| Grampians | 0.575 | 0.538 | 0.935 | Decreasing |
| Lower Murray | 1.000 | 0.500 | 0.500 | Decreasing |
| Portland Coast | 0.881 | 0.562 | 0.639 | Decreasing |
| South Gippsland | 0.814 | 0.722 | 0.887 | Decreasing |
| South West | 0.454 | 0.396 | 0.874 | Decreasing |
| Westernport | 1.000 | 0.460 | 0.460 | Decreasing |

## Appendix 3b
## DEA scores for large wastewater utilities: 2003

| Wastewater Utility | *Technical efficiency measure:* | | | Returns to scale |
|---|---|---|---|---|
| | Pure | Overall | Scale | |
| Albury | 0.532 | 0.443 | 0.834 | Decreasing |
| Armidale Dumaresq | 0.422 | 0.414 | 0.980 | Increasing |
| Ballina | 0.704 | 0.507 | 0.721 | Decreasing |
| Bathurst | 0.660 | 0.532 | 0.806 | Decreasing |
| Byron | 0.316 | 0.262 | 0.829 | Decreasing |
| Coffs Harbour | 0.538 | 0.456 | 0.847 | Decreasing |
| Cooma-Monaro | 0.395 | 0.273 | 0.691 | Increasing |
| Corowa | 0.576 | 0.552 | 0.957 | Increasing |
| Cowra | 0.789 | 0.762 | 0.966 | Increasing |
| Deniliquin | 0.660 | 0.645 | 0.978 | Increasing |
| Dubbo | 0.708 | 0.569 | 0.804 | Decreasing |
| Eurobodalla | 0.364 | 0.298 | 0.820 | Decreasing |
| Forbes | 0.707 | 0.636 | 0.899 | Increasing |
| Gosford | 0.631 | 0.472 | 0.748 | Decreasing |
| Goulburn | 0.364 | 0.353 | 0.970 | Increasing |
| Grafton | 0.476 | 0.473 | 0.995 | Decreasing |
| Griffith | 0.491 | 0.458 | 0.934 | Decreasing |
| Gunnedah | 1.000 | 1.000 | 1.000 | Constant |
| Hastings | 1.000 | 0.759 | 0.759 | Decreasing |
| Inverell | 0.535 | 0.498 | 0.932 | Increasing |
| Kempsey | 0.507 | 0.330 | 0.651 | Decreasing |
| Lismore | 0.576 | 0.553 | 0.961 | Decreasing |
| Maclean | 0.438 | 0.429 | 0.978 | Increasing |
| MidCoast (Combined) | 0.470 | 0.363 | 0.772 | Decreasing |
| Moree Plains | 0.385 | 0.343 | 0.891 | Increasing |
| Mudgee | 0.503 | 0.497 | 0.987 | Increasing |
| Muswellbrook | 0.506 | 0.485 | 0.958 | Increasing |
| Nambucca | 0.740 | 0.556 | 0.752 | Decreasing |
| Narrabri | 0.553 | 0.156 | 0.283 | Increasing |
| Orange | 0.967 | 0.806 | 0.834 | Decreasing |
| Parkes | 1.000 | 0.895 | 0.895 | Decreasing |
| Queanbeyan | 0.687 | 0.561 | 0.816 | Decreasing |
| Richmond Valley | 0.540 | 0.400 | 0.741 | Decreasing |
| Shoalhaven | 0.369 | 0.288 | 0.780 | Decreasing |
| Singleton | 0.969 | 0.659 | 0.681 | Decreasing |
| Snowy River | 0.579 | 0.529 | 0.914 | Increasing |
| Tamworth | 0.481 | 0.414 | 0.861 | Decreasing |
| Tumut | 0.498 | 0.453 | 0.909 | Increasing |
| Tweed | 0.800 | 0.598 | 0.747 | Decreasing |
| Wagga Wagga | 1.000 | 1.000 | 1.000 | Constant |
| Wingecarribee | 0.500 | 0.460 | 0.920 | Decreasing |
| Wyong | 0.680 | 0.507 | 0.746 | Decreasing |

## Appendix 3b
## DEA scores for large wastewater utilities: 2003

| Wastewater Utility | *Technical efficiency measure:* | | | Returns to scale |
|---|---|---|---|---|
| | Pure | Overall | Scale | |
| Central Highlands | 1.000 | 0.689 | 0.689 | Decreasing |
| Coliban | 0.679 | 0.534 | 0.786 | Decreasing |
| Gippsland | 1.000 | 0.728 | 0.728 | Decreasing |
| Goulburn Valley | 0.858 | 0.629 | 0.732 | Decreasing |
| North East | 0.764 | 0.548 | 0.717 | Decreasing |
| Western | 0.825 | 0.550 | 0.667 | Decreasing |
| East Gippsland | 0.517 | 0.397 | 0.767 | Decreasing |
| Glenelg | 1.000 | 0.561 | 0.561 | Decreasing |
| Grampians | 0.635 | 0.514 | 0.810 | Decreasing |
| Lower Murray | 1.000 | 0.484 | 0.484 | Decreasing |
| Portland Coast | 0.752 | 0.530 | 0.706 | Decreasing |
| South Gippsland | 0.929 | 0.737 | 0.794 | Decreasing |
| South West | 0.626 | 0.485 | 0.775 | Decreasing |
| Westernport | 1.000 | 0.498 | 0.498 | Decreasing |

## Appendix 3b
## DEA scores for large wastewater utilities: 2004

| Wastewater Utility | *Technical efficiency measure:* | | | Returns to scale |
|---|---|---|---|---|
| | Pure | Overall | Scale | |
| Albury | 0.479 | 0.475 | 0.992 | Increasing |
| Armidale Dumaresq | 0.417 | 0.404 | 0.970 | Increasing |
| Ballina | 0.587 | 0.485 | 0.826 | Decreasing |
| Bathurst Valley | 0.604 | 0.595 | 0.985 | Decreasing |
| Byron | 0.358 | 0.331 | 0.922 | Decreasing |
| Coffs Harbour | 0.455 | 0.452 | 0.993 | Increasing |
| Cooma-Monaro | 0.426 | 0.220 | 0.517 | Increasing |
| Corowa | 0.606 | 0.576 | 0.950 | Increasing |
| Cowra | 0.824 | 0.756 | 0.917 | Increasing |
| Deniliquin | 0.632 | 0.607 | 0.960 | Increasing |
| Dubbo | 0.296 | 0.296 | 0.999 | Increasing |
| Eurobodalla | 0.263 | 0.257 | 0.978 | Increasing |
| Forbes | 0.624 | 0.499 | 0.800 | Increasing |
| Gosford | 0.491 | 0.490 | 0.999 | Increasing |
| Goulburn | 0.401 | 0.378 | 0.944 | Increasing |
| Grafton | 0.485 | 0.455 | 0.939 | Decreasing |
| Griffith | 0.508 | 0.483 | 0.949 | Increasing |
| Gunnedah | 1.000 | 1.000 | 1.000 | Constant |
| Hastings | 0.768 | 0.739 | 0.962 | Decreasing |
| Inverell | 0.580 | 0.514 | 0.886 | Increasing |
| Kempsey | 0.553 | 0.365 | 0.660 | Decreasing |
| Lismore | 0.566 | 0.563 | 0.996 | Increasing |
| Maclean | 0.446 | 0.429 | 0.963 | Increasing |
| MidCoast (Combined) | 0.366 | 0.354 | 0.969 | Decreasing |
| Moree Plains | 0.531 | 0.522 | 0.981 | Increasing |
| Mudgee | 0.483 | 0.476 | 0.987 | Increasing |
| Muswellbrook | 0.570 | 0.546 | 0.959 | Increasing |
| Nambucca | 0.538 | 0.535 | 0.994 | Decreasing |
| Narrabri | 0.915 | 0.823 | 0.899 | Increasing |
| Orange | 0.797 | 0.792 | 0.993 | Increasing |
| Parkes | 1.000 | 1.000 | 1.000 | Constant |
| Queanbeyan | 0.528 | 0.526 | 0.997 | Increasing |
| Richmond Valley | 0.642 | 0.505 | 0.786 | Decreasing |
| Shoalhaven | 0.298 | 0.297 | 0.999 | Increasing |
| Singleton | 0.795 | 0.731 | 0.920 | Decreasing |
| Snowy River | 0.851 | 0.756 | 0.889 | Decreasing |
| Tamworth | 0.650 | 0.647 | 0.995 | Increasing |
| Tumut | 0.582 | 0.536 | 0.921 | Increasing |
| Tweed | 0.565 | 0.536 | 0.949 | Decreasing |
| Wagga Wagga | 0.977 | 0.959 | 0.982 | Increasing |
| Wingecarribee | 0.430 | 0.426 | 0.991 | Increasing |
| Wyong | 0.448 | 0.446 | 0.996 | Decreasing |

## Appendix 3b
## DEA scores for large wastewater utilities: 2004

| Wastewater Utility | *Technical efficiency measure:* | | | Returns to scale |
|---|---|---|---|---|
| | Pure | Overall | Scale | |
| Central Highlands | 0.906 | 0.709 | 0.783 | Decreasing |
| Coliban | 0.495 | 0.495 | 0.999 | Increasing |
| Gippsland | 1.000 | 1.000 | 1.000 | Constant |
| Goulburn Valley | 0.703 | 0.680 | 0.967 | Decreasing |
| North East | 0.593 | 0.544 | 0.917 | Decreasing |
| Western | 1.000 | 0.553 | 0.553 | Decreasing |
| East Gippsland | 0.551 | 0.407 | 0.739 | Decreasing |
| Glenelg | 0.955 | 0.558 | 0.584 | Decreasing |
| Grampians | 0.643 | 0.642 | 0.998 | Increasing |
| Lower Murray | 1.000 | 0.546 | 0.546 | Decreasing |
| Portland Coast | 0.661 | 0.443 | 0.671 | Decreasing |
| South Gippsland | 0.831 | 0.769 | 0.924 | Decreasing |
| South West | 0.544 | 0.544 | 1.000 | Increasing |
| Westernport | 1.000 | 0.535 | 0.535 | Decreasing |