FINAL REPORT

Top down efficiency review of SA Water

Prepared for
Essential Services Commission of South Australia

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Executive Summary

ESCoSA is in the process of developing the initial regulatory arrangements for SA Water. One important component of a regulatory review is the assessment of the efficiency of forecast operating and capital costs.

This project

This project provides analysis of how SA Water's historical costs and outputs compare with water and sewerage utilities across Australia in terms of its efficiency. This comparison is expected to form one part of ESCoSA's considerations in regards to efficiency of future expenditure projections, in conjunction with a detailed bottom-up analysis of SA Water's costs.

We build on work undertaken within the Essential Services Commission (ESC) of Victoria, comparing performance across urban water utilities in Australia. We consider unit costs, productivity measures and statistical efficiency measures to consider the relative performance of SA Water's capital and operating expenditures to provide water and wastewater services to customers within Adelaide, compared to other Australian utilities. Each method has merit and provides insights. Equally each method has limitations, and these are also highlighted.

Comparing efficiency

Comparing efficiency across Australian water utilities is complicated by many factors. These include differences in the area serviced (its topography and rainfall), government requirements and standards, different industry structures across jurisdictions, and the varying costs of obtaining water. Some of these differences can be accounted for in analysis but there will always remain factors that will influence the comparability of efficiency across utilities.

In addition to these complications that are relevant to most cross-firm productivity comparisons, there are specific factors relevant to water and wastewater utilities:

- Utilities are capital intensive, and measures of capital utilised across businesses are often not comparable.
- There has been substantial expenditure by water utilities, including SA Water, aimed at improving water security. Water security is not an easily observed output, at least in the short term. Hence efficiency analysis will conclude that this expenditure equates to a reduction in efficiency. This may or may not be the case, but such a conclusion cannot be drawn from efficiency analysis of the sort conducted in this study.

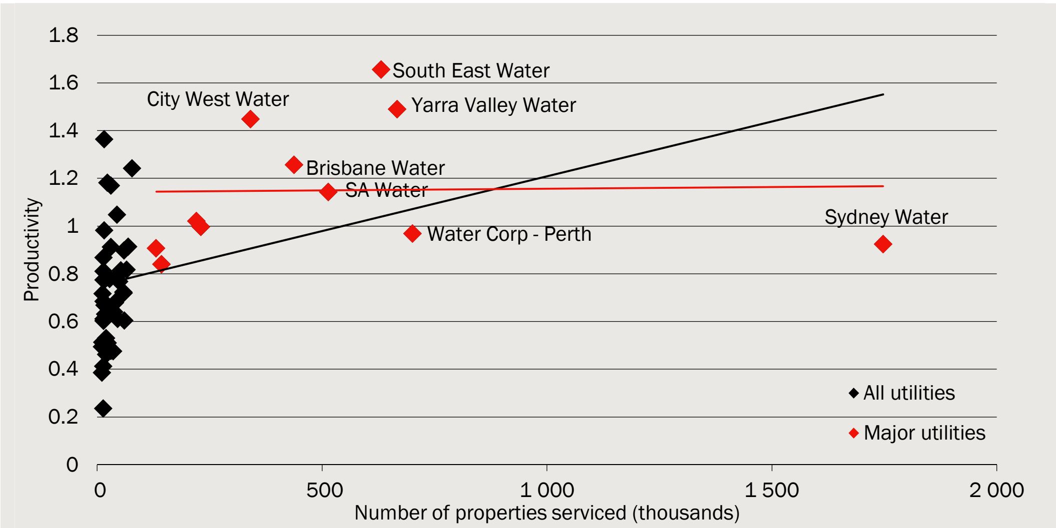
We seek to deal with these issues through testing alternative models of efficiency.

Our findings

On a simple unit cost basis, we find that SA Water has amongst the lowest operating costs per property of Australian urban water utilities. Historically, SA Water also has relatively low capital expenditure. However, recent capital expenditure for the Adelaide Desalination Plant has pushed SA Water well above average capital expenditure per property for the provision of water.

The productivity analysis, in our view, most clearly highlights the performance of SA Water (chart 1). This shows productivity measured on the basis of average operating and capital expenditures against average outputs. SA Water has relatively high productivity compared to most of the smaller firms and about the average of the major utilities included in the sample (shown in red). A number of utilities of similar size in Victoria have much higher productivity (South East Water, City West Water and Yarra Valley Water). Conclusions about SA Water's relative performance hence hinges to a significant degree on which set of utilities it is compared to. There are good reasons to expect that SA Water should be more productive than smaller utilities. There are also good reasons for the Melbourne utilities to be considered a difficult benchmark to meet, partly because their pumping costs are well below those of SA Water.

1 Total factor productivity – average capital expenditure



Data source: The CIE.

A large part of SA Water's recent capital expenditure is from the Adelaide Desalination Plant. When all expenditures related to desalination facilities and desalinated water (both for SA Water and other relevant utilities) are excluded from the analysis, SA Water has a higher level of productivity.

We also examined SA Water's performance using statistical techniques such as Stochastic Frontier Analysis. Based on this analysis SA Water varies from about average performance to being in the top 25 per cent of utilities. Its level of inefficiency varies from around 5 per cent in some plausible models to as much as 50 per cent in others. The models displayed a level of 'instability', particularly with respect to the measure of capital, that casts doubt on their reliability as a measure of SA Water's performance. Further, the weights estimated using the statistical analysis on differing cost inputs did not match expectations of the cost structure of urban water utilities.

Application of findings

Overall, SA Water performs relatively well in its efficiency in most of the models tested in this study, typically being around the 25th percentile of utilities or better. SA Water performs less well against other major utilities than it does against the sample as whole. SA Water's water business appears to perform better than its wastewater business. This is due to the desalination plant and may also reflect the relatively high level of water recycling, as recycling expenditures are captured as relating to provision of water.

SA Water's expenditures over the past 12 years are substantially higher than would have occurred if the Adelaide Desalination Plant had not been constructed. Excluding desalination expenditures, SA Water has the highest productivity in terms of outputs per unit of expenditure (over the last 12 years) of all utilities in the sample. This suggests high efficiency although there may be other factors affecting the potential productivity of each of the water utilities that are not able to be fully accounted for in this analysis, as discussed above.

There are exceptions to the finding that SA Water is relatively efficient, largely from using alternative measures of the capital base. The comparatively high WDV of its asset base impacts materially on the perceived level of efficiency. This may reflect the legacy network of assets inherited by SA Water and may not reflect SA Water's more recent performance. It may also reflect the different accounting approaches used by water utilities to calculate the WDV.

The results from the analysis suggest that, while from a tops-down perspective there is likely to be scope for efficiency gains from SA Water, the magnitude of these gains may be moderate, particularly in expenditures unrelated to the desalination plant. There may be opportunities for achieving efficiency gains in relation to the future operation of the desalination plant, although these have not been able to be assessed in this study as it focuses on a time period over which the plant has not been operating.

The finding that SA Water is relatively efficient in the provision of services, particularly in relation to recent expenditures, does not match pricing outcomes for water and wastewater services. ESCoSA has found that SA Water's prices are higher than other major utilities. Efficiency does not automatically translate into lower prices for consumers. SA Water earns a higher return on its assets than other utilities, which is one of the drivers of its higher prices. This reflects that many other utilities are regulated and have regulated asset bases (RABs) that are heavily discounted against the WDV of their assets.

1 Overview of project

There is a wide range of water utilities in Australia. The majority of water utilities provide water and sewerage services. Australia's urban water sector provide a range of services that include:

- planning, procuring and supplying water of appropriate quality to households and commercial users, with security of supply;
- collecting, treating and disposing or recycling of wastewater (sewage and tradewaste)
- managing drainage and stormwater for flood mitigation, environmental protection, disposal or recycling purposes.[1]

The urban water sector is diverse even though almost all utilities providing drinking water are controlled by state, territory or local governments. The structural, institutional, governance and regulatory arrangements vary between jurisdictions and between metropolitan and regional areas. In 2008–09, there were 32 major urban, 51 non-major urban and 194 minor urban providers of water and wastewater services. Collectively, they had revenues of about $10 billion. The structure of the sector has changed over the past two decades. In metropolitan areas, there has been some vertical separation of the supply chain and corporatisation of utilities. In regional areas, most utilities are vertically integrated. In some jurisdictions, small regional utilities have been aggregated (with some of these corporatised).

Over the past decade many of the water utilities experienced periods of significant drought. This has triggered significant new investments to augment supplies to enhance water security in the regions. These significant investments have also been a driver of further changes in the industry structure. For example, in South East Queensland, a separate authority (the SEQ Water Grid Manager) was established to manage the Water Grid. It purchases storage and treatment of bulk water, and production of desalinated and purified recycled water from Seqwater. It also purchases transportation services for bulk water from LinkWater.[2] In July 2010 Allconnex Water was also formed part of the Queensland Government's South East Queensland Water Reform to ensure water security for the region. AllConnex was an amalgamation of the Gold Coast, Logan and Redland City Council water utilities. In 2011/12 the newly elected Queensland Government has split AllConnex Water into its original three separate utilities.

The extent of private sector involvement in the utilities is also a point of difference between the utilities. SA Water has had a long standing involvement of the private sector, discussed below. The other major metropolitan utilities have also had a longstanding

1 Productivity Commission (2011), *Australia's Urban Water Sector, Inquiry Report*, August.Vol 1, p xvii.

2 http://seqwgm.qld.gov.au/about-us

relationship with the private sector. Melbourne's desalination plant, for example, is being delivered as a PPP project with AquaSure (consisting of Suez Environment, Degremont, Thiess and Macquarie Capital Group). Melbourne Water is charged an ongoing operating fee which is reflected in higher operating costs to urban water retailers. Sydney's desalination plant was also established under a PPP arrangement with Sydney Water, Veolia Water and John Holland.

The different industry structures and the way services are delivered have a bearing on the efficiency analysis and on how these services flow through into costs.

Services provided by SA Water

SA Water is the provider of water and wastewater services for South Australia. Its main function is to provide potable quality water to urban and rural customers in South Australia and to remove and treat sewage to an environmentally acceptable standard. SA Water is responsible for water treatment and wastewater treatment.

SA Water currently provides services to around 500 000 residential customers and 30 000 non-residential customers in Adelaide and to customers in regional areas of South Australia.[3] The majority of customers serviced by SA Water are in Adelaide. Services are also provided to over 200 towns outside of Adelaide.

While SA Water retains ownership of its assets, SA Water contracts out the operation, maintenance and management of the entire Adelaide water supply and wastewater system.[4] In addition, the Victor Harbour Wastewater Treatment Plant is currently operated under a 20 year contract with Trility Pty Ltd[5] and Adelaide's desalination plant will be operated and maintained under a 20 year contract, by AdelaideAqua Pty Ltd. (comprising Acciona Agua Adelaide Pty Ltd and Trility Pty Ltd).[6]

Over the past decade South Australia, like most jurisdictions throughout Australia, has faced water shortages due to drought conditions. Unlike many other jurisdictions, Adelaide is also indirectly impacted by drought conditions in the wider Murray Darling Basin catchment as well, given the reliance of water extraction from the Murray River.

Regulation of SA Water

SA Water's operations are bound by the Water Industry Act 2012. SA Water is also bound by the Public Corporations Act 1993 under which the SA Water Board is charged with the responsibility to 'secure continuing improvements of performance' (section 14)

3 National Water Commission, National Performance Report 2010–11.

4 The AllWater Joint Venture recently successfully tendered for this contract over the next 10 years from 1 July 2011. http://www.sawater.com.au/NR/rdonlyres/C4672F06-DDF7-43A9-97CD-C248187F2BB6/0/MedRelAllwaterAlliance300611.pdf

5 Trility was formerly known as United Utilities Australia. http://trility.com.au/projects/victor-harbor-wastewater-treatment-plant/

6 SA Water (2011), *Adelaide Desalination Plant - Procurement process and documentation - Fact Sheet*, November, p2.

one of the drivers of improved efficiency. There is an array of other operational legislative instruments that directly impact on the manner in which SA Water provides its services.

In regards to economic regulation, SA Water is currently regulated by the South Australian Government. However, in setting prices the South Australian Government is guided by the pricing principles outlined by the National Water Initiative (NWI) and the South Australian Government's commitment to state-wide pricing.[7]

SA Water is currently in the process of transitioning to full economic regulation by an independent regulatory authority. The form of regulation of SA Water is expected to match that of other water utilities in being based on building block regulation. As part of this ESCoSA will be seeking to ensure that the costs passed through to customers in prices represent only the 'efficient' costs of providing services

Efficient costs

Efficiency of costs can be interpreted broadly or narrowly. In a narrow sense, efficiency depends on a firms cost of providing specified services, commonly known as technical efficiency. A firm is considered more technically efficient where it can lower the cost of providing the specified service. In a broader sense, efficiency is also about whether the levels of water quality, security and reliability are provided to an efficient level, at which willingness to pay for marginal service improvements matches the marginal costs of improvement.[8] This is more difficult to assess in a regulated environment.

Determining the efficiency of a regulated business is inherently difficult. The main methods available are:

- reviews of operating and capital expenditure of the regulated business by engineering experts — this can be used to assess technical efficiency. This is the normal approach used by Australian regulators and assesses efficiency given service level constraints that are imposed on a regulated business;
- benefit cost analysis of service levels — this can be used to assess broader economic efficiency that not only encompasses technical efficiency, but includes answers to questions such as whether a major project is estimated to have benefits to customers in excess of costs; and
- benchmarking across similar businesses — this can be undertaken as part of engineering reviews (for instance for unit costs of connecting new customers or wage rates) or separately across the entire business activities.

7 http://sawater.com.au/NR/rdonlyres/9E8738B6-8BCA-44D6-B469-7EF0DC621BFF/0/SettingWaterandSewerPrices.pdf

8 The terms productivity and efficiency are often used interchangeably, however there is a point of difference. Measures of productivity assess the ratio of outputs to inputs without reference to costs or to any optimum attainable ratio, whilst measures of efficiency compare an observation to an optimal value. For example, efficiency measures compare observed values of output and input with optimum values as defined in terms of production possibilities.

This project

This project is focused on the third efficiency approach noted above, the benchmarking across similar businesses. The focus of the benchmarking analysis is only on SA Water's operations in Adelaide rather than across South Australia, reflecting data availability and the approach to be adopted to the regulation of SA Water. We adopt the narrow definition of efficiency, by considering the direct inputs and outputs of SA Water given that there are already a range of service standards that are set by the SA Government as well as national guidelines (eg drinking water standards). Some adjustments are made for quality across utilities and through time, but no attempt is made to assess the value that consumer's place on different levels of water quality or the environmental value of different levels of sewage treatment.

This project builds and extends on the recent urban water utilities benchmarking analysis undertaken by the ESC of Victoria.

This project considers a range of different methods that can be used for a comparative efficiency analysis of urban water utilities. We show analysis of:

- unit costs of providing services;
- productivity measures allowing for multiple inputs and outputs; and
- statistical analysis of efficiency — known as Stochastic Frontier Analysis (SFA).

While formal statistical analysis is typically viewed as providing a more complete measure of efficiency, there are a number of issues and complexities that can be better understood through simpler measures

The focus of this work is very much on updating and extending the ESC's analysis. In particular, the work does not seek to collate additional data that may shed light on the efficiency of the level of water security.

ESCoSA is separately undertaking an 'opex-capex' review to assist in determining SA Water's efficient costs that would be passed on to customers in regulated prices. As part of the opex-capex review separate decisions will be made regarding the 'catchup' and 'ongoing' efficiency adjustments. Specifically, this project will help to inform ESCoSA on the level of any catch-up'effciency targets that should be applied in the final determination on the efficiency level of costs.

Report structure

The report proceeds as follows:

- **chapter 2** sets out the theoretical background to the measurement of efficiency and outlines the key approaches to measuring productivity;
- **chapter 3** discusses issues unique to the urban water sector that need to be considered in an efficiency analysis;
- **chapter 4** discusses the data available to measure efficiency of water utilities and provides unit cost comparisons using this data;
- **chapter 5** considers unit cost measures of efficiency;

- **chapter 6** considers total factor productivity measures of efficiency;
- **chapter 7** undertakes econometric analysis of efficiency of water businesses; and
- **chapter 8** provides comment on SA Water's country operations; and
- **chapter 9** discusses how efficiency findings should be interpreted in a regulatory context.

Acknowledgments

Staff from the ESC of Victoria (Michael Cunningham and Marcus Crudden) have assisted in providing data and spreadsheets from their own analysis. This has been very helpful in allowing us to build on their work and in understanding their approach.

Thanks also to Tom Carpenter of the Institute of Quality Asset Management for his assistance and advice on the comparability of data across water utilities and understanding of the National Water Commission (NWC) benchmarking data.

2 *Efficiency benchmarking analysis*

Comparative benchmarking analysis has been undertaken across the world over several decades for a wide range of industries. In Australia there has been an increased interest in benchmarking urban utilities, including in water. This has increased as confidence grows in the quality of data collected by the NWC and reported in the National Performance Reports (NPR).

There are a range of different possible choices of techniques for measuring and benchmarking efficiency. This chapter broadly outlines the theoretical background to efficiency analysis, discusses the advantages and disadvantages of the different techniques and the preferred technique (the Stochastic Frontier Analysis, SFA) which forms the basis for the analysis in subsequent chapters.

Defining efficiency

Efficiency measures can be input-orientated or output-orientated. *Input-orientated* measures compared the observed input to the minimum potential input required to produce a given quantity of output. Input-orientated inefficiency is then represented by the quantity of inputs used in excess of the minimum required input quantity. *Output-orientated* measures compare the observed output to the maximum potential output obtained from a given quantity of inputs. [9] The difference between the observed output and the maximum potential output represents the output-orientated inefficiency.

The overall efficiency of a producer can be measured in terms of its *economic efficiency* which is a combination of its technical, productive and allocative efficiency. A producer is:

- **technically efficient** (i) if inputs are used in the most technologically efficient manner to produce the maximum quantity of outputs given that set of inputs or (ii) if the producer is able to minimise input use, given technology, to produce the required output;
- **productively efficient** if the bundle of inputs used to produce a given output are a cost minimising (optimal) combination given their respective input prices and given the available production technology; and
- **allocatively efficient if it is producing the quantity of output that is desired by society.**[10]

9 Fried, H. O., Lovell, C. A. K., and Schmidt, S. S. 2008. *Efficiency and Productivity* in Fried, H. O., Lovell, C. A. K., and Schmidt, S. S. (eds.) *The Measurement of Productive Efficiency and Productivity.* New York: Oxford University Press.

10 http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1115526/

A firm which is both technically and productively efficient is said to be economically efficient. If a firm is technically efficient but productively inefficient (or vice versa) then the firm is not producing the output at the least cost .[11] Box 2.1 provides an illustration of the difference between technical and productive efficiency.

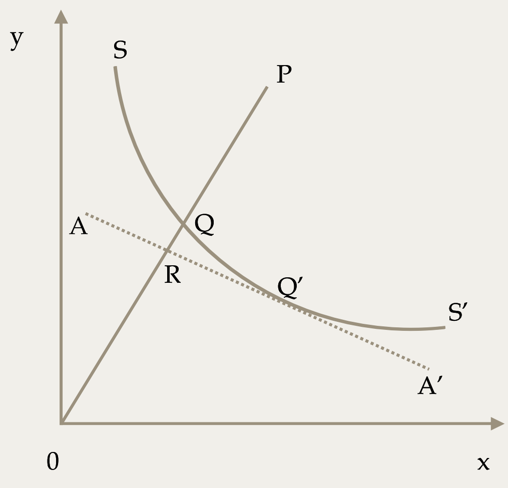
2.1 Technical and productive efficiency[12]

Technical and productive inefficiency can be demonstrated in the simple case of two inputs (x,y) used to produce a single output. The various combinations of the two inputs that an efficient firm might use to produce a given level of output are represented by the isoquant *SS'.* An isoquant represents the lower bound of the set of various combinations of inputs which, given technology, can produce the same quantity of output.

Point Q represents a technically efficient firm using a combination of the two inputs that is on the isoquant. Point P represents a technically (and, as explained, productively) inefficient firm which is using the same *ratio* of inputs as firm Q. Firms like P however are either:

- using inputs greater than Q to produce a given level of output (input-orientated); or
- producing less output than Q using the same quantity of inputs (output-orientated).

The technical efficiency of firm P is estimated with the ratio OQ/OP. When a firm like P produces the same level of output using the same quantities of inputs as firm Q, then OQ/OP = 1 and firm P is a technically efficient firm. However as the quantity of inputs required by firm P to produce a unit of output increase, P moves further away from Q and technical efficiency of P, OQ/OP decreases.



Both firms Q and Q' are technically efficient because they produce on the same isoquant. But only firm Q' is *productively* efficient because it takes into account input prices. This is identified by firm Q' lying on AA' which has a slope equal to the ratio of the prices of the two inputs, x and y. The costs of production at Q' are lower than Q by a fraction OR/OQ of Q.

In this simple case, firm Q' is technically and productively efficient.

11 Fried, H. O., Lovell, C. A. K., and Schmidt, S. S. 2008. *Efficiency and Productivity* in Fried, H. O., Lovell, C. A. K., and Schmidt, S. S. (eds.) *The Measurement of Productive Efficiency and Productivity.* New York: Oxford University Press.

12 Material for this sourced from Farrell, M. J., 1957, *The Measurement of Productive Efficiency*. Journal of the Royal Statistical Society. Series A (General), Vol. 120, No. 3. pp.253-290.

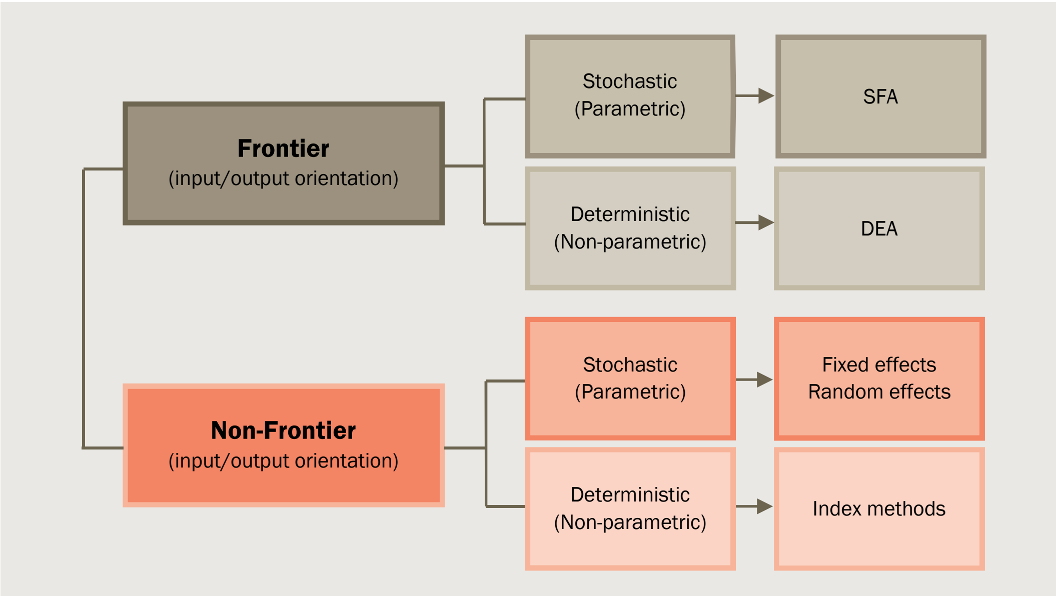
The context and the availability of data will influence which approach is used and which types of efficiency (technical, productive and allocative) can be measured. Technical and productive efficiency are most commonly used for comparative efficiency of water utilities given that output prices are typically regulated and output standards are also pre-specified by health and environmental regulators.

The two common sets of data in efficiency analysis are *cross-section data* and *panel data*. Cross-section data includes observations for multiple firms in one time period, whilst panel data includes observations for multiple firms over multiple time periods. Observing each firm over multiple periods increases the ability to achieve 'better' estimates of efficiency than can be obtained from a single cross section.[13]

Technical efficiency, but not productive efficiency, can be estimated when only quantity data is available. However when both quantity and input price data are available then technical and productive efficiency can be measured.[14]

Efficiency measurement approaches can be distinguished by whether they are the so-called 'frontier' or 'non-frontier' approaches and whether they are stochastic or deterministic (chart 2.2).

2.2 Overview of different methods for measuring efficiency



Data source: The CIE

13 Fried, H. O., Lovell, C. A. K., and Schmidt, S. S. 2008. *Efficiency and Productivity* in Fried, H. O., Lovell, C. A. K., and Schmidt, S. S. (eds.) *The Measurement of Productive Efficiency and Productivity*. New York: Oxford University Press.

14 Fried, H. O., Lovell, C. A. K., and Schmidt, S. S. 2008. *Efficiency and Productivity* in Fried, H. O., Lovell, C. A. K., and Schmidt, S. S. (eds.) *The Measurement of Productive Efficiency and Productivity*. New York: Oxford University Press.

Frontier approaches

Frontier efficiency approaches seek to construct the production frontier of the fully efficient firm and is measured using production data from a sample of firms.[15] The efficiency of a specific firm is measured relative to the constructed efficient frontier.

Frontier efficiency approaches can either estimate a *stochastic frontier* (eg SFA) or a *deterministic frontier* (eg Data Envelopment Analysis, DEA). Both stochastic and deterministic approaches estimate the frontier by completely enveloping the sample data such that no observation lies outside the frontier.[16] The efficiency of each firm is measured relative to the constructed envelope or frontier.

The key difference between a stochastic frontier approach and a deterministic frontier approach is the technique used to construct the frontier:

- in the **deterministic approach** the frontier is estimated using *non-parametric* techniques. Non-parametric techniques do not specify a particular shape of the frontier. That is, they do not specify a general relationship (equation) relating output and input.
- In the **stochastic approach** the frontier is estimated by pre-specifying the functional form of the relationship between the outputs and inputs, commonly referred to as *parametric* techniques. SFA is an econometric approach which focuses on the 'residuals' of the regression analysis. The residuals detail how far firms lie from the theoretical production frontier in frontier approaches[17]

The different method for constructing the frontier results in different accommodations for random noise and flexibility in the production function.[18] This difference can be clearly seen in the shape of the hypothetical frontiers developed by both methods (chart 2.3). Both show frontiers that might be constructed from the input and output data of the same sample of firms, represented by the scatter of dot points. The piece-wise linear convex frontier of the non-parametric approach contrasts with the smooth convex production function constructed using parametric techniques in the econometric approaches. In addition the non-parametric approach envelopes the sample data much more tightly than the econometric approach.

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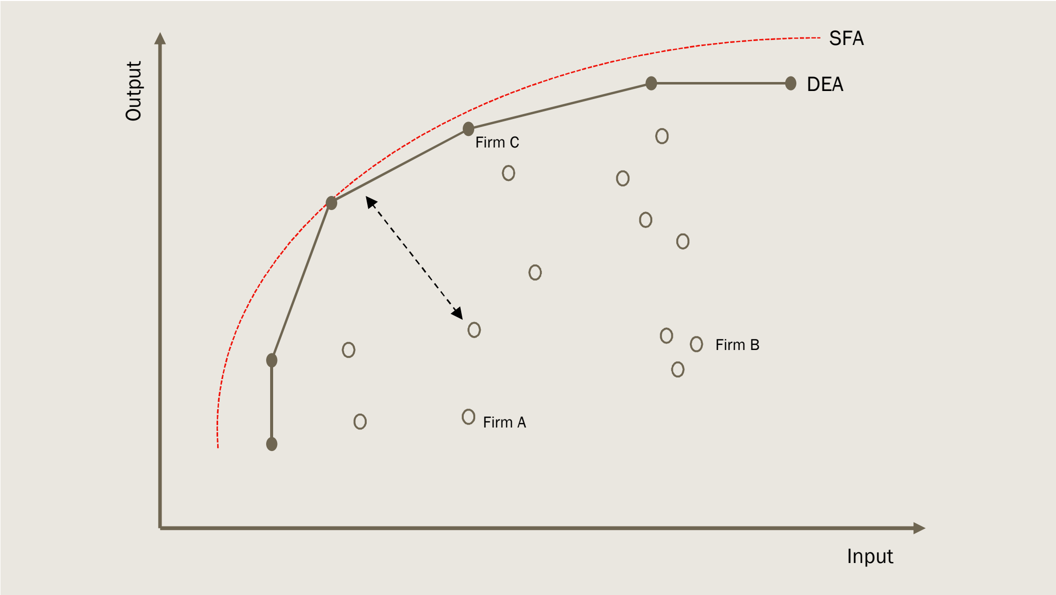
15 Worthingon, A., 2004. *Frontier efficiency measurement in healthcare: a review of empirical techniques and selected applications*. Author's version of a paper later published in *Medical Care Research and Review 61 (2):pp. 1-36.*

16 Worthingon, A., 2004. *Frontier efficiency measurement in healthcare: a review of empirical techniques and selected applications*. Author's version of a paper later published in *Medical Care Research and Review 61 (2):pp. 1-36.*

17 Greene, W., 2007. *Chapter 2: The econometric approach to efficiency analysis* in *The Measurement of Productive Efficiency and Productivity Growth*.

18 Worthingon, A., 2004. *Frontier efficiency measurement in healthcare: a review of empirical techniques and selected applications*. Author's version of a paper later published in *Medical Care Research and Review 61 (2):pp. 1-36.*

2.3 Construction of hypothetical production frontier under two approaches



Data source: Worthington, A., 2004. *Frontier efficiency measurement in healthcare: a review of empirical techniques and selected applications*. Author's version of a paper later published in *Medical Care Research and Review 61 (2):pp. 1-36.*

The frontiers estimated will also depend on the sample of firms used in the analysis. The extent to which the sample changes could also potentially change the shape and position of the frontier.

From a practitioner's perspective, non-parametric techniques are often appealing because they are simpler and require fewer assumptions to be made regarding the relationship between inputs and outputs.

The primary disadvantage of the non-parametric approach is that all deviations from the frontier are attributed to inefficiency.[19] Statistical noise and measurement error in the model are absorbed in the inefficiency effect and therefore outliers or anomalies in the data can exaggerate inefficiency estimates in this approach. As a result of these limitations, DEA is being applied less in recent efficiency analysis literature[20] because of this limitation and the lack of naturally produced standards errors on the coefficients required for statistical inference. [21]

19 Coelli, T., Rao, D. S. P, and Battese, G. E. 1998. *An Introduction to Efficiency and Productivity Analysis*. Published by Springer, 1998.

20 Fried, H. O., Lovell, C. A. K., and Schmidt, S. S. 2008. *Efficiency and Productivity* in Fried, H. O., Lovell, C. A. K., and Schmidt, S. S. (eds.) *The Measurement of Productive Efficiency and Productivity*. New York: Oxford University Press.

21 Fried, H. O., Lovell, C. A. K., and Schmidt, S. S. 2008. *Efficiency and Productivity* in Fried, H. O., Lovell, C. A. K., and Schmidt, S. S. (eds.) *The Measurement of Productive Efficiency and Productivity*. New York: Oxford University Press.

Non-frontier approaches

Non-frontier approaches seek to provide a ranking of the efficiency of a firm relative to other firms in the sample. That is, they allow a ranking of firms according to their relative efficiency. However, they do not provide guidance on how much further a firm that may be relatively efficient could improve. Non-frontier approaches can also be classified as stochastic and deterministic.

Index approaches

Index methods are both deterministic and non-frontier and generally used as a measure of productivity rather than efficiency. These methods are deterministic because random noise and statistical error are not taken into account.

In the simplest case of one input and one output, productivity is measured as the ratio of output over input. Extending to the general case of multiple inputs and multiple outputs, the measure of total factor productivity is the ratio of an output index and an input index. Each index is generally estimated as a weighted sum of all outputs or inputs, respectively. Price data is usually required to estimate both the input and output index, where cost shares are used in the input index and revenue shares are used in the output index. The index number formula most commonly used in TFP calculations is the Törnqvist index.[22]

$$TFP = \frac{output\ index}{input\ index}$$

The primary advantage of TFP index approaches is the limited data required for analysis. For instance only two data points are required in the simplest case for TFP index methods whilst frontier methods require data on a large number of firms. The disadvantage of TFP index approaches is that they cannot be broken down into the various contributors of TFP growth. Frontier efficiency approaches are required for this task.

Fixed and random-effects models

Non-frontier stochastic approaches include random- and fixed-effects models which compare technical efficiency relative to an estimated average production function. These models are similar to SFA in many respects. The difference is that the shape of the estimated production (or cost) function will be matched more closely to *average firms*' performances rather than seeking to match a frontier, because firms can display positive or negative errors (or constants in the case of the fixed effects model) relative to the fitted production function.

The general form of the fixed and random-effects models have two key disadvantages that are of importance for efficiency analysis:

22 Coelli, T., Estache, A., Perelman, S., Trujillo, L. 2003. *A Primer for Efficiency Measurement for Utilities and Transport Regulators.* The World Bank, Washington, D.C.

- Time-invariance— both models assumed inefficiency is time invariant, meaning that each individual firm's deviation from its efficiency frontier is independent of which time period is observed. This assumption is particularly difficult to maintain in a long panel sample.23 Greene (2008) found that inefficiency estimates were generally robust to distributional assumptions, to the choice between fixed or random effects and to methodology. They were, however, quite sensitive to the assumption of time invariance.24
- Misidentified inefficiency—both models capture differences across firms that do not change through time in the firm specific inefficiency term. These differences will be absorbed into the inefficiency term, even when they are unrelated to inefficiency. It is not possible to distinguish whether the inefficiency estimate represents technical/cost inefficiency alone, other factors unrelated to efficiency, or a mixture of both.25 Random effects models and SFA allow for the inclusion of known differences that are unrelated to efficiency, while fixed effects does not.

Choice of approach for this project

We use unit cost measures, productivity measures and SFA in this project. Each has advantages in what it can communicate. SFA has advantages over alternative deterministic techniques, such as DEA, because its parametric form enables statistical inference and the estimation of random errors separate from inefficiency effects. This is particularly important in the context of urban water utilities where different operating environments (rather than relative efficiency differences) are commonly argued to be a key explanator of the differences in a firm's performance. This approach is also one of the approaches used by utility benchmarking undertaken by the ESC of Victoria.[26]

However, because we find that the results from SFA are not always well aligned to an understanding of the cost structure of the water industry, we also consider alternatives, such as productivity measures. We actually find these to be more informative than SFA in understanding the relative performance of SA Water.

Other aspects of our proposed SFA approach are discussed below.

Efficiency measurement of multiple outputs

Efficiency analyses (other than index number applications) have traditionally estimated the production or cost frontiers across a sample of firms producing a single output. However, neither form is particularly useful in the case of multiple outputs.

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23 Greene, W., 2002. *Fixed and Random Effects in Stochastic Frontier Models.* http://pages.stern.nyu.edu/~wgreene/publications.htm

24 Greene, W., 2007. *Chapter 2: The econometric approach to efficiency analysis* in *The Measurement of Productive Efficiency and Productivity Growth*.

25 Greene, W., 2002. *Fixed and Random Effects in Stochastic Frontier Models.*

26 Cunningham, M. 2010, *An analysis of the productivity of the Victorian water industry,* Essential Services Commission of Victoria Staff Research Paper, No. 2012/1, March.

Common methods of measurement in the multiple output case include aggregating outputs into a single output index or estimating the cost function instead of the production function. Greene et al. (1996) note limitations with both methods; the first requiring output prices to be observable and the second requiring an assumption of cost-minimising behaviour. An alternative method to measure efficiency in the case of multiple outputs is to estimate a *distance function*.[27]

Distance functions are particularly appropriate in efficiency analysis of regulated industries where multiple outputs are produced and the assumption of cost minimisation may be violated.[28]

Distance functions are a generalisation of the production or cost function and can take an input- or output- orientation. [29] The choice between input- or output-orientation is dependent on the nature of the inputs and outputs. For example, an input distance function is generally used when the inputs are endogenous (matters of choice for the utility) and the outputs are exogenous (set as a licence or other obligation), such as the case for water utilities. The concept of a distance function is most easily illustrated in the simple case of a single output and a single input. For each given level of input, the possible production of output is illustrated by the production possibilities curve (chart 2.4). The output distance function is estimated as the distance each production point lies below the production possibilities curve. For the point A, the output distance function is equal to the distance DA/DB. The input distance function is a measure of the proportional reduction in inputs required, for a given level of output, to lie on the input-orientated production possibilities curve. For point A, the input distance function is equal to the distance FA/FE.[30] These distance measure concepts are readily generalisable to the case of multiple inputs and outputs.

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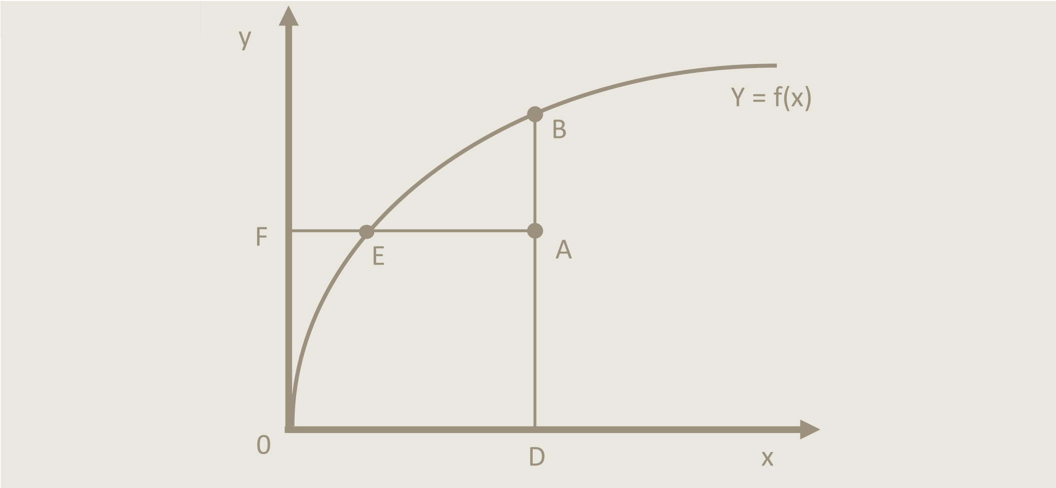
27 Coelli and Perelman, 1996. *Efficiency measurement, multiple-output technologies and distance functions: with application to European Railways: Draft.* http://orbi.ulg.ac.be/bitstream/2268/35665/1/105.%20CREPP%209605%20Coelli-Perelman.pdf

28 Coelli, T., Estache, A., Perelman, S., Trujillo, L. 2003. *A Primer for Efficiency Measurement for Utilities and Transport Regulators.* The World Bank, Washington, D.C.

29 Coelli, T., Estache, A., Perelman, S., Trujillo, L. 2003. *A Primer for Efficiency Measurement for Utilities and Transport Regulators.* The World Bank, Washington, D.C.

30 Coelli and Perelman, 1996. *Efficiency measurement, multiple-output technologies and distance functions: with application to European Railways: Draft.* http://orbi.ulg.ac.be/bitstream/2268/35665/1/105.%20CREPP%209605%20Coelli-Perelman.pdf

2.4 Distance functions in simple one input, one output case



Data source: Coelli and Perelman, 1996. *Efficiency measurement, multiple-output technologies and distance functions: with application to European Railways: Draft.*

In our analysis SFA has been used to estimate the *input-orientated distance function* to estimate inefficiency. This is the same approach taken by the ESC of Victoria in their recent benchmarking analysis of urban water utilities.[31]

Functional form of the efficiency frontier

The functional form used for the distance function is an important decision for SFA. The chosen functional form can impose restrictions on aspects of the production technology such as factor substitution, economies of scale or input demand elasticities.[32]

The appropriate specification of the functional form of the production function is important to avoid specification errors which can cause systematic errors in the measurement of efficiency.[33]

The two most common functional forms applied in econometric approaches of efficiency analysis are the Cobb-Douglas and translog models, each has its advantages and disadvantages for efficiency analysis. The Cobb-Douglas is a relatively straightforward and convenient functional form which is partly why it remains a popular choice. However the Cobb-Douglas can be too restrictive for some contexts because of the assumptions that all firms have the same production elasticities, same scale elasticities, and unitary elasticities of substitution.[34]

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31 Cunningham, M. 2010, *An analysis of the productivity of the Victorian water industry,* Essential Services Commission of Victoria Staff Research Paper, No. 2012/1, March.

32 Greene, W., 2007. *Chapter 2: The econometric approach to efficiency analysis* in *The Measurement of Productive Efficiency and Productivity Growth*. page. 172

33 Greene, W., 2007. *Chapter 2: The econometric approach to efficiency analysis* in *The Measurement of Productive Efficiency and Productivity Growth*. page. 172

34 Coelli, T., Estache, A., Perelman, S., Trujillo, L. 2003. *A Primer for Efficiency Measurement for Utilities and Transport Regulators.* The World Bank, Washington, D.C.

A more flexible functional form that is commonly used is the translog functional form.[35] The translog is slightly more difficult to estimate and interpret than the Cobb-Douglas, but is generally the preferred functional form because it does not impose the restrictions on production of the Cobb-Douglas functional form.[36]

For the purposes of our analysis we test both the Cobb-Douglas and translog functional forms. Although, as discussed later, the Cobb-Douglas form produces more reasonable estimates of input and output elasticities. It is, therefore, the preferred functional form for the analysis.

35 See Appendix.. for the general form of a translog stochastic production frontier.

36 Coelli, T., Estache, A., Perelman, S., Trujillo, L. 2003. *A Primer for Efficiency Measurement for Utilities and Transport Regulators.* The World Bank, Washington, D.C.

3 Measuring efficiency for Australian water utilities

There is a range of conceptual issues that need to be considered when measuring efficiency in the Australian water industry. This chapter discusses a number of these issues including:

- whether the efficiency frontier for different utilities differs because of the size of the utility or the characteristics of the area that it serves (such as weather, topography, urban density);
- trade-offs between operating and capital expenditure and implications for understanding the time involved in achieving efficiency gains;
- the reliability of measures of capital value and the implication of sunk capital costs for potential efficiency change;
- the ability of efficiency assessment to consider the potential for lagged relationship between inputs and outputs and/or unobserved outputs, such as water security; and
- the appropriate benchmarks from efficiency analysis for application by a regulator. That is, should the standard be the best utility, the average utility or something in between?

Efficiency frontiers across different water utilities

Standard efficiency analysis measures a production or cost frontier that is assumed to be largely the same for all businesses. In its simplest form, possibilities for economies (or diseconomies) of scale are allowed for through a flexible form of the production or cost function. However, the possibility exists that the frontier is actually different across firms for reason such as the rainfall conditions, topography or urban density.

As the Productivity Commission (2011)[37] noted the costs of providing water are influenced by factors such as:

- the nature of primary sources — affects the costs of extracting water;
- geography and topography — influences transportation costs. Pumping water longer distances, or up hills, will increase costs;
- health and environmental requirements — more stringent requirements might result in higher treatment costs;
- degree of treatment — treatment to a higher standard is more expensive;
- number of connections/growth in connections — a higher number of connections will generally increase immediate costs; and

37 Productivity Commission (2011), *Australia's Urban Water Sector,* Inquiry Report, No. 55, Volume 1, p16.

- asset life cycles — more recently constructed assets such as distribution systems might be cheaper to maintain than older assets.

The costs are also influenced by factors such as the density of connections, arising from different land use patterns.

Reflecting these differences, a common argument against comparative efficiency analysis is that there are many factors outside a utility's control that impact on the quantum of costs or differences in the quality of services delivered.

Where these factors can be identified and measured across the sample of businesses then they can be allowed for in analysis. Accounting for all possible influences is, however, impractical.

For this study, we seek to account for these different influences where possible. This includes:

- measuring efficiency over a period from 1998–2011 where data permits;
- allowing for the share of groundwater as an influence on costs;
- allowing for economies of scope through including a variable for the proportion of total connected properties with sewerage services; and
- testing whether a measure of density (properties connected per kilometre of mains) changes the results.

Measuring costs of providing services

The provision of water and wastewater services requires significant capital and significant operating expenses. In most utilities, returns on and of capital and operating costs are roughly equal. Utilities can make trade-offs between how much they spend on capital and how much they spend on operating expenses. (For instance, higher quality pipes could be used to limit the need for ongoing maintenance.) Trade-offs can also occur through the way that contracts are structured between utilities and providers of bulk water or other contracted services. For example, capital related to bulk water is an operating expense for utilities such as Sydney Water and Melbourne's water retailers, because they purchase bulk water from respectively the Sydney Catchment Authority/Sydney Desalination Plant and Melbourne Water. However, for other utilities, such as SA Water, this capital is in its own capital base.

The concept the whole-of-life and life-cycle costing is the fundamental principle of asset management for urban water utilities.[38] Given this, where utilities are adopting asset management life-cycle costing principles in their strategic planning, it is the total cost of service delivery over a time period that it relevant. In this context the optimisation of the whole of life cost of delivering the service is likely to involve utilities taking account of the opex-capex mix in their investment decisions.

The ability to trade-off (and optimise) capital and operating costs and the influence of corporate structures on how these costs are allocated indicates that efficiency analysis

38 ISO 55000 standard (2012), *Asset management — Overview, principles and terminology,* draft

needs to include both operating costs and capital costs. Analysis that focused on only one measure may not provide good guidance.

Unfortunately, from a regulator's perspective, there are differences in implied efficiency gains depending on whether inefficiency is in operating costs or in capital costs. This is because capital costs are sunk. Hence, while inefficiency may not be passed through in prices to customers, it is not possible to quickly incentivise greater efficiency. The analysis presented in this report does not allow a regulator to make a distinction between whether efficiency is from operating costs or a sunk capital base.

- **Efficiency analysis of water utilities should include measures of capital costs and measures of operating costs**

Capital services

The amount of capital used to provide services is an important component of efficiency for water and wastewater businesses. Past analysis of efficiency of Australian water utilities found that capital formed the dominant part of the cost drivers for water utilities, accounting for 80 per cent of the costs of providing water for Australian water utilities in his sample.[39]

Capital services are difficult to measure and are lumpy. Accounting measures, such as the written down value (WDV), are subject to substantial revaluations that, if used in efficiency analysis, imply substantial changes in efficiency. These are in evidence over the history of the collection of this information through the NWC, with significant revaluations of the value of capital already spent. Even adding an extra year of data to that used by the efficiency analysis of Cunningham (2012) substantially changed the capital value of many utilities. For example:

- the combined WDV for Gosford City Council's water and sewerage assets roughly doubled from $0.94 billion in 2010 to $1.86 billion in 2011; and
- The combined WDV for Barwon Water's water and sewerage assets increased from $1.17 billion in 2010 to $1.86 billion in 2011;

These changes partly reflect capital expenditure but mainly a change in valuation of existing assets. Similar substantial changes are observed across many utilities in previous years.

Capital expenditure can be lumpy, leading to capital profiles that go up and down without any necessary efficiency implications. For example, when a utility undertakes a major capital project its capital base will rise. Over subsequent years its capital base will then fall. This is due to capital expenditure being triggered by the need to expand the capacity of the system, but the size of the expansion reflecting expected future growth and needs and optimal efficiency tied to staging and technical constraints.

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39 Cunningham, M. 2012, *An analysis of the productivity of the Victorian water industry,* Essential Services Commission of Victoria Staff Research Paper, No. 2012/1, March.

Reflecting these issues, previous analysis by Cunningham (2012) used a capital stock measure based on the most recent WDV[40] (in 2010 for their analysis) and back calculated the value of the asset in prior years by adjusting for actual capital spend and for depreciation. The key benefit of this measure is that it avoids the issue of changes in WDV over time due to factors unrelated to a utilities' investment profile. The ESC's study also uses an alternative measure of physical capital which includes measure of the length of pipes amongst other physical parameters.

For this study, we take an alternative approach that focuses more attention on recent capital expenditures rather than relying on a recent WDV. This reflects the view that for this project, it is of more concern whether utilities have had inefficient capital expenditure — the efficiency or not of the underlying water and wastewater pipe network is of less concern for the future. The approach used is to:

- estimate the average WDV per property in 1998 (for water and sewerage and adjusted to 2009/10 dollars) and apply this as a constant across all utilities for which data begins in 1998;
- for utilities whose data begins later, begin the capital base at the average per property capital base of utilities for which there is data;
- add capital expenditure for each year; and
- subtract depreciation at a rate of 2 per cent per year, as used by Cunningham (2012).

This means that it is variations in capital expenditure (over the period for which we have utility data) that determines variations in the capital stock.

We test alternative specifications using the length of mains instead of this measure as a proxy for the capital base. We do not use both measures together as they are seeking to measure the same economic concept.

Issues arising from the lumpiness of the capital base are implicitly incorporated into the analysis and dealt with through the use of a time period covering (at most) 13 years and through the use of the capital base rather than the annual capital expenditure in the year incurred. This smooths capital expenditure over this period, and, consequently, estimates of efficiency do not move much between years. Even this length of time may be too short in the context of capital expenditure patterns in the water sector.

- **Capital services should be measured through the stock of capital.**
- **Efficiency analysis needs to test the robustness of alternative capital measures, given the uncertainty around measuring this important input.**

Lagged relationships and unobserved outputs in water utilities

In urban water sector, there may be a lag between the timing of expenditure and the output achieved. That is, the expenditure incurred by a utility in a given year may not be reflected in service performance for a number of years.

40 WDV is also called book value or net book value.

In the context of utility regulation, this issue has been a topic of discussion for some years, particularly in relation to expenditure on infrastructure assets. These discussions relate to concerns that expenditure reductions by utilities may not be true efficiency gains, being accompanied by reductions in service standards (which may not be observed for many years).[41]

The provision of water is also about risk. Water may be able to be provided more cheaply but with greater risk that there will be periods when demand cannot be met and restrictions are required or when water security (assurance that supplies will not run out) is compromised. The risk around water outcomes may reflect particular weather conditions, such as drought. Outcomes from expenditure to manage risk or to improve water security may not be reflected in measured data over a short time period or even at all if rainfall is favourable. Implied water security and reliability can be derived from hydrological models. However, there is not a consistent approach across jurisdictions that could be used within the scope of this project.

The inability to observe some part of the water supply service, such as security, is important in the context of SA Water and many of Australia's other urban water providers in recent years. There has been considerable expenditure on desalination plants, recycling schemes, dam augmentations and water loss reduction programs mainly to improve water security during drought.

- **Longer term measures of efficiency may be more useful for the urban water industry, given lags between inputs and outputs**
- **There is a need to consider the efficiency of utilities with costs related to recent water security investments removed**

The appropriate benchmarks for efficiency

Efficiency analysis is conducted through comparison of a utility to a production or cost frontier measured with reference to all utilities in the sample. In most cases, no utility is actually at the estimated frontier, with each differing according to its degree of inefficiency.

For a regulator, two issues are important in considering the outputs from efficiency analysis.

- What is the appropriate benchmark within the sample of utilities considered for efficiency?
- Is it likely that the set of utilities in the sample provide a good guide to the production or cost frontier?

It would seem too steep a benchmark to consider that a utility should be on the frontier, as almost all utilities would fail this requirement. Reflecting this, we show benchmarks of

41 OFWAT, for example, now monitors the concept of asset 'serviceability' which is the capability of a system of assets to deliver a reference level of service to customers and to the environment now and into the future". See http://www.ofwat.gov.uk/regulating/reporting/ltr_rd1506_assessservicbilty

the *degree of inefficiency* of SA Water, showing how it compares to *average* inefficiency and how it compares to the top 25 per cent of utilities.

As noted in chapter 2, frontier analysis forms a frontier only around the businesses that are in the sample. In Australia, urban water utilities are all government owned. In addition, many of the major utilities are governed by similar regulatory arrangements that may drive inefficient capital investment patterns. This may imply a narrower view of efficiency in that the analysis considers the degree of inefficiency amongst government owned businesses. It is possible that the frontier estimated from this is not the frontier of privately owned and/or operated businesses. This cannot be tested with the data that we have and we do not explore this issue further.[42]

- **SA Water should be compared to average inefficiency and the 25th percentile (upper quartile) of most efficient utilities, as well as showing its estimated level of inefficiency — its distance from the frontier.**

42 Evidence on the performance of government owned versus privatised water utilities in other countries is mixed. For example, Saal and Parker 2001 found that while there was a substantial reduction in labour used in UK water utilities post privatisation, there was also an increase in capital. This analysis faced the difficulty that the regulatory arrangement and ownership changed at the same time. Saal, D. and D. Parker (2001). “Productivity and Price Performance in the Privatized Water and Sewerage Companies of England and Wales”. *Journal of Regulatory Economics*: 20(1): 61-90.

4 Data for this project

This chapter discusses the key data sources used for the analysis and identifies caveats with the data. The chapter also discusses the key input and output measures and adjustments to these indicators. Finally we report the summary statistics of the data that will form the basis of analysis in later sections.

Data for this project

The focus of this analysis is on comparing the productivity and efficiency of water retail and distribution utilities only. It does not include bulk water suppliers such as Melbourne Water and the Sydney Catchment Authority. The costs of the bulk suppliers, however, do flow-through to the productivity measures of the retail/distribution utilities and, in this sense, have an indirect impact on productivity.

National Performance Reports

The data used in this study is based on published data by the NWC in their most recent 2010/11 NPR. The NPR dataset developed provides the most comprehensive and robust dataset of performance indicators for Australian urban water utilities currently available. The most recent NPR dataset only extends back to 2006/2007.

We have also utilised the dataset prepared by the ESC of Victoria in their recent benchmarking study of urban water utilities. This data extends back to 1997/98 for larger water utilities. The ESC's dataset was based on data from earlier NPR reports and published data by the Water Services Association of Australia (WSAA). Other information was also obtained directly from water utilities, city councils and other agencies, particularly for drinking water quality, bulk water purchases and water restrictions. We have collected separate information to extend the time series for these indicators to 2010/11.

Sample of utilities

The selection of utilities used in the analysis was in large part influenced by the availability of data. There are 54 utilities included in the sample, all of which have both water supply and sewage collection functions. The utilities cover a range of regional and larger metropolitan areas.

For larger utilities the data series typically extends from 1997-98 to 2010/11, while for smaller utilities data was available for 2005-06 to 2010/11. Not all the 54 utilities in the sample reported data to the NWC for the 2010/11 year. The water utilities in South East Queensland (Brisbane Water, Gold Coast Water, Ipswich Water and Logan Water), for example, did not report recent data due to the recent restructuring of the industry. A number of other utilities also did not report information for 2010/11. The resulting dataset is an unbalanced panel of 463 observations, with on average 8.6 years of data per utility.

Within the sample of 54 utilities, there are 11 major urban utilities of a scale (greater than 100 000 customers) that makes them directly comparable to SA Water.

Time period for analysis

As noted above, capital expenditure is typically lumpy. Operating expenditure is also not always smooth (see appendix C) and, therefore, the results of the efficiency analysis could be distorted by the selection of the time period. For the purposes of the base model we have utilised the 'full' dataset which extends from 1997/98 to 2010/11 for the large metropolitan utilities. However, as part of the sensitivity analysis we also test a shorter period to align with the 2010/11 NPR from 2005/06 to 2010/11.

Caveats with the data

While the NPR dataset developed provides the most comprehensive dataset currently available it is important to recognise the potential limitations of the data.

- Quality of data reported. The data are reported by the individual utilities and is, therefore, reliant on the robustness of each of the utilities reporting. The National Water Commission has introduced rolling 3 year audits of the data which is expected to enhance the robustness of the data. Nevertheless some anomalies are likely to exist, particularly in earlier years. Where identified, we have 'corrected' anomalies.
- Changes in definitions of particular indicators. In some utilities, there have been changes in the methodology for reporting information. This is evident in some 'stepped' changes in the time series reported for some indicators, particularly for WDV. For example, there are substantial changes in indicators such as the WDV for ACTEW and South East Water and the length of water mains for ACTEW and Gold Coast Water (see Appendix C), as well as previously mentioned changes for utilities WDV in 2010/11 versus 2009/10.[43] It is also possible that there are some minor differences in definition between the NPR and the earlier WSAA datasets.
- As noted there is a range of additional indicators collected beyond the NPR and WSAA data. Information for water restrictions, for example, was collected from a range of different sources. In some years, there were changes to the level of restrictions during the year. In this instance we report the level of restrictions that was in place for the largest part of the year.
- There were some gaps in the data reported. Where these gaps could not be filled through other sources the data set was extrapolated using, for example, an average of information for other years reported by the utilities.

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43 In the case of Gold Coast Water this may reflect the boundary issues between the other water utilities in the surrounding areas.

Data for outputs

As noted earlier the urban water utilities selected for our analysis provide multiple outputs. The outputs for a water utility are a safe, secure supply of water and safe removal and treatment/disposal of effluent. Recycled water has also increasingly formed part of the range of outputs delivered by the utility. Output measures could include quantity and quality measures.

Water utilities can be characterised as responding to demand, given that they are required to service a particular area. Hence they are likely to be able to have only small impacts on the number of properties supplied and the amount of water supplied.[44] Their outputs are also typically regulated in terms of quality, such as standards for drinking water and standards for recycled water.[45]

Despite not necessarily being able to control the level of output, different utilities do meet different output levels. Hence it is necessary to have measures of the quality of outputs achieved by different utilities. The NWC dataset includes output measures such as:

- number of properties connected
- amount of water provided and sewage collected
- treatment standards for sewage
- quality of water (health and aesthetic qualities), and
- interruptions to water availability.

The data does not cover water pressure or security of supply (such as for drought). The latter is an important issue as many utilities, SA Water amongst them, have incurred substantial expenditures to buy insurance against running out of water by investing primarily in large supply augmentation projects and water recycling.

Selected output measures

For the purposes our analysis, we have selected three output measures:

- number of customers supplied;
- volume of water supplied to customers (excluding water losses) – adjusted for both drinking water quality and normalised for the effects of water restrictions; and
- volume of sewage treated – adjusted for quality (for sewage treatment levels).

Adjustments for water restrictions

Temporary water restrictions have an impact on productivity because they arise from factors that are unexpected and only arise for a short period. Hence reduced output due to temporary restrictions may not be considered (at least in a short-term framework) as implying reduced efficiency. The volume of water consumed by customers has therefore

44 Utilities are often incentivised to reduce their short term outputs through reduced water consumption, such as through water restrictions.

45 Australian Drinking Water Guidelines 2011, Australian Recycled Water Guidelines 2006.

been normalised to remove the effects of temporary water restrictions.[46] We have adopted the same approach as that used in the Cunningham (2012), which makes the following assumptions:[47]

- the impact of water restrictions is a linear function of the water restrictions stage;
- water restrictions only impact on proportion of customer water use – assumed to be 25 per cent of residential water use and 13.5 per cent of commercial water use; and
- at the maximum stage of restrictions the full impact is to reduce impacted water use to zero.

While these assumptions present a pragmatic approach given the data availability, there are likely to be differences across utilities. For example, for Sydney the impact of water restrictions is not linear across the levels of restrictions.[48] Further, Sydney Water has previously estimated that outdoor use for single dwelling residential properties is 38 per cent of total use and 32 per cent for multiple dwelling properties.[49]

There are also questions around the extent to which consumption would 'bounce-back' to pre-restriction levels, after restrictions have been removed– effects that are not accounted for in our assumptions. This reflects changes in consumer behaviour but also consumer investments in water-efficiency measures that could reduce consumption and the imposition of government legislation and product standards that can result in permanent changes in consumption.

Finally, water restrictions also have a complex interaction with rainfall and temperature. No adjustment has been made for these interactions in our analysis.

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46 While restrictions are targeted at outdoor use they can also change behaviour as impact on indoor use as well, thereby, impacting on wastewater volumes. No adjustment has been made for this in our analysis.

47 Cunningham, M. 2012, *An analysis of the productivity of the Victorian water industry,* Essential Services Commission of Victoria Staff Research Paper, No. 2012/1, March.

48 In the modelling undertaken for the most recent Sydney metropolitan water plan it was assumed that Level 1 introduced at 55 per cent Total Storage achieves a 7 per cent reduction in consumption; Level 2 introduced at 45 per cent Total Storage: achieves a 11 per cent reduction; and Level 3 introduced at 40 per cent Total Storage: achieves a 12 per cent. (CIE (2010), Cost Effectiveness Analysis — 2010 Sydney Metropolitan Water Plan, prepared for NSW Office of Water, April.)

49 CIE (2010), p 40.

Approach to quality adjustment

For the purposes of this analysis, we have adopted the ESC's approach for water quality and sewage quality adjustments. The ESC's index of water quality is described as,

> Drinking water quality has been measured as of the product of: the percentage of zones in which health-related microbiological standards were met and the percentage of zones in which health-related chemical standards were met. The product of these measures can be interpreted as an indicator of the probability that any one zone may be receiving non-compliant water (assuming no correlation between microbiological and chemical non-compliance).[50]

The sewage quality index adopted by the ESC is described as,

> The quality of sewage treatment (WWQ) is measured by the following index: WWQ = (% primary × 1 + % secondary × 2 + % tertiary × 3) / 3.[51]

Inclusion of density variable

The density of water and sewerage properties serviced by a water utility influences the length of water and sewerage mains required and hence the associated capital and operating costs. The density of serviced properties differs across water utilities.

We have included a density variable in some of the models estimated to allow for this impact. The density variable constructed is properties connected per kilometre of water and sewerage mains.

We have considered alternative measures of density based on land areas and populations. However, there is no consistent source for land areas, particularly given the different structures of the industry across states. For example, while NSW land area density measures could be constructed because utilities service a town, this is more difficult in Victoria where utilities service an area. There are also likely to be differences in water utility service area and town boundaries that could not be accounted for in this approach. For these reasons we do not use such a measure.

A limitation of our density variable is that when this variable is included then differences in the efficiency of the layout of water mains is allocated as a difference in density. If mains have been laid more or less efficiently across utilities then this will be missed in measures of inefficiency. Given this, we have treated the density adjustments as a sensitivity test rather than in the base model.

Other environmental variables

Similar to the ESC of Victoria's recent analysis, other environmental factors included adjustment for the proportion of water sourced from groundwater; the proportion of

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50 Cunningham, M. 2012, *An analysis of the productivity of the Victorian water industry,* Essential Services Commission of Victoria Staff Research Paper, No. 2012/1, March, Summary report, p16.

51 Cunningham, M. 2012, *An analysis of the productivity of the Victorian water industry,* Essential Services Commission of Victoria Staff Research Paper, No. 2012/1, March, Summary report, p17.

customers with sewerage connection; and the proportion of wastewater collected that is trade waste.

Unobserved security of supply

As noted above, there is no readily available data of the changes in the security of supply for urban water utilities over time. Nevertheless, over the past decade there has been significant investment by urban water utilities in projects to enhance security of supply. The combined capital expenditure program of 30 of Australia's largest water utilities is approximately $30 billion over the period 2005/06 to 2011/12, including significant expenditure by SA Water.[52] Some of these projects have also been funded through Australian Government contributions [53]

Table 4.1 provides a list of recent investments in desalination facilities, some of which are not yet completed. Apart from desalination facilities there have also been significant investments in wastewater recycling facilities, the largest being the Western Corridor project in South East Queensland (table 4.2).

4.1 Recent desalination plant investments

Location (project)	Initial investment	Capacity	Maximum expandable capacity	Initial (and expandable capacity, % total water supplied in 2009-10)	Completion date
	$m	GL/year	GL/year	%	
Sydney (Kurnell)	1 890	90	180	18 (36)	2010
Melbourne (Wonthaggi)	3 500	150	Up to 200	43 (57)	2012
South-east Queensland (Tugun)	1 200	49		25	2009
Adelaide (Port Stanvac)	1 830	100		80	2012
Perth (Kwinana)	387	45		18	2006
Perth (Binningup)	1 400	100		40	2012

Source: Productivity Commission (2011), Volume 1, p26.

In Adelaide there have also been some large investments in stormwater harvesting, totalling almost $150 m, some of which projects will be completed in 2013.

Related to the issue of security of supply is expenditure on measures that provide an 'option value'. For example, this could relate to purchases of land that provide the utility with the opportunity to develop, say, a new dam. Such expenditure would not be reflected in short-term output measures. One example is the reserve sites on the

52 Productivity Commission (2011), *Australian Urban Water Sector Inquiry*, Volume 1, Chapter 2 p24.

53 In the case of Adelaide's desalination plant, for example, the Australian Government is providing $328 million: $100 million for the 50 gigalitre plant and $228 million for the expansion of the plant to 100 gigalitres per year. http://www.environment.gov.au/water/policy-programs/urban-water-desalination/projects-table.html

Queensland Water Commission's list of possible sites for future desalination plants (Lytton and either Marcoola or Bribie Island are the priority sites).

4.2 Wastewater recycling projects

Location	Project	Estimated cost	Supply/ Capacity	Completion date
		$m	GL/year	Year
Sydney	St Mary's Replacement Flows Project Rouse Hill Water Recycling Scheme Rosehill-Camellia Recycled Water Scheme	250 60[b] 100	18 4.7 4[c]	2010 2008 2011
Wollongong	Wollongong Water Recycling Plant	25	>7.3	2006
Melbourne	Eastern Treatment Plant – Tertiary Upgrade	380		2012
South-east Queensland	Western Corridor Recycled Water Project Murrumba Downs Sewage Treatment Plant	2 600 197	36[d] 11[e]	2008 2010
Adelaide	Glenelg to Adelaide Park Lands Recycled Water Project	76	5.5	2010
Perth	Kwinana Recycled Water Scheme Alkimos Wastewater Treatment Plant Stage 1 and Quinns Main Sewer	28 336	6 7.3	2004 2010

Source: Productivity Commission (2011), *Australian Urban Water Sector Inquiry,* Volume 1, p26

Without output measures for security of supply, then expenditures that enhance security of supply would be reflected as productivity losses.[54] Another option, as discussed below, is to remove expenditure associated with security of supply and to examine how the efficiency results change. This is the approach adopted in this study.

Data for inputs

The key inputs into the provision of water and wastewater services included in our analysis are:

- operating costs; and
- a measure of the capital stock.

Capital stock measures

The measure of capital stock is problematic given that there is no robust measure readily available. The Written Down Value (WDV) of fixed water supply and sewerage assets for each utility provides a basis for calculating capital stock. A key challenge for the usefulness of this measure is that it is likely to be impacted by factors unrelated to a utilities' investment. In particular it could be impacted by changes in the valuation

54 Expenditure to enhance security of supply could still be considered to be inefficient where the additional costs are greater than the incremental improvements in water security.

approach used. Cunningham 2012 also notes other possible reasons for differences including:[55]

- differences in the extent of headwork assets between utilities that source their own surface water and those that buy water in bulk, furthermore, utilities in Melbourne own little sewerage treatment plant
- differences in the cost of construction, for example, due to the terrain, soil conditions, depth of mains, pipe materials used; and
- differences in asset age. Coelli & Walding (2006) emphasised that the differences in age of assets between utilities were likely to make accounting-based measures unreliable.

An alternative approach, utilised by the ESC, was to recreate a capital stock measure by using the most recent WDV of assets. The capital stock measure in earlier years would be based on a cumulative adjustment of actual capital expenditure and a depreciation allowance (an allowance of 2 per cent per annum was assumed).

As discussed in chapter 3, we adopt an alternative approach to seek to focus on more recent capital expenditures by utilities. This sets the *initial* capital base for each utility equal to a common value and then adds subsequent capital expenditure and deducts depreciation (at a rate of 2 per cent). Utilities that do not have data in 1997/8 are given a starting capital base equal to the average for other utilities in the year in which they first have data.

As discussed further in chapter 6, we find substantive differences in results using different approaches to measuring the capital stock. We report results for our capital stock measure, the measure used by Cunningham (2012) and the length of pipes (also used by Cunningham 2012).

Adjusting for expenditures related to security of supply

Under the base model for our analysis we do not make adjustments for a utility's expenditure related to the security of supply. As noted above, this means that expenditures that enhance security of supply would be reflected as reduced efficiency (or negative technical change across the whole industry).

We construct a capital stock measure including and excluding major water security measures (largely desalination plants) to test whether this makes a difference to our results.

During the analysis period three water utilities constructed desalination plants, including:

- Sydney Water Corporation —constructed desalination plant and pipeline
- Water Corporation Perth—constructed two desalination plants, Perth Seawater desalination plant and Southern Seawater desalination plant.
- SA Water Adelaide—constructed desalination plant and North South Interconnector

55 Cunningham, M. 2012, *An analysis of the productivity of the Victorian water industry,* Essential Services Commission of Victoria Staff Research Paper, No. 2012/1, March, Summary report, p19.

The capital cost expended in each financial year during the construction phase of these desalination plants for the three water utilities was identified (table 4.3). For a given water utility in a given financial year the capital cost associated with desalination was deducted from the total capital cost for the water utility.

4.3 Desalination capital costs ($millions 200–10 dollars)

Financial year	SA Water – Adelaide	Water Corporation – Perth	Sydney Water Corporation
2004-05		15.05	
2005-06		353.51	
2006-07		64.16	
2007-08	11.4	20.36	470.4
2008-09	400.3	168.02	854.2
2009-10	850.4	499.98	267.5
2010-11	370.2	287.03	5.3

Note: Includes expenditure funded through Government grants.

Source: The CIE.

Sydney Water Corporation and Water Corporation Perth sourced water from a desalination plant during the analysis period (table 4.4). Water volumes sourced from desalination in a given year were deducted from the total water supplied in the respective year.

4.4 Water sourced from desalination

Year	Sydney Water Corporation		Water Corporation - Perth	
	quantity (ML)	% total water supply	Quantity (ML)	% water supply
2006-07	0	0	18 120	7
2007-08	0	0	26 565	11
2008-09	0	0	33 160	13
2009-10	19 952	4	32 034	12
2010-11	77 102	15	28 541	11

Note: Based on data from ESC

Source: The CIE

There is a range of other potential adjustments that could be made for other investments in security of supply. These include, for example, expenditure on recycled water projects that have been undertaken. The problem, however, is that public information is not readily available on many of these items. Given this, our focus has been on the large items where information is available.

Operating cost measures

Operating costs are sourced from the NPR dataset. We have adjusted this data to align with the adjustment to water supplied due to restrictions and, for those models where applied, adjust operating costs to remove costs associated with desalination plants. These adjustments are detailed below. We also discuss the potential to adjust for costs imposed by government programs, although do not make any adjustment for this study.

Bulk water costs - normalising for water restrictions

As noted above, the output measure volume of water consumed by customers has been adjusted to normalise for the level of water restrictions in place during the year for the particular utility. The volume of bulk water purchased has been also been normalised for water restrictions using the same approach discussed above.

This could also result in a reduction in bulk water costs depending on the pricing arrangements for bulk water. This requires collection of data on the variable prices paid for bulk water – the fixed charges would remain the same irrespective of the volume of water purchased. The challenge is that information is not readily available for bulk water charges over the time period for this analysis.

We have therefore relied on the average (combining fixed and variable charges) price data collected by the ESC for their benchmarking study. Some updates to the ESC data were made to reflect the variable only charge for Sydney Catchment Authority, Melbourne Water, Gosford/Wyong. For Rous Water a fixed-only charge applies.

- Information is not always available on bulk water charges. In some instances, only average prices are reported (which includes both fixed and usage charges).
- For 2011, for most cases, we have assumed that charges remain at 2010 levels adjusted for inflation. For the other Victorian water utilities we have maintained the ESC's calculated effective price.

Operating costs associated with desalination plants

It was assumed that a water utility pays operating costs associated with the desalination from the first year water is sourced from the plant. The operating cost[56] was based on a plant operating at full capacity and was estimated to be:

- $81.52 million for Sydney Water Corporation, assuming total capacity of 90GL capacity; and
- $40.76 million for Water Corporation-Perth assuming total capacity of 45 GL capacity.

These costs were deducted from the total operating cost for Sydney Water Corporation and Water Corporation Perth in the years that water was sourced from a desalination plant.

The efficiency of all water utilities was estimated after deducting capital and operating costs and water volumes associated with desalination.

Adjustments for Government expenditure

There are a range of Government programs that may have been required to be undertaken by utilities. In Victoria, for example, under existing arrangements for water

56 Based on estimated operating unit cost (c/kL) for Sydney water in 2011-12, assuming full capacity, in Halcrow, 2011 *Review of Operating and Capital Expenditure by Sydney Desalination Plant Pty Ltd:* Prepared for Independent Pricing and Regulatory Tribunal. Operating cost in 2009-10 dollars.

planning and management some of the activities are delegated to water businesses (and other bodies such as catchment management authorities). Some of the activities include salinity mitigation plans, intensive groundwater management and water quality risk management plans. The costs are recovered through levies to all rural and urban water utilities that pass through this cost to their customers. Currently the levy is set at 5 per cent of revenue for urban water supply authorities and 2 per cent of revenue for rural water supply authorities.[57]

ACTEW Corporation in the ACT also undertakes some water planning and management functions. For example, it undertakes water quality monitoring and flow monitoring activities in liaison with the ACT's EPA in relation to urban water supply. The costs of water management activities is recovered through a Water Abstraction Charge that is levied on all urban water users (and collected by ACTEW).

While we recognise that these programs impose costs, there are likely to be a range of other activities that are undertaken by other agencies at the directive of Government. Some of these examples include Backlog Sewerage program where the water utility is compensated for providing services that would be uneconomic without Government support. Such expenditures would also be reflected in the accounts of these utilities.

Given that we do not have sufficient information to make adjustments across all utilities we do not adjust for these costs.

Summary of indicators

Table 4.5 below presents the summary statistics of the key input and output indicators used in the modelling.

4.5 Summary of data used

	Number of observations	SA Water (mean)	Whole sample (mean)
Output indicators			
Water properties (thousand)	455	491	184
Sewerage properties (thousand)	455	462	172
Water volume (ML)	455	138 617	52 103
Sewage collected (ML)	455	89 449	43 438
Inputs			
Water opex per prop (real $2009/10)	455	218	346
Sewerage opex per prop (real $2009/10)	455	159	315
Water capex per prop (real $2009/10)	455	284	340
Sewerage capex per prop (real $2009/10)	455	133	360

(Continued on next page)

57 ACCC (2009), *Water planning and management charges rules*, Final advice, July, p10.

	Number of observations	SA Water (mean)	Whole sample (mean)
Inputs (continued)			
Water WDV (nominal, $000)	399	2 382 188	840 021
Sewerage WDV (nominal, $000)	400	2 130 065	1 119 964
Water Capital Stock (real $2009/10, $000)	455	2 362 993	981 715
Sewerage Capital Stock (real $2009/10, $000)	455	3 160 966	1 608 944
Water mains (km)	455	8,838	3 162
Sewerage mains (km)	455	6 936	2 848

Source: The CIE.

5 Unit cost measures

Unit cost measures are the simplest comparison possible across utilities. They measure the amount of inputs for a given quantity of outputs, such as operating costs per property. We present these measures as it allows for easier understanding of later results from stochastic frontier analysis, even though these measures do not capture the full range of inputs and outputs.

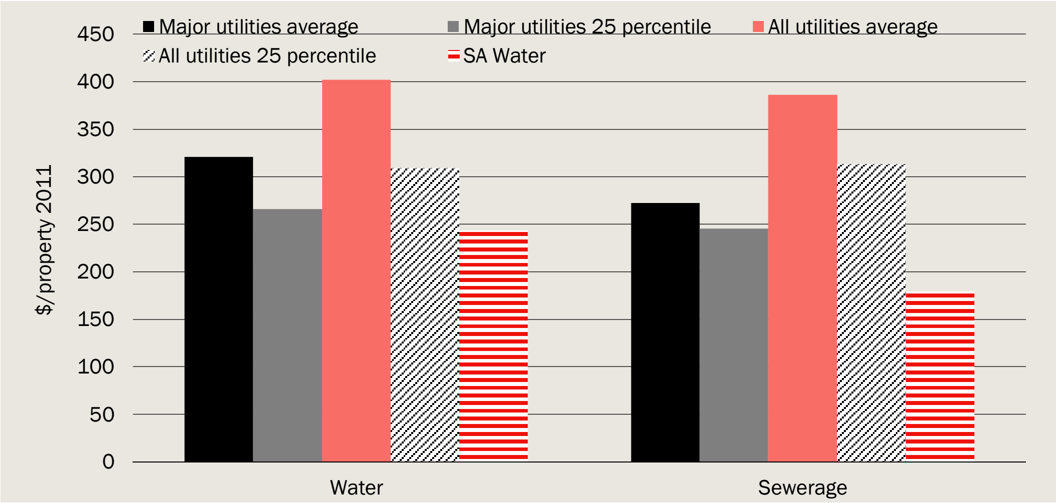
We present unit cost comparisons on the basis of dollars per property, as used in the National Water Commissions National Benchmarking Report. We present results from 2011 and for an average over the period for which we have data for utilities.

Unit cost comparisons for 2011

Unit cost comparisons are revealing. They indicate that:

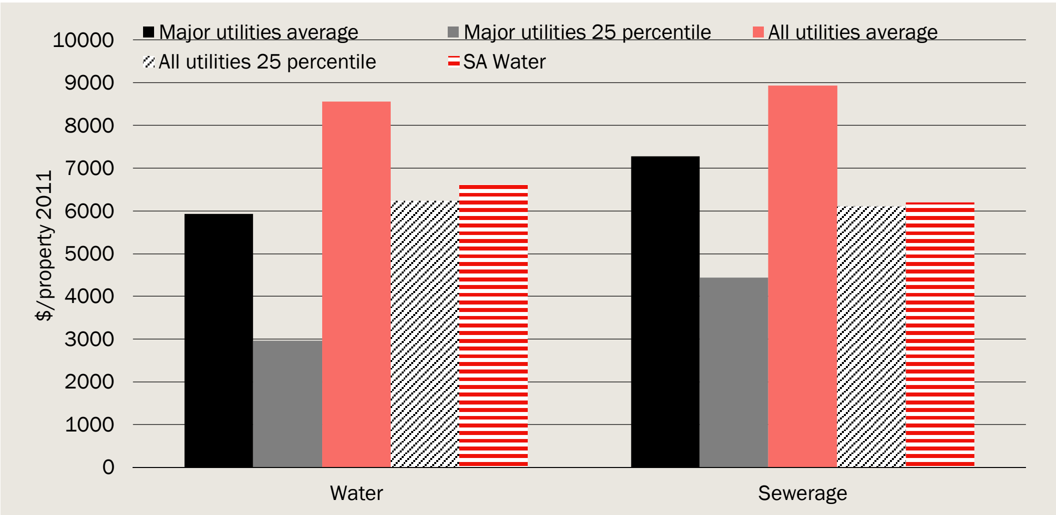
- SA Water has low operating costs per property compared to major utilities and all utilities (chart 5.1). In 2011, it had the lowest reported operating costs per property for sewerage of all utilities reporting. Its' operating costs per property for water is also lower than the 25 percentile of best performing utilities. Partly this reflects that SA Water does not incur operating costs from purchasing bulk water as it is vertically integrated.
- SA Water's written down capital stock per property is close to average across major utilities for water (and better than average for all utilities) (chart 5.2). SA Water's written down capital stock per property for sewerage is better than average.
- SA Water has undertaken a much greater amount of capital expenditure per property on average over the past 3 years in water than other utilities (chart 5.3). In water, its capital expenditure has been more than twice the average for major utilities and the average for all utilities.

5.1 Operating costs per property for water utilities 2011



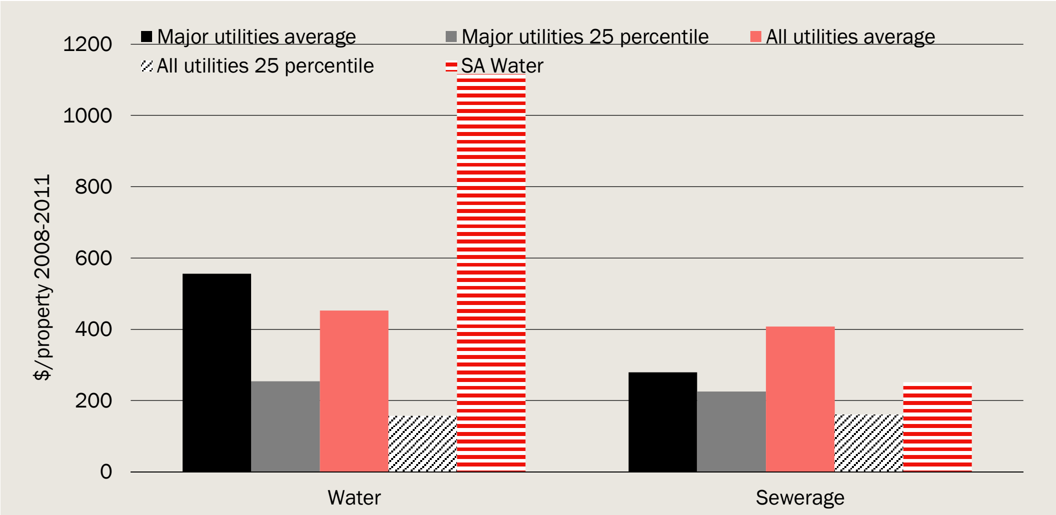
Note: Major utilities are those servicing greater than 100 000 properties.
Data source: National Water Commission, National Benchmarking Reports.

5.2 Written down capital stock per property for water utilities 2011



Note: Figures are in 2010-11 dollars. Major utilities are those servicing greater than 100 000 properties.
Data source: National Water Commission, National Benchmarking Reports.

5.3 Average capital expenditure per property 2008-2011

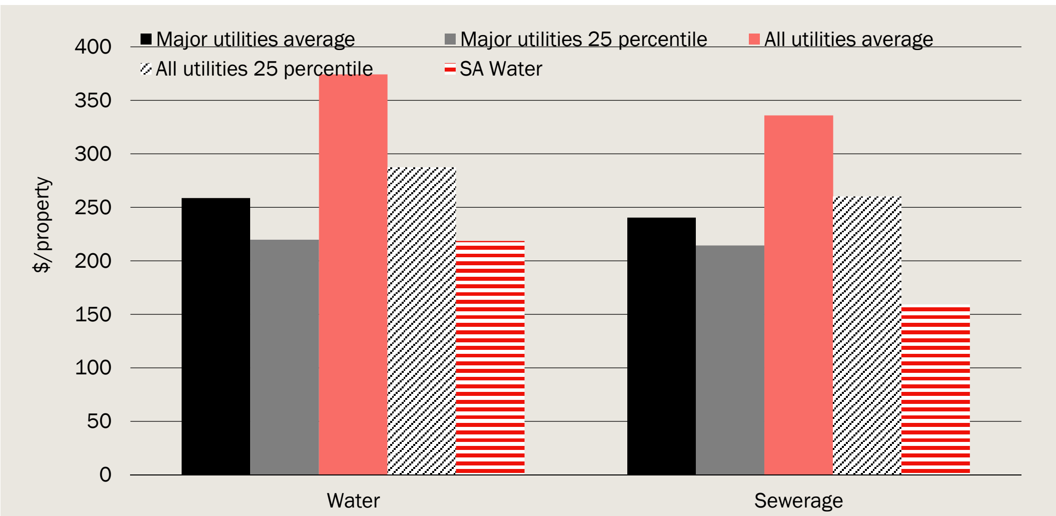


Note: Major utilities are those servicing greater than 100 000 properties.
Data source: National Water Commission, National Benchmarking Reports.

Unit cost comparisons for period of data

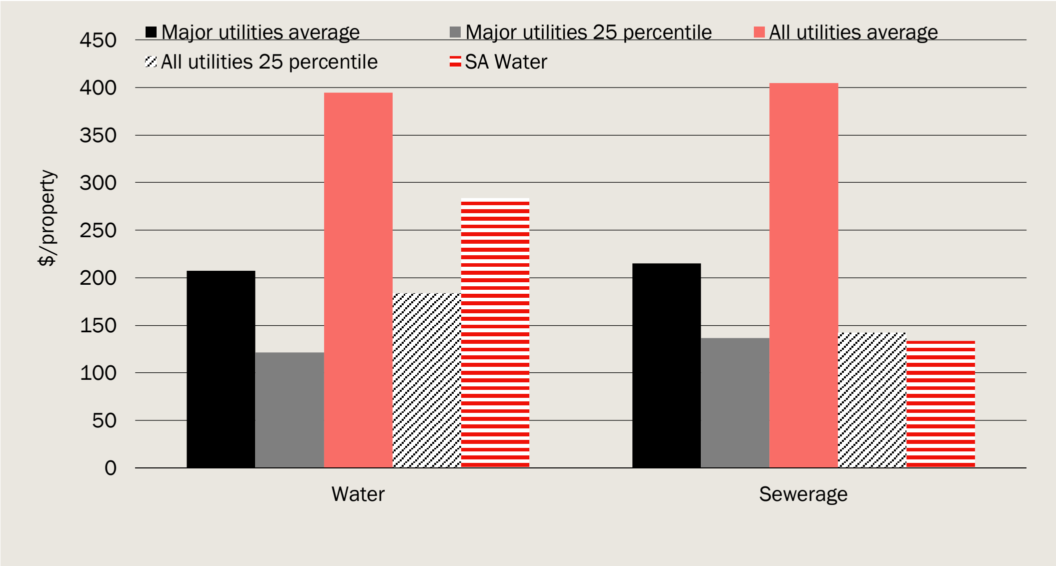
Over a longer period (1998-2011 for SA Water and other major utilities and often shorter for smaller utilities), SA Water has lower than average operating costs and capital expenditure relative to the sample of Australian utilities (charts 5.4 and 5.5). It is within the top (best performing) 25^{th} percentile for all and major utilities for operating expenditure per property for water and sewerage and for capital expenditure per property for sewerage. Recent high capital expenditure for the Adelaide desalination plant means that SA Water is not in the top 25^{th} percentile for water capital expenditure per property. (Prior to 2009 there was very little capital expenditure by SA Water.)

5.4 Average operating costs per property for water utilities 1998-2011



Note: Figures are in 2008-09 dollars and cover the period over which each utility reported. Major utilities are those servicing greater than 100 000 properties.
Data source: National Water Commission, National Benchmarking Reports.

5.5 Average capital expenditure per property 1998-2011



Note: Figures are in 2009-10 dollars and cover the period over which each utility reported. Major utilities are those servicing greater than 100 000 properties.

Data source: National Water Commission, National Benchmarking Reports.

6 Productivity analysis

Productivity can be measured using an index of outputs relative to inputs. This requires developing weights for multiple input and multiple output businesses such as urban water utilities. The level of productivity can be compared across utilities, potentially shedding light on the differences between utilities.

Measuring TFP

TFP is measured as the ratio of an output index to an input index. Using the Cobb Douglas production function, where y equals output, k equals capital input, l equals labour input, a is the constant and α and β are the input share weights:

$$y = a * k^{\alpha} l^{\beta}$$

Total factor productivity is estimated using the ratio of the output index over the input index:

$$TFP = a = \frac{y}{k^{\alpha} l^{\beta}}$$

TFP is not a measure of efficiency (or inefficiency) because there is no specified frontier, or level of productivity, that is measured as attainable and because no allowance is made for external factors that impact on the attainable productivity for each utility.

Input cost shares

Conceptually, input cost shares should reflect the marginal elasticity of outputs with respect to each type of input. This could be estimated using statistical analysis.

Rather than adopting this approach, we have estimated input cost shares based on the share of operating expenditure in allowed regulated revenue for major regulated utilities (table 6.1). This suggests that operating costs and capital cost have relatively similar cost shares.

6.1 Proportion of operating and capital cost in regulated revenue

Utility	Operating expenditure	Capital cost (return on and of capital)
	Share of total regulated revenue	Share of total regulated revenue
Hunter Water[a]	0.40	0.60
Gosford City Council[b]	0.53	0.47
Wyong Shire Council[b]	0.55	0.45
Sydney Water[c]	0.48	0.52
Yarra Valley Water[d]	0.67	0.33
City West Water[e]	0.73	0.27
South East[f]	0.71	0.29
ACTEW[g]	0.43	0.57
Average	0.56	0.44

[a] Independent Pricing and Regulatory Tribunal (IPART), 2009. *Review of prices for water, sewerage, stormwater and other services for Hunter Water Corporation.* Determinations and Final Report. July 2009. [b] IPART, 2009. *Gosford City Council, Wyong Shire Council: Prices for water, sewerage and stormwater drainage services from 1 July 2009 to 30 June 2013.*Determinations and Final Report May 2009. [c] IPART, 2008. *Prices for Sydney Water Corporation's water, sewerage, stormwater and other services*. Final Determination No. 1, 2008. [d] Essential Services Commission (ESC), 2009. *Metropolitan Melbourne Water Price Review 2009: Yarra Valley Water Determination 1 July 2009 – 30 June 2013.* [e] ESC, 2009. *Metropolitan Melbourne Water Price Review 2009: City West Water Determination 1 July 2009 – 30 June 2013.* [f] ESC, 2009. *Metropolitan Melbourne Water Price Review 2009: South East Water Determination 1 July 2009 – 30 June 2013.* [g] Independent Competition and Regulatory Commission (ICRC), 2008. *Water and Wastewater Price Review: Final Report and Price Determination.* Report 1 of 2008.

The reason why we have used cost shares rather than statistical analysis is the view that statistical analysis generally provides too low a weight on operating expenditure. This is because operating expenditure can bounce up and down through time for a utility, while outputs increase much more steadily, similar to capital. Statistical analysis then places most weight on capital because its pattern of growth through time more closely aligns with the pattern of growth of outputs.[58]

Output cost shares

Output cost shares are used as estimated by Cunningham 2012. These have been estimated statistically and imply marginal costs of additional output that look relatively sensible in the context of the water industry. That is, additional water or sewerage output increases costs only by a small amount, with costs instead being predominantly driven by customer numbers.

TFP comparisons

An average TFP for the period 2006 to 2011 was estimated for each utility. Capital and operating costs were weighted using the input cost shares in table 1.1 to form the input index. Three outputs, number of customers, adjusted water supply and adjusted sewage

58 If instead we estimated outputs against inputs with no allowance for different firm specific inefficiencies then the weight instead shifts to operating expenditure. That is, across utilities, operating expenditure is more closely aligned to outputs, but through time, capital expenditure is more closely aligned to outputs.

collected were weighted using output cost shares used by ESC in its analysis of the productivity of the Victorian Water Industry (table 6.2).

6.2 Input and output cost share weights

	Water only	Sewage only	Combined
Input cost shares			
Capital	0.44	0.44	0.44
Operating costs	0.56	0.56	0.56
Output cost shares			
Customers	0.89	0.89	0.80
Water supply, normalised & quality adjusted	0.11	--	0.10
Sewage collected, quality adjusted	--	0.11	0.10

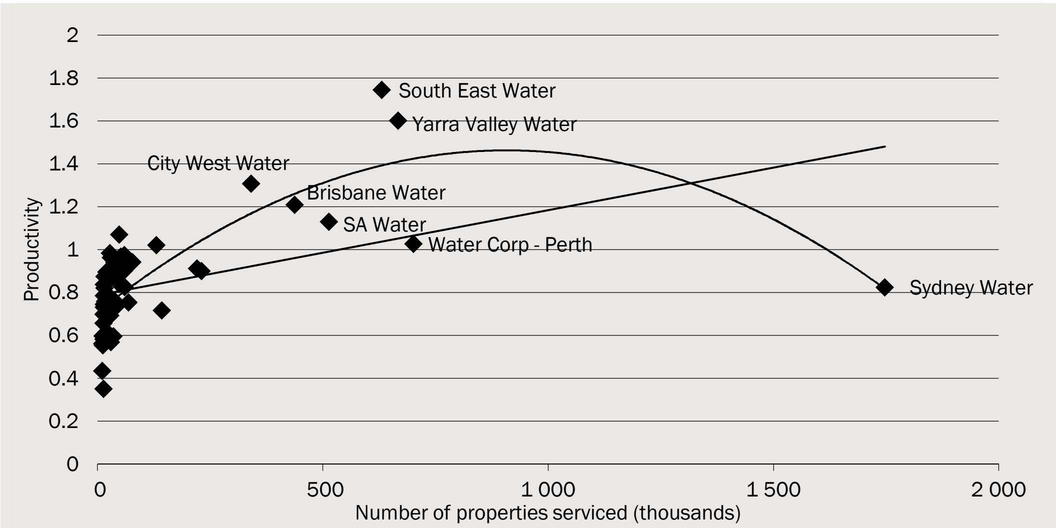
[a] Input cost share weights based on average proportion of operating costs and capital costs of regulated utilities in NSW, VIC and ACT.
Source: The CIE and ESC, 2012 *An analysis of the productivity of the Victorian Water Industry*, Technical Report.

The TFP of utilities was calculated using two different measures of capital, written down value and average real annual capital expenditure over the time period over which data is available.

The relationship between TFP and the average number of customers serviced by a utility is presented in charts 6.3 and 6.4 for the different capital measures. The TFP estimates do not vary greatly between the two different capital measures. In both chart 6.3 and 6.4 SA Water is above average relative to a linear trendline and below average relative to a polynomial trendline.

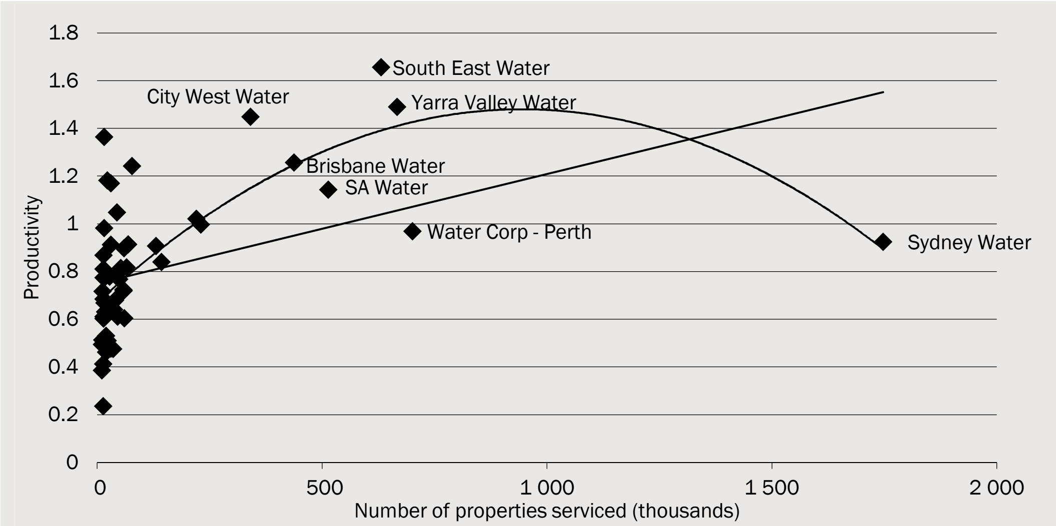
Sydney Water Corporation is an outlier in both charts 6.3 and 6.4 because of the relatively large number of customers it services and a relatively low level of productivity.

6.3 Total factor productivity – written down value



Data source: The CIE.

6.4 Total factor productivity – average capital expenditure



Data source: The CIE.

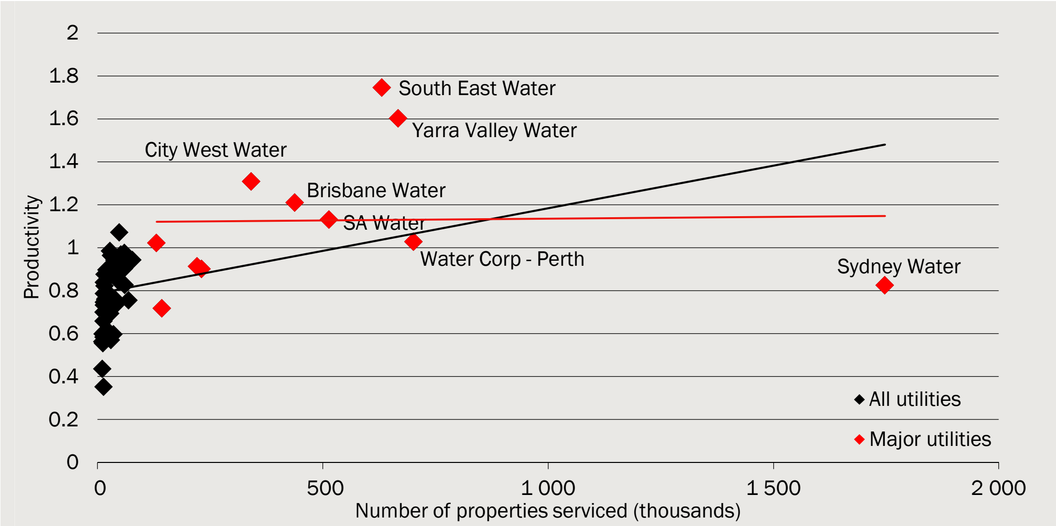
The measures of TFP show the importance of the set of comparators used in terms of their size. SA Water has measured productivity that is high relative to all utilities but low relative to utilities of a similar size. Depending on how economies of scale are taken into account in any analysis will hence change the measure of SA Water's efficiency.

We can look more closely at the larger utilities to understand what is driving the differences between them (charts 6.5 and 6.6). The two most productive utilities are South East Water and Yarra Valley Water. They have similar operating costs to SA Water but much lower capital costs (table 6.7). The lower capital costs reflects that the role of Melbourne's water and wastewater businesses is smaller than SA Water's, with Melbourne Water responsible for providing bulk water, treating water and disposing of sewage. Interestingly, the operating expenditure of Yarra Valley Water and South East Water is still very close to that of SA Water, even though it includes the payments that these businesses make to Melbourne Water for the services that it provides.

Sydney Water and Water Corporation — Perth have higher capital and operating costs per customer than SA Water.

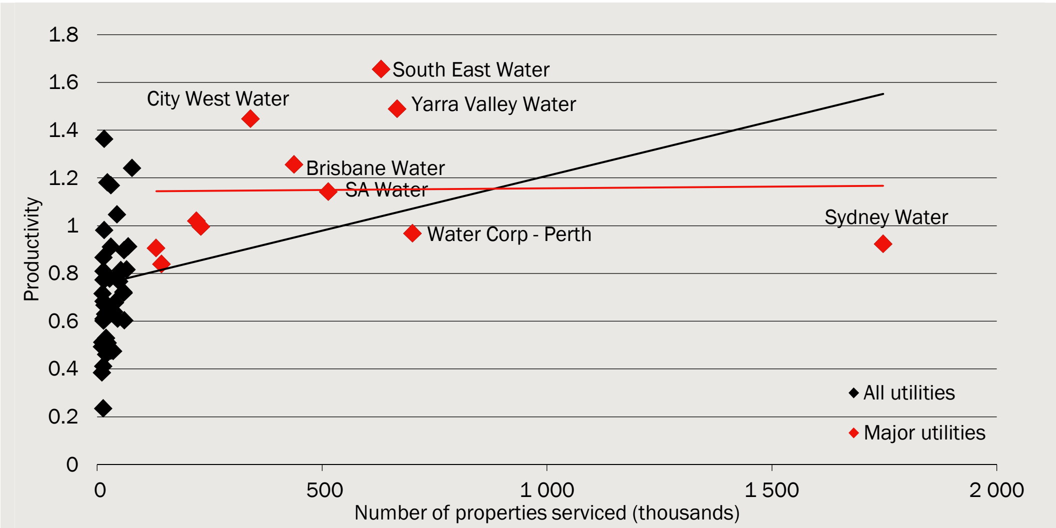
In charts 6.5 and 6.6 SA Water is approximately average relative to the linear trendline for the sample of major utilities only (shown in red).

6.5 Total factor productivity – written down value – focus on major utilities



Data source: The CIE.

6.6 Total factor productivity – average capital expenditure – focus on major utilities



Data source: The CIE.

6.7 Input and output values for major utilities

	Cap (wdv)	Non-cap	Cust.	Water	Sewage	Cap/cust	Noncap/ cust
	Unit	Unit	Unit	Unit	Unit	Unit	Unit
Written down value							
ACTEW	1.19	1.06	0.78	0.81	1.03	1.53	1.37
Barwon Water	0.54	0.78	0.71	0.65	0.47	0.76	1.09
Brisbane Water	1.73	2.20	2.38	1.97	3.08	0.73	0.93
City West Water	1.01	1.91	1.85	1.82	2.27	0.55	1.03
Gold Coast Water	1.58	1.29	1.25	1.12	1.64	1.26	1.03
Hunter Water Corporation	1.63	1.17	1.20	1.10	1.74	1.36	0.97

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	Cap (wdv)	Non-cap	Cust.	Water	Sewage	Cap/cust	Noncap/ cust
	Unit	Unit	Unit	Unit	Unit	Unit	Unit
Written down value (continued)							
Sydney Water Corporation	13.55	9.76	9.49	9.51	7.74	1.43	1.03
South East Water Ltd	1.06	2.96	3.43	2.57	2.98	0.31	0.86
SA Water - Adelaide	2.55	2.34	2.79	2.40	2.78	0.92	0.84
Water Corporation - Perth	4.37	3.36	3.81	4.62	3.76	1.15	0.88
Yarra Valley Water	1.44	3.10	3.62	2.71	3.86	0.40	0.85
Average capital expenditure							
ACTEW	0.84	1.06	0.78	0.81	1.03	1.08	1.37
Barwon Water	0.71	0.78	0.71	0.65	0.47	0.99	1.09
Brisbane Water	1.59	2.20	2.38	1.97	3.08	0.67	0.93
City West Water	0.80	1.91	1.85	1.82	2.27	0.43	1.03
Gold Coast Water	1.26	1.29	1.25	1.12	1.64	1.00	1.03
Hunter Water Corporation	1.27	1.17	1.20	1.10	1.74	1.06	0.97
Sydney Water Corporation	10.47	9.76	9.49	9.51	7.74	1.10	1.03
South East Water Ltd	1.19	2.96	3.43	2.57	2.98	0.35	0.86
SA Water - Adelaide	2.49	2.34	2.79	2.40	2.78	0.89	0.84
Water Corporation - Perth	5.00	3.36	3.81	4.62	3.76	1.31	0.88
Yarra Valley Water	1.70	3.10	3.62	2.71	3.86	0.47	0.85

Note: Values are normalised so that the average across the entire sample of utilities over time is 1.
Source: The CIE.

Impact of desalination on TFP estimates

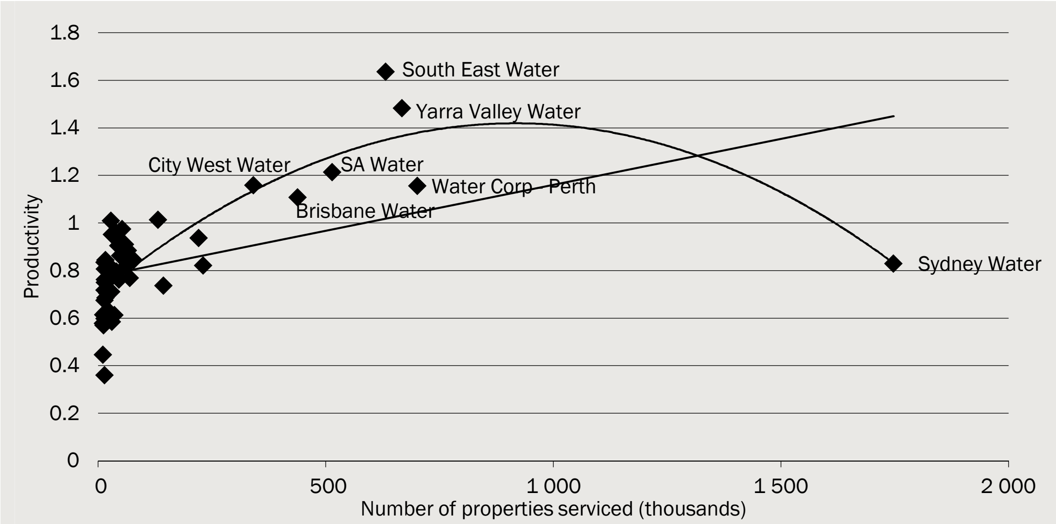
The TFP for each utility has also been estimated excluding desalination capital and operating costs and water volumes sourced from desalination. This increases the measured productivity of Sydney Water, SA Water and Water Corporation — Perth.

The relationship between TFP and the average number of customers serviced by a utility is presented in charts 6.8 and 6.9 for the different capital measures excluding inputs and outputs associated with desalination. The TFP estimates do vary between the two different capital measures, in particular for SA Water. In chart 6.8 SA Water is above average relative to the linear trendline and below average relative to the polynomial trendline. The polynomial measure of economies (and diseconomies) of scale is unlikely to provide a good comparator, as SA Water's productivity is exceeded only by two utilities and is still below the average line.

In chart 6.9 SA Water is above average relative to both the linear and polynomial trendline and is estimated as the most productive of all utilities in the sample. That is, based on expenditures since 1998 and excluding desalination expenditures, SA Water produces more outputs per unit of inputs than any other water utility.

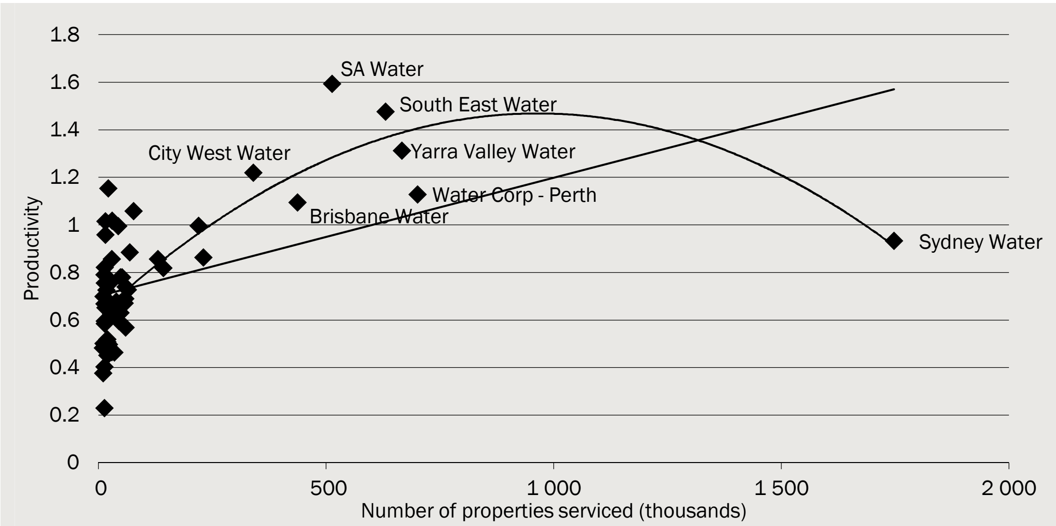
The full set of data for these measures is contained in table 6.10.

6.8 Total factor productivity – written down value excluding desalination



Data source: The CIE.

6.9 Total factor productivity – average capital expenditure excluding desalination



Data source: The CIE.

6.10 Input and output values for major utilities – excluding desalination

	Cap (wdv)	Non-cap	Customers	Water	Sewage	Cap/cust	Noncap /cust
	Unit	Unit	Unit	Unit	Unit	Unit	Unit
Written down value							
ACTEW	1.21	1.01	0.78	0.81	1.03	1.56	1.29
Barwon Water	0.55	0.78	0.71	0.65	0.47	0.77	1.10
Brisbane Water	1.76	2.55	2.38	1.99	3.08	0.74	1.07
City West Water	1.03	2.35	1.85	1.84	2.27	0.55	1.27
Gold Coast Water	1.60	1.52	1.25	1.13	1.64	1.28	1.21
Hunter Water Corporation	1.66	1.11	1.20	1.11	1.74	1.38	0.92

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	Cap (wdv)	Non-cap	Customers	Water	Sewage	Cap/cust	Noncap /cust
	Unit	Unit	Unit	Unit	Unit	Unit	Unit
Written down value (continued)							
Sydney Water Corporation	13.36	9.73	9.49	9.30	7.74	1.41	1.03
South East Water Ltd	1.07	3.29	3.43	2.59	2.98	0.31	0.96
SA Water - Adelaide	2.33	2.22	2.79	2.42	2.78	0.84	0.79
Water Corporation - Perth	4.09	2.82	3.81	4.18	3.76	1.08	0.74
Yarra Valley Water	1.46	3.52	3.62	2.73	3.86	0.40	0.97
Average capital expenditure							
ACTEW	0.95	1.01	0.78	0.81	1.03	1.22	1.29
Barwon Water	0.81	0.78	0.71	0.65	0.47	1.13	1.10
Brisbane Water	1.81	2.55	2.38	1.99	3.08	0.76	1.07
City West Water	0.91	2.35	1.85	1.84	2.27	0.49	1.27
Gold Coast Water	1.43	1.52	1.25	1.13	1.64	1.14	1.21
Hunter Water Corporation	1.44	1.11	1.20	1.11	1.74	1.20	0.92
Sydney Water Corporation	10.25	9.73	9.49	9.30	7.74	1.08	1.03
South East Water Ltd	1.35	3.29	3.43	2.59	2.98	0.39	0.96
SA Water - Adelaide	1.26	2.22	2.79	2.42	2.78	0.45	0.79
Water Corporation - Perth	4.33	2.82	3.81	4.18	3.76	1.14	0.74
Yarra Valley Water	1.93	3.52	3.62	2.73	3.86	0.53	0.97

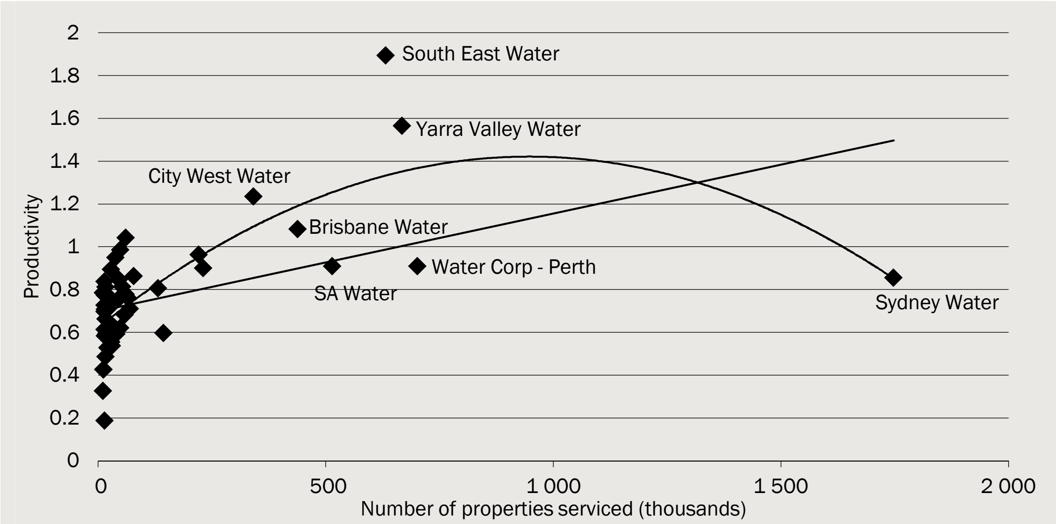
Source: The CIE.

Separate measures for water and sewerage

Separate productivity measures can be constructed for sewerage and water using a measure of capital based on written down value and a measure of capital based on average capital expenditure (charts 6.13 to 6.18). Results are shown in the six charts below.

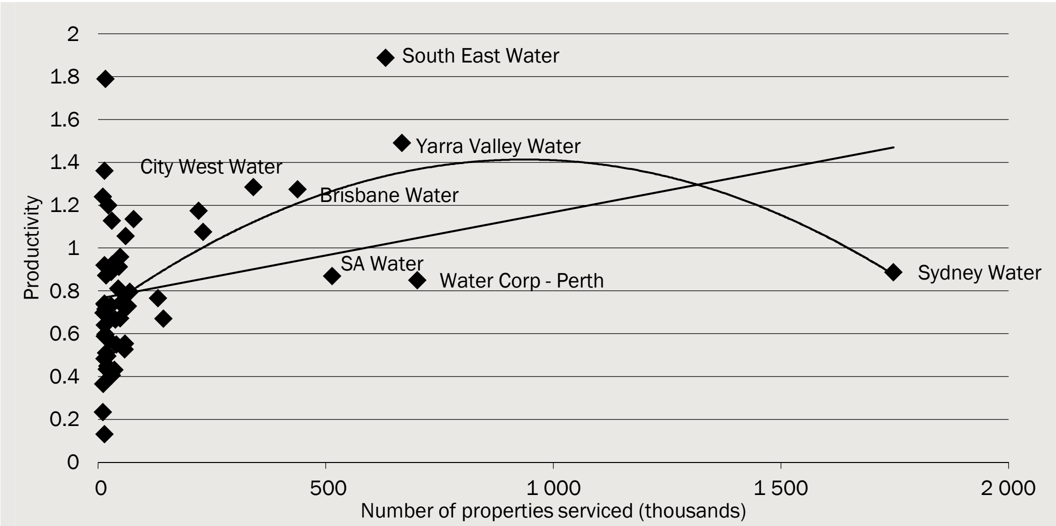
- SA Water is around the average or slightly below the average productivity expected for a utility of its size in water provision (charts 6.13 and 6.14), allowing for linear increasing returns to scale. If diseconomies of scale are allowed for then SA Water is well below the productivity expected for a utility of its size in water provision. A large part of this productivity result reflects the capital investment in the Adelaide Desalination Plant.
- Excluding costs and volumes of water associated with desalination, SA Water is above the average productivity in water provision (charts 6.15 and 6.16), allowing for linear increasing returns to scale for both capital measures. SA Water is also above average productivity in water provision using the average real capital expenditure measure and allowing for diseconomies of scale.
- SA Water shows above average productivity in the provision of sewerage services (charts 6.17 and 6.18).

6.11 TFP estimates for water services – WDV



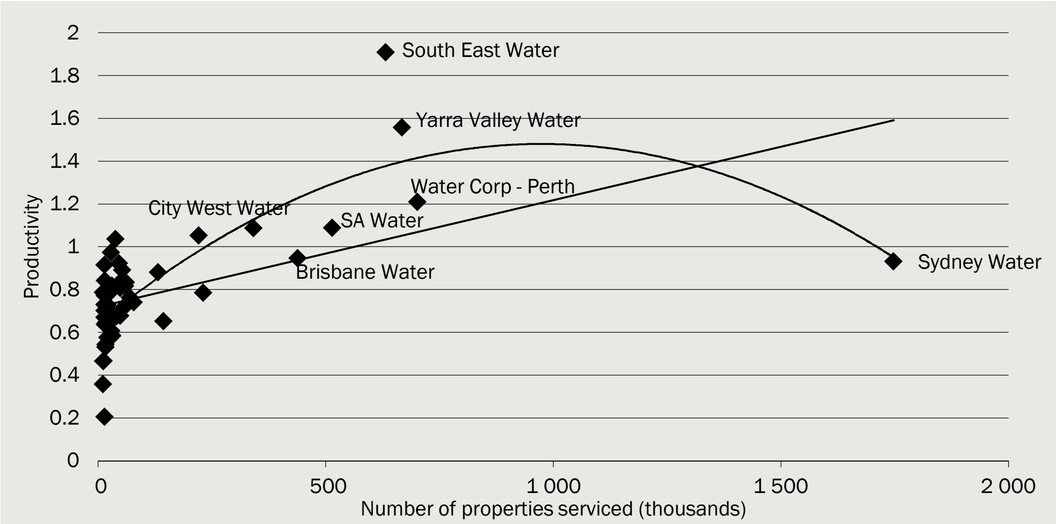
Data source: The CIE.

6.12 TFP estimates for water services – average capital expenditure



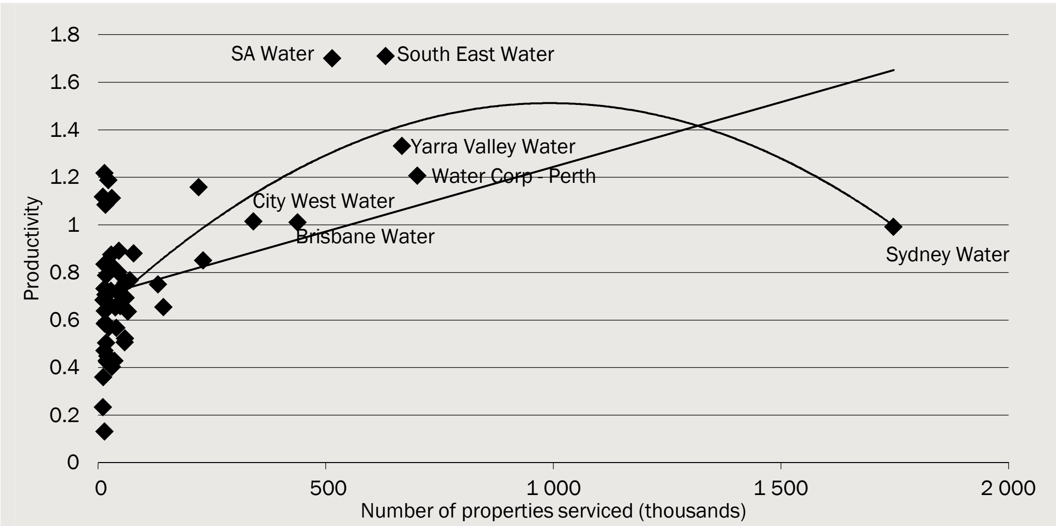
Data source: The CIE.

6.13 TFP estimates for water services – WDV excluding desalination



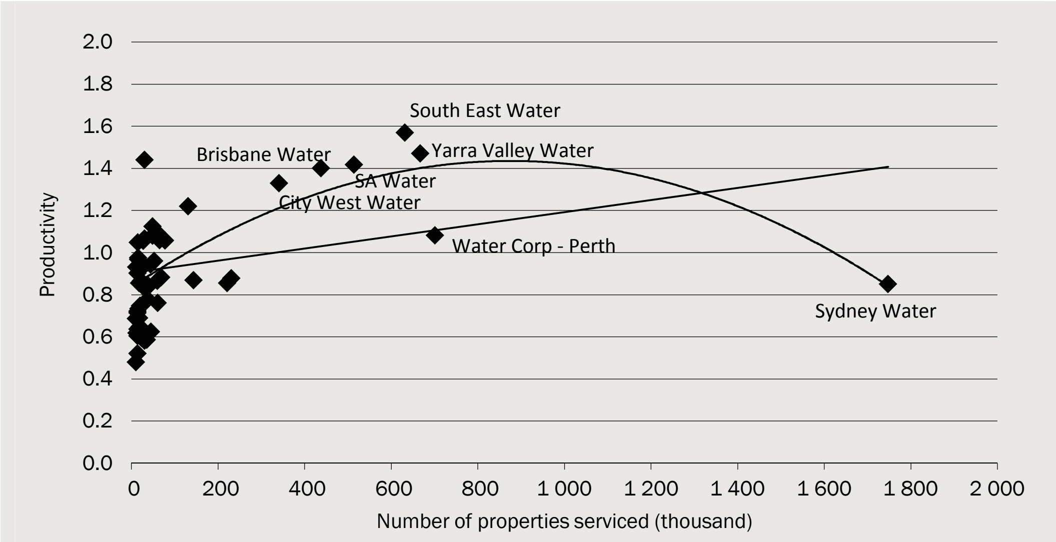
Data source: The CIE.

6.14 TFP estimates for water services – average capital expenditure – excluding desalination



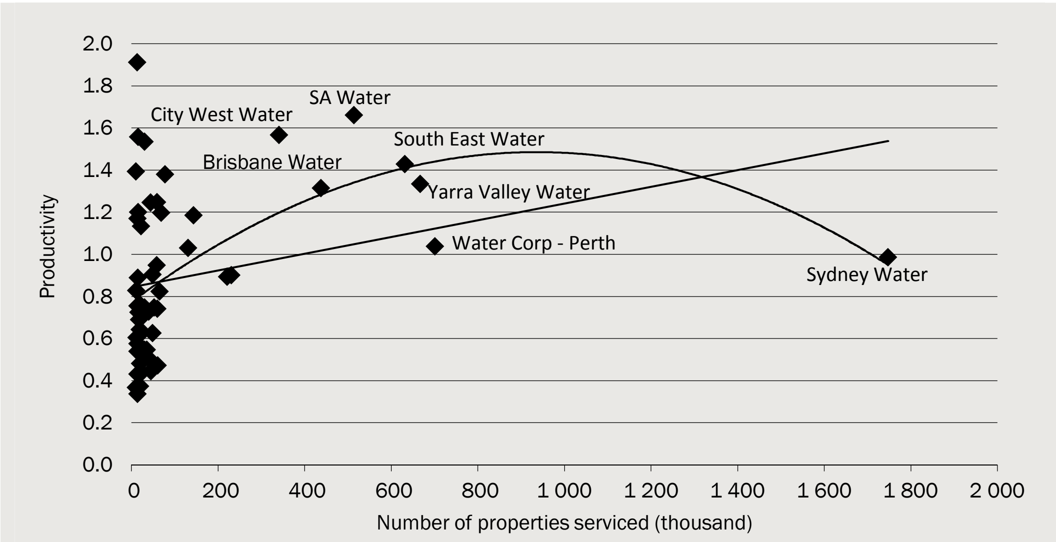
Data source: The CIE.

6.15 TFP estimates for sewerage services – WDV



Data source: The CIE.

6.16 TFP estimates for sewerage services – average capital expenditure



Data source: The CIE.

7 *Efficiency analysis – statistical models*

Unit cost and productivity estimates provide a basis for comparing the performance of SA Water's metropolitan operations to other utilities. An alternative method is to use formal statistical analysis. This has three main potential advantages over other measures for the purposes of analysing the efficiency of SA Water.

- It can potentially allow for the inclusion of other factors that influence productivity that are outside the control of the utility.
- It estimates of the weights on inputs and outputs rather than specifying these weights independently.
- It allows for a more flexible relationship between inputs and outputs, including estimating the economies of scale observed in water utility data.

However, for water utilities, the findings from efficiency analysis are also not always easy to interpret and estimated weights placed on inputs and outputs are not always sensible. Further, we find that for SA Water, its measure of inefficiency can be quite sensitive to the assumptions made, particularly in regards to the measurement of capital services.

This chapter sets out the models tested and statistical results.

The structure of the models estimated

The 'basic' statistical model involves three input components:

- a set of inputs — operating costs and a measure of capital;
- a set of outputs — number of properties serviced, amount/quality of water supplied and amount of sewage treated and quality it is treated to; and
- a set of 'environmental' factors that influence the relationship between inputs and outputs — such as the type of water sources or waste.

These input components are then combined through a specific functional form and the relationships estimated using assumptions about the way that inefficiency changes through time and the distribution of inefficiency across utilities.

- We consider a Cobb-Douglas and a Translog functional form. The first functional form implies that economies of scale are constant, while the second allows for more flexibility in economies of scale. While typically more flexibility will be viewed as an advantage, this may not be the case for this sample of utilities because Sydney Water is an outlier in its size and this may have an overly large impact on the shape of an implied cost function.

- We consider only a model where inefficiency of a utility is invariant through time. This means that we are estimating an average level of inefficiency of a utility. The reasons for this are discussed in box 7.1.
- The distribution of inefficiency across utilities is estimated as a truncated normal, with the location of truncation estimated as part of the statistical analysis.

7.1 Time variation in efficiency

SFA analysis allows for the inefficiency of utilities to decay (or increase) systematically through time. For example, if a utility was 10 per cent inefficient in year 1 and there was a 10 per cent decay each year, then it would be 9 per cent inefficient in year 2.

The decay of inefficiency is the same under SFA for all utilities. Hence the ranking or relative inefficiency of a utility is the same across time.

The measure of decay or increase in inefficiency spreads the estimated inefficiencies in each year. If inefficiency increases through time, then utilities will have a small range for estimated inefficiency in the first year and a wider range in later years.

We have found that the time decay is relative unstable and can change markedly with the specifications. This is because there are a substantial number of time trends allowed in the functional form, but only 14 years of data. We would also expect some approaches that we have used for the capital measure to lead to a wider range of inefficiencies in 2011 than in 1998, because the initial capital base for utilities is the same, but then varies thereafter.

Reflecting these issues, we use a time-invariant measure of inefficiency.

The basic model

The preferred model that we use is based on a capital measure built up from historic capital expenditure, applied to a similar starting point for capital for each utility (on a per property basis). We use a Cobb-Douglas specification and include variables for the share of groundwater sourced, the share of trade waste processed and the share of customers also receiving sewerage services. This model is closely based on the analysis of Cunningham 2012[59], with the exception of a different measure of capital services.

The empirical results from this specification are shown in the table below. The coefficient on the capital cost ratio, which measures the elasticity of each input is -0.74. This indicates that the elasticity of the input index with respect to capital is 0.74 and the elasticity of the input index with respect to non-capital is 0.26.

[59] Cunningham, M. 2010, *An analysis of the productivity of the Victorian water industry,* Essential Services Commission of Victoria Staff Research Paper, No. 2012/1, March.

The coefficient on the number of properties is 0.92, indicating that a 10 per cent increase in the number of properties is associated with a 9.2 per cent increase in the costs associated with servicing these properties. The coefficients on water and sewerage are positive but close to (and statistically insignificant to) zero. This indicates that these outputs are unrelated to costs.

For the environmental variables, having a higher share of customers with sewerage as well as water leads to higher cost. For instance, moving from 80 per cent of customers with sewerage to 90 per cent would increase costs by around 10 per cent. Increasing the share of groundwater and trade waste are also associate with higher costs, although the coefficients on not statistically distinguishable from zero.

Mu, which measures the mean of the truncated normal distribution of firm inefficiency is 0.07. That is, the normal distribution is centred on a positive level of inefficiency, meaning that there will be a small number of firms close to the frontier and then a greater number with moderate levels of inefficiency. Finally, the average firm inefficiency is 0.13 — 13 per cent from the frontier — and the standard deviation of firm inefficiency is 0.08. The larger is the standard deviation the greater the dispersion in estimated firm inefficiency.

7.2 The basic model

Variable	Coefficient	P-value
The dependent variable is non-capital costs.		
Capital cost to non-capital cost ratio	-0.74	0.00
Number of properties	0.92	0.00
Quality adjusted water	0.01	0.39
Quality adjusted sewerage	0.01	0.54
Share of customers with sewerage	1.03	0.00
Share of water sourced from groundwater	0.03	0.61
Share of waste that is trade waste	0.14	0.46
Constant	4.63	0.00
Other statistics		
Log-likelihood	362.6	
Number of observations	444 (54 utilities)	
Mu	0.07	
Average firm inefficiency	0.13	
Standard deviation of firm inefficiency	0.08	

Source: The CIE.

Combining the three coefficients on outputs (0.94) provides a measure of the implied returns to scale. This means that a 10 per cent increase in outputs is associated with only a 9.4 per cent increase in costs and that there is hence some evidence of economies of scale.

In terms of SA Water's efficiency, SA Water has an efficiency measure of 0.94 (out of 1), implying a level of inefficiency of 6 per cent (table 7.3). This is 8 per cent above the average for the sample and about equal to the top 25 per cent of utilities.

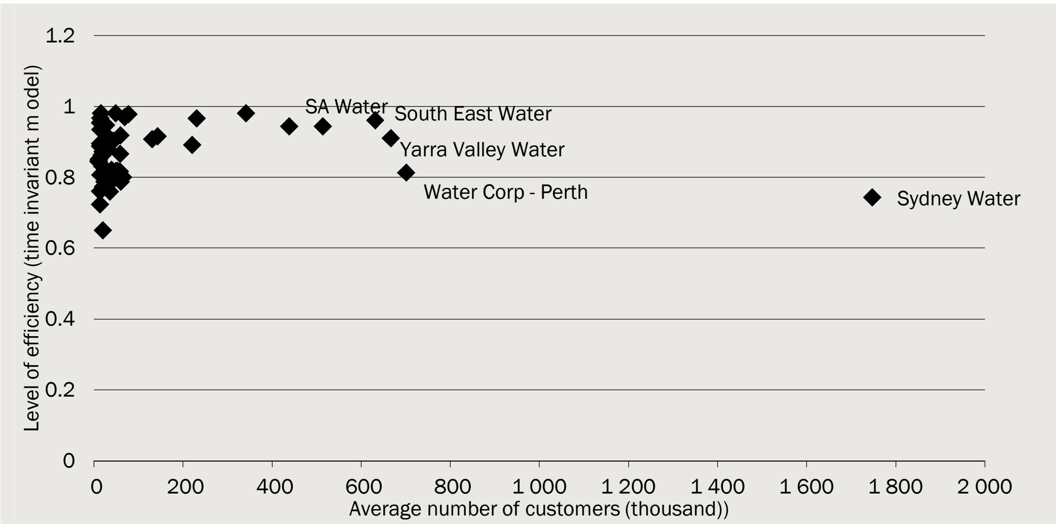
7.3 SA Water's efficiency in the base model

Statistic	Value Unit
SA Water efficiency measure	0.94
SA Water relative to best utility	0.96
SA Water relative to 25th percentile utility	1.00
SA Water relative to average across sample	1.08

Source: The CIE.

The efficiency of utilities arranged by number of customers serviced is shown in chart 7.4. There is substantial variation in efficiency for the smaller utilities, while mid-sized utilities are all fairly similar, except for Water Corporation — Perth. Sydney Water is estimated as having relatively low efficiency.

7.4 Efficiency across utilities



Data source: The CIE.

Alternative measures of capital services

Measuring capital services is extremely problematic, particularly given the importance of capital in the delivery of water and sewerage services. We have constructed four variations to the capital measure used in the basic model to seek to understand how SA Water performs under alternative measures.

- **Basic model adjusted for the role of the utility** — this sets the initial capital base of utilities that source bulk water from a supplier to a different (and lower) level to utilities that have this role themselves. This impacts on Melbourne's water utilities, Sydney Water, utilities serviced by Rous Water (Ballina, Byron and Lismore) and South East Queensland utilities.

- **Own initial written down value** — the capital variable is constructed using the initial WDV for each utility and rolled forward by adding capital expenditure and deducting depreciation of 2.5 per cent.
- **Own final written down value** — the capital variable is constructed using the most recent WDV for each utility and back calculating the capital base by deducting capital expenditure and adding depreciation.
- **Written down value** — the capital variable is constructed from the WDV of a given utility in a given year.

As expected, these different methodologies produce quite different results, particularly for SA Water (table 7.7). In all specifications the average firm inefficiency is far higher than for the basic model, with the average firm inefficiency being 0.71 for the model using own initial written down value. The variation in efficiency is also higher as would be expected as we allow for greater variation in the capital per property serviced.

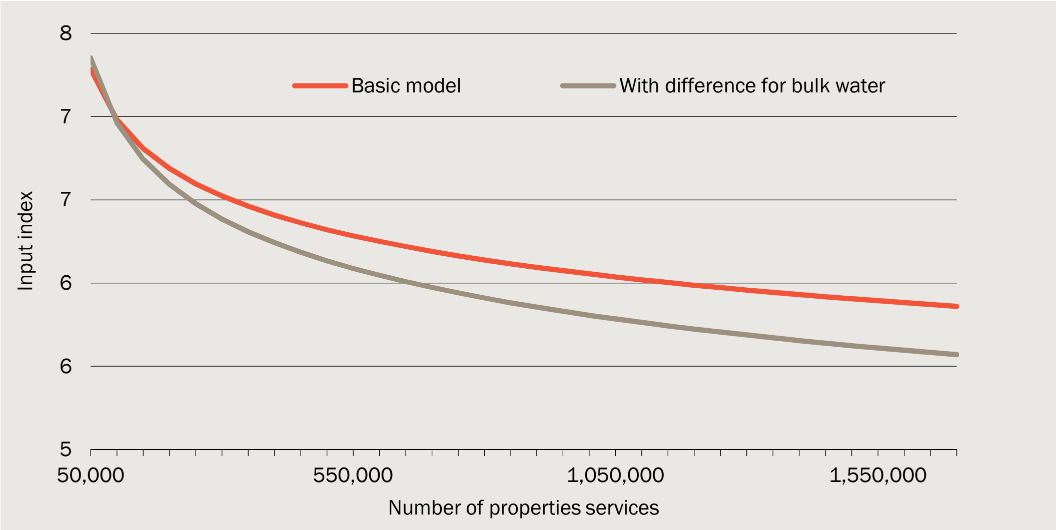
The elasticity of inputs with respect to capital is around 70-80 per cent in all specifications except that using actual (real) written down value. In this specification the weight on capital is lower. This reflects that the often substantial revaluations in WDV are not linked to changes in output and hence imply a lower weight on this measure of capital statistically.

The weights on outputs all place most weight on the number of customers and very small (and often insignificant) weights on water and sewerage.

The implied economies of scale varies across specifications. The basic model implies that a 10 per cent increase in outputs is associated with a 9.4 per cent increase in inputs. This is lower in other specifications. For example, using the own final written down value method implies that only an 8.7 per cent increase in inputs would be necessary.

The cost frontiers implied by the model differ. In chart 7.5 we show estimated cost frontiers for the basic model and the model that allows for a difference in starting capital for those utilities sourcing from bulk water providers. In the second model, the cost frontier is lower as the Victorian utilities and Sydney Water establish a lower cost frontier than previously. This of course makes SA Water appear less efficient relative to the frontier.

7.5 Cost frontiers from two models

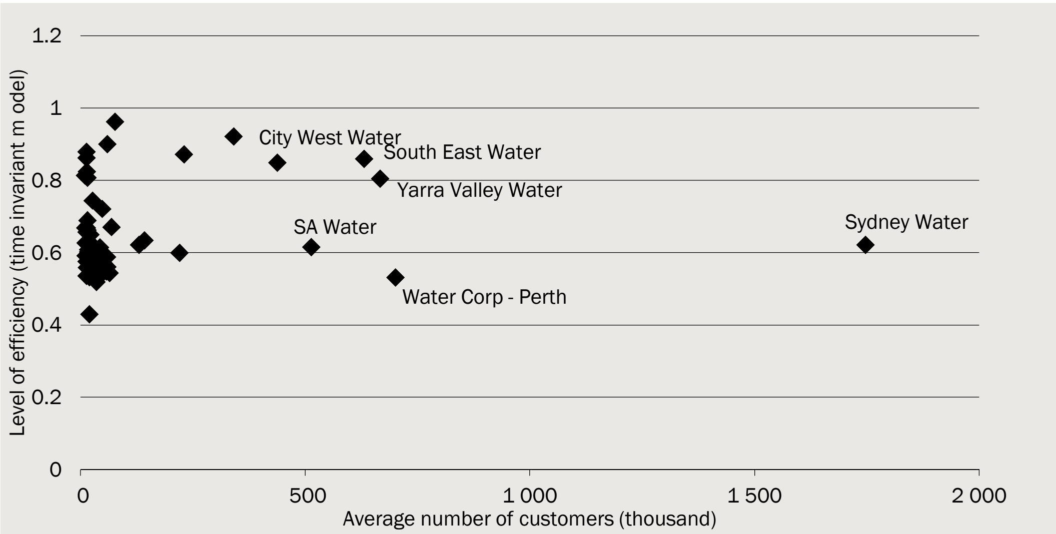


Data source: The CIE.

SA Water performs better than an average utility in terms of inefficiency in 3 of the specifications shown in table 7.7. It performs more poorly in the model where utilities sourcing bulk water from other providers are allowed a different initial asset base. It also performs poorly when a utility's own initial WDV is used as the basis for rolling forward the capital base.

The performance of each utility for the model where the initial capital level is adjusted depending on whether the utility purchases bulk water is shown in chart 7.6. This looks similar to the productivity results in chapter 6 with an adjustment for scale.

7.6 Utility results for model adjusted for the role of the utility



Data source: The CIE.

The substantive differences in results even though capital expenditure profiles and operating expenditures are maintained through the first four models (from table 7.7) highlights the sensitivity to the measurement of capital services.

7.7 Alternative capital specifications

Variable	Basic model		Basic model adjusted for the role of the utility		Own initial written down value		Own final written down value		Written down value each year	
	Coef.	P-value	Coef.	P-value	Coef.	P-value	Coef.	P-value	Coef.	P-value
The dependent variable is non-capital costs.										
Capital cost to non-capital cost ratio	-0.74	0.00	-0.79	0.00	-0.73	0.00	-0.80	0.00	-0.32	0.00
Number of properties	0.92	0.00	0.89	0.00	0.91	0.00	0.84	0.00	0.72	0.00
Quality adjusted water	0.01	0.39	0.01	0.33	0.00	0.60	0.00	0.70	-0.01	0.54
Quality adjusted sewerage	0.01	0.54	0.03	0.34	-0.00	0.95	0.03	0.24	0.11	0.00
Share of customers with sewerage	1.03	0.00	1.18	0.00	1.31	0.00	1.36	0.00	0.85	0.00
Share of water sourced from groundwater	0.03	0.61	0.06	0.36	0.12	0.30	0.16	0.05	0.04	0.60
Share of waste that is trade waste	0.14	0.46	0.21	0.45	-0.60	0.26	-0.66	0.14	0.06	0.78
Constant	4.63	0.00	4.94	0.00	3.00	0.42	5.05	0.00	-1.21	0.01
Other statistics										
Log-likelihood	362.6		364.0		248.3		361.77		182.33	
Number of observations	444		444		390		452		395	
Mu	0.07		0.45		1.72		0.78		-2.22	
Average firm inefficiency	0.13		0.35		0.71		0.51		0.12	
Standard deviation of firm inefficiency	0.08		0.13		0.13		0.15		0.09	
SA Water efficiency	0.94		0.61		0.20		0.50		0.91	
SA Water relative to average	1.08		0.94		0.69		1.03		1.03	
SA Water relative to the top 25th per cent	0.94		0.86		0.61		0.88		0.97	

Source: The CIE.

Alternative specifications

A main purpose of the analysis is to test how robust the findings for SA Water are to alternative specifications of the statistical model. For this reason we run the models set out in table 7.8. The specifications vary according to the sample (years and utilities), whether desalination costs are included or stripped out (excluded), the inclusion of factors for density and other 'environmental' variables.

7.8 Statistical models used

No.	Name	Capital services measure	Time sample	Utility sample	With desalination costs	Time varying efficiency
1	Base	Rolled forward	1998–2011	All	Yes	No
2	Recent years	Rolled forward	2006–2011	All	Yes	No
3	Density of water network	Rolled forward	1998–2011	All	Yes	No
4	Excluding desalination	Rolled forward	1998–2011	All	No	No
5	Major utilities	Rolled forward	1998–2011	Major	Yes	No
6	Random effects	Rolled forward	1998–2011	All	Yes	No

Source: The CIE.

We present the full results for the base model and only results for SA Water for other models.[60]

All models have inputs as a measure of capital and a measure of operating costs and measures of outputs as customers connected, water delivered (with adjustment for quality) and sewerage treated (again with adjustment for quality), following the specification used by Cunningham (2012).

Key parameters from these models are set out in tables 7.9 and 7.10. The weights are relatively similar except for the models only using more recent years in which the weight placed on capital is much lower.

60 Additional statistics can be provided on request and can be included in the final report if required.

7.9 Estimation across models – Basic model

No.	Model	Weight on properties	Weight on water	Weight on sewerage	Weight on capital
		Ratio	Ratio	Ratio	Ratio
1	Base	0.92	0.01	0.01	0.74
2	Recent years	0.87	0.00	0.05	0.58
3	Density of water network	0.91	0.01	0.02	0.74
4	Excluding desalination	0.93	0.01	0.00	0.74
5	Major utilities	0.91	-0.07	0.13	0.81
6	Random effects	0.91	0.01	0.02	0.76

Source: The CIE.

7.10 Estimation across models – bulk water adjustment

No.	Model	Weight on properties	Weight on water	Weight on sewerage	Weight on capital
		Ratio	Ratio	Ratio	Ratio
1	Base	0.89	0.01	0.03	0.79
2	Recent years	0.84	0.01	0.05	0.57
3	Density of water network	0.89	0.01	0.03	0.79
4	Excluding desalination	0.91	0.01	-0.01	0.78
5	Major utilities	0.95	-0.11	0.12	0.85
6	Random effects	0.89	0.01	0.03	0.79

Source: The CIE.

The efficiency of SA Water for the other models tested is reported in table 7.11 and 7.12.

- For most specifications using the same initial capital base method, SA Water is similar to the efficiency level of the top 25 per cent of water utilities. The exception is the model using only major utilities. SA Water performs about average in this model.
- The removal of desalination expenditure slightly improves SA Water's efficiency.
- For specifications using the capital base allowing for differences for those purchasing bulk water and others, SA Water has a level of inefficiency lower than the average utility. This reflects that many of the larger utilities are impacted by this change, making the frontier more difficult to achieve for SA Water. The exception is for recent years, where SA Water performs around the level of the top 25 per cent of utilities.

7.11 Results across models – Basic model

No.	Model	SA Water efficiency	SA Water relative to average	SA Water relative to 25th percentile	SA Water rank
		Ratio	Ratio	Ratio	No.
1	Base	0.943	1.084	1.002	13
2	Recent years	0.978	1.082	1.017	5
3	Density of water network	0.946	1.082	1.001	13
4	Excluding desalination	0.971	1.096	1.024	6
5	Major utilities	0.915	1.006	0.937	8 (out of 11)
6	Random effects	0.871	1.076	1.000	15

Note: Rank out of 54 unless otherwise specified.
Source: The CIE.

7.12 Results across models – bulk water adjustment

No.	Model	SA Water efficiency	SA Water relative to average	SA Water relative to 25th percentile	SA Water rank
		Ratio	Ratio	Ratio	No.
1	Base	0.615	0.939	0.863	27
2	Recent years	0.874	1.123	1.002	14
3	Density of water network	0.616	0.938	0.866	28
4	Excluding desalination	0.634	0.940	0.872	30
5	Major utilities	0.650	0.825	0.675	6 (out of 11)
6	Random effects	0.631	0.953	0.893	26

Note: Rank out of 54 unless otherwise specified.
Source: The CIE.

Estimation of the model using a translog functional form

The analysis above has used a Cobb-Douglas functional form, which implies relatively strong assumptions about the shape of the cost function. An alternative more flexible functional form is the translog form. Unfortunately, while also being more flexible, it is also more difficult to generate results that are sensible in the context of parameters that would be reasonable for the water and wastewater industry.

The translog form allows for inputs and outputs to be inter-related. For instance, rather than there being constant elasticities of cost with respect to alternative outputs, these can vary with the amount of output, giving the potential for diminishing returns to scale.

The statistical outputs from two alternative translog models are shown in tables 7.13 and 7.14. The first uses the same starting capital value as used in our basic model. The second adjusts for whether the utility purchases bulk water. We show coefficients as x and y's due to inter-relationships, and also report average elasticities.

These models give counter-intuitive relationships for sewerage, with greater sewerage associated with lower cost, on average.[61]

7.13 Statistical output for translog models

Variable	Base model variables in translog form		Basic model adjusted for the role of the utility in translog form	
	Coefficient	P-value	Coefficient	P-value
Dependent variable: log of operating costs				
y1	-0.98	0.00	-0.92	0.00
y2	-0.04	0.10	-0.05	0.03
y3	0.00	0.93	0.05	0.14
y11	-0.13	0.07	-0.35	0.00
y12	0.03	0.10	0.07	0.00
y13	0.14	0.02	0.30	0.00
y22	-0.02	0.00	-0.02	0.00
y23	-0.02	0.42	-0.05	0.01
y33	-0.13	0.01	-0.26	0.00
y1x1	-0.05	0.36	-0.07	0.16
y2x1	-0.03	0.24	-0.02	0.44
y3x1	0.04	0.46	0.08	0.06
y1t	-0.01	0.00	-0.01	0.00
y2t	0.00	0.05	0.00	0.28
y3t	0.00	0.35	0.01	0.02
x1	1.00	0.00	0.91	0.00
x11	0.17	0.04	0.24	0.00
x1t	0.04	0.00	0.02	0.00
z1: Trade waste share	-0.04	0.07	-0.05	0.06
Z2: Sewerage customer share	-0.68	0.00	-0.63	0.00
Z3: Groundwater share	-0.01	0.03	-0.01	0.02
Time	0.02	0.00	0.02	0.00
Time squared	-0.01	0.00	-0.01	0.00
Constant	-0.90	0.00	-0.99	0.00

Note: y1 is –ln(customer numbers); y2 is –ln(water volume adjusted for quality); y3 is –ln(sewerage volume adjusted for quality); x1 is –ln(capital stock/operating costs); yii is yi^2/2; yij is yi*yj, yixi is yi*xi; zi are measure as negatives; time and time squared are measured as negatives; xit and yit are interactions with time.

Source: The CIE.

61 The volume of sewage treated is in part influenced by the volume of stormwater ingress into the sewerage network. So in periods of high rainfall, the volume of sewage treated also increases. However, this is unlikely to explain inverse relationship between volume of sewage treated and treatment cost.

7.14 Statistical output for translog models

Variable	Base model variables in translog form Coefficient	Basic model adjusted for the role of the utility in translog form Coefficient
Mu	0.11	0.28
Observations	444	444
Number of panels	54	54
Log likelihood	558.79	540.28
Average firm inefficiency	0.14	0.24
Standard deviation of firm inefficiency	0.08	0.12
Average elasticity – properties	-1.13	-1.04
Average elasticity – water	-0.01	-0.04
Average elasticity – sewerage	0.04	0.12

Source: The CIE.

Under the basic translog model, SA Water's measure of inefficiency is 0.93. That is, it is estimated to be 7 per cent below the efficiency frontier on average over the period 1998 to 2011 (table 7.15). This efficiency score is within the top 25 per cent of utilities. If allowance is made for bulk water utilities then SA Water's performance is much poorer, because most other large firms have lower capital, shifting the frontier for larger firms in particular.

7.15 SA Water's efficiency – translog model

Statistic	Basic model Value	Basic model with adjustment Value
SA Water efficiency measure	0.93	0.65
SA Water relative to best utility	0.94	0.66
SA Water relative to 25th percentile utility	1.02	0.78
SA Water relative to average across sample	1.08	0.86

Source: The CIE.

Comparison to ESC analysis

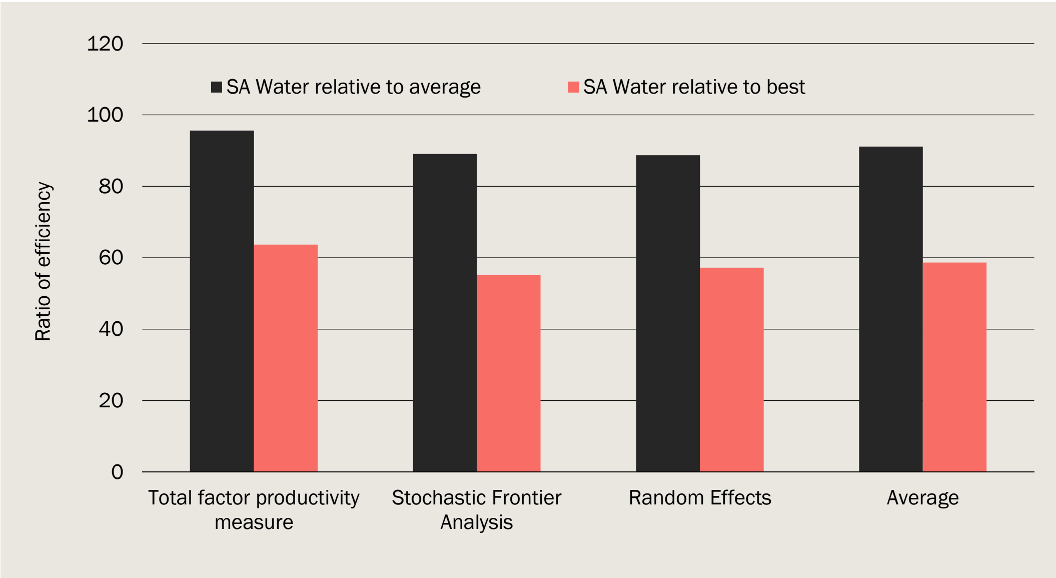
Our results suggest that SA Water is relatively efficient compared to other water utilities in Australia, although perhaps less so relative to major utilities. This differs from the findings of previous analysis in Cunningham (2012).[62] This analysis found that SA Water was less efficient than the average utility and had measure of inefficiency of about 40 per cent (chart 7.16).

The difference between this result and ours reflects the method of calculating capital services. Cunningham 2012 uses a physical measure of the capital (mainly based on the

62 Cunningham, M. 2010, *An analysis of the productivity of the Victorian water industry,* Essential Services Commission of Victoria Staff Research Paper, No. 2012/1, March

length of water and sewer mains) and a measure based on the most recent written down value rolled backwards using capital expenditure and depreciation. The majority of weight is placed on the physical capital measure. Hence SA Water has a low level of efficiency because it has more pipes per property than other utilities of similar size and a relatively high WDV. This is one measure of efficiency but is likely to be of less use to ESCoSA as it does not directly relate to expenditures incurred by SA Water.

7.16 ESC efficiency analysis



Data source: Cunningham, M. 2010, *An analysis of the productivity of the Victorian water industry,* Essential Services Commission of Victoria Staff Research Paper, No. 2012/1, March.

When we replicate the methodology used by the ESC for the stochastic frontier analysis we find similar results, as shown in table 7.17. (Note that some slight changes are made to the method in terms of the exclusion made by the ESC to remove expenditures related to environmental levies.)

7.17 SA Water's efficiency – updated ESC model

Statistic	CIE results using update of ESC method
	Value
SA Water efficiency measure	0.54
SA Water relative to best utility	0.55
SA Water relative to 25th percentile utility	0.75
SA Water relative to average across sample	0.83

Source: The CIE.

8 SA Water's country operations

The analysis in this report has focused on the efficiency of SA Water's operations in Adelaide, as this is the basis for the structure of the regulation of SA Water. SA Water's operations outside Adelaide are far most expensive than within Adelaide on a per customer basis (table 8.1). For example, water expenses, which includes operating expenses, depreciation and borrowing costs, are 250 per cent higher in SA Water's country areas relative to Adelaide and sewerage expenses are double in country areas. To service the same population more than five times the length of mains pipes is used in country areas, relative to metropolitan areas.

8.1 SA Water's country operations

Item	Adelaide	Country
Expenses per customer — water ($)	397	1028
Expenses per customer — sewerage ($)	352	717
Fixed assets written down value ($000) [a]	6 623 538	3 791 561
Asset value per property ($)[b]	12 831	28 063
Length of mains (kms)	9 020	17 532
Length of sewers (kms)	7 252	1 451
Water delivered (ML)	129 000	67 665
Estimated population served - water	1 140 000	417 000
Estimated population served - sewerage	1 076 000	163 000

[a] Country written down value is based on total SA Water infrastructure, plant and equipment value of $12.874 billion less the fixed asset written down value for water and sewerage for Adelaide operations reported by SA Water to the National Water Commission. [b] Average of water and sewerage properties. [c] The profit component represents the return on equity less the part of this return that is capitalised. Note that borrowing costs are nominal, so this is below the full return on equity.

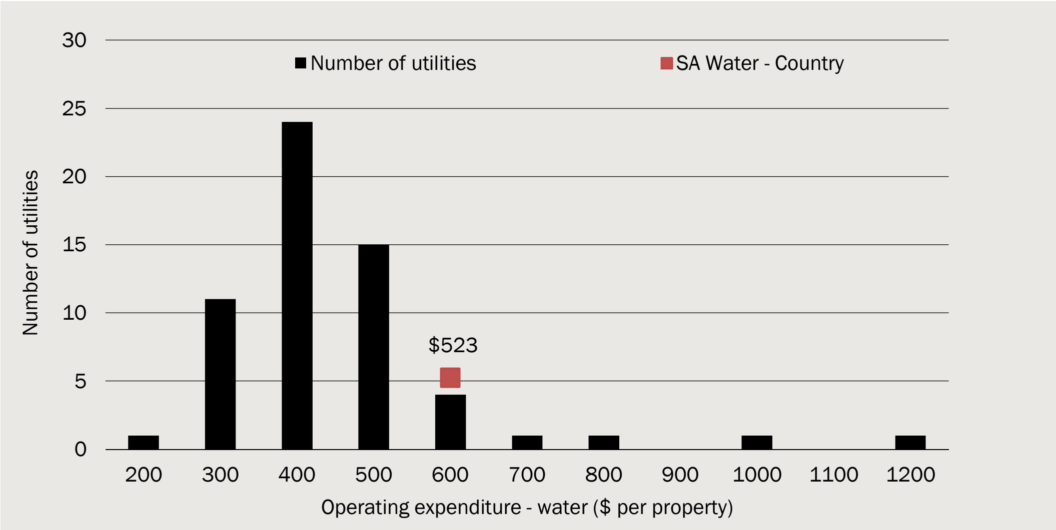
Note: The population to property ratio is calculated as 2.15 based on information for Adelaide operations. Depreciation and borrowing costs are incorporated into expenses.

Source: CIE analysis; SA Water Annual Report 2010/11; National Water Commission National Performance Indicators.

We can consider SA Water's Country operations for the latest year against those of all other utilities in our sample. SA Water's country operations are towards the highest cost end of the spectrum for water operating expenses per property and written down value per property, and around average for sewerage operating costs per property (charts 8.2 to 8.4).[63]

63 We have had to estimate operating costs from data provided on total expenses, which includes depreciation and borrowing. We have done this using the share of operating expenses in total expenses for SA Water as a whole.

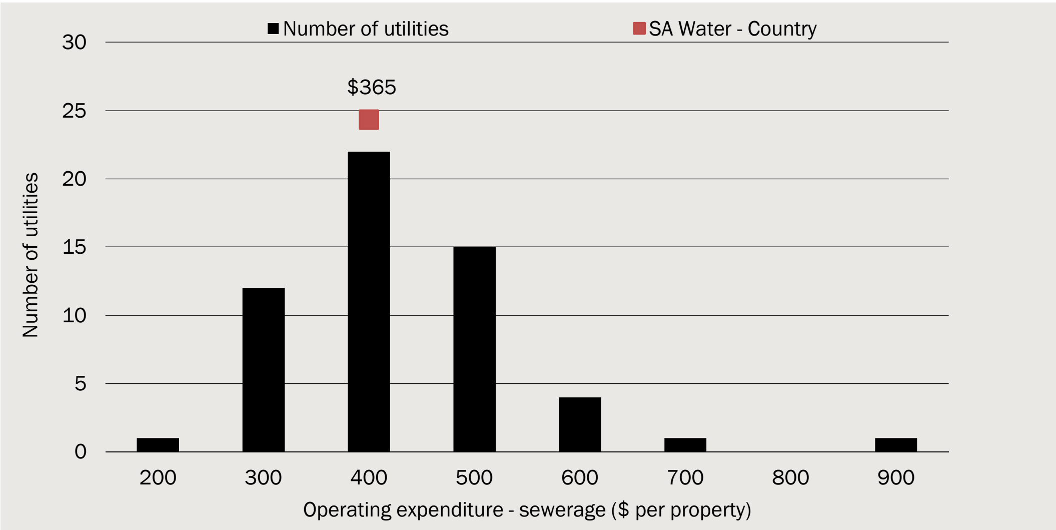
8.2 SA Water country water operating expenditure per property



Note: Comparison is for 2010/2011 financial year. The expenses per customer reported in the SA Water Annual Report have been adjusted downward to remove borrowing and depreciation costs.

Data source: National Water Commission 2011, National performance Report; SA Water Annual Report 2011.

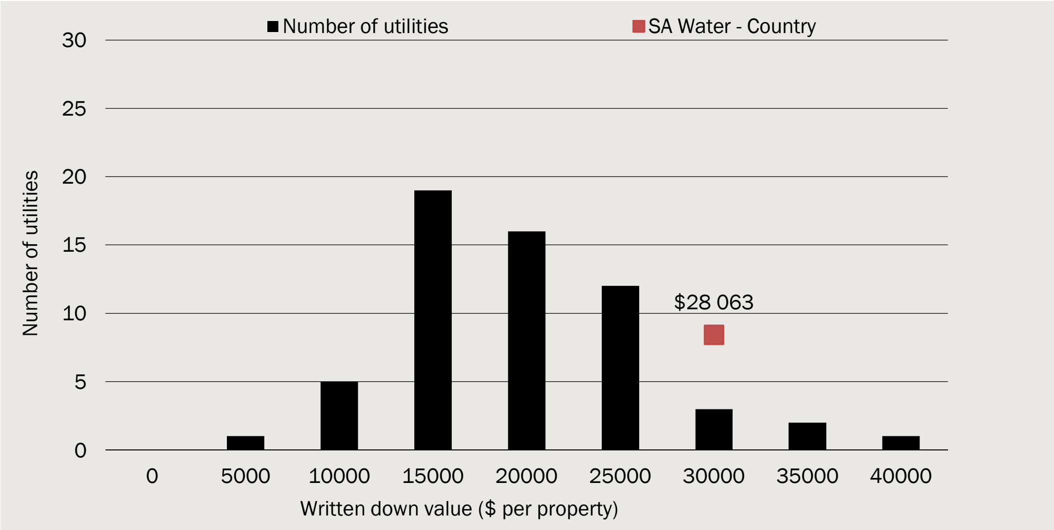
8.3 SA Water country sewerage operating expenditure per property



Note: Comparison is for 2010/2011 financial year. The expenses per customer reported in the SA Water Annual Report have been adjusted downward to remove borrowing and depreciation costs.

Data source: National Water Commission 2011, National performance Report; SA Water Annual Report 2011.

8.4 SA Water country written down value per property



Note: Comparison is for 2010/2011 financial year.

Data source: National Water Commission 2011, National performance Report; SA Water Annual Report 2011.

Many of SA Water's country operations will be smaller than the sample of utilities that we have. This makes it difficult to draw conclusions about the efficiency of SA Water's country operations in any meaningful way.

9 Interpreting efficiency for SA Water review

There are many issues (as discussed in chapter 3) that influence the weight that should be placed on efficiency analysis across Australian water utilities. In this section we discuss the implications of the results from our analysis and how they should be interpreted in considering the efficiency of SA Water for regulatory purposes.

Summary of results

SA Water performs relatively well in its efficiency in most of the models tested in this study, typically being around the 25th percentile of utilities. SA Water performs less well against other major water utilities than it does against the sample as a whole, but appears to perform better in more recent years (post-2006) than when a full sample from 1998 is used.

There are exceptions to the finding that SA Water is relatively efficient, largely from using alternative measures of the capital base.

These results suggests that while from a tops-down perspective there is likely to be scope for efficiency gains from SA Water, the magnitude of these gains may be moderate.

Confidence in results

The measured efficiency of SA Water is extremely sensitive to some aspects of the estimation, such as the capital stock, highlighted between the difference between our findings and those of Cunningham (2012) for SA Water. The sensitivity to the capital stock measure suggests that the results should be viewed with caution.

There also remain a number of potential differences across utilities that are not accounted for in our analysis. These include topographical characteristics of the systems serviced, differences in available input prices and differences in water availability. Utilities will be able to point to specific factors influencing the possible efficiency of their operations, which also suggests caution in deciding that SA Water is or is not capable of substantial efficiency gains.

Finally, even where a utility is efficient, it may be difficult or slow to remove inefficiency if this inefficiency is related to sunk capital investments, such as water supply options. (It may be more feasible to focus on the appropriate use of water supply options instead to encourage efficiency.)[64]

We have included or tested for a number of potential uncontrollable factors into the productivity analysis, such as density. One factor that was not included but is an

64 One example of this relates to the potential operating rules of Adelaide's desalination plant.

important component of expenditure is the amount of pumping required to move water and sewage through the networks. The greater the amount of pumping required the greater the electricity costs and likely the higher the capital and maintenance costs associated with pumping equipment. Pumping could reflect the topography of the system and sources of water, although they could also be higher due to inefficiencies in the network or pumping system.

We do not have specific information on electricity used for each utility. However, we do have a measure of the net GHG emissions that each utility produces.[65] This is likely to be a close proxy for electricity use, with the major difference being where a utility uses green energy. Green energy is used for most desalination plants but we understand that it is not common practice to use green energy for pumping. To be a useful measure, the GHG emissions need to be added up across the supply chain, so that differences in the total system can be established. For instance, GHG emissions for Melbourne Water need to be added to those of the Melbourne retailers to provide a measure of system GHG emissions.

SA Water's Adelaide operations has a relatively high GHG emissions per property served of 588 tonnes per thousand properties (table 9.1). This compares to Melbourne and Sydney utilities with less than half of this. The level of GHG emissions is similar to Perth, where there is a lot of pumping of water sourced from groundwater. For SA Water, GHG emissions relate to the amount of water pumped directly from the River Murray and can therefore be very volatile. SA Water's GHG emissions per 1000 properties reached almost 1000 tonnes in 2007-08.

Outside of Adelaide, SA Water faces even greater GHG emissions from pumping water from the Murray. Whyalla accesses water from the Murray through two pipelines running almost 400 kilometres each. Its average GHG emissions per 1000 properties served is 2311 — about 4 times that of SA Water's Adelaide operations.

The impact of the above differences on costs will reflect the electricity prices that water utilities can access. For SA Water as a whole, electricity has comprised around 10 per cent of costs. (This will be much higher once the desalination plant is operating.) Hence if its electricity profile were closer to that of other major utilities in Melbourne and Sydney then its operating costs would be around 5 per cent lower.

65 Information on GHG emissions is relatively patchy. For this reason we have not included this measure in the statistical analysis but instead consider the influence of pumping costs as a separate discussion.

9.1 Net GHG emissions per 1000 properties

Utility	Bulk water provider	Utility	Total
	Tonnes per 1000 properties	Tonnes per 1000 properties	Tonnes per 1000 properties
Major utilities			
SA Water — Adelaide		588	588
Yarra Valley Water	212	34	246
South East Water	212	48	260
City West Water	212	15	226
ACTEW		350	350
Water Corporation — Perth		531	531
Sydney Water [a]	75	187	262
Other			
SA Water — Whyalla		2 311	2 311
SA Water — Mount Gambier		321	321
All utilities			485

[a] Sydney Catchment Authority taken from www.sca.nsw.gov.au, accessed 23/8/2012.

Note: Utilities have data for different periods of time and there is substantial variation through time. SA Water Adelaide, the Melbourne retailers and ACTEW report data from 2005/06, Water Corporation – Perth and Sydney Water from 2006/07 and SA Water's non-Metropolitan operations from 2007/08. Melbourne Water reports only for 2009/10 and 2010/11 and Sydney Catchment Authority has no reported data. There is also no data available for Brisbane utilities.

Source: National Water Commission National Performance Indicators.

SA Water bills and SA Water costs

The analysis above suggests that SA Water has relatively moderate costs compared to other water utilities and is around average for major utilities. ESCoSA has compared the prices of services provided by SA Water and found that these prices are typically higher than other major utilities.[66] In particular, ESCoSA has found that, for 2012/13:

- SA Water's average residential water usage charge per kL is $2.76, which is higher than all other capital city water suppliers;
- SA Water's annual residential water supply charge is $293 per customer, which is higher than all other capital city water suppliers — the next highest is $188;
- SA Water's annual residential sewerage bill per customer is relatively low at $488 per customer; and
- SA Water's annual total water and sewerage bill for a representative customer is the highest of all capital city utilities and $200 per customer above the median bill of other utilities.

There are a number of reasons why SA Water's prices may be relatively high, of which inefficiency is only one.[67]

66 Essential Services Commission of South Australia 2012, *Economic regulation of SA Water's revenues: Statement of approach,* July.

67 Another possibility not able to be assessed here include the use of different depreciation rates by businesses and allowed for in prices.

- SA Water is incurring high costs per customer outside of Adelaide, which are being subsidised by higher prices in Adelaide because of postage stamp pricing.
- SA Water has a higher asset base relative to other utilities than allowed for in the method used in this study or is earning a higher return on its assets than other water utilities.
- SA Water has a higher than average bill based on the same consumption but a closer to average bill based on the consumption patterns of each utility.

Cross-subsidisation should not be occurring because the price difference is paid by the SA Government as a community service obligation The latter two explanations are considered below.

SA Water asset base and return on its asset base

As discussed in earlier chapters, one measure of the asset base of a water utility is the written down value of its fixed assets. On a per property basis, SA Water —Adelaide has a written down value similar to or below other major utilities in terms of the information reported to NWC (in 2010/11). Hence this is not a reason for pricing differences. SA Water's annual report appears to have a higher written down value for 2010/11 than that reported to the NWC, with $12.9 billion in infrastructure, plant and equipment assets reported in SA Water's 2010/11 Annual Report, compared to $10.4 billion for the written down value of fixed water and sewerage assets reported by the NWC.

SA Water does appear to earn a higher return on its assets than other major utilities on average (table 9.2). In 2010, SA Water's returns were 5 per cent across water and sewerage assets for its Adelaide operations, compared to an average across other major utilities of 2.8 per cent. Returns have also been higher for SA Water Adelaide over the period 2005/06 to 2010/11. There have been utilities with higher returns than SA Water. For instance, Queensland Urban Utilities reported a combined return of 9.3 per cent for 2010/11.

9.2 Return on assets

Utilities	Service	2010/11	Minimum 2010/11	Maximum 2010/11	Average for 2005/06 to 2010/11
		Per cent	Per cent	Per cent	Per cent
SA Water — Adelaide					
	Water	4.9			3.8
	Sewerage	5.1			6.8
	Combined	5.0			5.2
Other major utilities					
	Water	2.8	-1.6	11.7	2.3
	Sewerage	3.1	-1.6	10.2	3.6
	Combined	2.8	-0.3	9.3	2.8

Source: CIE analysis; NWC National Performance Indicators.

The higher return earned by SA Water on its assets likely reflects that other utilities are regulated with regulated asset bases well below the written down value of fixed assets (table 9.3). Most RABs are set at levels below 50 per cent of the WDV and hence the return on WDV is relatively low.

9.3 Written down values and RAB 2010/11

Utility	WDV	RAB (CPI inflated)	RAB/WDV	RAB (PGFCF inflated)	RAB/WDV
	$bn	$bn	No.	$bn	No.
Hunter Water	4.64	1.97	0.42	1.76	0.38
Gosford City Council	1.86	0.49	0.27	0.44	0.24
Wyong Shire Council	0.96	0.42	0.44	0.38	0.39
Sydney Water	34.91	13.59	0.39	12.12	0.35
Yarra Valley Water	3.67	2.93	0.80	2.61	0.71
City West Water	3.16	1.38	0.44	1.23	0.39
South East Water	3.00	2.30	0.77	2.05	0.69
ACTEW	3.34	1.51	0.45	1.51	0.45
Melbourne Water	6.83	6.87	1.01	6.13	0.90
Total	62.38	31.47	0.50	28.22	0.45

Note: RAB values from regulatory decisions are in real dollars typically for 2008/09. These have been inflated to 2010/11 dollars using either the CPI or Public Gross Fixed Capital Formation price indices — values using both methods are shown.
Source: Various regulatory determinations; NWC data and CIE analysis.

A 100 basis point higher return on the 2010/11 written down value for SA Water's Adelaide operations is equivalent to about a $125 increase in the average bill per property. With SA Water's returns being around 200 basis points higher than the average of other major utilities, this would amount to an additional $250 per customer in charges on average.

Consumption patterns

The ranking of urban utilities according to average household bill is influenced by which variable is used to construct the average. ESCoSA (2012) estimated the annual residential water and sewerage bill by jurisdiction based on a representative level of consumption of 180 kL.[68] The efficiency analysis has found little relationship between costs and the amount of water produced. Hence, if SA Water customers were using less water on average then it would be expected that they would face higher prices, even if their final bills did not end up higher.

The typical annual residential bill estimated by National Water Commission (2012) based on the average household consumption for each utility is shown against ESCoSA's estimates based on a representative consumption of water (table 9.4). SA Water's annual bill is closer to average under the NWC performance indicators. This is somewhat surprising as SA Water reported average residential water consumption of 180kL, compared to an average across other major utilities of 169kL. The better performance of

68 ESCoSA, 2012. *Economic regulation of SA Water's revenues: statement of approach.*

SA Water in the NWC measures may therefore reflect more rapidly rising prices in SA since 2010/11 than in other jurisdictions.

9.4 Alternative methods to estimate average annual household bill

Major utility	Average annual bill for each utility[a] 2010–11$	Average annual bill across major utilities[b] 2012–13$
(100 000+ connected properties)		
Sydney Water	1 039	1 074
Water Corp – Perth	1 053	1 074
Yarra Valley Water	763	1 023
South East Water	722	956
Queensland Urban Utilities	963	1 133
SA Water – Adelaide	938	1 278
City West Water	687	901
Hunter Water	841	949
ACTEW	962	1 138
Barwon Water	843	1 094
Average	881	1 062

[a] National Water Commission (NWC) 2012, *National Performance Report 2010-11: Urban water utilities.* [b] ESCoSA, 2012. *Economic regulation of SA Water's revenues: statement of approach.*

Source: As noted above.

Summary

We consider that the results of the top-down efficiency analysis will be most useful when combined with engineering style analysis of SA Water. The tops down analysis provides a guide as to what might be expected in terms of the order of magnitude of efficiency gains possible, but also suggests that the standard that SA Water is held to from this analysis should be carefully considered against the standards of other water utilities in Australia.

A Theory of efficiency analysis

Stochastic frontier analysis

The general stochastic frontier model originated in work by Aigner, Lovell and Schmidt (1977) specified a composite error term made up of two components, comprising the error component v_i which represents the symmetric disturbance and is assumed to be independently and identically distributed as $N(0,\sigma_v^2)$ and an error component u_i which represents the inefficiency with assumptions of truncated half normal distribution and independence of v_i.[69]

The general model as proposed by Aigner, Lovell and Schmidt (19770 is now the basis for efficiency analysis: [70]

$$lnyi \quad = \alpha + \beta^T x_i + v_i - u_i$$

The literature includes variations to the assumption of u_i having a truncated half normal distribution. In addition to the original assumption, Aigner, Lovell and Schmidt (1977) also propose a model based on the exponential distribution of the inefficiency term.[71] Subsequent modifications include a two-parameter gamma distribution (Greene (1990, 2003) and a truncated normal distribution of the inefficiency where the mean is not restricted to zero.[72]

Non-frontier stochastic approaches

Fixed-effects model

The fixed-effects model has been applied to the frontier modelling framework in the literature. The general model can be written as:

$$y_{it} = \alpha_i + \beta' x_{it} + \varepsilon_{it}$$

where α_i is treated as the firm specific inefficiency term and firms are compared on the basis of:[73]

$$\alpha_i^* = max_i \alpha_i - \alpha_i$$

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[69] Aigner, D., Lovell, C. A. K., and Schmidt, P. 1977. *Formulation and estimation of stochastic frontier production function models*. Journal of Econometrics 6: 21-37.

[70] Chpt2

[71] Aigner, D., Lovell, C. A. K., and Schmidt, P. 1977. *Formulation and estimation of stochastic frontier production function models*. Journal of Econometrics 6: 21-37.

[72] Greene, W., 2002. *Alternative Panel Data Estimators for Stochastic Frontier Models.*

[73] Greene, W. 2002. *Alternative panel data estimators for stochastic frontier models*.

The fixed-effects model does not impose a distributional assumption on the inefficiency term, u_i, and allows it to be correlated with the error term, v_{it} and explanatory variables, x_{it}.

Disadvantages of the fixed-effects model are created by the absence of a distribution assumption on the inefficiency term, u_i, and include:

- the efficiency estimation in this model is only relative to the 'best' firm in the sample;[74]
- time invariant effects in the model are absorbed into the inefficiency term even in cases where the time invariant effects do not influence inefficiency. Time invariant effects may vary across producers but not through time, for example locational characteristics and regulatory regime; and[75]
- efficiency estimates from a fixed effects model with a small sample are unreliable.[76]

Random-effects model

The random-effects model is distinguished from the fixed-effects model by the inefficiency term, u_i, allowed to be random, with unspecified distribution having constant mean and variance, but assumed to be uncorrelated with the v_{it} and x_{it}.

The tighter parameterisation of the random-effects model compared to the fixed-effects model allows time-invariant attributes which vary by firm to be included in the model. Greene (2008) notes the random-effects regression model is easily adapted to the stochastic frontier model.[77]

The main disadvantage of the random-effects model is it requires a strong assumption that the inefficiency effects are time invariant and uncorrelated with the variables in the model.[78]

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74 Greene, W., 2002. *Fixed and Random Effects in Stochastic Frontier Models.* NYU Stern Publications. *http://people.stern.nyu.edu/wgreene/fixedandrandomeffects.pdf*

75 Fried, H. O., Lovell, C. A. K., and Schmidt, S. S. 2008. *Efficiency and Productivity* in Fried, H. O., Lovell, C. A. K., and Schmidt, S. S. (eds.) *The Measurement of Productive Efficiency and Productivity.* New York: Oxford University Press.

76 Greene, W., 2002. *Fixed and Random Effects in Stochastic Frontier Models.* NYU Stern Publications. *http://people.stern.nyu.edu/wgreene/fixedandrandomeffects.pdf*

77 Greene, W., 2007. *Chapter 2: The econometric approach to efficiency analysis* in *The Measurement of Productive Efficiency and Productivity Growth*. page. 172

78 Greene, W., 2002. *Fixed and Random Effects in Stochastic Frontier Models.* http://pages.stern.nyu.edu/~wgreene/publications.htm

Translog functional form

Production frontier

A general translog stochastic production frontier as defined by Coelli et al. (2003) can be written as:[79]

$$y_{nt} = \alpha_0 + \sum_{i=1}^{K} \alpha_i x_{int} + \frac{1}{2}\sum_{i=1}^{K}\sum_{j=1}^{K} \alpha_{ij} x_{int} x_{jnt} + \sum_{i=1}^{K} \delta_i x_{int} t + \lambda_1 t + 0.5\lambda_{11} t^2 + v_{ny} - u_{nt}$$

n= 1,2,…..,N; t = 1,2,…, T.

where y_{nt} is the log of outputs quantity; x_{int} is the log of i-th input quantity; t is a time trend; v_{nt} is a noise error term and u_{nt} is the inefficiency term, entered with a negative sign because inefficiency means less output. The subscripts n and t index firm and time period, respectively.

Translog input-orientated distance function

In the multiple output case where we wish to estimate an input distance function, the equivalent translog input distance function with multiple outputs, M, and multiple inputs, K, can be written as:[80]

$$\begin{aligned} d_{nt} = \alpha_0 + \sum_{m=1}^{M} \beta_m y_{mnt} \\ + \frac{1}{2}\sum_{m=1}^{M}\sum_{i=1}^{M} \beta_{mi} y_{mnt} y_{int} + \sum_{k=1}^{K} \beta_k x_{knt} + \frac{1}{2}\sum_{k=1}^{K}\sum_{j=1}^{K} \alpha_{kj} x_{knt} x_{jnt} \\ + \sum_{k=1}^{K}\sum_{m=1}^{M} \gamma_{km} x_{knt} y_{mnt} + \sum_{i=1}^{K} \delta_i x_{int} t + \sum_{i=1}^{M} \phi_i y_{int} t + \lambda_1 t + 0.5\lambda_{11} t^2 \end{aligned}$$

Where d_{nt} is the log of the input distance, y_{mnt} and x_{knt} are outputs and inputs respectively and the Greek letters represent parameters to be estimated.[81]

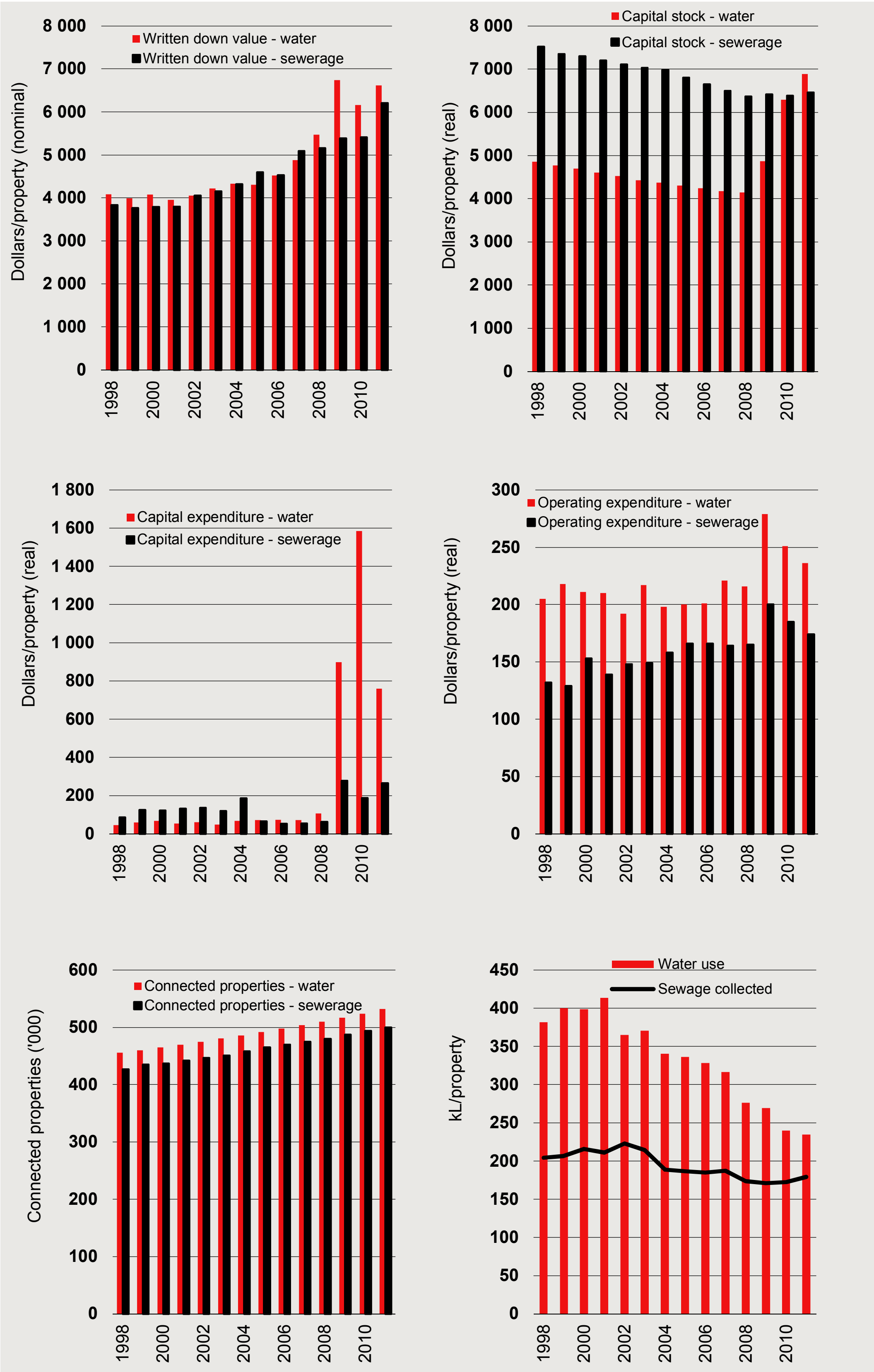
79 Coelli, T., Estache, A., Perelman, S., Trujillo, L. 2003. *A Primer for Efficiency Measurement for Utilities and Transport Regulators.* The World Bank, Washington, D.C.

80 Coelli, T., Estache, A., Perelman, S., Trujillo, L. 2003. *A Primer for Efficiency Measurement for Utilities and Transport Regulators.* The World Bank, Washington, D.C.

81 Coelli, T., Estache, A., Perelman, S., Trujillo, L. 2003. *A Primer for Efficiency Measurement for Utilities and Transport Regulators.* The World Bank, Washington, D.C.

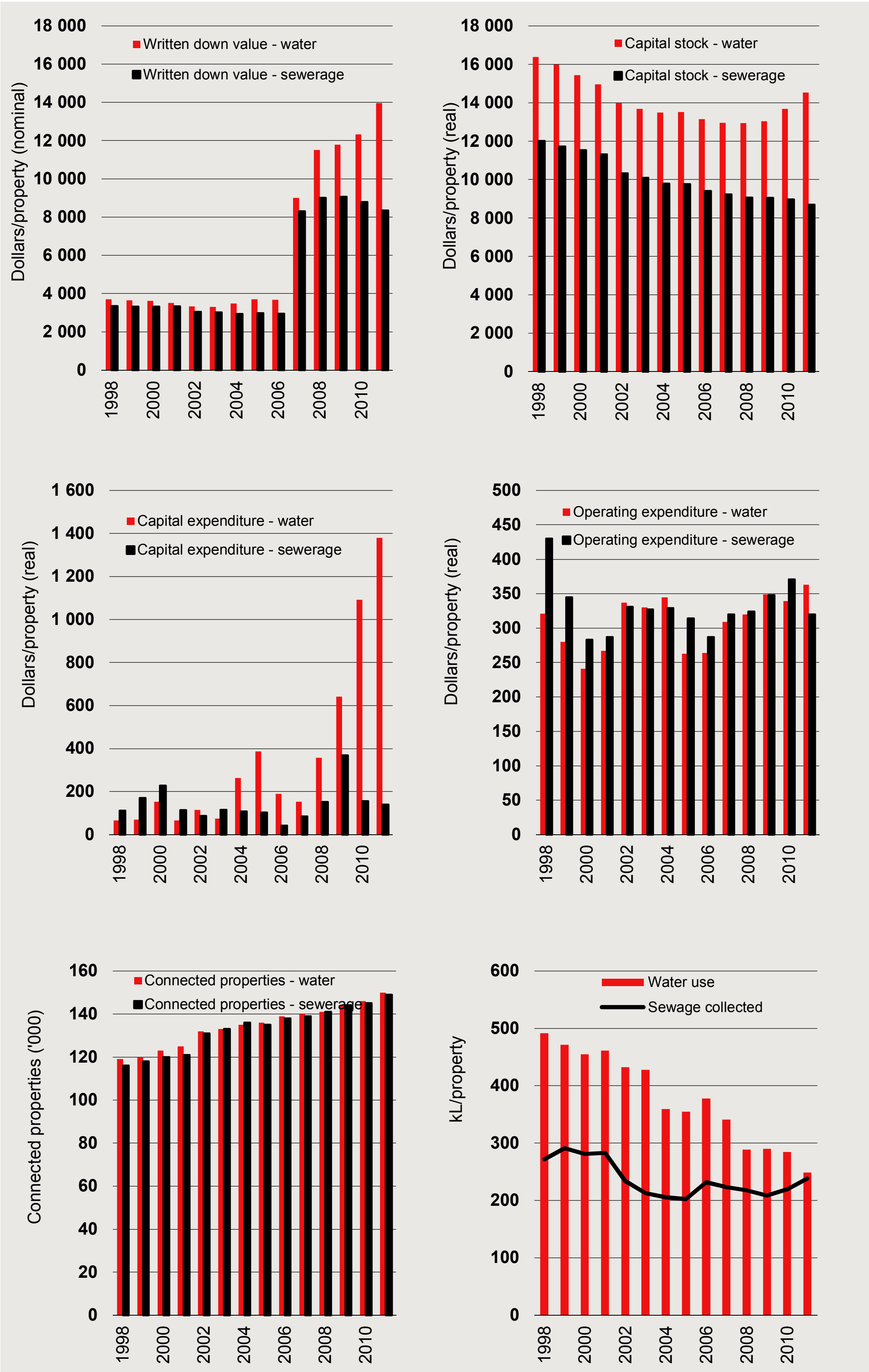
B Data for major utilities

B.1 SA Water



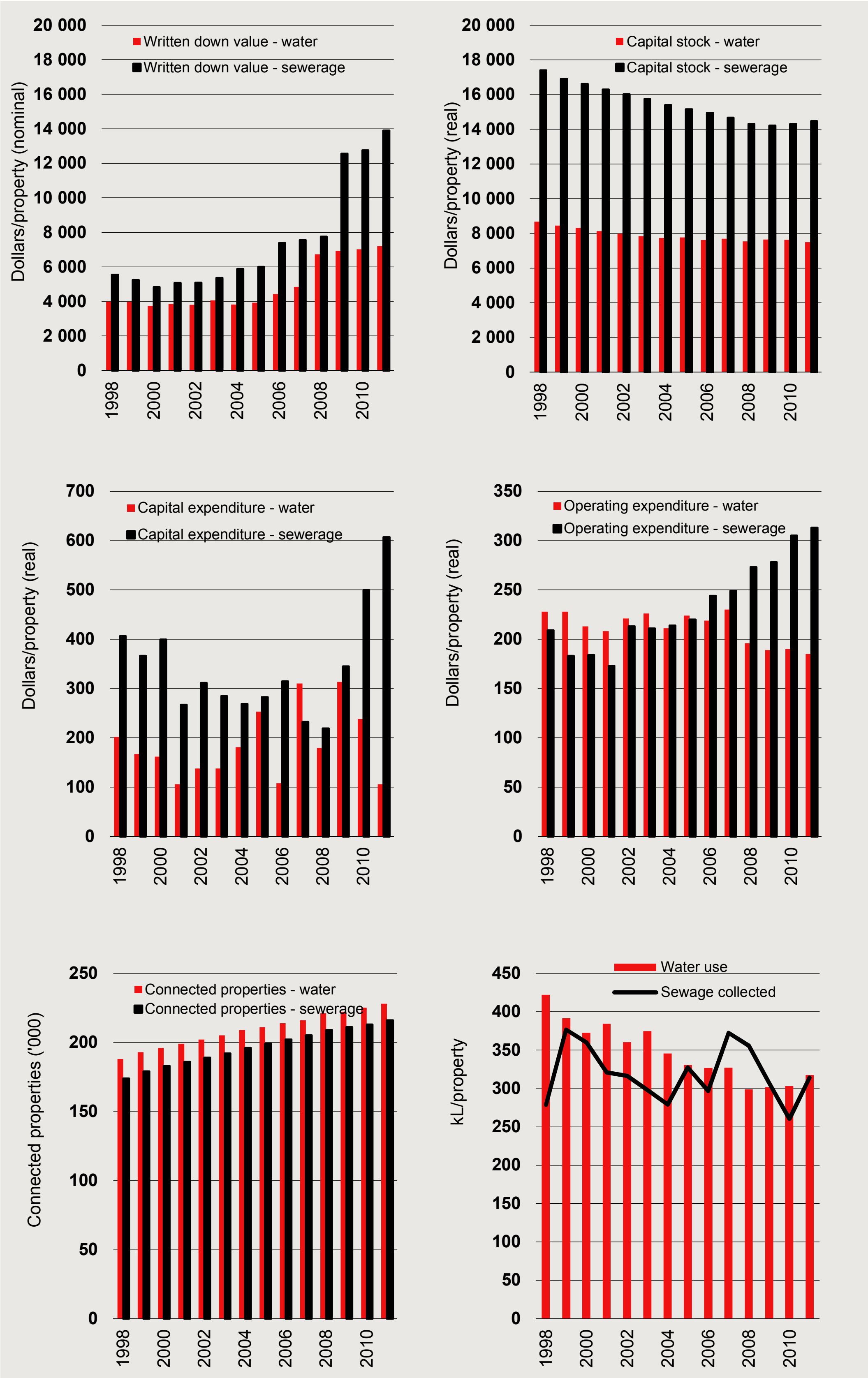
Data source: The CIE

B.2 ACTEW



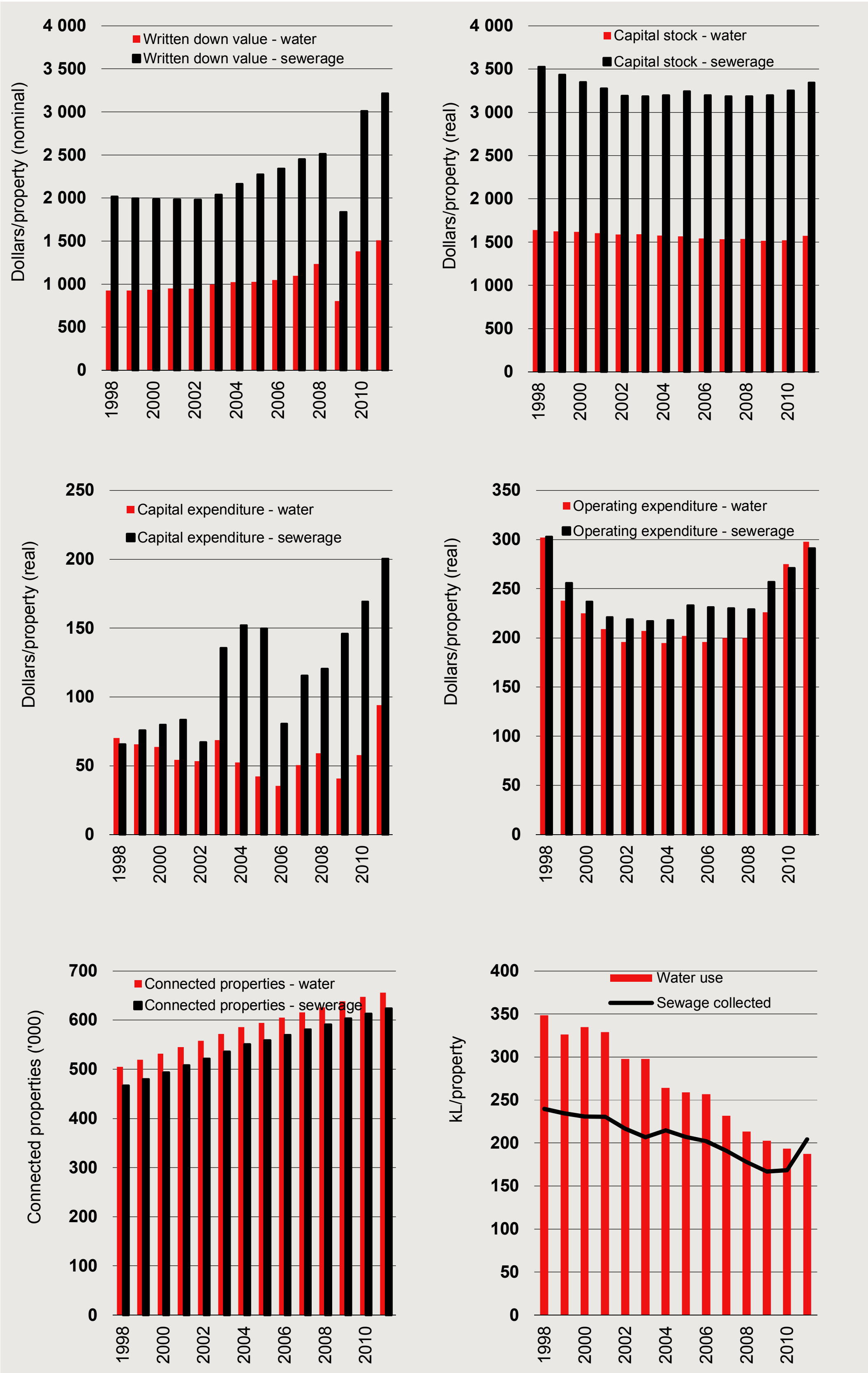
Data source: The CIE

B.3 Hunter Water Corporation



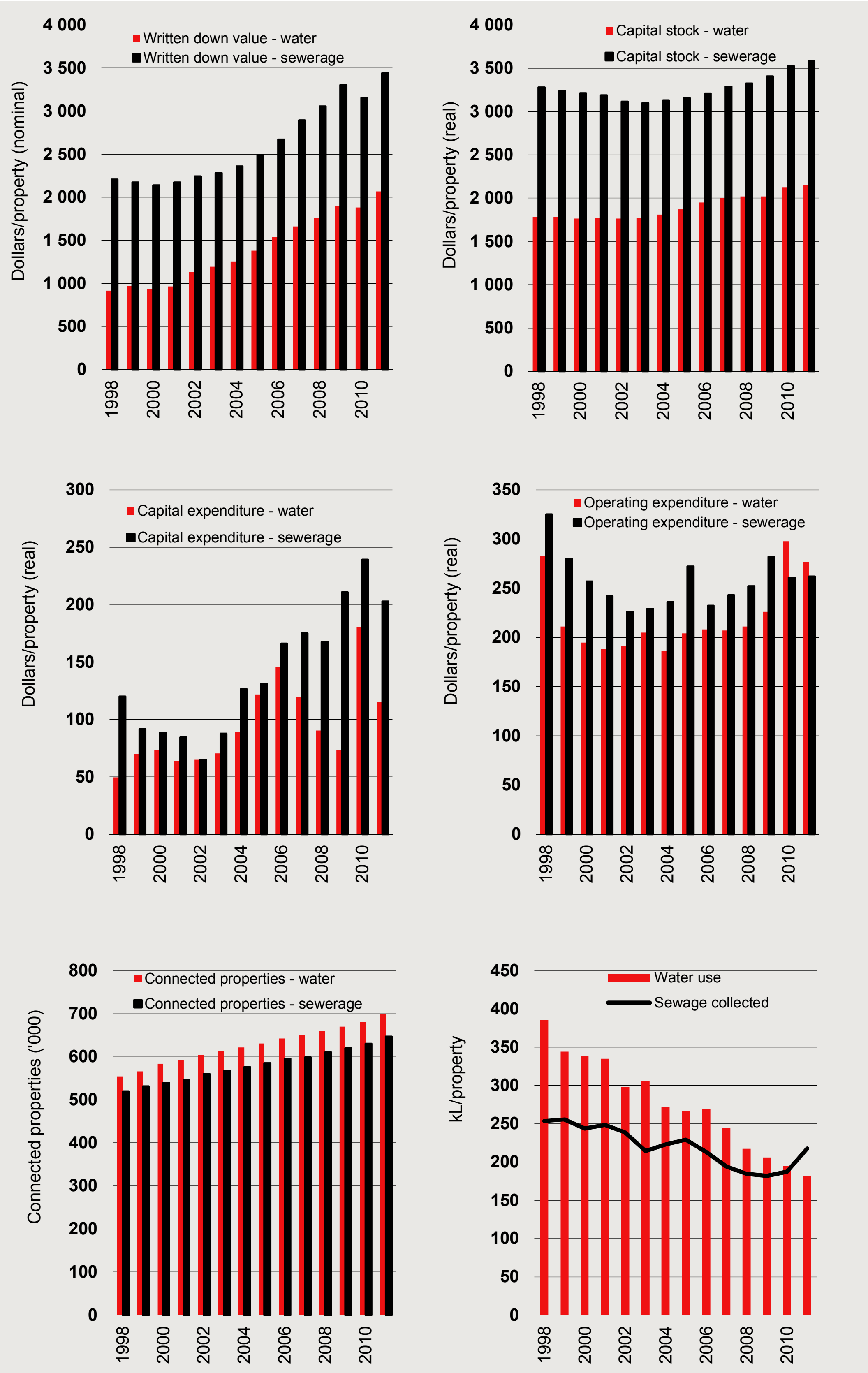
Data source: The CIE

B.4 South East Water Ltd



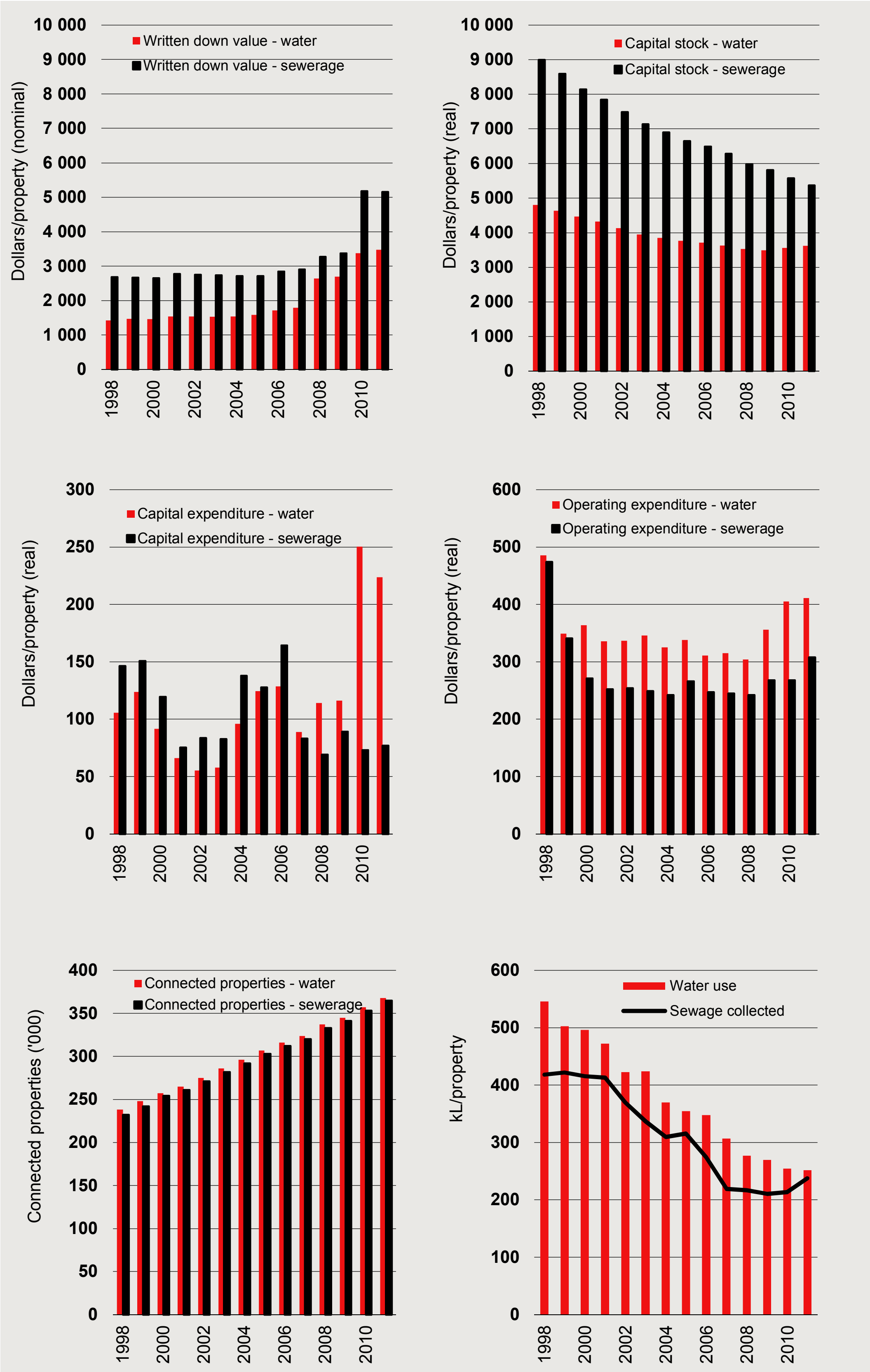
Data source: The CIE

B.5 Yarra Valley Water



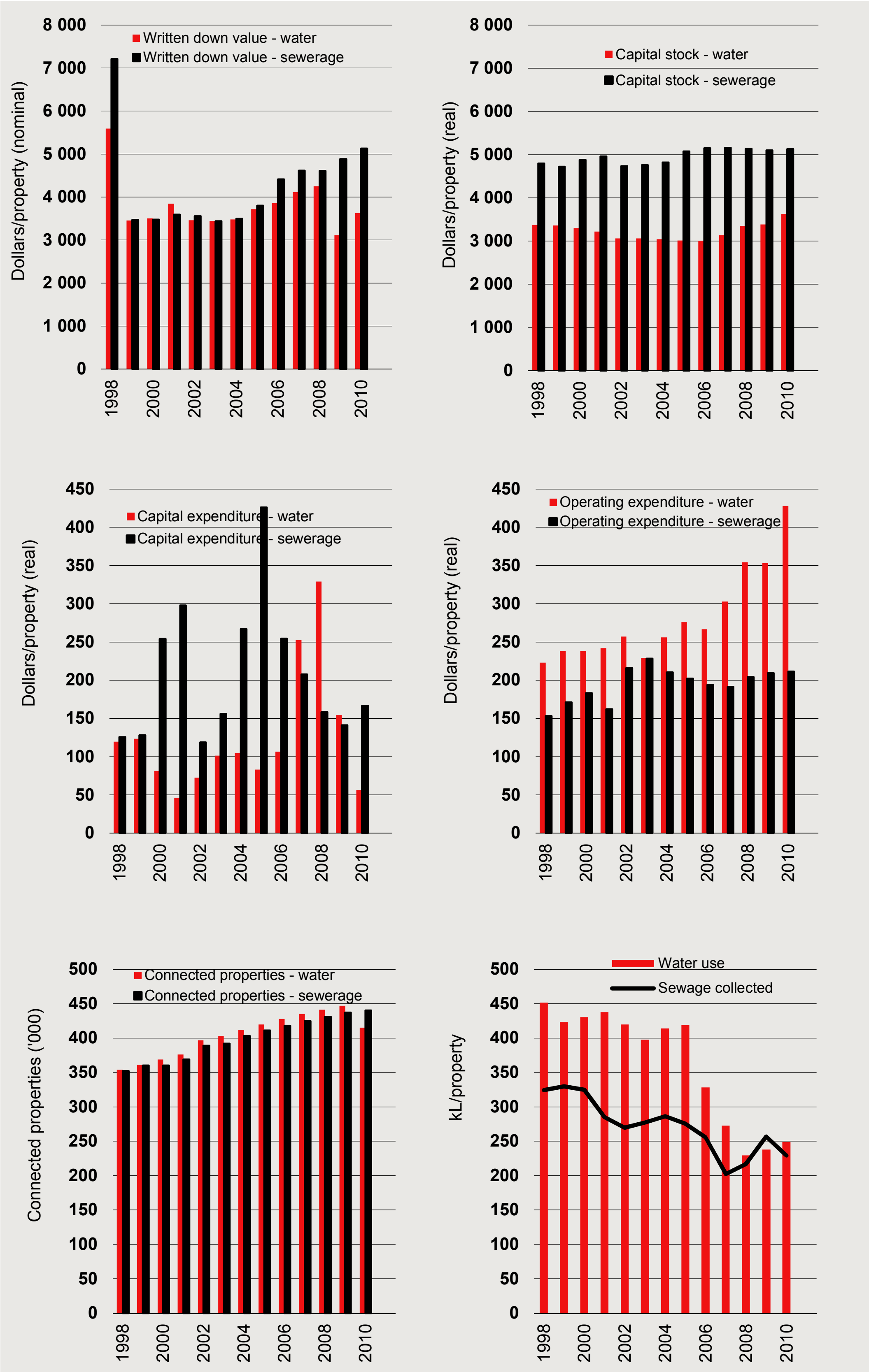
Data source: The CIE

B.6 City West Water



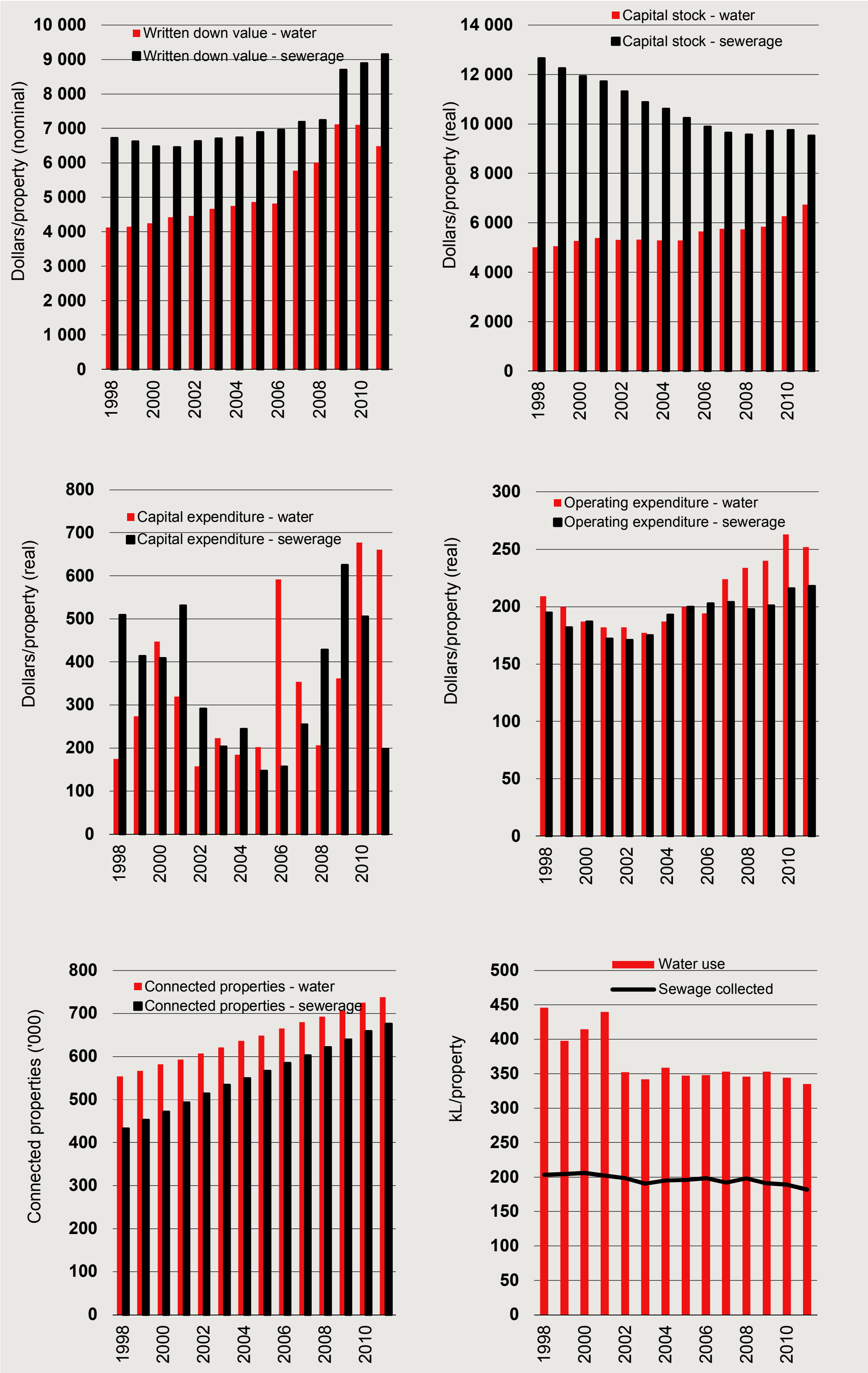
Data source: The CIE

B.7 Brisbane Water



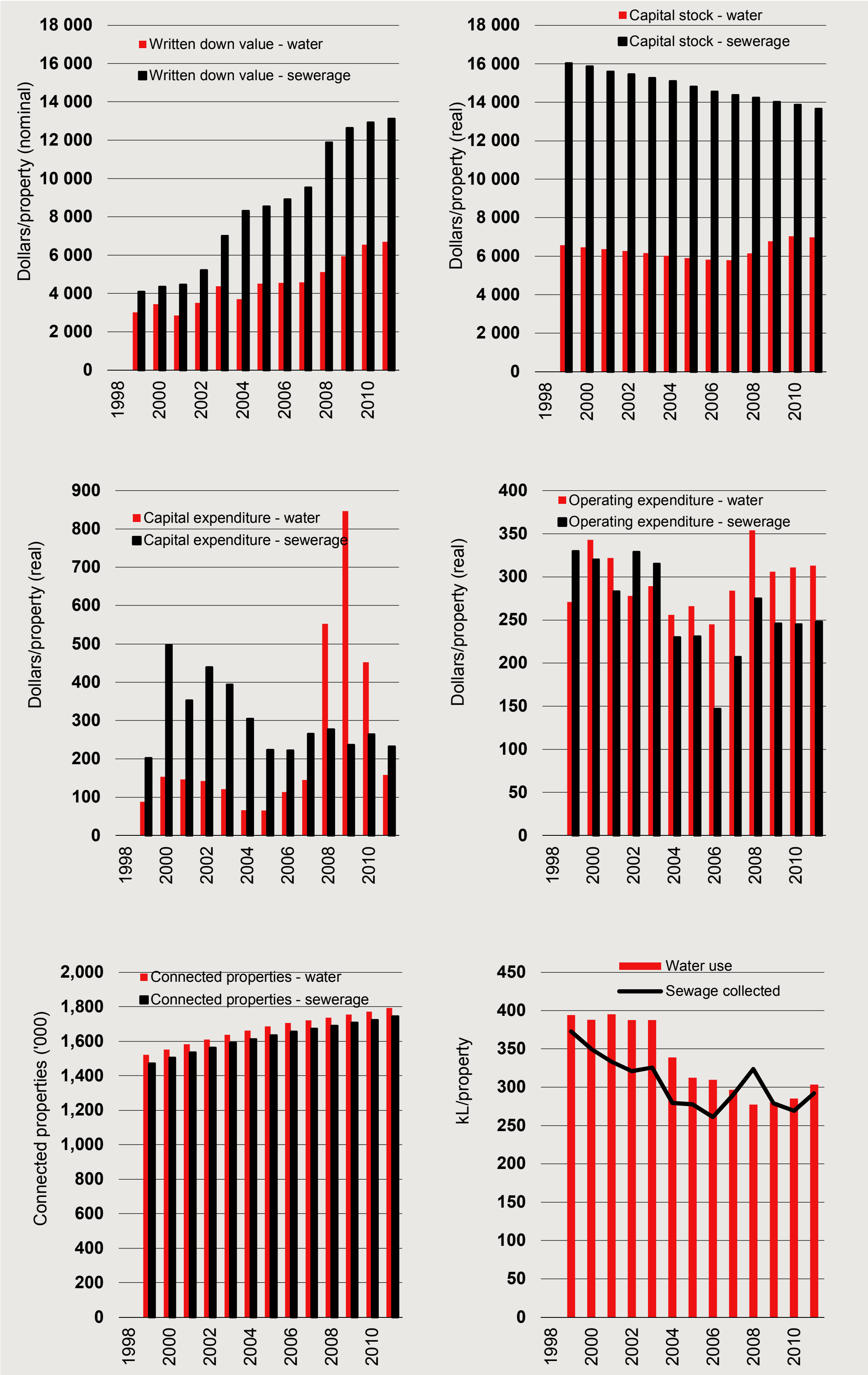
Data source: The CIE

B.8 Water Corp WA



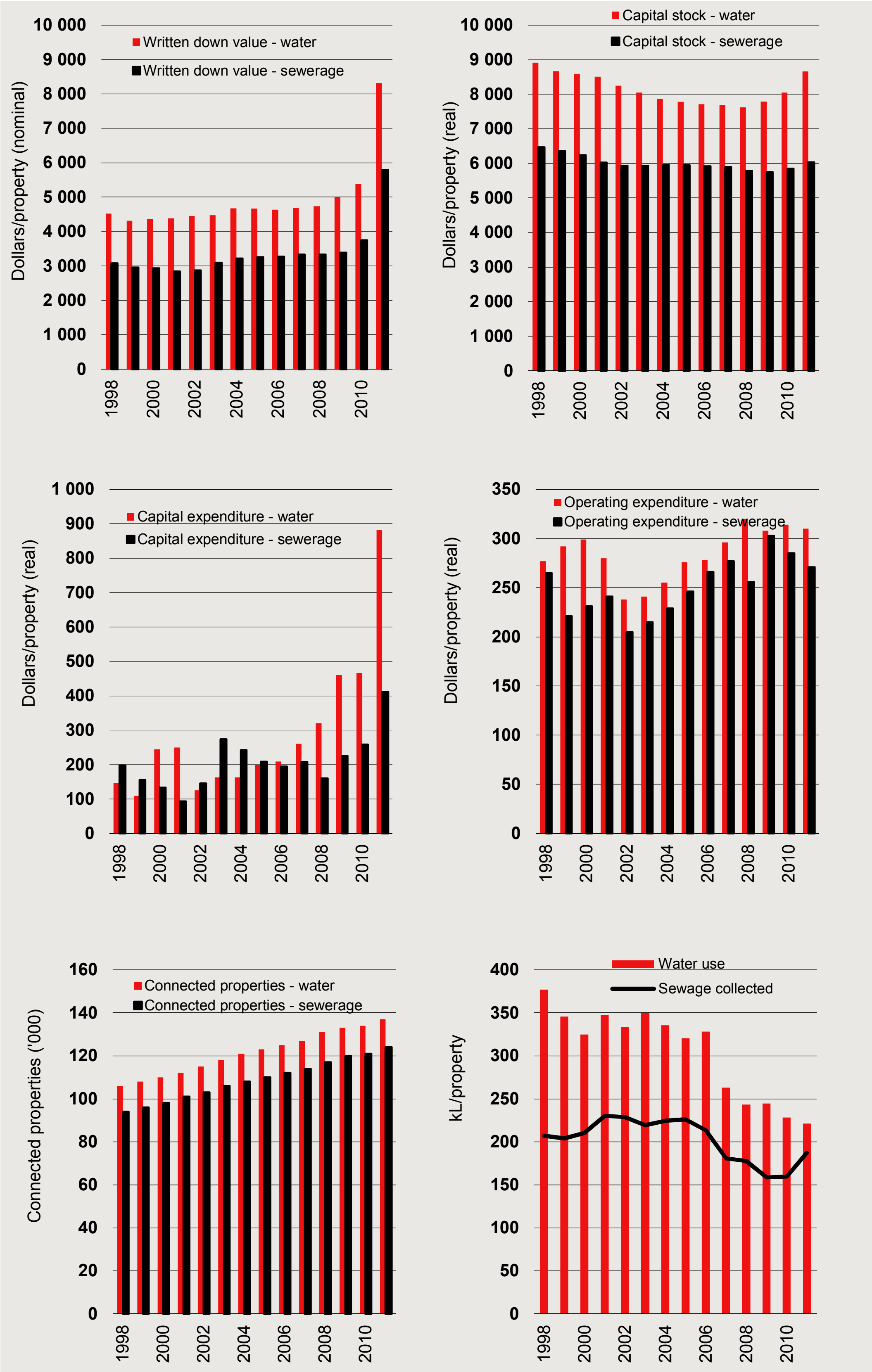
Data source: The CIE

B.9 Sydney Water



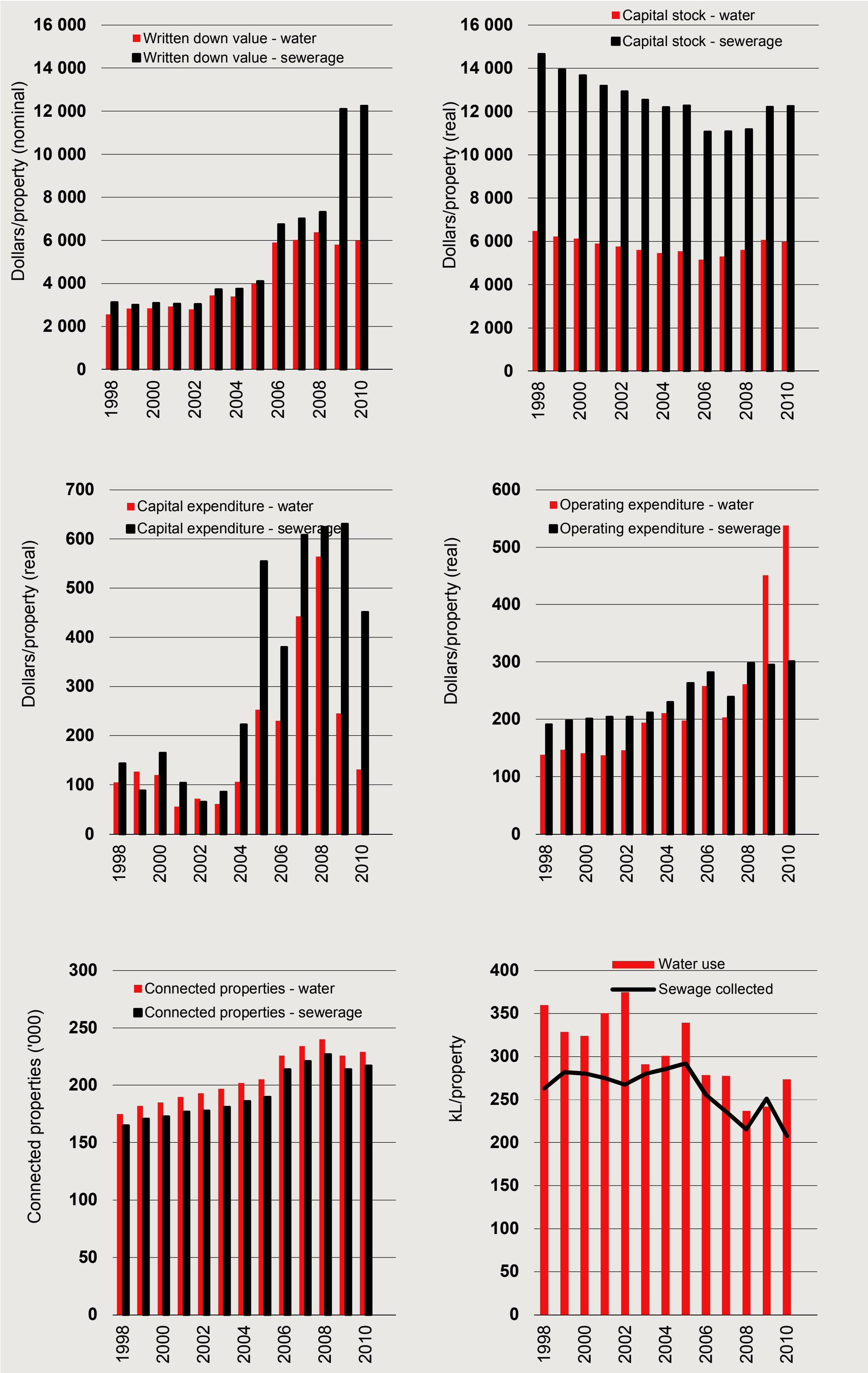
Data source: The CIE

B.10 Barwon Water



Data source: The CIE

B.11 Gold Coast Water



Data source: The CIE

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