Author name: P. Coombes

Date of submission: Monday, 9 December 2024

Your submission for this review:
Dear IPART Water Please find attached my response to the Sydney Water price submission. The response includes a letter, the Coombes (2024) peer reviewed journal paper on regulation, and the Coombes (2022) report to DPE on BASIX. The sum these documents is the reponse. Thank you for the opportunity Peter Coombes

ABN: 470 9364 5777

Ms. Carmel Donnelly

Chair IPART

By email to: ipart@ipart.nsw.gov.au

9 December 2024

Dear Ms Donnelly,

Review of Sydney Water pricing from 1 July 2025

Thank you for the opportunity to provide input to the review of Sydney Water pricing from 1 July 2025. This letter is a response to the Sydney Water Price Proposal[1] and the IPART Issues Paper.

Doubling of water bills, household welfare and need for a user pays pricing

Sydney Water propose a 103% increase in fixed charges and 18% higher water usage charges to 2029-30 in a substantive departure from the principles of user pays pricing. This regime of proposed prices minimises the opportunity of citizens to use less water to improve their household welfare. It is a disincentive to better management of water to improve the resilience of Greater Sydney to climate change and population growth as shown in Figure 1.

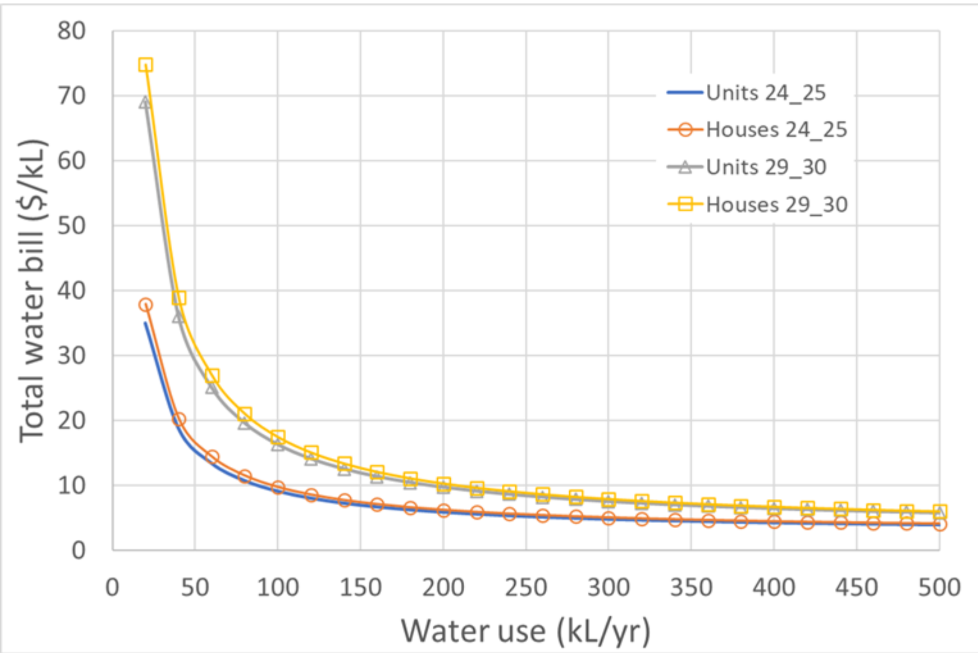


Figure 1: Impact of the proposed Sydney Water 2024-25 and 2029-30 prices on households

[1] Sydney Water (2024), Price proposal 2025-30

70 Howden Street Carrington NSW 2294 ■ Tel: 0419 439 124 ■ [redacted] ■ www.urbanwatercyclesolutions.com

Figure 1 demonstrates that dwellings with lower water use will pay significantly higher rates of total costs for water and sewage services in 2024-25 and 2029-30. These total cost rates are greater than $25/kL for dwellings using 50 kL/annum of mains water in 209-30. The dominance of fixed tariffs in these prices provide inequitable outcomes for households with diminished opportunity to change this circumstance.

These changes in pricing policy are proposed at the time when citizens are coping with persistent unemployment and under-employment with low real wage growth.[2] The housing industry is also experiencing record low approvals and completions which increases the prices of housing and rents.[3]

An environment of ongoing wage stagnation and price inflation is adding to the lasting negative socioeconomic and economic impacts of diminished housing affordability. Sydney is experiencing a crisis in housing supply and affordability that coincides with unusually weak growth in wages.

It is not an ideal time to increasing the costs of providing housing and the costs of living in housing whilst removing the user pays opportunity to reduce water use and associated Sydney Water bills.

Improved equity and greater economic efficiency can be achieved by the use of a single usage charge for combined water and sewage services. The proposed price regimes versus full usage charges (no fixed tariffs) are presented in Figure 2.

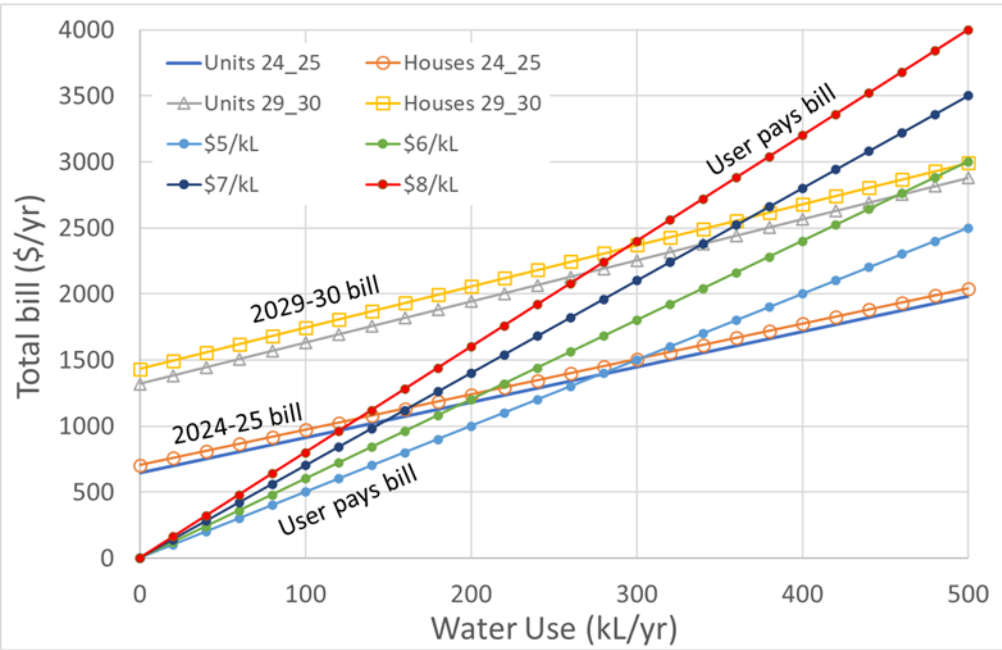


Figure 2: The proposed prices versus full usage charges on total household water bills

Figure 2 demonstrates that full usage charges provide better opportunities for households to manage the costs of water bills by reducing water use. The Author's research demonstrates that the application of full usage charges (no fixed tariffs) for water and sewage services

[2] Stewart A., Stanford, J and Hardy T., (2023), The wages crisis revisited, The Australia Institute Centre for Future Work.

[3] Urban Taskforce Australia (2024), October Housing Approvals – a huge task ahead, 2 December 2024

provides substantial economic benefits to the water utility, improved household welfare and reduced impact on the environment.[4]

The Author's previous work on these important challenges of economic efficiency and equity for customers was acknowledged in the previous IPART price determination for Sydney Water.[5]

This research was presented as the spatial costs and prices of water, sewage and stormwater services to Greater Sydney to highlight the strong spatial cross subsidies that apply. These spatial differences in costs highlight the opportunities to manage costs that cannot be understood by average analysis as demonstrated by Barry and Coombes (2018).[6]

A full usage charges policy was shown to generate substantial reductions in the growth of water demands (10%), sewage discharges (5%) and costs incurred by Sydney Water to 2050.[7] These benefits included a significant deferral of the need for water security augmentation of the water supply and wastewater systems at the net present value of $5.2 billion. This strategy provides for small decrease in the revenue growth that coincides with a larger decline in cost growth for Sydney Water. A $1 reduction in revenue coincided with a $7 decrease in costs.

However, these calculated water and wastewater usage changes ($5 - $7/kL) can be applied as a single rate to entire residential sector (at say $6/kL). This simpler and fairer pricing policy can also apply to the non-residential sector using wastewater discharge factors that account for land use typologies. The impacts of property scale rainwater harvesting on the ratio of water use to sewage discharge can also be counted in a full user pays policy.

Recommendation

1. Application of a **full usage charge** of $6/kL for water and wastewater services (with no fixed tariffs) to all residential dwellings in Sydney for the 2025-30 regulatory period. This initiative will foster water efficient behaviours from Sydney's households whilst providing strong opportunities for families to reduce water use to improve household welfare and environmental impacts.

   It is proposed that progress on water demands, wastewater discharges and Sydney Water revenue can be reviewed by Sydney Water and IPART on an annual basis. The usage charge could be reviewed each year. Implementation of this user pays policy is expected to send the better price signal to Sydney Water and IPART on residential water use.

Unprecedented increases in Sydney Water costs and review of regulation.

This submission to the IPART review of Sydney Water prices from 1 July 2025 is supported by two key documents (attached):

1. Coombes P.J., (2024), The influence of regulation on preference for utility infrastructure investment to generate income for Australian water corporations,

[4] Coombes, P. J., (2022), A systems perspective on characterising resilience in urban water markets, OzWater 2022, Australian Water Association, Brisbane, Australia.
[5] IPART, (2020), Review of prices for Sydney Water from 1 July 2020, pp. 99-100, 108, 288, Box L1
[6] Barry, M.E., and Coombes, P.J., (2018), Planning resilient water resources and communities: the need for a bottom-up systems approach, Australasian Journal of Water Resources, 22(2), 113-136.
[7] Urban Water Cycle Solutions and Kingspan Water and Environment (2020), Alternative water strategy for Sydney, September 2020.

Australasian Journal of Water Resources, 28(2), 151-172. This peer reviewed publication refers directly to the IPART task is respect to Sydney Water.

2. Coombes P.J., (2022), Modelling the Impact of Changes to BASIX for Department of Planning, Industry and Environment, Urban Water Cycle Solutions, 26 August 2022. This report has not been included in review of Sydney Water or the published Departmental review of BASIX which suggests a need for IPART to address the management of government monopolies and the crowding out of perceived competition to government monopoly.

Price regulation of Sydney Water services is based on the building block or rate of return methodology that is linked to regulated asset values and costs. The historical record of the Regulatory Asset Base (RAB) and Nominal Revenue Requirement (NRR) for Sydney Water from 2000-01 to 2023-24 was sourced from Sydney Water Annual Reports and IPART Price Determinations (see Coombes, 2024 for more detail). The NRR is the revenue that the utility is permitted to earn via price determinations.

The historical (CPI adjusted) 2024 dollar values for Sydney Water's RAB and NRR with the key explanatory variables of depreciation, net capital and operation expenses, and return on assets are presented in Figure 3.

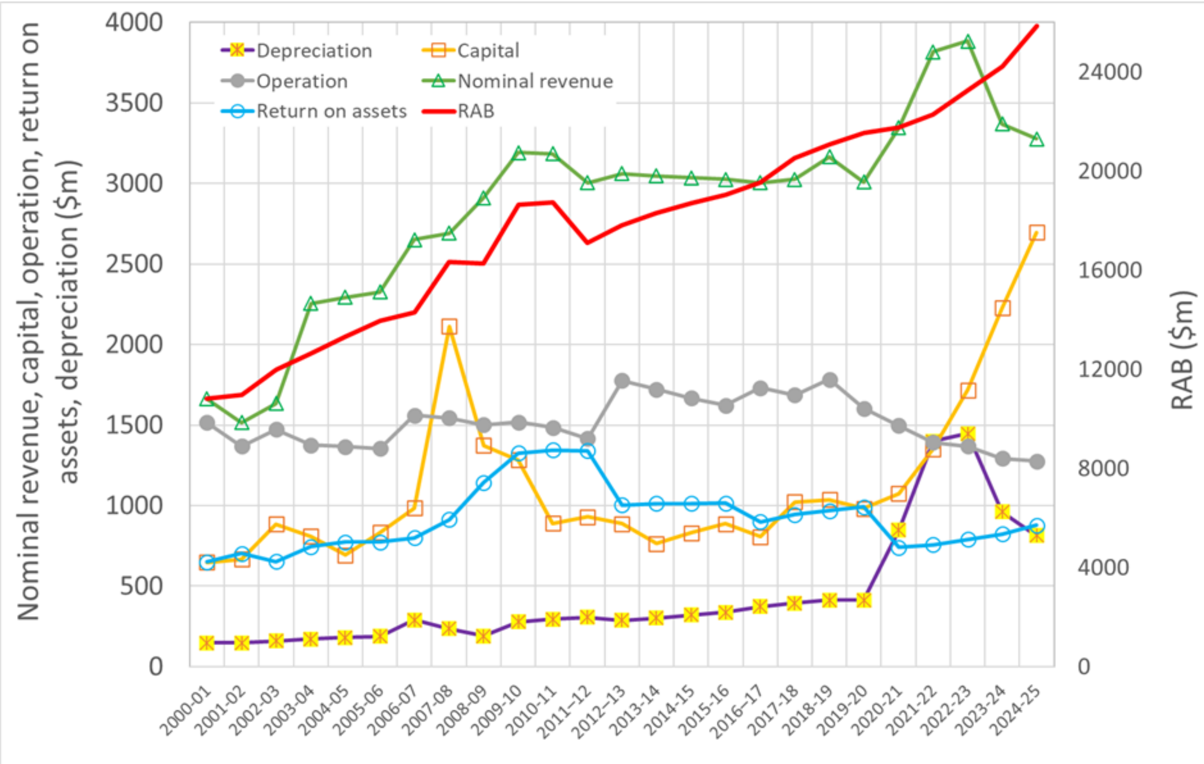


Figure 3: The CPI adjusted values (2024 dollars) for the regulatory asset base (RAB) and nominal revenue (NRR) for Greater Sydney with capital, operation and depreciation expenses, and return on assets for the period 2000-01 to 2023-24.

Figure 3 reveals 139% real (CPI adjusted) growth in the RAB and 97% increase in revenue (NRR) for Sydney Water. Growth in the RAB was driven by 316% increase in capital expenses and 453% growth in depreciation costs, and a 16% decrease in operating costs. It is noteworthy that Sydney Water's capital expenses have unusually grown rapidly by 175% since 2019-20. This change in capital expenditure is in excess of the previous IPART determination (see Table 1) and has driven higher values for the RAB and NRR.

Table 1: IPART approved capital expenses versus actual capital expenses

Source	**Capex ($m) in each financial year**				
	2020-21	**2021-22**	**2022-23**	**2023-24**	**2024-25**
Actual	1074.5	1351.4	1717.4	2226.6	2697
IPART 2020	1389.8	1185.4	1123.8	1081.3	-

Table 1 highlights that the Sydney Water's growth in capital expenditure is already substantially greater than accepted by IPART in 2020 and was more than double the agreed magnitude in 2023-24.

Sydney Water have requested a two to three fold increase in expenses from IPART and the community, and this growth in expenditure has already commenced.

The unprecedented growth in expenses, a doubling of water bills and departure from user pays principles requested by Sydney Water is justified as a response to population growth, climate change and aging assets.

These are valid concerns that have been addressed as a continuum throughout each regulatory period by Sydney Water, IPART and the community. The proposed sudden and large increase in expenses does need careful, independent and transparent scrutiny.

A change of preferred water security strategy (such as supplementing the drinking water supply with treated sewage) cannot be a reason for a different expenses and pricing strategy without proper process. Such a process should include a comprehensive assessment of multiple options across whole of society and include an agreed decision with the community on the preferred path to resilience.

As outlined in the Coombes (2024) paper, the regulatory process is driving preference for utility supply side infrastructure to generate increased revenue and is crowding out alternatives such as local water sources and water conservation.

The Sydney Water price submission asked for $32 billion with only 0.16% of the requested budget assigned to water conservation and no allowance for supporting local water sources. It is noteworthy that Sydney Water and the Department are strongly opposed to household rainwater harvesting (for example).

Recommendations

2. Expenditure that is proposed as a response to concerns about water security should not be included in the Regulatory Asset Base (RAB).

3. The proposed large increases in expenses should be independently reviewed and include options to address all emerging challenges and opportunities
4. Sydney Water should provide a programme and adequate budget to facilitate water conservation, local water sources and demand management
5. The IPART regulatory process should recognise the environmental and social benefits provided by innovative servicing options in a whole of society framework that combines utility and non-utility services;
6. Sydney Water should be rewarded for facilitating customer access to traditional and non-traditional servicing arrangements. This will involve revising the objectives for the successful governance and operation of Sydney Water;
7. Sydney Water and IPART must provide open, transparent, and freely accessible information about the performance of Sydney Water' water cycle systems to all stakeholders and the community. This complete information should be available in a common location and format.

Thank you for the opportunity to provide this response. I am willing to meet with IPART to answering any questions and expand on the detail underpinning this response.

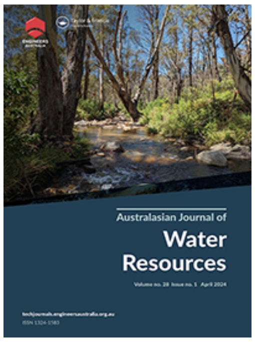
Yours sincerely

[redacted]

Prof Peter Coombes FIEAust CPEng EngExec NER APEC Engineer IntPE(Aus)

[redacted]

[redacted]



Australasian Journal of Water Resources

ISSN: (Print) (Online) Journal homepage: www.tandfonline.com/journals/twar20

The influence of regulation on preference for utility infrastructure investment to generate income for Australian water corporations

Peter J. Coombes

To cite this article: Peter J. Coombes (26 Aug 2024): The influence of regulation on preference for utility infrastructure investment to generate income for Australian water corporations, Australasian Journal of Water Resources, DOI: 10.1080/13241583.2024.2393933

To link to this article: https://doi.org/10.1080/13241583.2024.2393933

Published online: 26 Aug 2024.

AUSTRALASIAN JOURNAL OF WATER RESOURCES
https://doi.org/10.1080/13241583.2024.2393933

The influence of regulation on preference for utility infrastructure investment to generate income for Australian water corporations

Peter J. Coombes [a,b]

[a]Crawford School of Public Policy, Australian National University; [b]Urban Water Cycle Solutions

ABSTRACT
Effects of price regulation and preference for utility supply infrastructure on Australian urban water utilities and urban water markets are examined using historical data, models of the future and a case study of Greater Sydney. Australian regulators utilise the building block method based on operating and capital costs, and a Regulatory Asset Base to set nominal revenue requirements and ultimately prices for water utility services. Regulation of water utilities that is dependent on a Regulatory Asset Base drives preference for utility infrastructure and is remote from market mechanisms of consumer demands for water and sewage services. These regulatory processes are not linked to the operation of the urban water market of government owned utility and distributed solutions, and act to crowd out viable complementary solutions including water efficiency, distributed water sources and alternative pricing models. Government regulation, ownership and operation of utilities may produce strong performance from the perspective of urban water corporations but decrease economic efficiency, resilience and social welfare in urban water markets. The role of major water corporations needs to be redefined in a market recognising multiple complementary water sources and services. Regulation of utility services should have regard to the entire market, market demand, environmental health and consumer welfare.

ARTICLE HISTORY
Received 1 October 2023
Accepted 14 August 2024

KEYWORDS
Urban water; policy; regulation; infrastructure; prices

1. Introduction

The sustainable delivery of secure urban water services to meet broad socioeconomic and ecosystem objectives is a critical challenge for cities in Australia, and the world (IPCC 2021). Australian urban water utilities manage water, sewage and some stormwater infrastructure that has a current aggregate written down value of AUD $170 billion with annual capital investments of AUD $5.2 billion and annual revenue of AUD $20 billion (BOM 2014–2022). Most Australian urban regions are supplied with water, sewerage and partial stormwater services provided by utilities owned by state or local governments that operate at a centralised scale (BOM 2014–2022; Byrnes et al. 2010). These government owned utilities provide an essential service. Reporting and regulatory processes for urban water management are almost solely focused on utility services (Productivity Commission 2020; IPART 2020; Infrastructure Australia 2017). The urban water market also includes other sources of water supply, conservation and sanitation that occur at distributed scales from household and business to the region (Aisbett and Steinhauser 2011; P. J. Coombes, Barry, and Smit 2018).

Australian urban water management has transformed since the 1990s to include greater efficiency, transparency and stakeholder engagement (Productivity Commission 2020). The urgent challenge of the Millennium Drought motivated the integration of multiple solutions, conservation and innovation into the urban water strategy (Infrastructure Australia 2017). The Millennium Drought included severe rainfall, streamflow, soil moisture and groundwater deficits with hotter conditions across most of Australia during the period 1997 to 2009. These persistent dry conditions almost exhausted urban water supplies to cities, towns and rural communities. These initiatives combined water solutions from diverse actors with utility services to improve the resilience of water management in Australian cities. During the 2000s, Australian regulators adopted the Rate of Return or Building Block pricing strategies that are based the regulated value of infrastructure (Regulatory Asset Base) paid for by water utilities (IPART 2020). This regulatory process responds to proposals from water monopolies who are also the approval authority for infrastructure solutions.

Good progress with more efficient urban water management was followed by stalled urban water reforms and a current need to respond to the challenges of population growth, climate change, environmental and economic shocks (Infrastructure Australia 2017; Productivity Commission 2020). The learnings from the Millennium Drought and subsequent challenges have not been reflected in regulatory and

CONTACT Peter J. Coombes peter@uwcs.com.au

governance frameworks, and there is a need for greater independence and accountability (Commonwealth of Australia 2015b; P. J. Coombes, Barry, and Smit 2018; Infrastructure Australia 2017).

Ownership, regulation, operation and administration by government may be driving a narrow focus on the monopoly perspective of state owned water utilities (Commonwealth of Australia 2015b). A barrier to entry for water solutions from multiple actors may be linked to perceived threats to revenue streams of government utilities which manifests as a preference for utility owned infrastructure (NSW Audit Office 2020; Commonwealth of Australia 2015a, Troy 2008). These shortcomings in governance and project selection processes are seen by the Productivity Commission (2020) to indicate a need for community driven objectives and a greater commitment to independent economic regulation.

The NSW Audit Office (2020) found that the narrow focus on utility infrastructure has resulted in limited investigation, implementation and support for including utility demand management, complementary water sources from multiple actors and conservation in urban water strategies. Inclusion of these complementary water solutions was hampered by inadequate price signals, limited action to remove barriers to entry and assessment methods that favour utility owned supply infrastructure. This preference for utility supply infrastructure and crowding out of complementary solutions is described by the NSW Audit Office (2020) as decreasing the economic efficiency, resilience and social welfare of cities in response to population growth and climate change.

Commonwealth of Australia (2015a) and Finkel et al. (2017) reported similar challenges in the regulation of energy utilities that included over investment in utility infrastructure to seek higher revenue allocations. These outcomes were created by application of excessive reliability and security standards, and information asymmetry resulting in higher capital and operating costs.

A key principle of systems thinking is to observe the drivers of complex systems to understand and replicate the actual purpose of the system (P. Coombes, Smit, and Macdonald 2016; Meadows 2008). These processes can reveal the real-world processes, values and models that are imposed on decisions about government management of urban water resources. Previous systems analysis of Greater Sydney region and the BASIX water efficiency policy revealed greater economic efficiencies and household welfare than other regions (P. J. Coombes, Barry, and Smit 2018, 2019).

This study examines sources of water corporation income to understand if prices are determined by market responses to supply and demand for services delivered to water corporation customers. A key objective of this investigation is to explore the impact of regulatory processes on preference for utility infrastructure and other solutions.

The characteristics of the regulatory process used to set revenue and maximum prices for water corporations are explored in the Background Section to understand the preference for utility infrastructure. This includes presentation of the building block regulation, the urban water market and examination of the insights from government inquiries and auditors, researchers and regulators.

The Section on Analysis of the Past and Future provides an overview of the historical performance of the Australian urban water sector. A case study of building block price regulation for the Greater Sydney and Melbourne regions was used to incorporate real world complexity into the investigation and subsequent insights. The historical results from the Greater Sydney region were then utilised to examine the future impacts of price regulation that focuses on the value of utility infrastructure.

These processes were utilised in the Discussion Section to identify a series of key insights about the impact of price regulation of government owned water utilities and the urban water market.

2. Background

Meadows (2008) highlights the importance of understanding the real purpose or impact of a regulatory system which is not necessarily expressed and can only be deduced by observing the operation of a system.

2.1. *Monopoly pricing and markets, setting the context for analysis*

Water is essential to life and is subject to broad legislative objectives. The overarching NSW Water Management Act 2000 includes ecological, environmental, social and best practice management objectives. The National Water Initiative (NWI) COAG (2014) and IPART (2012) pricing principles require a real return on the written down value of assets to ensure sufficient revenue for efficient delivery of utility services. These principles include full cost recovery to promote efficient investment, operation and use of regulated services (Chu and Grafton 2021).

The National Water Initiative also encourages improved water efficiency and innovation in urban water servicing. A narrow focus on real returns from utility assets in economic regulation that inhibits innovative urban water servicing options can directly conflict with NWI policy commitments.

Australia has experienced a significant movement towards a market-based economy over the last 50 years (Health 2017) that has also influenced approaches to provision of utility water and sewage services to our cities (Infrastructure Australia 2017). Most of the major urban water monopolies in Australia are managed as water corporations and the government regulatory process attempts to replicate competitive markets (IPART 2020). The assumptions of Australian National Competition Policy that competitive markets can provide the best service to consumers and society are applied to these activities.

The free market philosophy is based on the concepts that 'the market' is the best allocator of resources, government should only play a minor role, industry should practice self-regulation and growth is the dominant objective (Jones 2020). Like all big ideas, there are advantages and disadvantages to this approach. A private business might have a stronger and simpler focus than a government, and there is arguably better measurement and reporting (Helm 2020; Stigler 1971). From the corporate perspective there may also be more efficient allocation of resources and this approach can work very well within an adequate regulatory framework or competitive market with many buyers and sellers of a similar product. The disadvantages are particularly relevant for government monopoly services. Jones (2020) describes the emphasis on individualism in the market based approach that rejects the concept of the public good. Thinking about water in this context reveals the complexity of the role of water as a private and public good that is dependent on location, time and context. Water is mobile, is a critical component of the biosphere and can have multiple different uses and ownership. The status of water varies from public good to private commodity that is altered by engineering, market and regulatory structures (Clarke and Stevie 1981; Coase 1947). The costs, ownership and classification of water also depend on the location of water within the system from river to dam storage to distribution network to consumers to disposal networks to waterways. There is a need to take a systemic viewpoint of the cumulative value and status of water. Urban water utilities are a special case where governments are required to balance their competing roles of owner, regulator and policy maker (Infrastructure Australia 2017).

Stigler (1971) recognises an idealistic perspective of the government regulation of public monopolies in economic thinking. It is an argument that the private operator must respond to shareholders and achieve growth in profits which is a stark contrast to the government monopoly that is beholden to citizens to realise public good. However, the State has the power to supply regulation that benefits particular industry and economic groups (Helm 2020; Stigler 1971). This can provide subsidy by regulation and grants the power to prefer solutions to the government entity.

Helm (2020) found that the behaviours of water monopolies are shaped by regulation rather than ownership. A narrow framing of regulation and governance objectives acts to reduce wholistic ideals of public good to narrow discussions about centralised infrastructure that increase the viability of the monopoly. Dollery and Wallis (1997) describe this process as government failure where the government business acts in its own interests which is different to the public good. Government regulation of its water corporations also requires a real return on investment in an increasing asset base (Chu and Grafton 2021; Helm 2020) which has similarity to the private sector situation.

Tan (2012) explains that government monopolies are dependent on private partnerships to deliver infrastructure solutions. These processes can result in selective infrastructure investments that are associated with rent seeking behaviours in an environment where state subsidies dilute risks and incentives.

It is also commonly assumed that urban water corporations are natural monopolies. A natural monopoly is expected to provide goods and services to an entire market at lesser economic costs than multiple businesses supplying parts of the market, and experiences economies of scale with average cost (AC) and marginal cost (MC) declining as the quantity of outputs increase as shown in Figure 1.

Figure 1 highlights that a natural monopoly maximises profits when marginal revenue (MR) is equal to marginal cost at lower output (Q_m) and higher prices (P_m). Regulators aim to manage monopoly behaviour and market power by setting prices at P_r where AC equals average revenue AR to foster larger output Q_r at zero excess profit. Note that average revenue AR is also demand.

The theory of natural monopolies is also characterised by high fixed costs that are not dependent on outputs and low marginal costs. Many authors, such as Saddler (2016), Hilmer (2014), Friedman (2002), Dollery and Wallis (1997), Di Lorenzo (1996) and

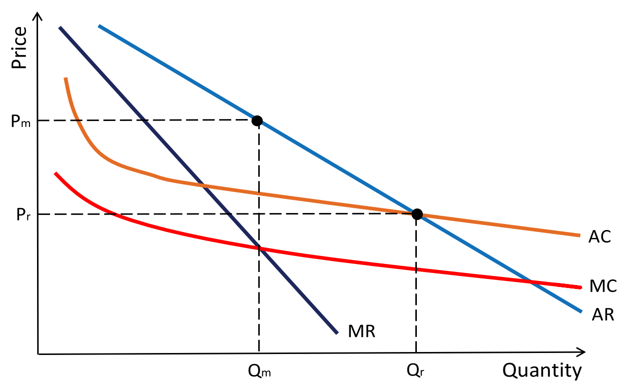


Figure 1. A natural monopoly with price regulation (after Hubbard et al. 2013).

Coase (1947), highlight that natural monopolies are created by government intervention to grant franchises to public utilities. This involves barriers to entry and regulation that protects 'sunk' infrastructure investments from competition. Large-scale and capital-intensive enterprises do not lead to natural monopolies (Di Lorenzo 1996). The provision of urban water and sewage services is not a natural monopoly process due to diseconomies of scale and the contribution of other solutions permitted by technological advances (Clarke and Stevie 1981; Guldmann 1985; Hilmer 2014; Saddler 2016). Stern (2013) explains that the regulation based on the RAB protects utilities from competition and favours capital-intensive infrastructure. The RAB approach can also be problematic for state owned industries as it can protect inefficient investments.

Pricing for utility services also utilises two part pricing methods where fixed and marginal costs are used to derive fixed and variable prices paid by consumers to maintain utility revenue in a regulated environment. Marginal costs are also used in the assessment of alternative water sources and conservation for inclusion in urban water strategy. The water industry assumption that many costs are fixed which are 'sunk' costs that are not counted in derivation of marginal costs produces artificially low values that are used in assessment of alternative strategies and favours selection of utility infrastructure (NSW Audit Office 2020). These processes also apply more broadly to the government utilities in the water and energy sectors (Commonwealth of Australia 2015a, 2015b; Finkel et al. 2017; Hilmer 2014).

Pricing decisions can favour demand for utility services and infrastructure by setting low comparative values for water conservation and complementary services. Regulation of monopolies seeks to promote and protect sunk investments (Biggar 2009) and can lead to an overwhelming resistance to any risk of stranded assets that might result from innovative solutions or policies (Simshauser 2017). For example, the economic level of water conservation (ELWC) is emerging in the water sector and employed in the Greater Sydney region to currently assume that water saving measures that cost more than $0.31/kL are not viable and utility supply infrastructure should be preferred (SWC 2022b). In contrast, the variable tariff for water services is greater than $2.35/kL, the total water and sewage bill for a household with a water use of 200 kL/annum is greater than $5/kL, and spatial costs of providing water and sewage services range from $2/kL to greater than $20/kL (IPART 2020; P. J. Coombes 2022). The prices of alternative (non-utility) water sources are also set at 80% of the regulated variable price for utility water supply (IPART 2020; NSW Audit Office 2020).

Friedman (2002) and Hubbard et al. (2013) explain that government regulatory and pricing methodologies can act to block entry of competing solutions to the market by crowding out innovation and technical progress. The derivation of marginal cost should count all costs and in the long run all costs are variable as better solutions may be available. These issues associated with selection of prices and cost comparisons that crowd out conservation and competitors, and favour utility infrastructure also apply to electricity markets (Commonwealth of Australia 2015a; Finkel et al. 2017).

This investigation explores the regulation of water utilities using the pricing method and the assumptions of natural monopoly in Figure 1 on preference of utility infrastructure.

2.2. Government owned water monopolies and corporations

Most Australian water and sewerage utilities are owned by state and local governments. The ownership structure of urban utilities has evolved from public water and sewerage boards in the late 1880s to statutory corporations in the 1990s. Since 1994, many of the utilities servicing capital cities and significant regions have been transferred to state owned water corporations in accordance with National Competition Policy and the National Water Initiative (COAG 1994; Tisdell, Ward, and Grudzinski 2002).

An example of the changing landscape of the ownership, governance and regulation of urban water utilities is the origin of Sydney Water as the Board of Water and Sewerage in 1888 enabled by New South Wales state legislation (Government of NSW 1888). The Water Board was replaced with the Sydney Water Corporation Limited as an unlisted public company owned by the NSW government and represented by ministers of parliament in 1995 (Government of NSW 1994). Sydney Water Corporation replaced Sydney Water Corporation Limited as a state-owned statutory corporation in 1999 and is currently providing utility water, sewerage and drainage services to the Greater Sydney region.

The evolution of government owned water utilities is characterised by the transformation of urban water and sewage services from a public good to a private commodity, and change from public to corporate governance. During the 2021–22 year, Sydney Water Corporation supplied 508,476 ML of water and provided sewerage, stormwater and recycled water services to 5.3 m people in 2.1 m properties across a 12,870 km^2 area of operations (SWC 2022a).

The shareholding in Sydney Water is vested in a Portfolio Minister and Shareholder Ministers with portfolio interests in water, environment, finance and treasury. The operation of Sydney Water is regulated by the Independent Pricing and Regulatory Tribunal (IPART) which was established in 1992 (Government of NSW, 1992).

Similar to most Australian water corporations, Sydney Water Corporation is required by its enabling legislation (for example The Sydney Water Act), an operating licene and the Corporations Act (2001) to operate as a successful business and in the best interests of the corporation. These legislated business objectives include maximising the value of the state's investment in the corporation and directors are also required to act in good faith and in the interests of the corporation (Australian Institute of Company Directors 2020; Corporations Act 2001). The interests of the corporation are its own commercial benefit which is regulated by IPART.

2.3. Building block model for water pricing

The setting of tariffs for utility water, sewerage and drainage services is ultimately the responsibility of state and local governments that own and regulate urban utilities (Connell, Dovers, and Grafton 2005). These decisions about price regulation are justified to the independent regulators such as the Essential Services Commission in Victoria and the Independent Regulatory and Pricing Tribunal in New South Wales. There is substantial recent history of Commonwealth government decisions about allocation of scarce water resources, mainly focused on the Murray Darling Basin, using objectives for environmental, social and economic outcomes (Kelly 2011). These processes mostly originated from the Council of Australian Governments (COAG) 1994 agreement to implement a framework for an efficient and sustainable water industry (COAG 2014; Connell, Dovers, and Grafton 2005). This reform of water policy and regulation aimed to transform water governance to include environmental sustainability and economic efficiency (Godden and Foerster 2011).

In 2004, COAG agreed to a National Water Initiative (NWI) as a national plan for water reform which included urban water management and influenced the setting of tariffs for urban water utilities (COAG 2014). The NWI incorporates the key principles of the 1994 COAG water reform framework which includes objectives for efficient and sustainable use of water resources and infrastructure assets which include:

- Implement consumption-based tariffs which also provide important demand management (conservation) outcomes;
- Achieve full cost recovery for water and sewerage services for viability of businesses and avoid monopoly rents by implementing upper bound pricing;
- Public reporting of community service obligations and strategies to remove the need for these requirements; and
- Use independent bodies to review and set prices, and oversee the process of setting prices.

The NWI base standard for urban water pricing also includes building block pricing methods that include a Regulatory Asset Base (RAB) and a derivative Nominal Revenue Requirement (NRR) which are preferred by Australian economic regulators (ESC 2005 – 2018; IPART 2020). An example of the components of a building block model utilised by IPART (2020) in the determination of prices for water corporations (Sydney Water example) is presented in Figure 2.

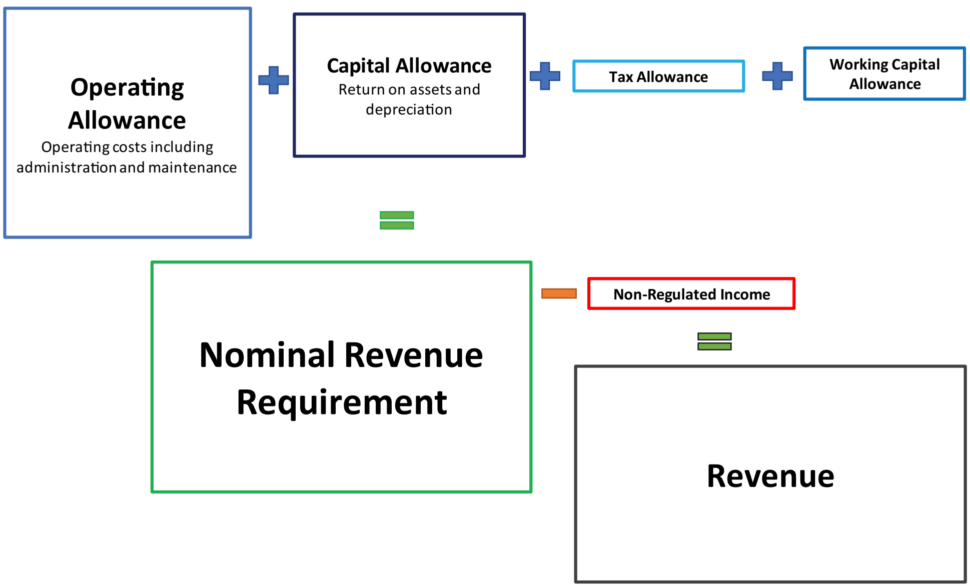


Figure 2. Components of the building block model used to determine revenue requirements for water utilities (scale of boxes based on the Sydney water 2020 price determination).

Figure 2 reveals that regulated allowances for operating and capital expenses, taxes and working capital are the key components of the nominal revenue requirement (NRR). Operating and capital allowances are dominant proportions of the determination of revenue needed to ensure a utility is viable. A capital allowance is derived from returns on and depreciation of the regulatory asset base (RAB) and the determination also includes a range of smaller components such as non-regulated income. The stated aim of the regulatory process using the building block method is to set maximum prices based on the Nominal Revenue Requirement (NRR) to efficiently provide water, sewage and stormwater services, and earn a return on the utility asset base (IPART 2008).

The regulatory asset base (RAB) is an assumed market value of the sale of a utility that represents potential to earn revenue in accordance with current pricing policies and has no relationship with the actual value of the physical assets (IPART 2003). The RAB is a key component of the building block method and is utilised to determine the returns and depreciation on capital in deriving the nominal revenue requirement (NRR).

An initial value of the RAB (for example in 2000 for Sydney Water Corporation) was derived as the net present value of revenue earned by the utility over a particular time horizon. The RAB is then determined in subsequent years by adding net capital expenditure (NetCap), depreciation (Depr), disposal of assets (Disp) and inflation (Inf) to the previous value of the RAB as follows:

$$RAB_t = RAB_{t-1} + NetCap_t - Disp_t - Depr_t + Inf_t \quad (1)$$

where t is the year.

The NRR is derived as the sum of the operation expenses (Opex), maintenance expenses (ManEx), administration expenses (AdmEx), allowance for working capital (WEx), return of capital (Depr), return on capital (CapR), taxation allowance (Tax), working capital (Wcap) and unregulated income (NoRIn) as:

$$NRR_t = Opex_t + ManEx_t + AdmEx_t + WEx_t + Depr_t + CapR_t + Tax_t + Wcap_t - NoRIn_t \quad (2)$$

Where $CapR_t = RAB_t.WACC_t$ and WACC is value for the weighted average cost of capital set by the regulator.

Equations 1 and 2 underpin the building block model used to determine the revenue requirement and to set prices for utility services, and are utilised in this investigation. The WACC is the weighted average of debt and equity costs of infrastructure investment that are compared to efficient businesses. The NRR is combined with long-run marginal costs of services to set the fixed and variable tariffs for utility services.

Regulators are also expected to apply regulatory judgement to modify the building block model determination to include consideration of social and environmental impacts in pricing decisions (IPART 2008). However, governing legislation for regulation of utilities and performance of company officers prioritise corporate performance and viability over consideration of whole of society objectives (for example; Corporations Act 2001; Essential Services Act 1994). Khosroshahi et al. (2021) discuss the emerging initiatives in Victorian regulation where the setting of the WACC is dependent on the level of engagement and trust derived from utility selected customer groups.

The processes of developing the building block pricing determinations are based on a draft report by the regulator, proposals from a water utility about infrastructure and revenue requirements, public submissions and review by the regulator assisted by water industry consultants (IPART 2020; ESC 2005 – 2018). This process is typically dominated by water utility information that is increasingly unavailable for public scrutiny due to commercial in confidence restrictions which creates strong asymmetry of information limitations to the regulatory process (NSW Audit Office 2020; Infrastructure Australia 2017; Commonwealth of Australia 2015b).

The derivation of the Regulatory Asset Base (RAB) is also partially decoupled from expanding water, sewage and stormwater networks associated with growth in connections (IPART 2022; ESC 2022). The mechanism for providing infrastructure for new growth which might expand the network (and utility infrastructure costs) is that developers or land owners (not utilities) pay for infrastructure in new developments, and this infrastructure value is not attributed to the utility until there is a need to replace or repair the asset at some future date. These 'gifted assets' or 'Asset Free of Charge (AFOC)' to the utility as defined by the regulator are recorded in the utility's asset register for statutory and tax purposes but are not included in the RAB. Only assets purchased by the utility are included. Importantly, the utility is the approval authority that determines the type of infrastructure provided by developers.

2.4. The urban water market is more than government utility infrastructure

Figure 1 assumes that the monopoly is, by definition, only one firm which provides all the goods and services. This approach is consistent with Chadwick paradigm (Troy 2008) for urban water management that is based on piped supply of fresh water from dams into the city and piping sewage out of the city to avoid contamination. This linear model is exclusively focussed on water supply to the city and sewage outputs at the utility or city scale.

The linear Chadwick model may be well suited to monopoly pricing principles based on the building block method for specifying utility infrastructure but does not account for an urban water market operating at multiple scales with feedback loops created by human interventions and environmental processes. There has been a profound transformation in scope of water solutions in response to increasing populations and variable climate since development of the Chadwick paradigm in 1843. Systems thinking and observation in the modern era have motivated conceptual models of reality that account for greater complexity (Delgado et al. 2021)

The components of the urban water market may not be adequately considered in the centralised Chadwick model or the current building block pricing approach which only considers utility scale infrastructure. Barry and Coombes (2018) also found that linear average analysis at a single centralised scale produced inconsistent insights that heavily influence infrastructure decisions that were biased against complementary solutions at different scales.

The urban water market is also narrowly defined around utility services in regulation and measurement as demonstrated in National Performance Reporting (NPR) by the Bureau of Meteorology (BOM) and information sources utilised in Water Reform Reports by the Productivity Commission that mostly focus on the utility market segment (for example; BOM 2014–2022; Productivity Commission 2020). This sole focus on utility services leads to perceptions of natural monopoly and associated regulatory assumptions.

P. J. Coombes, Barry, and Smit (2018) and P. J. Coombes (2022) highlight that urban water utilities only supply part of the market for urban water services, and distributed solutions and water conservation are significant complementary contributors to urban water markets. Data from BOM 2014–2022, P. J. Coombes, Barry, and Smit (2018) and published reports on private recycled water schemes by local governments (for example by City of Sydney) were utilised to estimate the urban water market for the Greater Sydney and Melbourne regions as shown in Figures 3 and 4.

Where WEA are water efficient appliances, RWH is rainwater harvesting and SWH is stormwater harvesting.

Figures 3 and 4 demonstrate that a considerable proportion of the urban water market consists of complementary solutions to the utility water supply and losses. It is noteworthy that the proportions of the different urban water market solutions presented in Figures 3 and 4 are likely under-estimated because there is limited collated reporting on non-utility water solutions and utility demand management, and these results will vary across years and are dependent on government policy settings and market processes.

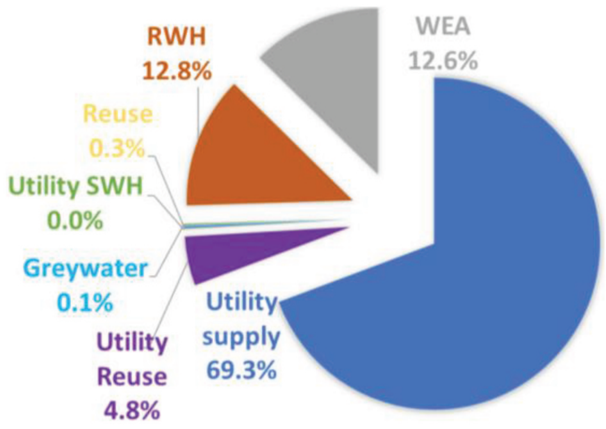


Figure 3. Components of the urban water market based on volumes of water supplied and saved for Greater Sydney.

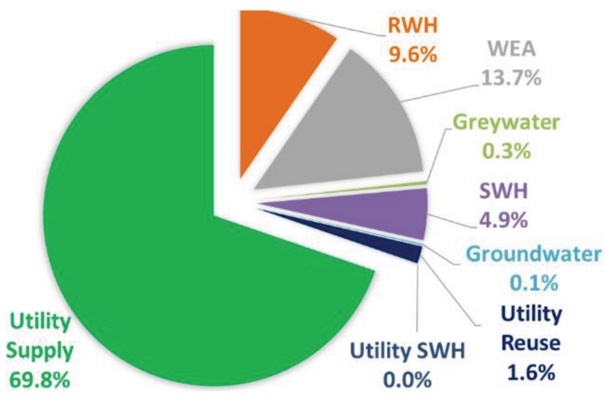


Figure 4. Components of the urban water market based on volumes of water supplied and saved for Greater Melbourne.

Urban water markets often include a single dominant corporation with many distributed participants (classified as a dominant firm oligopoly) where pricing and planning decisions for or by the corporation dominate all other contributions and solutions. The urban water market includes multiple solutions and contributors. Different and more inclusive regulatory processes are needed to maximise the opportunity for all participants and solutions in the market, the environment and for society.

2.5. Challenges for monopoly price regulation

Dollery and Wallis (1997) highlight that there can be substantial social costs of monopoly power. These processes include rent seeking, institutional capture and construction of unnecessary infrastructure (or failure to construct infrastructure) to maintain, increase and exercise monopoly power (Commonwealth of Australia 2015; Helm 2020; Pindyck and Rubinfeld 2015).

These challenges apply to the scenario where governments have competing roles as owner, regulator, operator and policy maker for urban water utilities (Infrastructure Australia 2017). Market failure is created when policymakers do not have sufficient information about market processes that are necessary to design rational government regulation and leads to government failure as the inability to achieve its announced intentions in an efficient manner, and allocative inefficiency such as excessive provision of public goods and services (Dollery and Wallis 1997). The ultimate outcome can be legislative failure where the bureaucracy fails to implement policy efficiently and leads to rent seeking involving wealth transfers to groups that support a particular paradigm or solution (Spinesi 2009; Di Lorenzo 1996; Dollery and Wallis 1997).

It is the Australian experience from the energy and telecommunications industries that shows government regulation creates natural monopolies and increases in monopoly power by limiting complementary solutions to meeting market demands (Commonwealth of Australia 2015a; Finkel et al. 2017; Hilmer 2014). The markets for most urban services, including water and sewerage services, incorporate a range of complementary solutions from other sources and advances in technology at distributed scales that alters the economies of scale with respect to the entire market (Commonwealth of Australia 2015b; P. J. Coombes, Barry, and Smit 2018; Finkel et al. 2017).

Helm (2020) highlights that the framing of regulation can change the objectives and governance of utilities from public benefit to narrow preference for centralised technology. This can limit the ability of the utility to respond to emerging challenges and opportunities in the interest of society (customers).

A key objective of price regulation is to achieve efficient provision and use of regulated services whilst encouraging investment in government owned utilities (Chu and Grafton 2021; IPART 2020; COAG 2014). Pricing strategies can also achieve multiple social and political objectives, management of water demand and incentivise complementary solutions. Regulators interpret full cost recovery underpinning efficient pricing as fixed tariffs derived from utility fixed costs and connections, and volumetric charges determined from marginal cost of water supply and distribution (Chu and Grafton 2021; IPART 2020; ESC, 2015). In contrast to these considerations, maximum prices for monopoly water services are commonly based on rate of return regulation that is focused on a utility's cost of capital based on the building block method that is underpinned by a fair rate of return on a regulatory asset base (Zetland 2021).

Chu and Grafton (2021) explain that this approach to pricing utility services may not be economically efficient as it does not maximise social surplus, and can be unaffordable for poor households. Mack, Wrase, and Meliker (2017) reported diminished household welfare associated with declining efficiency of water utilities in North America. The regulated price for utility water services is not the market price because it only represents the private costs of the utility and does not include external social and environmental costs (Grafton, Chu, and Wyrwoll 2020).

The determination of monopoly prices dominated by operation and provision of utility infrastructure can serve to embed increasing amounts of infrastructure and perceived fixed costs for utilities which in turn drives higher requirements for revenue (Commonwealth of Australia 2015a).

2.6. Recognising that urban water markets include complementary solutions

Urban water markets include services provided by government utilities and complementary solutions from many other providers including households. This integration of solutions across providers and consumers is understood in the electricity industry (Finkel et al. 2017). Distributed water sources and conservation ensured that many Australian urban areas did not exhaust water supplies during the millennium drought from 2000 to 2010 (AWA Water Efficiency Specialist Network 2012; Turner et al. 2016). Australian governments mandated limited water conservation measures in the wake of the Millennium Drought including Water Wise Guidelines in New South Wales, Permanent Water Savings Rules in Victoria and a national Water Efficiency Labelling and Standards scheme, but additional water conservation policies subsequently failed to appear.

The performance of utility water supplies and the water security of cities was improved by actions that increased local supply and water conservation (P. J. Coombes, Barry, and Smit 2018, 2016).

This historical experience highlighted the importance of solutions that both increase local supply and reduce demand for utility water supply, and the effectiveness of strong demand management programs in uniting the community in meeting water saving targets (Aisbett and Steinhauser 2011).

More recently the benefits of demand side strategies were contested or not well understood and utility supply side infrastructure solutions were preferred. Specifically, water restrictions, distributed water sources and conservation were considered to be economically inefficient when compared to utility water supplies and resulted in reduced revenue earned by utilities (Productivity Commission 2011, 2017, 2020). It was argued that it is also difficult to measure and value non-utility contributions (Productivity Commission, 2017). The loss of utility revenue due to water restrictions during drought and as a result of demand management have led to calls for scarcity pricing where water prices increase during droughts (IPART 2020).

National reporting processes (for example BOM 2014–2022) are focused on utility services and do not report on demand management, alternative water sources, conservation and health outcomes. Reporting on alternative water sources and conservation by the Australian Bureau of Statistics (for example ABS 2013 Environmental Issues) ceased in 2013. Daniell, Coombes, and White (2014) highlights that innovation occurring at distributed scales encounters barriers associated with the actions of multi-layer governance systems. The dominance of the paradigm of supply side utility infrastructure in central government and asymmetry of information can lead to regulation that does not consider complementary solutions and conservation provided at distributed scales. For example, evaluation of the NSW Government's State Environmental Planning Policy BASIX that mandates household water and energy savings by NERA (2010) only considered estimated reductions in expenditure on utility water usage tariffs and excluded all other potential benefits as externalities.

The NSW Audit Office (2020) found that water conservation and distributed water sources have not been effectively investigated, implemented or supported. A focus on utility supply side solutions provided by utilities has prioritised investment in utility infrastructure over demand management and distributed solutions. As a consequence, the utility water supply to Greater Sydney may have diminished resilience to population growth, climate variability and drought. This outcome is expected by the NSW Audit Office (2020) to increase the costs of providing water and sewage services with greater impacts on household welfare and environments. Increased utility water use resulting from diminished household water efficiency and rainwater harvesting was found by P. Coombes, Smit, and Macdonald (2016) to drive higher utility debt and diminished household welfare from increased utility bills in South East Queensland. Feinglas, Gray, and Mayer (2014) found that water conservation diminished growth in the costs of water and sewage services, and associated household bills. Increased reliance on utility scale supply side solutions were found by the Queensland Audit Office (2013) to correspond with diminished economic efficiency of utility urban water supply and the need to levy higher tariffs. These impacts on household welfare, preference for utility infrastructure and decline in economic efficiency of utility services are also experienced in the energy sector (Commonwealth of Australia 2015a; Finkel et al. 2017; Saddler 2016).

3. Analysis of the past and future

This investigation examines the incentives that are reported to drive preferences for utility owned infrastructure in an urban water market that actually includes multiple opportunities for additional water sources and savings. The preference for utility infrastructure is outlined in previous sections as a function of natural monopoly assumptions that includes the building block pricing methodology that is based on utility asset values.

This section explores the impact of growth or decline in utility capital and operating expenses in defining the RAB and the growth in revenue NRR for a Water Corporation, and therefore the regulatory success of the business. These issues are considered by examination of historical data from the Australian urban water services, the application of building block pricing approaches for Greater Sydney and Melbourne, and analysis using a simple model of future scenarios.

The Australian urban water sector has responded to population growth, ageing infrastrastructure, increasingly variable climate and economic shocks during the last two decades. The growth in utility expenses and tariffs are compared to growth in serviced population and urban water demands to examine the preference for utility infrastructure in decision making.

3.1. Australian urban water services

The performance of the Australian urban water sector was estimated using data from multiple sources such as regulators (for example: IPART 2020; ESC 2005 – 2018), annual reports (for example: SWC 2022b), National Performance Reports (NPR) (NWC 2004; BOM 2014–2022) and National Accounts (ABS 2022a). The aggregate urban water use, water and sewage tariffs (Utility Tariffs), utility capital and operating costs, serviced population and non-farm gross domestic product (GDP) is presented in Figure 5.

Figure 5 reveals strong growth in utility costs and tariffs corresponds with inceases in serviced population and the economy with variable and decreasing demand for utility water supply. Note that non farm GDP was chosen to represent urban economic growth as it excludes variable agricultural effects. This investigation focuses on the NPR that provides annual data from 2002 to 2022 about urban utilities and on economic data from the ABS National Accounts. Whilst it is acknowledged that these data sources do not represent all urban water services in Australia, the available data for 81 utilities and councils was sufficient to indicate the aggregate relationships between the key variables.

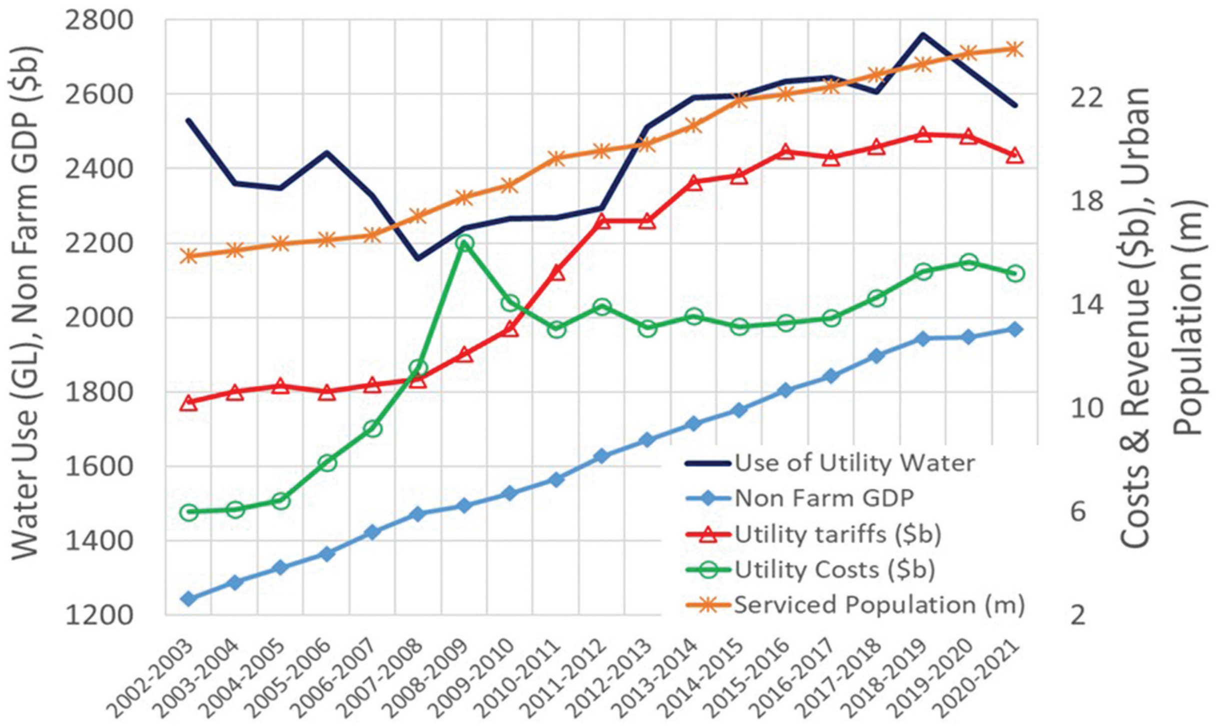


Figure 5. Aggregate values of demand for utility water, serviced population, utility revenue, utility costs and non-farm GDP (economic values in 2022 dollars).

The Australian urban water sector experienced droughts during the periods 1997 to 2009, and 2017 to 2019. The responses from urban areas are characterised by restrictions on use of utility water supplies to conserve capacity, purchases of water efficient appliances and complementary water sources to reduced demand for utility water, and subsequent investment in additional supply sources by utilities. Urban areas also experienced a range of economic shocks including the 2008 Global Financial Crisis (GFC) with subsequent stimulus payments and 2020 COVID-19 Pandemic.

The relative behaviour of the key variables was separated from the changes in the value of money by using 2022 monetary values (CPI adjusted) and from population growth by using per-capita values as shown in Table 1.

Table 1 demonstrates that the real (2022 dollar values) national aggregate of water and sewage tariffs has increased by 93% which is significantly greater than changes in population growth (+50%), total water use (+2%) and non-farm GDP (+58%). The increase in water and sewage tariffs is not solely attributed to population and economic growth or demand for utility services. Increases in utility capital and operating costs (+154%), associated with provision of utility infrastructure, are substantially higher than all the selected key parameters. Utility operating costs also include maintenance, replacement and renewal of existing infrastructure, and payments for purchase of water supply and treatment infrastructure services (IPART 2020).

Table 1. Real aggregate and per-capita changes in urban water services since 2002/03 financial year.

Criteria	Aggregate change (%)	Per capita change (%)
Tariffs ($)	+93	+29%
Water Use (GL)	+2%	−32%
Capital and Operating Costs ($)	+154	+69
Serviced Population (people)	+50	-
Non-Farm GDP ($)	+58	+21%

Removing the population effects by examining the real per capita values of the parameters confirm the growth in tariffs (29%), non-farm GDP (21%), and capital and operating costs (69%) for significant decline in per capita water use (−32%). These results indicate increases in tariffs and investment in utility assets that are greater than economic and population growth, and per-capita demand for utility services.

Figure 5 shows that the peak of increased utility costs to provide water security infrastructure in 2008–09, rapid growth in utility tariffs from 2007–08 to 2015–16 and substantial reductions in demand for utility water supply during the period 2004–5 to 2011–12. The response to the drought involved substantial reductions in demand for utility water due to water restrictions, water conservation and complementary water sources. This situation led to findings (for example: Productivity Commission 2011) that utility infrastructure and supply of services are preferred to water restrictions, water conservation and alternative water sources. The utility costs of increasing water supply capacity occurred following a period of diminished revenue from demands for utility services (Infrastructure Australia 2017). Increased tariffs were leveed to recover lost revenue and pay for infrastructure.

The aggregate data for Australian urban water services shows that growth in expenditure on utility infrastructure and tariffs is greater than changes in water use, population and economy. These effects are most likely smoothed due to spatial and temporal variability of weather and implementation of the building block price regulation.

3.2. Application of building block regulation for Greater Sydney

This section presents the historical record of the Regulatory Asset Base (RAB) and Nominal Revenue Requirement (NRR) for Sydney Water from 2000–01 to 2019–20 that was sourced from Sydney Water Annual Reports and IPART Price Determinations. The historical (CPI adjusted) 2022 dollar values for Sydney Water's RAB and NRR with the key explanatory variables of depreciation, net capital and operation expenses, and return on assets are presented in Figure 6.

Figure 6 reveals 121% real (CPI adjusted) growth in the Regulatory Asset Base for Greater Sydney. The growth in the Regulatory Asset Base is consistent over the 20-year period which includes investment in the Kurnell desalination plant from 2006 to 2011 and after divestment of the desalination plant in 2012. Growth in the Regulatory Asset Base was driven by 83% increase in capital expenses and 245% growth in depreciation costs, and a smaller 16.9% growth on operating costs.

Figure 6 reveals 40% growth in the nominal revenue requirement (NRR) that translates into utility prices and therefore represents a real increase in cumulative charges to customers over that period. The growth in the NRR was driven by increases in operation and depreciation expenses, and return on the regulatory asset base (RAB). The proportion of the NRR driven by variables associated with the RAB (return on assets and depreciation) has increased (in real terms) from 34% to 46% in the period 2000–01 to 2020–21.

The context of these historical regulatory outcomes for Greater Sydney is provided by annual growth in customer connections, urban water use, average household water bill (CPI adjustment to 2022 dollar values) sourced from SWC (2022b) and IPART (2016, 2022), and annual rainfall from Parramatta provided by BOM, (2014–2022) as shown in Figure 7.

Figure 7 demonstrates a decrease in total urban water demands (6.8%) during the 2003 to 2021 period and real increases in total household utility bills (8.3%) in the context of a 25.3% increase in connections to utility water services. An increase in wastewater discharges (26.8%) will also impact on the costs of providing utility services.

The nominal increase in total household bills was 53% during this time period and the real increase (8.3%) represents increases in household costs above

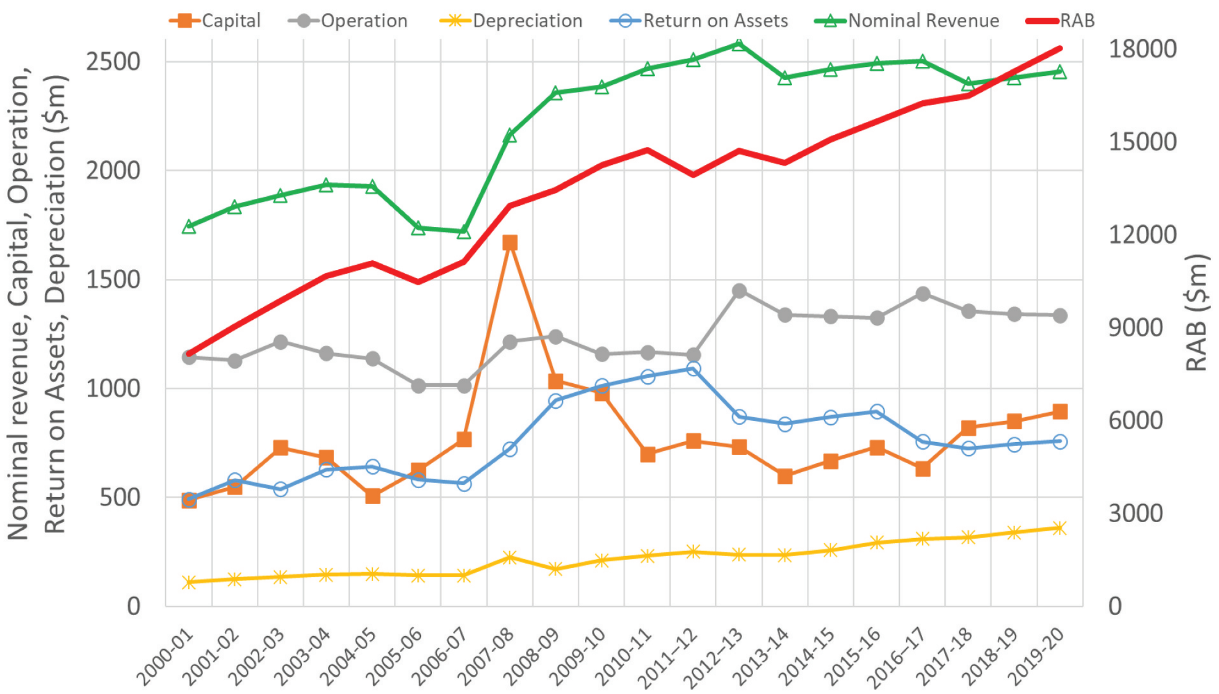


Figure 6. The CPI adjusted values (2022 dollars) for the regulatory asset base (RAB) and nominal revenue (NRR) for Greater Sydney with capital, operation and depreciation expenses, and return on assets for the period 2000–01 to 2019–20.

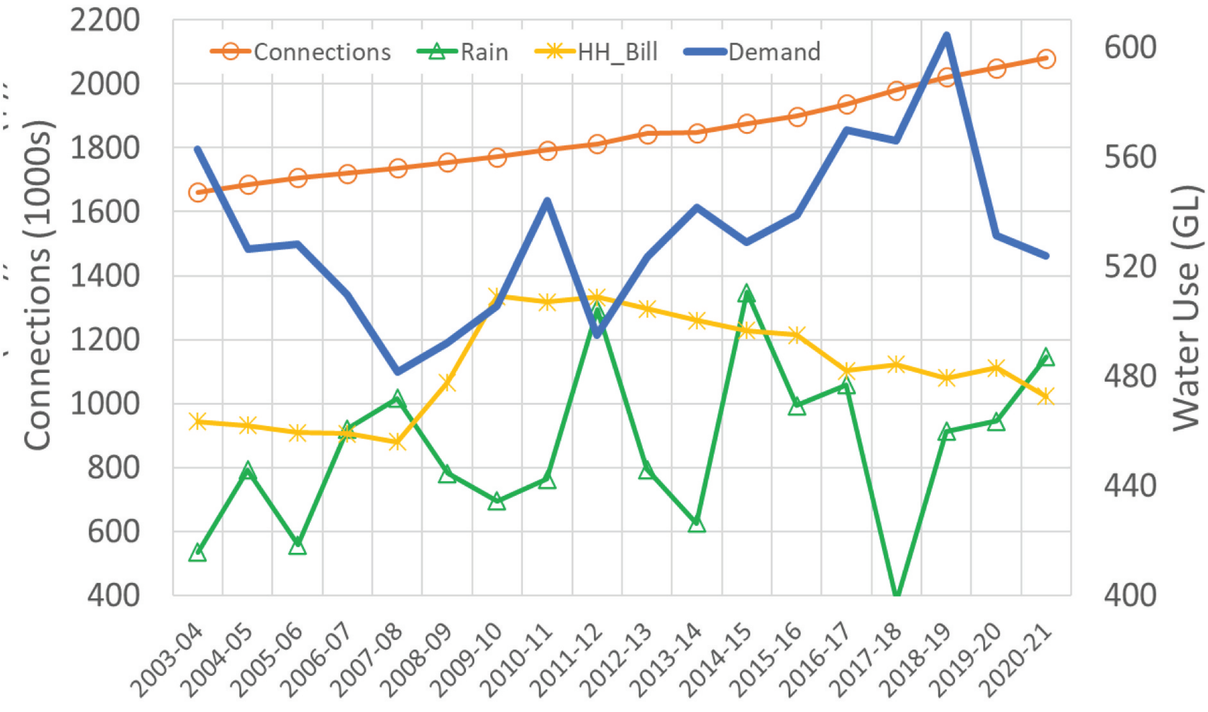


Figure 7. Growth in water connections, total household water bills (Hh_bill, 2022 dollars) and urban water use (demand) with annual rainfall from parramatta (rain).

the inflation rate during a period of limited real change in household income (Gilfillan 2019). This indicates a decline in household welfare associated with water utility tariffs. Growth in real wages has declined from 1.5% in 2008 to −1.2% in 2022 (ABS 2022b). In contrast the RAB and NRR were subject to substantially greater growth of 121% and 40% respectively.

It is noteworthy that total household bills for utility services were held low due to the very low Australian interest rate environment and a legacy of a higher level of household water efficiency in Sydney that was facilitated by the BASIX planning policy (P. J. Coombes, Barry, and Smit 2018).

The increases in the RAB and NRR are only partially associated with expanding infrastructure networks in response to increases in water and wastewater connections (25.3%, 26.1%) because infrastructure created by new developments is not paid for by the utility and not directly included in the RAB. The value (2022 dollars) of these 'gifted assets' increased from AUD $103 million in 2011/12 to AUD $236 million in 2020/21 and are a significant proportion of infrastructure investment that has increased from 13% to 27% of capital expenses. In the Greater Sydney region, gifted assets are ultimately included in operational expenses when maintenance is required and as capital or depreciation expenses when renewal or replacement of the infrastructure is needed in the future (IPART 2022).

It is also shown in Figure 6 that adding a desalination plant to the infrastructure portfolio increases the operating costs and the returns on assets during the period 2007–08 to 2011–12. The growth in the NRR can also be attributed to increases in the RAB, and provision of water security and wastewater treatment infrastructure which includes higher returns on assets and greater operation expenses. Nevertheless, the growth in regulated expenses associated with utility infrastructure is significantly higher than the growth in connections and the economy in the context of decreased water demands. These impacts have been mitigated by a low interest rate environment and strong water efficient behaviours supported by the BASIX policy.

3.3. Comparison to application of building block regulation for greater Melbourne

The application of the building block regulation for the Greater Melbourne region was examined as a comparison to the Greater Sydney region. This investigation defines Greater Melbourne as recieving water, sewage and partial stormwater services from the bulk provider Melbourne Water Corporation (MWC), and the retailers City West Water (CWW), South East Water (SEW) and Yarra Valley Water (YVW). The MWC also provide services to nearby regions and the jurisdiction of Greater Melbourne has recently expanded to incorporate Western Water.

This investigation utilised information from the Essential Services Commission (ESC 2005 – 2018), the NPR (NWC 2004 – 2013; BOM 2014–2022) and water utility annual reports to compile the historical record of the RAB and NRR for Greater Melbourne from 2004–05 to 2020–21. The historical (CPI adjusted) 2022 dollar values for the RAB and NRR for Greater Melbourne with the variables of depreciation, net capital and operation expenses, and return on assets are presented in Figure 8.

Figure 8 shows real (CPI adjusted) growth in the regulatory asset base (82%) and nominal revenue requirement (118%) during the period 2004–05 to 2020–21. The growth in capital and operating expenses also includes development of the Wonthaggi desalination plant and the Sugerloaf pipeline from 2007–08 to 2013–14. The high growth in the RAB and NRR is similar to the outcomes for Greater Sydney and was driven by increases in capital expenses (68%), depreciation expenses (117%), and operating costs (173%).

The growth in the return on assets (−4%), depreciation (117%) and capital expenses (68%) is less than Greater Sydney, and the increase in operation expenses (173%) is significantly greater. This represents the different allocation of Weighted Average Cost of Capital (WACC), and capitalisation and operation of the desalination plant. The substantial growth in the operation expenses is driven by security payments for the desalination plant which represents both operation and purchase of the plant. For example these security payments ranged from $677 million in 2015–16 to $493 million in 2021–02 which is 64% to 52% of operation expenses. During the same period the incremental capitalisation of the desalination plant represented 9%–5% of capital expenses.

Whilst there is some variation in the methods that account for the costs of utility infrastructure within the building block approach, the outcome of increasing RAB and NRR is similar. The RAB is also revalued at the commencement of each regulatory period to incorporate these contributions to utility infrastructure and the operating expense is a strong contribution to growth in the NRR.

The context of these historical regulatory outcomes for Greater Melbourne is provided by annual growth in customer connections, urban water use, average household water bill (CPI adjustment to 2022 dollar values) sourced from the ESC (2022) and NPR data, and annual rainfall for Melbourne provided by BOM (2014–2022) as shown in Figure 9.

Figure 9 shows real increases in household utility bills (60%) in response to growth in water connections (47%) and decline of total water demands (−2%) during the period 2003–04 to 2020–21. The costs of providing water utility services to the Greater Melbourne region was also influenced by the growth in connections to sewage services (46%) and increased sewage discharges (14%).

Figure 9 also reveals the substantial contribution of water restrictions, water conservation and complementary water sources to reducing demands of the utility water services during the 2003–04 to 2015–16 period in response to drought. These reductions

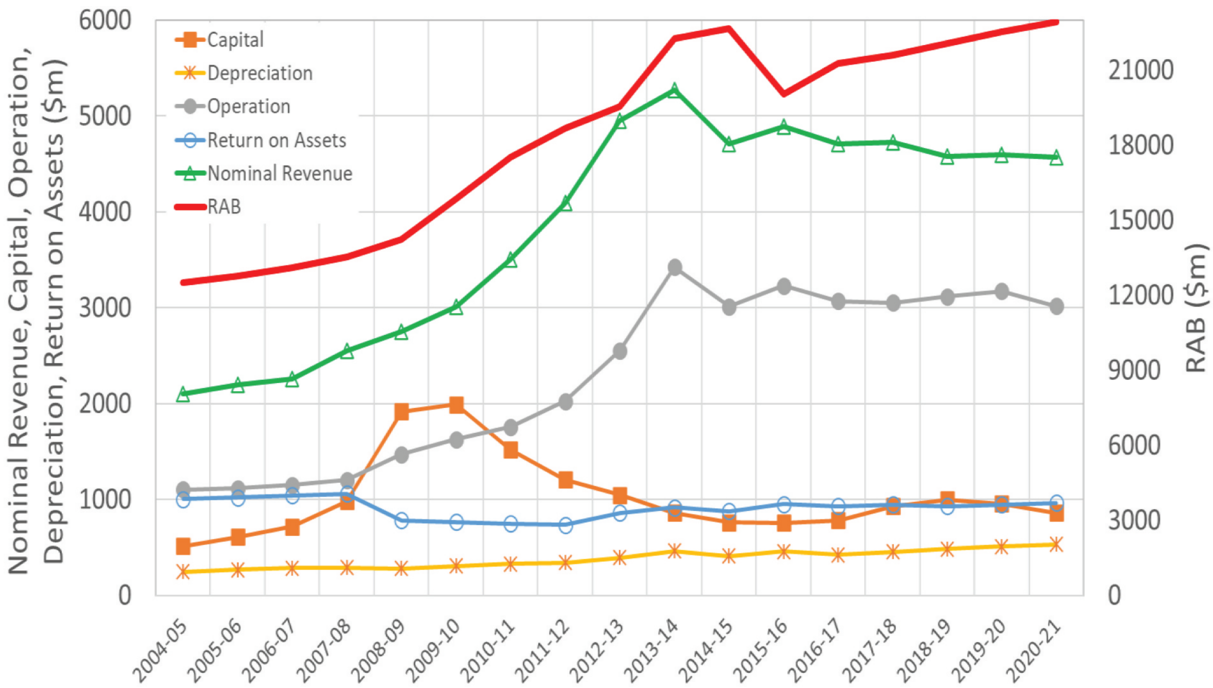


Figure 8. The CPI adjusted values (2022 dollars) for the regulatory asset base (RAB) and nominal revenue (NRR) for greater Melbourne with capital, operation, depreciation expenses, and return on assets for the period 2004–05 to 2020–21.

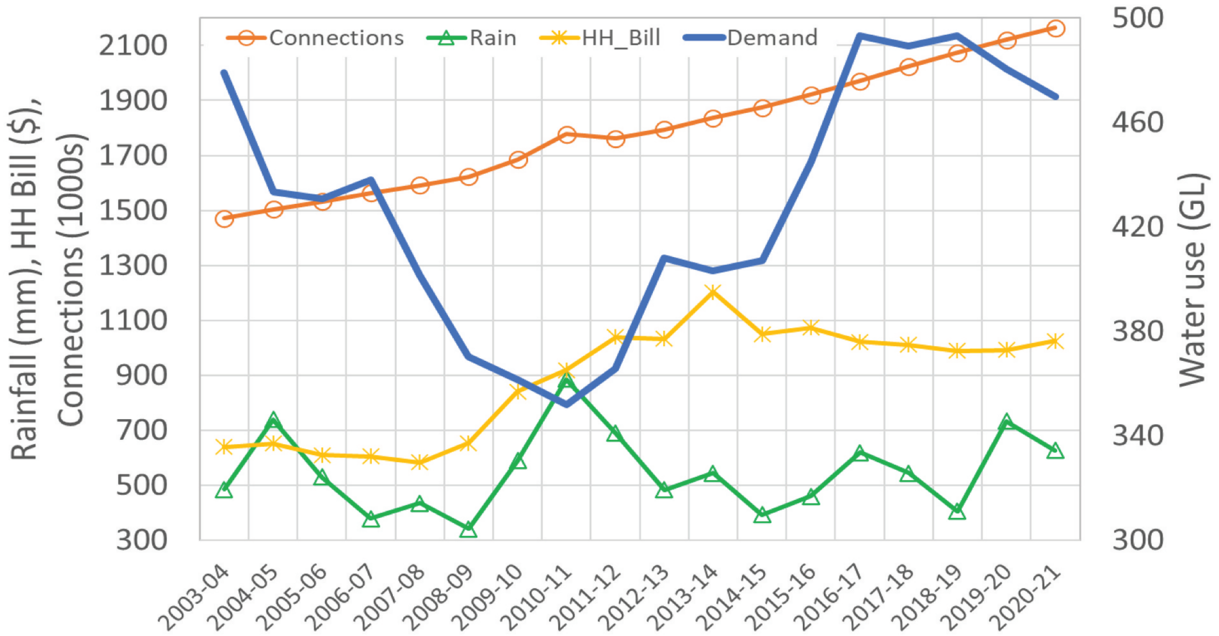


Figure 9. Growth in water connections, total household water bills (household bills in 2022 dollars) and urban water use (demand) with annual rainfall from Melbourne (rain).

in demand for utility water were expected to reduce the revenue earned from water sales. However, increases in utility tariffs have offset this potential decreased revenue.

The real growth in RAB (83%), NRR (118%) and household tariffs (60%) is significantly greater than increases in water (47%) and sewage (46%) connections, and economic growth (54%). In addition, the increases in water demands (−2%) and sewage discharges (14%) are substantially less than growth in the RAB and NRR that is based on provision of utility infrastructure. The expansion of utility infrastructure to service the Greater Melbourne region is also partially decoupled from the growth in the RAB by gifted assets provided by new developments that represent an additional 20% of capital expenses. The region has experienced a 46% growth in gifted assets that will ultimately transfer to the RAB when replacement, maintenance, renewal and depreciation is required.

The magnitude of the Return on Assets is dependent on the Weighted Average Cost of Capital (WACC) and the RAB which are, in turn, influenced by interest rates and inflation. The historical decline in national interest rates was expected to reduce the WACC and therefore diminish the Return on Assets component of the NRR. However, there was significant growth in the Return on Assets for Sydney and a small decline for Melbourne. The Reserve Bank of Australia (RBA 2022) cash rate and inflation is compared to the WACC for Sydney and Melbourne in Figure 10 to better understand this issue.

Figure 10 reveals a significant difference between the RBA cash rate and the WACC for Sydney after the 2008–09 year that are well above (greater than 2% higher than RBA rates) the margin applied to returns on assets in previous years. In contrast, the WACC for Melbourne was set substantially lower than the Sydney WACC during the period from 2008–09 to 2016–17 which may explain the diminished growth in the return on assets.

The similarity between RBA cash rate and inflation after 2008–09 suggests that the return on investments will be zero. This may explain the setting of the WACC at levels greater than 2% above the RBA cash rate to ensure a return on infrastructure value as part of setting revenue allowances. Nevertheless, the setting of the WACC and the value of the utility infrastructure in the RAB impacts on the revenue a utility is permitted to earn. The more recent increases in interest and inflation rates are expected to increase the WACC and returns to utilities.

Consider that a 2% variation in the WACC on a RAB of AUD $20b represents an additional annual income of AUD $400 m or 16% of Sydney Water's annual revenue of AUD $2.52b (SWC, 2020). The cumulative impact of the higher margin assigned to the Return on Asset component of the NRR results in higher tariffs to customers that are not related to service levels. The impact of these higher capital costs is currently distributed across a growing customer base which decreases the relative growth in prices for each customer.

3.4. Prediction of future RAB and NRR for Sydney

A model based on equations 1 and 2 was utilised to estimate future revenue (NRR) for Greater Sydney

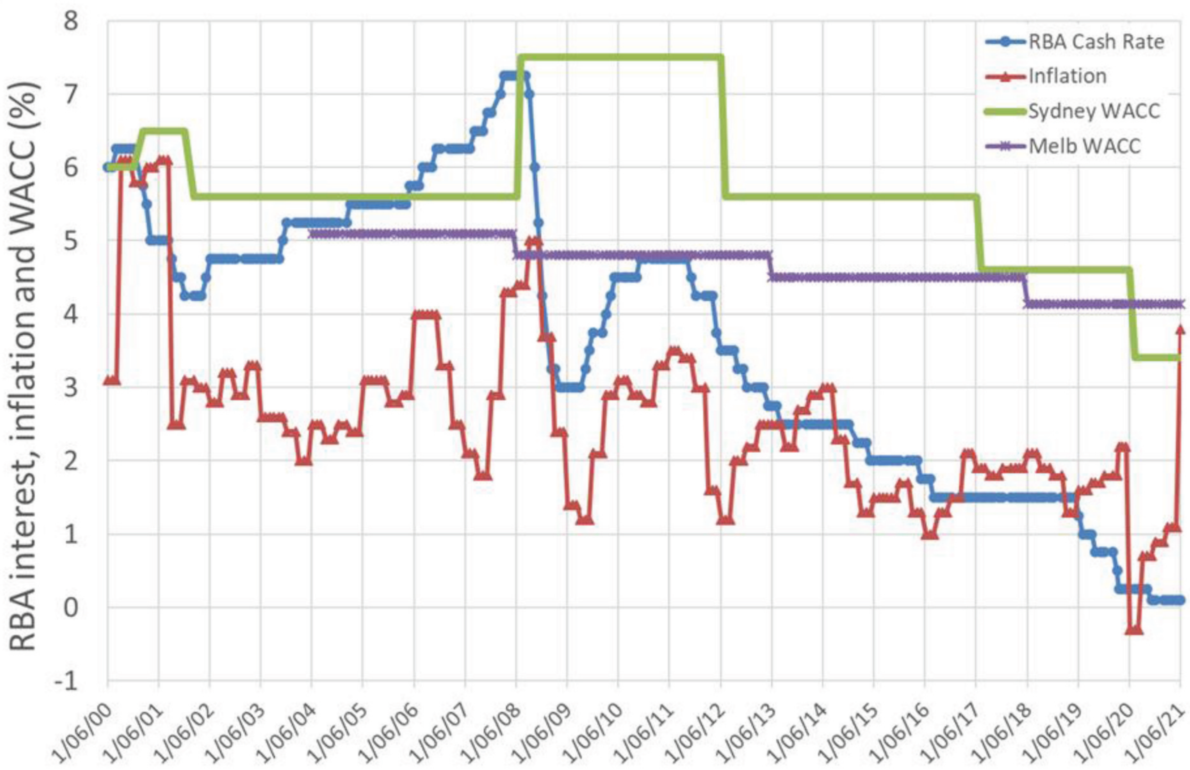


Figure 10. The RBA cash rate and inflation versus the WACC for Sydney and Melbourne for the period 2000 to 2021.

derived from the regulatory asset base (RAB) for the period 2020 to 2050. This model commenced with inputs of historical values for the 2019–20 financial year from IPART (2020) and used annual depreciation (2%), inflation (2.3%) and weighted average cost of capital (WACC) of 3.4% to derive annual values. The model also included annual growth in capital (Capex), operational (Opex) and depreciation (deprec) expenses as a function of RAB and time t that was derived from the 2010 to 2020 historical record for Sydney (see Figure 6) as follows:

$$Capex = (0.0476 + 0.00023_{t-2020})RAB_t \quad (3)$$

$$Opex = (0.071 - 0.00072_{t-2020})RAB_t \quad (4)$$

$$Deprec = (0.019 + 0.00051_{t-2020})RAB_t \quad (5)$$

The second time dependent parameter in equations 3 - 5 accounts for the delayed effect of gifted assets impacting the utility RAB by increases in depreciation and replacement costs. This model was utilised to compare the impacts of 0% and 8% annual growth in capital expenses to the performance of historical average 4.76% growth in capital expenses for Sydney by changing the first parameter in equation 3. These scenarios were explored to understand the proportion of NRR from the different futures for Return on Assets as shown in Table 2.

Table 2 demonstrates that 8% annual growth in capital expenses would increase the value of the RAB by AUD $59,670 million (154%) in 2050 which in turn increases the annual value of revenue NRR associated with utility infrastructure by AUD $7041 million compared to average growth. In contrast, a scenario with zero growth in capital expenses will diminish the associated annual value of revenue by AUD $3464 million (76%) compared to a stable asset base and the value of the RAB would decline by AUD $29,353 million in 2050.

Table 2. Predicted future asset value (2022 dollar values) and associated revenue to 2050.

	Growth in capex (%) versus RAB and NRR ($m)		
Criteria	Low (0%)	Average (4.76%)	High (8%)
RAB in 2050	9264	38,617	98,287
Annual revenue based on RAB in 2050	635	2645	6733
NRR in 2050	1093	4557	11,598

These results indicate that the utility is dependent on growth in capital and operating expenses to increase the value of RAB which generates higher annual revenue NRR. Zero growth in capital expenses creates substantial reductions in the revenue that the utility is permitted to earn. Increasing growth in capital expenses to increase value of the Regulatory Asset Base, which is the regulated value of the infrastructure the water corporation owns, is a key determinant of regulated future income for a water corporation. Increasing the quantum of utility supply side infrastructure results in higher asset values and annual revenue which is a crucial business strategy for a regulated utility.

4. Discussion

The study examined the relationship between regulation and behaviour of water corporations with respect to investment decisions to understand the impact of the building block method.

4.1. Urban water regulatory processes and market characteristics

Monopoly pricing should account for the welfare of citizens, health of the environment and viability of the utility (Chu and Grafton 2021). A focus on narrowly defined private costs of a utility can also produce high levels of social and environmental costs as externalities. This includes the crowding out, either by artificially low usage tariffs with high fixed tariffs or by monopoly influence, of complementary distributed solutions from the market (Dollery and Wallis 1997). This creates government and market failure with hidden opportunity costs associated with a preference for utility infrastructure. These outcomes are evidenced by responses of the Productivity Commission (2011, 2017, 2020), the NSW Auditor General (2020) and Infrastructure Australia (2017) which are consistent with the insights from this investigation.

Classical theory for setting monopoly pricing (Figure 1) may be inconsistent with the actual characteristics of the urban water market and application of regulation (Figures 2, 3 and 4) described in this investigation. The linear Chadwick paradigm of utility scale water and sewage services does not reflect the complexity and components of urban water markets. The Building Block method focussed on utility operational and capital allowances (Figure 2) does not reflect the broad objectives for urban water markets and could create economic and social inefficiencies associated with market failure as outlined by Dollery and Wallis (1997) and Chu and Grafton (2021). The mix of water corporation and complementary services should be considered to optimise public benefit (P. Coombes, Smit, and Macdonald 2018, 2016). These considerations also need to integrate both demand and supply opportunities across all scales.

The Commonwealth of Australia (2015a) summarised concerns about the operation of the building block method, the RAB and the WACC as an incentive for utilities to favour excessive capital expenditures which lock in higher prices and associated revenue. This investigation has demonstrated that selection of the rate of return (WACC) can also inflate the regulatory assessment of acceptable monopoly revenues. These processes can motivate a preference for utility supply infrastructure (IPART 2020; ESC 2005 – 2018) which can also crowd out more sustainable alternatives from local communities that could deliver higher social and environmental benefits (Infrastructure Australia 2017).

The building block model for setting maximum water utility prices is shown by this investigation to be remote from the urban water market and it may not respond to the market processes of supply and demand for water and sewage services which includes changes in water use behaviours. This is evidenced by growth in the weighted average cost of capital (WACC) that is greater than the RBA cash rate since 2008–09 and regulatory price setting that is internalised around increasing the asset value of the water corporation. This seems to be an inherent flaw of the WACC and the Building Block method as it allows significant increases and decreases in customer tariffs quite independent of the demand and supply of services or the efficiency of technology or society objectives. The setting of monopoly prices does not appear to be based on the market mechanisms of supply and demand for services. The process seems to maximise monopoly power by eliminating competition to utility infrastructure which is a perverse outcome of a regulatory process that aims to mitigate monopoly power.

This circular process locks in increasing growth in regulatory capital with declining incentive for water conservation and other market opportunities which in turn annually increases asset values that are assumed to be fixed or sunk costs resulting in declining estimates of marginal costs. In contrast, P. J. Coombes, Barry, and Smit (2018, 2019) demonstrated increasing marginal costs in the urban utility market based on all costs that were variable in the long run. These investigations also demonstrated that complementary water solutions that reduce requirement for utility infrastructure provide greater cost savings than potential loss of revenues.

Despite government owned water utilities being restructured as government corporations, it is difficult to understand how market principles have been applied to the building block method of setting maximum prices and determining appropriate income. This suggests even in a market economy the state still needs to effectively apply the appropriate market principles and that independent governance remains important (Helm 2020; Stigler 1971).

4.2. Historical observations

Figure 5 shows that the Australian urban water sector has provided large real increases in tariffs (+93%) and costs (+154%) that are significantly greater than the growth in serviced population (+50%), the economy (+58%) and urban water use (+2%).

The Greater Sydney region has experienced strong 121% real increases in its regulatory asset base over the last 20 years resulting in 40% increased revenue. These increases RAB and NRR are dominated by increases in capital (83%) and depreciation expenses (245%) in comparison to 16.9% increases operation expenses. The choice of a supply side water security augmentation was also shown to increase the value of regulatory asset base with associated higher operating and capital expenses which equate to higher revenue using the Building Block method. In contrast, Figure 7 shows that urban water demand decreased by 6.8% in response to a 23.5% increase in connections and 8.3% real increases in household utility bills during the same time period. The increases in household utility bills in a low interest rate environment with little or no wage growth equate to a decline in household welfare.

In comparison, the building block regulation of the Greater Melbourne region involves substantial real increases in the RAB (+83%), NRR (118%), capital (+68%), operating (+173%) and depreciation (+117%) expenses (Figure 8), and utility household bills (+60%) (Figure 9). The associated increases in water use (+2%), sewage discharges (+14%) and connections to services (water: +46%; sewage: +47%) are also substantially less than the growth associated with utility infrastructure.

These findings are also more significant given that the fate of the Regulatory Asset Base (RAB) is partially decoupled from expanding networks in response to growth in connections driven by new development. The mechanism for providing infrastructure for new growth which might expand the network is that developers or land owners pay for that infrastructure (not the utility), and the infrastructure value is not attributed to the Utility until there is a need to replace or repair the asset at some future date. These 'gifted assets' or 'Asset Free of Charge (AFOC)' to the utility as defined by the regulator are recorded in the Utility's asset register for statutory and tax purposes but are not included in the RAB. Only assets purchased by the utility are included in the RAB. It is noteworthy that the utility is also the approval authority that determines the type of infrastructure solutions permitted to service new development.

The Building Block method is demonstrated to favour investment in utility supply side infrastructure (83% and 68%% increase in capital expenses) and the Regulatory Asset Base (121% and 83% increase) over other forms of investment, such as demand management, leak reduction, distributed solutions from others and conservation, that do not contribute to the utility asset base. This insight is consistent with the findings of the NSW Auditor General (2020) that the regulatory process motivated increased demand for utility services and associated infrastructure. The security and resilience of urban water services may be diminished by preference for utility scale supply side infrastructure over more integrated solutions. P. J. Coombes, Barry, and Smit (2018) highlight the stronger performance of Sydney Water relative to other utilities for household welfare and operating costs due to legacy demand management provided by the BASIX policy and other initiatives. The impacts of the regulated preference for utility supply infrastructure on household welfare (as indicated by real increases in utility bills) was higher in the Greater Melbourne jurisdiction.

4.3. Future impacts

This investigation shows that the current regulatory process creates utility dependence on growth in expenses associated with utility owned infrastructure to ensure future revenue. A situation that involves zero growth in capital expenses for utility infrastructure is expected to result in a 76% decline in revenue by 2050 (Table 2). In contrast, 8% growth in capital expenses for utility infrastructure drives considerable increases 154% increases in RAB and NRR. The regulatory process locks in dependence and preference for utility supply infrastructure that is counted in the RAB.

These insights imply that changing water efficiency, distributed water sources and pricing policy have a direct impact on the operating and capital costs of the corporation. Increasing water efficiency and decreasing demand for utility water services (higher efficiency scenario) is likely to reduce the operating costs and growth in the Regulatory Asset Base which decreases future regulated revenue allowance. It also follows from this that decreasing water efficiency and water saving (lower efficiency scenario) increases operating costs and the regulatory asset base which drives higher future revenue. Scenarios with greater water efficiency are expected to make the water corporation more efficient by reducing growth in operating and capital costs. These savings however represent a potential for lost income to the water corporation in the context of the current building block regulation.

It is an important consideration that future increases in the RAB are unlikely to be buffered by lower interest rates. It is noteworthy that both interest and inflation rates are now increasing. Depreciation expenses will continue to increase as new and gifted assets are included at their full value and the arbitrary write downs of the asset base associated with the start of economic regulation in 2000 will become a lower proportion of the total asset base. This situation will ultimately lead to a strong escalation of regulated utility costs which may increase debt and will require higher prices.

An important practical consideration in this discussion is time. Utility assets are considered to have long asset lives of up to 90 years (IPART 2020; ESC 2005 – 2018). This implies that the impact of a growing Regulatory Asset Base will increase nominal revenue for the water corporation for nearly a century into the future. The higher regulated value of infrastructure in a low efficiency scenario, in the context of the building block regulation and natural monopoly assumptions, also leads to higher assumed fixed or sunk costs and artificially lower variable costs. The assumptions about the assumed fixed costs associated with natural monopoly and with infrastructure decisions also seem to be at odds with economic theory that in the long run all costs are variable (Friedman 2002).

4.4. The risk to complementary solutions

The results of this investigation indicate that the regulatory income model can create society risks due to loss of demand management, distributed solutions and conservation. This finding is consistent with the observations of the NSW Audit Office (2020). These complementary solutions provide systems benefits and reduce costs but are unlikely to increase investment in the Regulatory Asset Base or provide additional water corporation income.

It is difficult to see how the government owners of regulators and water corporations could support strategies that reduce demand for utility services as a successful utility business outcome.

4.5. Separation of powers

Urban water management is an example of market failure where government owns, regulates and operates urban water corporations (Infrastructure Australia 2017). State bureaucracies hold delegated responsibility for governance of utilities whilst also providing oversight of regulators. Water utilities provide their preferred solutions and data to regulators who rely on that information to implement economic regulation. Utilities and associated government agencies are also the planning and approval authorities for strategies and infrastructure solutions in the urban water market. This investigation has revealed a dichotomy of conflicts where building more infrastructure is seen to maximise performance of the government utility and shareholder interests, but this process can negatively impact on viable alternatives from others. This process encounters the profound conflicts associated with multi-level governance systems and competing innovations as explained by Daniell, Coombes, and White (2014) and requires intervention. The Australian Constitution is based on the concept of separation of powers to avoid concentrations of excessive power in segments of society which includes scale and hierarchy constraints (Joseph and Castan 2014). It would seem that the principles of separation of powers in the regulation and policy settings for government water utilities are needed to maximise overall urban water benefits to society and the environment. There is a need to separate the ownership and operation of government utilities from the planning and approval of infrastructure solutions. In addition, independent economic regulation should be focused on maximising the opportunity and value of the entire urban water market.

5. Conclusions

Meadows (2008) advised systems thinkers to look at behaviour to deduce the purpose of a system. This investigation considered the impacts of the price regulation of government owned urban water utilities using historical information and models of likely future behaviours.

The current regulatory paradigm assumes urban water corporations are natural monopoly providers of water and sewerage services. Regulation using the building block method to set maximum prices is based on the capital and operating expenses, and an assumed market value of utility assets. It was revealed that at least part of the behaviour, and therefore purpose, of urban water corporations is to build infrastructure to increase the Regulatory Asset Base and future income. The Australian urban water sector has experienced high growth in real (CPI adjusted) utility infrastructure costs and tariffs that are significantly greater than increases in serviced population, the economy and water demand. Indeed, urban water demand has declined over the last two decades and there has been significant contributions from utility water efficiency and non-utility solutions. Historical behaviours in the Greater Sydney and Melbourne regions demonstrate that regulators and utilities have acted to increase the Regulatory Asset Base far in excess of changes in the supplied water and sewage services, and the utilities have a regulated dependence on growth in utility owned infrastructure. These processes act as a barrier to more integrated solutions that include demand management and recycling, distributed solutions and water conservation.

The operation of the building block method provides a clear incentive to fund additional utility scale infrastructure in order to increase future revenue. A more expensive, less efficient solution provides a greater revenue benefit to the utility than a less expensive, more efficient solutions under this regulatory model. The contributions from people in households, whole of society and other solutions in the urban water market are not directly relevant to this model.

The urban water market is not limited to the operation of government water utilities and the characteristics of the market does not align with the regulatory model that is dependent on utility asset values. This finding is surprising at a number of levels. A considerable volume of demands in the urban water market and many market processes are not managed by the water corporation or considered in the pricing method.

The building block method for determining monopoly revenue is well established but in the context of this analysis is surprisingly one dimensional. There is significant evidence that the method prioritises the viability of the water monopoly over market forces, social and environmental considerations. These insights are consistent with economic text book definition of market and government failure associated with monopoly with novel integration of these issues to government owned monopolies (Dollery and Wallis 1997; Friedman 2002; Hubbard et al. 2013).

There is evidence that regulation of water utilities is driving investment in supply side infrastructure owned by utilities to build Regulatory Asset bases as the overriding purpose of regulatory models. In economic terms water corporations and regulators have done exactly what we asked them to do. This investigation has revealed a situation where government, regulators and utilities are bound within overlapping interests and a narrow partial market definition which does not permit consideration of the entire urban water market and associated opportunities, and emerging integrated systems paradigms.

This is a structural problem. The solution will require a redefinition of the market and for a regulatory structure with separation of powers to have regard to the entire urban water market.This discussion provides a prima facie case for a new market and regulatory regime that builds on the contribution of P. J. Coombes, Want, and Colegate (2012) and could include the following key elements:

(1) The regulatory process recognises the environmental and social benefits provided by innovative servicing options in a whole of society framework that combines utility and non-utility services;
(2) Water utilities are rewarded for facilitating customer access to traditional and non-traditional servicing arrangements. This will involve revising the objectives for the successful governance and operation of water utilities;
(3) Provide structural separation of planning, approval and operational processes involved in delivering water cycle services from the operation of water utilties. This will involve assigning water cycle planning and approval functions to an independent authority and broadening the objectives of the regulator, and
(4) Provide open, transparent, and freely accessible information about the performance of water cycle systems throughout cities to all stakeholders and the community. This information should be managed by an independent authority in each city and be available in a common location and format.

Acknowledgements

This paper is the product of a decade of discussion and collaboration around the economics, social and environmental performance of urban water markets from a systems perspective. In particular the effect of government regulation and policy on urban systems is the genesis of this investigation. The collaboration and advice of colleagues in the water industry, the regulators IPART and ESC and the improvements motivated by the anonymous reviewers are gratefully acknowledged. This manuscript benefited from the original proposal and recommendations from Michael Smit to explore the influence of the regulatory asset base on water utility decisions about infrastructure.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

The author(s) reported there is no funding associated with the work featured in this article.

Notes on contributor

Peter J. Coombes is an Honorary and Visiting Professor in the Crawford School of Public Policy at The Australian National University and is also the managing director of Urban Water Cycle Solutions that provides policy advice to government and industry. He is also a member of the steering committee for the CAMELLIA Community Water Management for a Liveable London at Imperial College London and a member of Australian Water Association Committee on Water Efficiency. Peter was an editor of the Urban Book of Australian Rainfall and Runoff, a Chief Water Scientist in the Victorian Government and a member of the PMSIEC water working group. He was previously Chair of Engineering, Professor of Water Resources Engineering and Associate Dean (Education) at the University of Southern Cross. He holds a PhD in environmental and civil engineering systems, and has qualifications in Surveying, Engineering, Economics and Law. His research interests include systems analysis, hydrology and water resources, molecular sciences, public policy, economics, law and sustainability.

ORCID

Peter J. Coombes http://orcid.org/0000-0002-1852-8263

References

ABS. 2013. *4602.0.55.003 - Environmental Issues: Water Use and Conservation*. Canberra, Australia: Australian Bureau of Statistics. https://abs.gov.au/ausstats/.

ABS. 2022a. *Expenditure and Product*. 5206.0. Canberra Australia: Australian Bureau of Stastics.

ABS. 2022b. *6401.0, Consumer Price Index Australia*. Canberra Australia: Australian Bureau of Statistics. June.

Aisbett, E., and R. Steinhauser. 2011. "Does Anybody Give a Dam? The Importance of Public Awareness for Urban Water Conservation During Drought." *SSRN Electronic Journal*. https://doi.org/10.2139/ssrn.1906962.

Australian Institute of Company Directors. 2020. "General Duties of Directors. Australian Institute of Company Directors. https://aicd.companydirectors.com.au/-/media/cd2/resources/director-resources/director-tools/pdf/05446-6-2-duties-directors_general-duties-directors_a4-web.ashx .

AWA Water Efficiency Specialist Network. 2012. *The Case for Water Efficiency - AWA Position Paper October 2012*. Sydney: Australian Water Association.

Barry, M. E., and P. J. Coombes. 2018. "Planning Resilient Water Resources and Communities: The Need for a Bottom-Up Systems Approach." *Australasian Journal of Water Resources* 22 (2): 113–136. https://doi.org/10.1080/13241583.2018.1497125.

Biggar, D. 2009. "Is Protecting Sunk Investments by Consumers a Key Rationale for Natural Monopoly Regulation?" *Review of Network Economics* 8 (2). https://doi.org/10.2202/1446-9022.1173.

BOM. 2014–2022. "Urban National Performance Reports." Bureau of Meteorology. Commonwealth Government of Australia.

Byrnes, J., L. Crase, B. E. Dollery, and R. Villano. 2010. "The Relative Economic Efficiency of Urban Water Utilities in Regional New South Wales and Victoria." *Resource and Energy Economics* 32 (3): 439–455. https://doi.org/10.1016/j.reseneeco.2009.08.001.

Chu, L. R., and Q. Grafton. 2021. "Dynamic Water Pricing and Risk Adjusted User Cost." *Water Resources and Economics* 35:100181. https://doi.org/10.1016/j.wre.2021.100181.

Clarke, R. M., and R. G. Stevie. 1981. "A Water Supply Cost Model Incorporating Spatial Variables." *Land Economics* 57 (2): 18–32. https://doi.org/10.2307/3145749.

COAG. 1994. *Water Reform Framework, Council of Australian Governments*, 25 February 1994. Hobart Australia: Communiqué.

COAG. 2014. "Intergovernmental Agreement on a National Water Initiative, Coalition of Australian Governments." s24(vi). (24 June, 2014).

Coase, R. H. 1947. *The Economics of Uniform Pricing Systems*, 139–156. 2nd ed., Vol. 15. Manchester England: Manchester School of Economics and Social Studies. https://doi.org/j.1467-9957-1947.tb00558.x

Commonwealth of Australia. 2015a. "Performance and Management of Electricity Network Companies, Interim Report, Environment and Communications References Committee, the Senate." Commonwealth of Australia.

Commonwealth of Australia. 2015b. *Stormwater Management in Australia, Environment and Communications References Committee*. Canberra Australia: The Senate Commonwealth of Australia.

Connell, D., S. Dovers, and R. Q. Grafton. 2005. "A Critical Analysis of the National Water Policy Initiative." *Australasian Journal of National Resources, Law and Policy* 10 (1): 82–107.

Coombes, P. J. 2022. *A Systems Perspective on Characterising Resilience in Urban Water Markets, OzWater 2022*. Brisbane: Australian Water Association.

Coombes, P. J., M. E. Barry, and M. Smit. 2018. *Systems Analysis and Big Data Reveals Economic Efficiency of Solutions at Multiple Scales, OzWater 2018*. Brisbane, Australia: Australian Water Association.

Coombes, P. J., M. E. Barry, and M. Smit. 2019. *Bottom Up Systems Analysis of Market Mechanisms for Pricing Water and Sewage Services OzWater19*. Melbourne: Australian Water Association.

Coombes, P. J., S., Want, and M. Colegate. 2012. "Development of Policies for Water Cycle Reform in Greater Melbourne and Sydney." In *Water and Climate – Policy Implementation Challenges*, edited by K. A. Daniell. Canberra: Engineers Australia.

Coombes, P., M. Smit, and G. Macdonald. 2016. "Resolving Boundary Conditions in Economic Analysis of Distributed Solutions for Water Cycle Management." *Australian Journal of Water Resources* 20 (1): 11–29. https://doi.org/10.1080/13241583.2016.1162762.

Corporations Act. 2001. "Commonwealth of Australia."

Daniell, K. A., P. J. Coombes, and I. White. 2014. "Politics of Innovation in Multi-Level Water Governance Systems." *Journal of Hydrology* 519 (C): 2415–2435. https://doi.org/10.1016/j.jhydrol.2014.08.058.

Delgado, A., D. J. Rodriguez, C. A. Amadei, and M. Makino. 2021. *Water in Circular Economy and Resilience (WICER)*. Washington, DC: World Bank.

Di Lorenzo. 1996. "The Myth of Natural Monopoly." *The Review of Austrian Economics* 9 (2): 43–58. https://doi.org/10.1007/BF01103329.

Dollery, B. E., and J. L. Wallis. 1997. "Market Failure, Government Failure, Leadership and Public Policy." *Journal of Interdisciplinary Economics* 8 (2): 113–126. https://doi.org/10.1177/02601079X9700800202.

ESC. 2005 – 2018. *Water Price Review for City West Water, South East Water and Yarra Valley Water*. Melbourne, Victoria: Victorian Government.

ESC. 2022. "Personal Communication, May – August 2022."

Essential services act. 1994. "Victorian Government."

Feinglas, S., C. Gray, and P. Mayer. 2014. "Conservation Efforts Limit Rate Increases for Colorado Utility." *Journal AWWA* 106 (4): 64–69. https://doi.org/10.5942/jawwa.2014.106.0057.

Finkel, A., C. Munro, T. Effeney, and M. O'Kane. 2017. "Independent Review into the Future Security of the National Energy Market. Blueprint for the Future." *Report by Australian Chief Scientist*. Commonwealth of Australia.

Friedman, L. S. 2002. *The Microeconomics of Public Policy Analysis*. Princeton and Oxford: Princeton University Press.

Gilfillan, G. 2019. *The Extent and Causes of the Wage Growth Slowdown in Australia, Department of Parliament Services*. Canberra Australia: Parliament of Australia.

Godden, L., and A. Foerster. 2011. "International Transitions and Water Law Governance." *Water Law* 22 (2/3): 53–57.

Government of NSW. 1888. "Metropolitan Water and Sewerage Amendment Act 1888 NSW."

Government of NSW. 1992. "Independent Pricing and Regulatory Tribunal Act 1992 NSW."

Government of NSW. 1994. *Sydney Water Act 1994 no.88 NSW Government of NSW, 1992*. Sydney New South Wales: NSW Government.

Grafton, R. Q., L. Chu, and P. Wyrwoll. 2020. "The Paradox of Water Pricing: Dichotomies, Dilemmas, and Decisions." *Oxford Review of Economic Policy* 36 (1): 86–107. https://doi.org/10.1093/oxrep/grz030.

Guldmann, J. M. 1985. "Economies of Scale and Natural Monopoly in Urban Utilities: The Case of Natural Gas Distribution." *Geographical Analysis* 17 (4): 302–317. https://doi.org/10.1111/j.1538-4632.1985.tb00852.x.

Health, A. 2017. *Structural Change in Australian Industry: The Role of Business Services*. Canberra Australia: Reserve Bank of Australia.

Helm, D. 2020. "Thirty Years After Water Privatization—Is the English Model the Envy of the World?" *Oxford Review of Economic Policy* 36 (1): 69–85. https://doi.org/10.1093/oxrep/grz031.

Hilmer, F. 2014. "New Technologies Will Crack Flawed NBN Model." *The Australian Financial Review*, 28/04/2014.

Hubbard, R. G., A. M. Garnett, P. Lewis, and A. P. O'Brien. 2013. *Microeconomics*. 3rd ed. Essex England: Pearson Education.

Infrastructure Australia. 2017. *Reforming Urban Water – a National Pathway for Change*. Canberra Australia: Commonwealth of Australia.

IPART. 2003. "Sydney Water Corporation. Prices of Water Supply, Wastewater and Stormwater Services." *From 1 July 2003 to 30 June 2005, Independent Pricing and Regulatory Tribunal*. New South Wales.

IPART. 2008. "Prices of Sydney Water Corporation's Water, Sewerage, Stormwater and Other Services." *Final Determination No.1 2008. From 1 July 2008 to 30 June 2012*. New South Wales: Independent Pricing and Regulatory Tribunal.

IPART. 2012. "Prices of Sydney Water Corporation's Water, Sewerage, Stormwater and Other Services." *From 1 July 2012 to 30 June 2016. Water - Final Report June 2012*. New South Wales: Independent Pricing and Regulatory Tribunal.

IPART. 2016. "Review of Prices for Sydney Water Corporation from 1 July 2016 to 30 June 2020." *Water - Final Report*. New South Wales: Independent Pricing and Regulatory Tribunal.

IPART. 2020. *Review of Prices for Sydney Water from 1 July 2020 - Final Report*. New South Wales: Independent Pricing and Regulatory Tribunal.

IPART. 2022. "Personal Communication, January 2022."

IPCC. 2021. "Summary for Policy Makers". In: *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press.

Jones, B. 2020. *What is to Be Done: Political Engagement and Saving the Planet*. Brunswick: Scribe Publications.

Joseph, S., and M. Castan. 2014. *Federal Constitutional Law. A Contemporary View*. 4th ed. Pyrmont NSW: Thomson Reuters.

Kelly, R. 2011. "Getting the Balance Right: Why the Murray Darling Basin Plan Can Implement the Triple Bottom Line Approach." *Canberra Law Review* 10 (178): 182–183.

Khosroshahi, S., L. Crase, B. Cooper, and M. Burton. 2021. "Matching customers' Preferences for Tariff Reform with managers' Appetite for Change: The Case of Volumetric-Only Tariffs in Australia." *The Australian Journal of Agricultural and Resource Economics* 65 (2): 449–471. https://doi.org/10.1111/1467-8489.12417.

Mack, E. A., S. Wrase, and J. Meliker. 2017. "A Burgeoning Crisis? A Nationwide Assessment of the Geography of Water Affordability in the United States." *PLOS ONE* 12 (1): e0169488. https://doi.org/10.1371/journal.pone.0169488.

Meadows, D. 2008. *Thinking in Systems, a Primer*. England: Chelsea Green Publishing.

NERA. 2010. *BASIX Post-Implementation Cost-Benefit Analysis. An Economic Evaluation of the State Environmental Planning Policy- Building Sustainability Index (BASIX)*. Sydney Australia: Government of NSW.

NSW Audit Office. 2020. *Water Conservation in Greater Sydney, Report by the NSW Auditor General*. Sydney: Parliament of NSW.

NWC. 2004 – 2013. "National Performance Reports: Urban Water Utilities." Canberra.

Pindyck, R. S., and D. L. Rubinfeld. 2015. *Microeconomics*. 8th ed. Essex England: Pearson Education.

Productivity Commission. 2011. "Australia's Urban Water Sector." *Final Inquiry Report No. 55, Canberra Productivity Commission, 2017, National Water Reform, Draft Report*.

Productivity Commission. 2017, National Water Reform, Draft Report.

Productivity Commission. 2020. *National Water Reform, Issues Paper*. Canberra.

Queensland Audit Office. 2013. "Maintenance of Water Infrastructure Assets, Report to Parliament 14: 2012–2013." Brisbane: Queensland Audit Office.

RBA. 2022. "Interest Rate Tables." Reserve Bank of Australia. Retrieved 6 October 2022. https://rba.gov.au/statistics/tables.

Saddler, H. 2016. "Rising Power Bills Signal the End of an Era for Australia's Electricity Grid." *Article from Australian National University Published in the Conversation*.

Simshauser, P. 2017. "Monopoly Regulation, Discontinuity & Stranded Assets." *Energy Economics* 66:384–398. https://doi.org/10.1016/j.eneco.2017.06.029.

Spinesi, L. 2009. "Rent-Seeking Bureaucracies, Inequality, and Growth." *Journal of Development Economics* 90 (2): 244–257. https://doi.org/10.1016/j.jdeveco.2008.09.009

Stern, J. 2013. "The Role of the Regulatory Asset Base as an Instrument of Regulatory Commitment, CCRP Working Paper No 22, Centre for Competition and Regulatory Policy (CCRP)." City University London.

Stigler, G. J. 1971. "The Theory of Economic Regulation." *Bell Journal of Economics and Management Science* 2 (1): 3–21. https://doi.org/10.2307/3003160.

Sydney Water. 2022a. "Annual Report 2021-21."

Sydney Water. 2022b. "The Current Value of Water Under the ELWC." Accessed August 22, 2022. https://www.syd neywater.com.au/about-us/our-organisation/what-we-do/operating-licence.html .

Tan, J. 2012. "The Pitfalls of Water Privatization: Failure and Reform in Malaysia." *World Development* 40 (12): 2552–2563. https://doi.org/10.1016/j.worlddev.2012.05.012.

Tisdell, J., J. Ward, and T. Grudzinski. 2002. *The Development of Water Reform in Australia*. Brisbane Australia: Cooperative Research Centre for Catchment Hydrology, Griffith University.

Troy, P. 2008. *Troubled Waters. Confronting the Water Crisis in Australian Cities*. Canberra Australia: ANU Press.

Turner, A., S. White, J. Chong, M. A. Dickinson, H. Cooley, and K. Donnelly. 2016. *Managing Drought: Learning from Australia, Prepared by the Alliance for Water Efficiency, the Institute for Sustainable Futures*. Sydney Australia: University of Technology Sydney and the Pacific Institute for the Metropolitan Water District of Southern California, the San Francisco Public Utilities Commission and the Water Research Foundation.

Zetland, D. 2021. "The Role of Prices in Managing Water Security." *Water Security* 12. https://doi.org/10.1016/j.wasec.2020.100081.

urban WaterCycle Solutions
Independent research and consulting

Modelling the Impact of Changes to BASIX

For

Department of Planning, Industry and Environment

by

Professor Peter Coombes

Urban WaterCycle Solutions
Independent research and consulting
ABN: 47093645777

peter@uwcs.com.au

September 2020

Revised on 26 August 2022

70 Howden Street Carrington NSW 2294 ■ Tel: 0419 439 124 ■ ■ www.urbanwatercyclesolutions.com

About the Author

Associate Professor Peter Coombes

Peter Coombes is a director of Urban Water Cycle Solutions, a fellow of Engineers Australia and Certified Practicing Engineer in Civil and Environmental Engineering, Leadership and Management. He was awarded the 2018 GN Alexander Medal for scientific contributions to Hydrology and Water Resources and the 2019 Presidents Medal for his role as a lead editor of Australian Rainfall and Runoff. Peter holds a PhD in Civil and Environmental Engineering, and degrees in Civil Engineering (honours) and Surveying (Honours). Peter Coombes has also almost completed a B.Econ/Dip. Law. qualification.

Peter is currently the Chair of Engineering at Southern Cross University and is an editor the Urban Book of Australian Rainfall and Runoff published by Engineers Australia. He has held senior academic positions at University of Newcastle, University of Melbourne and Swinburne University. Peter was a Chief Scientist in the Victorian Government and recently contributed to inquiries into stormwater management and flooding by the Senate of the Australian Parliament and into water resources by the Productivity Commission.

Peter was a managing director of Bonacci Water, a member of the water advisory group to the Prime Ministers Science, Engineering and Innovation Council, the advisory council on alternative water sources for the Victoria Government's Our Water Our Future policy, a member of the advisory panel on urban water resources to the National Water Commission, an advisor on alternative water policy to the United Nations and a national research leader of innovative WSUD strategies in the eWater CRC. He has generated over 250 scientific publications and designed more than 120 sustainable projects including settlements that generate all of their water resources and manage flooding. Professor Coombes was also a co-author of Australian Runoff Quality and a former chair of the Stormwater Industry Association. More information can be found at http://urbanwatercyclesolutions.com

Executive Summary

The Department of Planning, Industry and Environment (DPIE) commissioned Professor Peter Coombes to undertake systems modelling to understand the impacts of current BASIX policies and proposed changes to BASIX targets across the Greater Sydney region.

The aim of this investigation is to better understand the household and broader impacts of potential changes to BASIX policy and gain an insight into how BASIX can be used to help achieve the following aims:

a. Reduce potable water demand / improve water security

b. Reduce stormwater impacts

c. Increase the number of trees in residential areas

An additional aim was to set up a process for using systems modelling to satisfy cost benefit analysis requirements for proposed BASIX policy changes.

System Framework models developed for the Greater Sydney region over the previous 20 years were utilised for this investigation. The Systems Framework methodology was recognised in 2018 by Engineers Australia as leading water resources and hydrology research by the award of the GN Alexander Medal. This analysis methodology was enhanced for this investigation to incorporate more input data from the NSW Government and the rainwater industry, and additional advances analysis methods were included.

The Systems Framework was used to simulate and then compare five Options. The Business as Usual (BAU) Option considers current water cycle (water, sewage, stormwater and environment) management practices and BASIX policies across the Greater Sydney region. The second Option (NoBasix) examines the impacts of not implementing the BASIX policy in 2004 to document the benefits of the state planning policy. A third Option (SN1) includes higher water saving targets and two additional options (SN2 and SN3) include stormwater annual volume targets and increased water saving targets designed to address key challenges facing Greater Sydney.

Variants of the BASIX policy examined in this systems analysis provided substantial benefits to 2050 as follows:

- Reductions in annual utility water demands ranged from 122 GL to 153 GL
- Reductions in annual utility wastewater discharges ranged from 31 GL to 87 GL
- Decreased regional annual stormwater runoff volumes ranged from 53 GL to 148 GL
- Diminished annual nitrogen loads discharging to urban waterways ranged from

360 tonnes to 1137 tonnes

- Annual greenhouse gas emissions were lowered by 128 ktonnes - 178 ktonnes
- Reduced net present costs to operate the water utility by $2003 - $2833 million
- Reduced whole of net present costs to whole of society by $7424 - $17,156 million

It is a key finding of this investigation that the benefits of the current BASIX policy are significantly greater than the costs from the perspective of the water utility and whole of society within the Greater Sydney region. This result holds for discount rates ranging from 3% to 10%. The current and proposed Scenario 1 versions of BASIX provide significant improvements in household welfare for all households in response to real reductions in utility tariffs to 2050. The local value of water savings at households was not considered. Inclusion of stormwater management and green infrastructure in the BASIX increases household costs by 10% for scenario 2 and 6% for scenario 3 because there is no economic mechanism to transfer catchment scale stormwater benefits to households in council rates.

The systems analysis provided a rich dataset and only some of this information is provided in this report to address the Department's aims. A key insight from this investigation is that a combination of supply and demand management at multiple scales is more efficient than relying entirely on centralised supply solutions when considering utility and whole of society benefits. These demand management solutions include behaviour change, water efficient appliances, greywater reuse, rainwater harvesting, raingardens and urban greenspace including trees.

An example of these benefits of the BASIX policy is the significant deferral of centralised augmentation requirements. Inclusion of rainwater harvesting, rain gardens and green spaces that include trees as a stormwater management solution has both infrastructure and demand management benefits and is an efficient decentralised infrastructure asset that improves the performance of the linked water resources system.

This investigation highlighted the water and sewage transfer distances of over 50 km across Greater Sydney. Transporting water and sewage across these distances with significant changes in ground elevations represents high capital and operational costs and potential economic inefficiencies. In some parts of Greater Sydney, the shadow cost (medium run marginal cost) of delivering water and sewage services is greater than $16/kL, which is almost 8 times the household water usage tariff.

Enhancement of the BASIX policy to incorporate higher water targets and targets for reduced stormwater volumes provides the highest economic benefits from the perspective of the water utility and whole of society. BASIX with increased water savings target provides the highest economic benefits to households.

Incorporation of mechanisms to transfer some of the regional stormwater benefits to households (about $15 - $27 per household) or also counting non-market benefits (such as amenity and enjoyment of healthy waterways) in the analysis will indicate that the SN3 Option that combines increased water savings and stormwater targets is the Pareto Optimum solution for Greater Sydney from all perspectives.

Table of Contents

1 INTRODUCTION

The Department of Planning, Industry and Environment (DPIE) commissioned Professor Peter Coombes to undertake systems modelling to understand the impacts of changes to BASIX targets across the Greater Sydney region.

This request follows briefings to BASIX team about our Systems Framework analysis of the Greater Sydney region during 2019 – a workshop at UTS and an additional presentation in the DPIE offices, and many subsequent discussions.

We understand that the BASIX team at the DPIE would like to consider the household and broader scale impacts of the potential changes to BASIX policy and gain an insight into how BASIX can be used to help achieve the following aims:

- Reduce demand for drinking water and improve regional water security
- Decrease stormwater impacts
- Increase the number of trees and area of tree canopy in urban areas

In addition, DPIE would like a process set up to use systems modelling to satisfy Cost Benefit Analysis (CBA) requirements for BASIX policy changes.

Professor Peter Coombes and Urban Water Cycle Solutions have developed a Systems Framework model of Greater Sydney over the last two decades. This research was awarded the 2018 GN Alexander Medal by Engineers Australia for contribution to the science of Hydrology and Water Resources. An earlier version of this model was used to develop the original arguments for the regional water conservation strategy now known as BASIX.

The current version of the Systems Framework includes all land uses, town planning and policy layers as part of the Big Data layers underpinning the model. It was designed to include the entire system in answering policy, infrastructure and economic questions. This model is ideally suited to the proposed project. Applying systems thinking will allow us to identify policies that are the most beneficial overall, rather than most beneficial in terms of one parameter at a time. This study has undertaken systems modelling that includes at least the following outputs for each scenario modelled [with all impacts being relative to the Business as Usual (BAU) Option]:

- Impact on household operational potable water use, energy use and associated bills
- Impact on operational greenhouse gas emissions from utility water and sewage services
- A cost-benefit analysis of each scenario that aligns with the NSW Government Guide to Cost-Benefit Analysis

- Impact on stormwater flows and flooding
- Impact on wastewater flows
- Impact on local temperature and cooling energy use
- Impact on tree canopy cover
- Impact on energy demands associated with water and sewage services

This investigation considers the following Options for Greater Sydney:

- Business as Usual (BAU) continues the current water resources strategies and BASIX policies.
- No BASIX: assumed that the BASIX policy was never implemented
- Option 1: increase in the water target for new dwellings by 10% for detached dwellings, and 5% for semi-detached and unit dwellings in 2022
- Option 2: increase in the water target for new dwellings by 10% for detached dwellings and 5% for semi-detached dwellings in 2022. Also includes a stormwater target where stormwater runoff volumes are no more than twice the stormwater runoff volume from an undeveloped or landscaped site
- Option 3: increase in the water target for new detached and semi-detached dwellings by 20%, and by 10% for unit dwellings in 2025

2 BACKGROUND

The Greater Sydney region

The population of the Greater Sydney region is expected to increase from 4.3 million in 2010 to 6.8 million in 2050. The region includes twelve different water utility demand zones that are supplied from the Warragamba, Upper Nepean, Shoalhaven and Woronora river catchments (Sydney Water, 2010) as shown in Figure 1.[1]

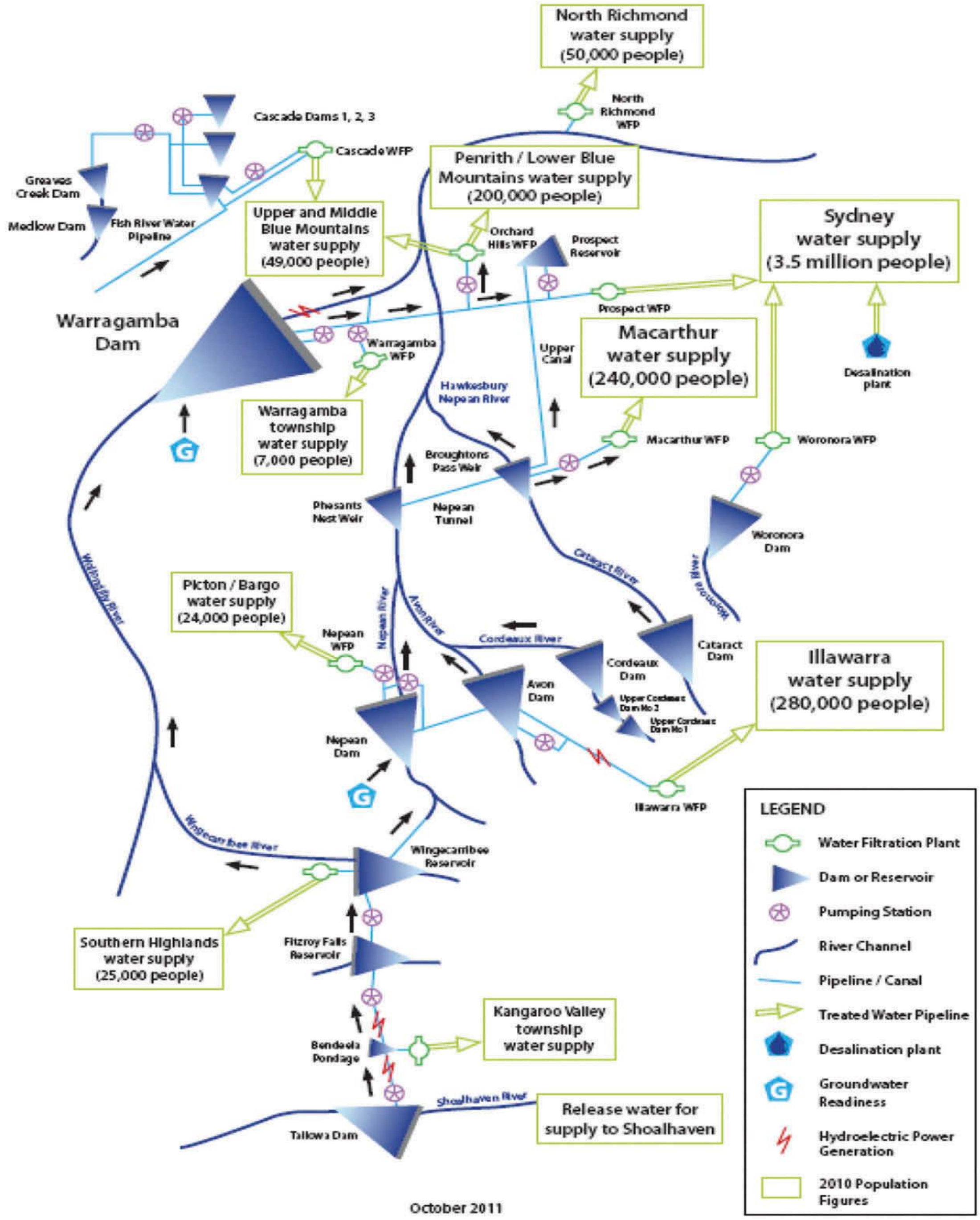


Figure 1: Schematic of the water supply system for Greater Sydney.

[1] Sydney Water. (2010). Annual Report. Sydney Water Corporation.

Water demands for the 45 local government areas in the Greater Sydney region and data from the nearest weather stations were combined in the regional analysis as shown in Figure 2.

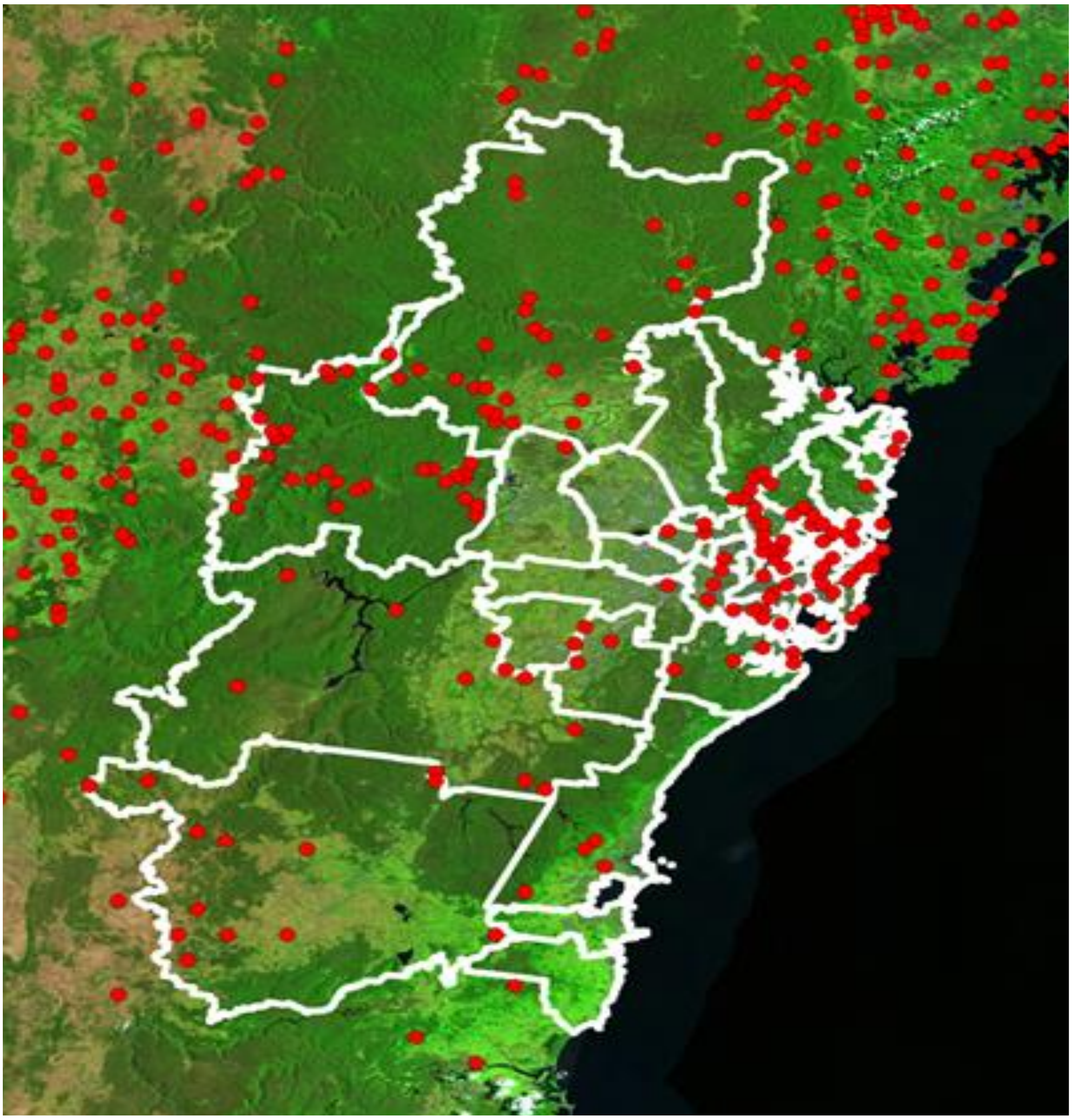


Figure 2: Sydney local government areas (white polygons) and Bureau of Meteorology weather stations (red markers)

Observations of daily water demand from 1976 to 2010 for the 14 water supply catchments and 45 local government areas were included in this investigation. This data sourced from Sydney Water, the NSW Government and the Bureau of Meteorology enabled development of local behavioural water demands and verification of these water demands at different scales.

Figure 1 shows that streamflow from the Warragamba catchment is captured at Warragamba Reservoir. Water from the Cataract, Cordeaux, Avon and Nepean

Dams located in the Upper Nepean catchment is conveyed via a system of pipes, natural river channels, weirs, tunnels and aqueducts to Prospect Reservoir whilst also supplying various communities along the transfer routes. The South Coast region is supplied with water from the Avon and Cordeaux Dams and Nepean Dam via the Nepean–Avon tunnel.

Streamflow from the Shoalhaven catchment is captured in Lake Yarrunga and Tallowa Dam where water is pumped to Wingecarribee Reservoir via Fitzroy Falls Reservoir when the water storage volume in Warragamba Dam is less than 65%. Water from the Wingecarribee Reservoir is distributed to Nepean Dam and Lake Burragorang via the Wingecarribee and Wollondilly Rivers. The townships of Mittagong and Bowral are also supplied with water from the Wingecarribee Reservoir. The water supply catchments within the Greater Sydney region that included in this investigation are presented in Figure 3.

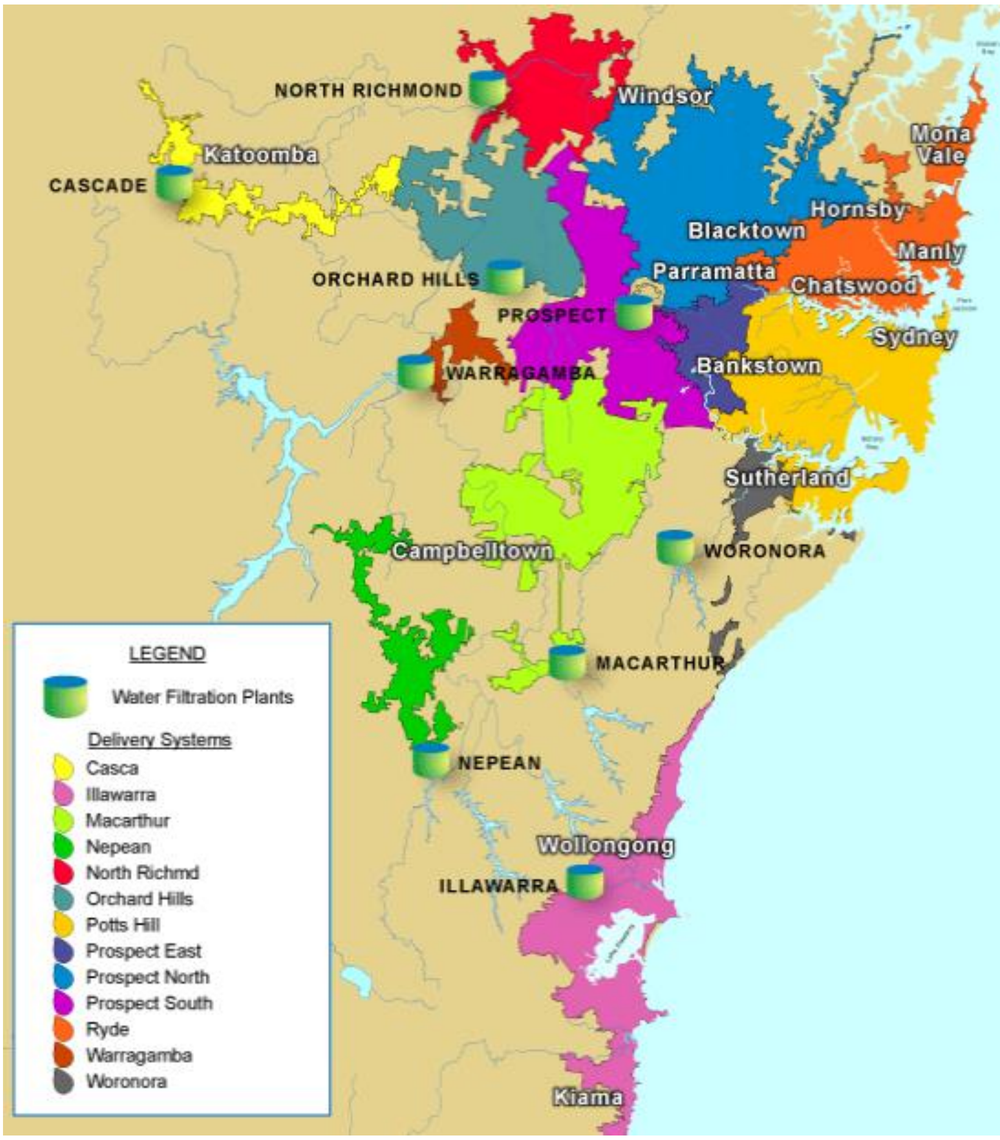


Figure 3: Water supply catchments for Greater Sydney

Desalination is used to supplement the water supply from the Potts Hill reservoir when total storages in dams are less than 80%. Restrictions on urban water demands are triggered when storage levels in Warragamba Dam or Avon Dam fall below 60%. The reported effectiveness of water restrictions in the Sydney region during the 1992–1998 drought by Deen (2000) was used to develop restriction criteria and subsequent demand reductions for domestic outdoor demand as shown in Table 1.

Table 1: Water restriction criteria for residential and non-residential demands.

Storage in dams less than (%)	60	55	50	40	30	20
Reduction in residential outdoor demand (%)	33	57	75	100	100	100
Reduction in residential indoor and non-residential demand (%)	0	0	5	10	15	20

This investigation also includes all of the wastewater treatment plants, recycling schemes and associated catchments as shown in Figure 3. The analysis also incorporates all of the stormwater and water supply catchments associated with the Greater Sydney region.

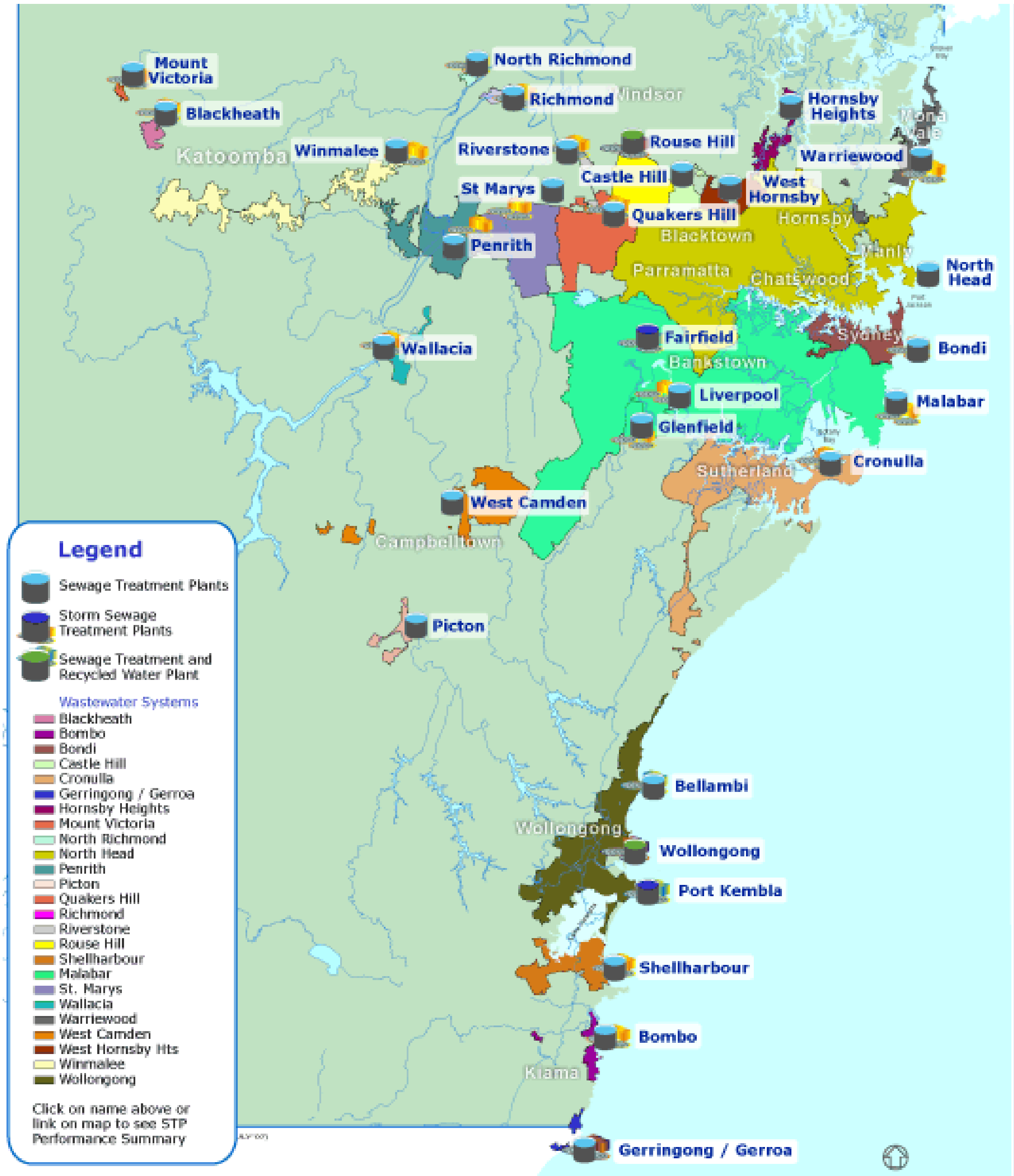


Figure 4: Water treatment plants, reuse schemes and associated catchments

The Systems Framework

The Systems Framework will be used, which incorporates local scale (people, buildings and land uses) inputs as a "bottom up" process. The analysis is constructed from the basic elements (local land uses, demographics, socioeconomic and urban form) that drive system behaviours and which account for the distributed, first principles, transactions which allow simulation of both the spatial and temporal performance of the system. Biophysical systems for a region are constructed using four basic components:

Demands – Local requirement for services and amenity

Sources – Regional and local water sources, catchments and waterways

Flux – Transport and treatment of water, sewage and stormwater throughout the region

Sinks – Stormwater runoff and wastewater disposal to waterways

This structure is anchored on detailed "big data" inputs, such as demographic and socioeconomic profiles, topography, climate and economic behaviours, and linked systems that account for water demands, water supply, sewage flows, stormwater runoff, water quality, human health and environmental considerations. The framework is a series of applications of continuous simulation of water balances that interact to span all relevant spatial and temporal scales including household or land use to city to national and global scales at timelines ranging between one second and 100 years.

The process includes multiple (Monte Carlo) replicates of climate sequences and linked responses that yield a probabilistic understanding of system behaviour and risks, rather than a single static solution. This includes water use and the associated linked generation of wastewater and stormwater runoff at the local scale, distribution infrastructure and information at the sub-regional or precinct scale, and also regional behaviours associated with infrastructure such as water extractions from dams and discharges of sewage to wastewater treatment plants and ultimately to receiving waters.

A general overview of the hierarchy that corresponds to a conceptual description of the Systems Framework is presented in Figure 5 and Figure 6. A more detailed description of the Systems Framework is provided in Coombes and Barry (2015)[2]. This demonstrates the linked scales that are underpinned by what are referred to as 'Big Data' (meaning the vast quantities of information that are interrogated and interpreted as a part of the analysis process) that are utilised in the Systems Framework. This process allows the simulation of linked flows of water, nutrients, finances, sediments, behaviours and energy throughout a city or a region.

The systems analysis includes a wide range of considerations extending from details of household behaviour and associated water balances (at time resolutions of seconds) to the long-term forecasting of infrastructure requirements (at time resolutions of years to decades in some cases). Figure 6 illustrates that the scales of analysis are linked by a hierarchy of processes that are modified by feedback loops. For example, the behavioural water demands at the local scale are impacted by water restrictions applied at the catchment scale, and climate and economic

[2] Coombes P.J., and Barry M.E., (2015). *A Systems Framework of Big Data for Analysis of Policy and Strategy*. WSUD2015 Conference. Engineers Australia. Sydney. Australia.

processes from the regional scale.

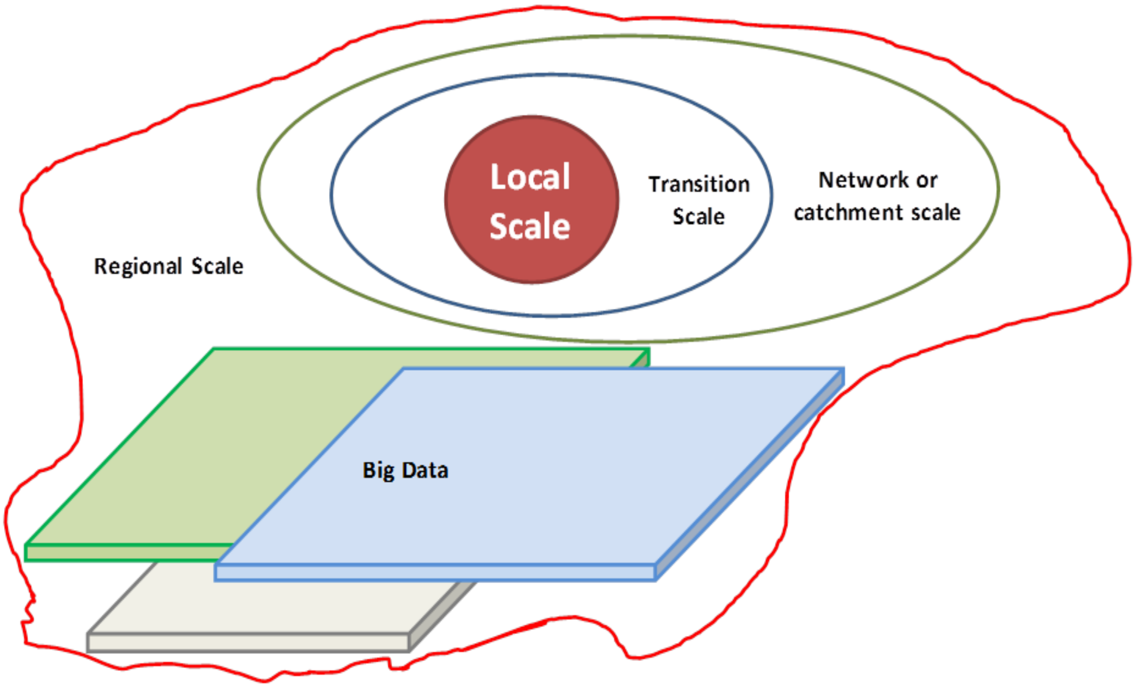


Figure 5: Conceptual Overview of the Systems Framework

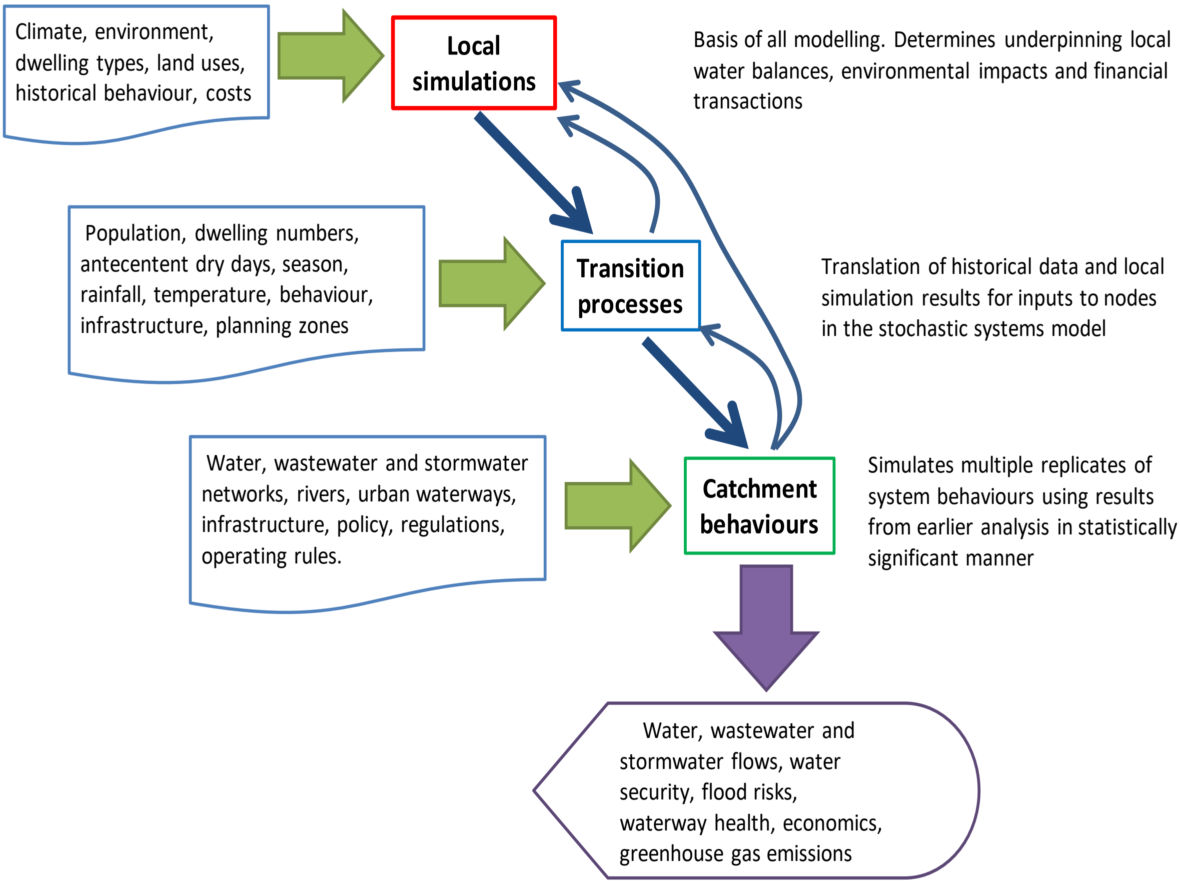


Figure 6: Overview of the Hierarchy in the Systems Framework

The System Framework model for Greater Sydney includes simulation of water, wastewater and stormwater utility services at four hierarchical and linked levels of spatial and temporal granularity: the local scale (individual dwellings and land uses); zone scale (suburbs or local government areas); catchment scale and the whole of system scale (Greater Sydney region). This approach has been developed over two decades to ensure that the systems model explicitly and accurately accounts for the spatial and temporal behaviour-driven variability of most parameters that characterise urban and non-urban areas. This systems approach ensures that this variability is included as it manifests in reality, from the bottom at the smallest spatial and temporal scales at the individual property or dwelling, upwards to the whole of system scale via the intermediary zone and catchment scales that include infrastructure processes.

Local scale

The local scale modelling is underpinned by continuous simulation of indoor and outdoor water use, wastewater and stormwater production across fifteen different residential dwelling possibilities (detached, semi-detached and units, each with occupancies of one to five people). The residential land uses were combined with non-residential agricultural, commercial, industrial, educational, medical, forested, irrigated parks and transport land uses using the methods described by Coombes and Barry (2018).

Each simulation (depending on the options adopted) included the operation of rainwater tanks (down to timescales of seconds), water efficient appliances and local greywater reuse. Climate data from the Bureau of Meteorology (including pluviograph data, daily rainfall and daily maximum and minimum temperatures) were used to force the local scale continuous simulations. Novel nearest neighbour spatial backfilling methods developed by Coombes (2002) were implemented to fill temporal gaps in these records and therefore support generation of one hundred year, six minute rainfall and temperature sequences to drive the local scale simulations.

The continuous simulation models were calibrated using average daily indoor and outdoor uses, demographic and socioeconomic data for each local government area. Residential land uses were combined with non-residential land uses noted above in the analysis as shown in Figure 7.

Local scale continuous simulations were completed for each dwelling type with different levels of known water efficient behaviours sourced from ABS (2017) and for land uses in each zone at time steps ranging from one second to six minutes using the local sequences of rainfall data. The key outputs from this highest spatial and temporal granularity modelling are local scale water demands, wastewater generation, stormwater runoff and energy use at a daily time step. These outputs served as resource files for subsequent execution of the zone scale model.

Zone Scale

The zone scale model combined household types, occupancy distributions, and land use types reported by the ABS with associated local scale simulations of each local government area, as shown in Figure 7.

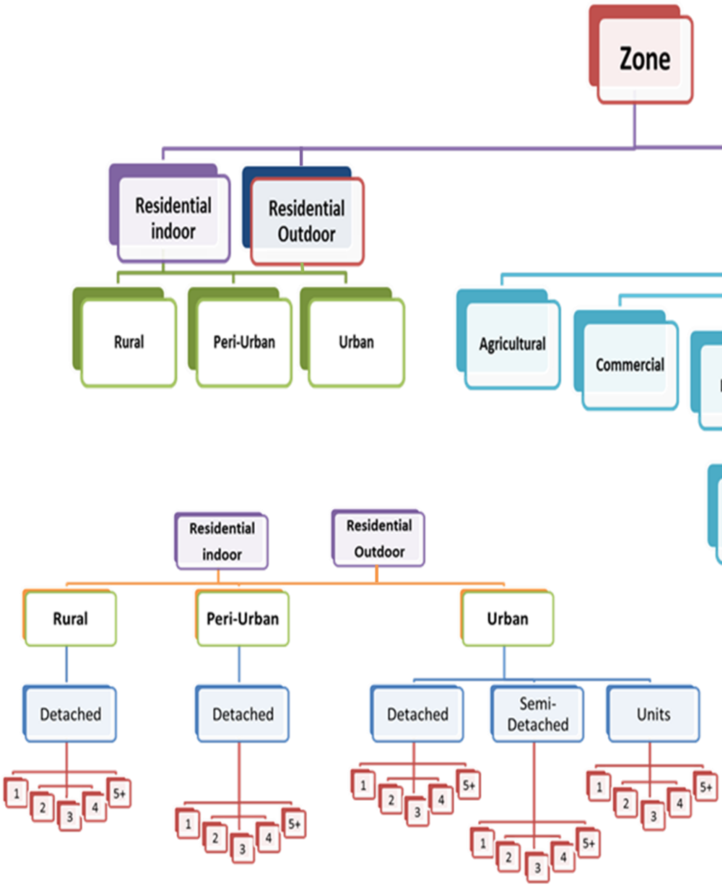


Figure 7: Structure for combining reference files of local land use behaviours at the zone scale

The structure presented in Figure 7 is used with projected growth and renovation rate statistics out to 2050 (for forecasting simulations), weather data, the local scale model reference files (long sequences of daily flows from the outputs of the local scale models) and other related data sets to develop sequences of daily household indoor and outdoor demands from 2010 to the simulation horizon.

The zone scale model used ABS data to define its individual zones of simulation (Local Government areas), with each zone being assigned its own weather data sequences. The Sydney model includes forty-five local zones.

This investigation builds on the methods outlined by Coombes and Barry (2016; 2014) that were upgraded by Barry and Coombes (2018) to include the known distributions of water efficient appliances already in place throughout Greater Sydney. The statistics for the historical installation of rainwater tanks and water efficient appliances were sourced from the Australian Bureau of Statistic (ABS) Environmental series publications, and from the detailed data underpinning these publications provided by ABS (2017). Moreover, more recent population growth statistics available through the NSW Department of Planning were used to drive the zone scale model in this investigation, which represents a significant enhancement over the previous studies of Coombes and Barry (2016).

The sequences of water use, wastewater flows, stormwater runoff, financial transactions and energy use from the local scale analysis are combined in each zone using town planning projections and replicates of daily spatial climate sequences as shown in Figure 8.

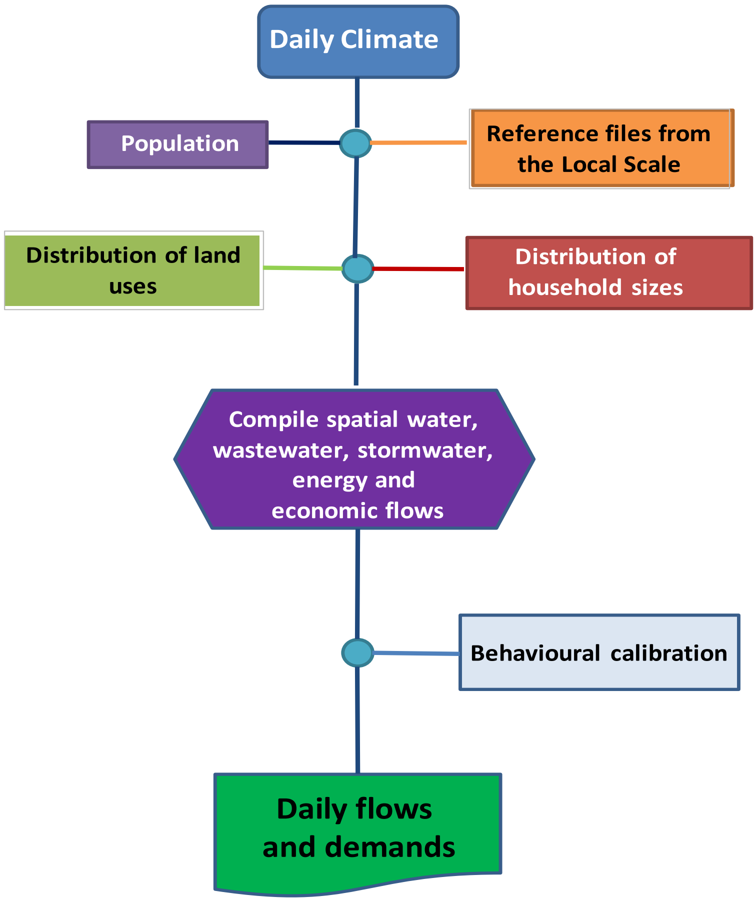


Figure 8: The transition framework for combining local land use behaviours at the zone scale

This transition framework is utilised to generate daily water cycle responses for each zone. Sequences of daily water and energy balance, and financial results from the local scale were linked using seasonal information and historical climate data (including daily rain depths, cumulative days without rainfall and average daily maximum ambient air temperature) to create resource files of water demand, wastewater generation, stormwater runoff, energy use and economic transactions at the zone scale.

The method of non-parametric aggregation from Coombes (2002; 2005)[3] is then used to generate daily outputs from each zone using the historical resource files of local simulations and climate replicates generated for the simulation of the regional system. Climate replicates are multiple sequences of equally likely future climate drivers (such as rainfall and temperature) that are generated using Monte Carlo processes.

To preserve the climatic correlation between the urban and water supply catchments, one hundred equally likely replicates of daily streamflow and climate in water supply catchments and zones are simultaneously generated for the simulation period using a multi-site lag-one Markov model to generate annual values that were then disaggregated into daily values using the method of fragments as described by Kuczera (1992).[4]

Replicates of daily climate sequences (rainfall, temperature, count of dry days and evaporation) and sampling from the local resource files were used to generate water demands within each zone (see Coombes, 2002; 2005). One hundred replicates, at a daily time step spanning forty years (2010 to 2050) are then produced for each zone. Non-residential demand was simulated on a per unit hectare basis, with local land use maps being used to scale these demands, wastewater and stormwater predictions to the correct current and future profiles, for each zone.

Catchment and regional scale

The Systems Framework combines water, wastewater and stormwater infrastructure networks with waterways and catchments in an integrated network. Spatial and temporal information generated by the lot scale simulations are combined at the zone scale as inputs to network simulations.

The regional scale of the Framework included water sources from ground water, surface water sourced from regional river basins, surface water shared with other

[3] Coombes P. J., Kuczera G. A., Kalma J. D., Argue J. R., (2002), An Evaluation Of The Benefits Of Source Control Measures At The Regional Scale, Urban Water, 4, 307- 320.
Coombes P. J., (2005), Integrated Water Cycle Management: Analysis of Resource Security, Water, 32, 21-26

[4] Kuczera, G., (1992), Water supply headworks simulation using network linear programming, Advances in Engineering Software, 14, 55-60

river basins, wastewater reuse and stormwater harvesting. The linked systems analysis utilised stream flows, reservoir storage volumes, wastewater discharges, information about the operation of water systems and data from global climate models as inputs. The simulations also includes operating rules and regional policies such as water restriction triggers and pricing decisions.

The Systems Framework utilises the WATHNET network model (Kuczera, 1992) at a daily timestep. In each case, the model includes the complete water supply processes in response to water demand sequences developed by the zone scale model (which in turn was generated from the local scale model), and wastewater and stormwater networks. These water demand, stormwater, wastewater and river networks are included in the network scale model to represent actual pathways and connections throughout the entire system. This includes sources such as reservoirs and desalination plants, sinks such as wastewater treatment plants, water and sewerage trunk infrastructure and all major relevant waterways.

Where appropriate, these networks are constructed to reflect potential interactions, such as stormwater infiltration to sewerage networks, leakage from water distribution networks, supply of demand from rivers and wastewater reuse. The behaviour of the System Framework was verified at the regional scale using a hindcasting processes that compare predicted and observed behaviours for key processes within historical time periods. The water resources systems for Greater Sydney are described by Barry and Coombes (2018) and further retails of systems analysis of the water supply system for Greater Sydney are provided by Coombes (2012; 2005).

3 METHODS

Systems framework models were established for five Options, namely Business as Usual (BAU), No BASIX (NoBasix), Scenario 1 (SN1), Scenario 2 (SN2) and Scenario 3 (SN3) and the performance of these Options was simulated. This allowed a comparison of the different policy options against the Business as Usual and No Basix Options. The previous Systems analysis of the Greater Sydney region published by Barry and Coombes (2018) was upgraded to incorporate the latest population and demographic data, information provided by the BASIX team, from IPART and the rainwater and water conservation industry. This process took several months using high end computers.

The reader is referred to the previous publications by Coombes and Barry (2018) and Barry and Coombes (2018) for a more detailed discussion of the Systems Framework model.[5]

The System Framework model of the Greater Sydney Region includes the simulation of water, wastewater and stormwater utility services at four hierarchical and linked spatial and temporal scales: the local scale (individual dwellings and land uses); zone scale (suburbs or local government areas); network or catchment scale and the whole of system scale (Greater Sydney region). Analysis of the Sydney water supply systems used daily water demands, streamflows, operational data and rules provided by Sydney Water Corporation and the NSW government.

This approach ensures that the model accounts for both the spatial and temporal behaviour-driven variability of most parameters that are well-known to characterise urban and non-urban areas. This systems approach ensures that this variability is included as it manifests in reality, from the smallest spatial and temporal scales at the individual property or dwelling, upwards to the whole of system scale via the intermediary zone scale that includes infrastructure processes.

3.1 The Systems Framework

This investigation is based on Systems Thinking and a whole of society perspective. Water management is part of a system that includes human and natural elements that can be analysed as a model to test different options. Water cycle management, environment, economy and urban areas are complex dynamic systems. Advances in the digital age permits powerful computing that can employ billions of pieces of

[5] Barry M. E., and Coombes P. J., (2018), Planning resilient water resources and communities: the need for a bottom-up systems approach, Australasian Journal of Water Resources, 22(2), 113-136

Coombes P. J., and Barry, M. E., (2018), Using surfaces of big data to underpin continuous simulation in systems analysis, 10th International Conference on Water Sensitive Urban Design: Creating water sensitive communities (WSUD 2018 & Hydropolis 2018), Engineers Australia, Perth, Australia information or big data to model the real world.[6] Once a model is developed, the rules of the model and the scenarios can be changed to explore better futures.

Systems thinking and models of system dynamics provide understanding of human and linked earth systems, and the trade-offs that are generated by proposed interventions.[7] A detailed description of the concept and modelling for the Systems Framework is available in Barry and Coombes (2018)[7] 'Planning for Resilient Communities' which was the recipient of the Engineers Australia 2018 GN Alexander prize for Hydrology and Water Resources.

Verification using hindcasting

The predictions of the system models were validated against available data, such as water treatment plant flows or reservoir levels and volumes. The 'bottom-up' process of generating local water use from dwellings and land uses in each zone was evaluated by comparison of historical observed water use to predicted water use for the entire Greater Sydney region.

3.2 Universal Assumptions

A number of assumptions are common to all options:

- Population projections and adoption of local scale solutions such as rainwater tanks, use of greywater and water efficient appliances were derived from the NSW State Government, industry data and Commonwealth Government reports.[8]
- Charges for water services and operating costs were obtained from the Independent Pricing and Regulatory Tribunal (IPART) and Sydney Water annual reports.[9]

---

[6] Coombes P.J., and Barry M.E (2015), A Systems Framework of Big Data Driving Policy Making – Melbournes Water Future", OzWater Conference. Australian Water Association. Brisbane.

[7] Barry, M. E., and Coombes, P. J. (2018). Planning resilient water resources and communities: the need for a bottom up systems approach. *Australasian Journal of Water Resources 22(2)*, 113-136

[8] ABS, 2017, Environmental Issues: water use and conservation (Mar, 2013), Cat No. 4602.0.55.003: customised report. Australian Bureau of Statistics,

ABS, 2016, Census of Population and Housing, Cat No. 2901.0; Household Income and Wealth, Cat No. 6523.0, Australia Bureau of Statistics,

NSW government, (2016; 2020), 2016 and 2020 New South Wales State and Local Government Area Population and Household Projections, and Implied Dwelling Requirements, Department of Planning and Environment.

[9] IPART. (2018). Review of prices for Sydney Water Corporation 1 July 2016 to 30 June 2020, Water, Final Report. Independent Pricing and Regulatory Tribunal.

IPART. (2018). Review of the Sydney Water Corporation Operating Licence 2015-2020. Sydney: Independent Pricing and Regulatory Tribunal.

- The operating regimes operated by Sydney Water and regulated by IPART continue into the future
- Rainwater tanks will operate for 20 years before requiring replacement
- Rainwater pumps and water efficient appliances will operate for 10 years before requiring replacement

3.3 Centralised Augmentation

This investigation includes the following regional water security augmentations that are utilised in the systems model in the following order as required.

1. Fitzroy Falls Reservoir to Avon Dam tunnel with 1750 ML/day capacity providing more efficient connection from Shoalhaven River catchment to Illawarra and south coast areas. The construction cost is $500 million.
2. Stage 2 of Sydney desalination plant with 250 ML/day capacity supplying Potts Hill demand catchment. The construction cost is $1 billion and the operating costs are $2.30/kL. Annual costs are already accounted for in phase one of this project. The electricity demand is 3925 kWh/ML.
3. New desalination plant with 500 ML/day capacity supplying Prospect Reservoir which broadens the water security effect of the augmentation (increased storage and distribution). Construction cost is $4.65 billion, annual cost is $390 million and operating cost is $2.30/kL with an electricity demand of 3925 kWh/ML.
4. New desalination plant with 100 ML/day capacity supplying the South Coast and Illawarra region. Construction cost is $2 billion, annual cost is $78 million and operating costs are $2.30/kL with an electricity demand of 3925 kWh/ML.
5. Transfer of sewerage (20 km) from South West Sydney catchments connected to Malabar sewage catchment to Prospect Reservoir for indirect potable reuse. It is proposed to build a pump station in the transfer main connected to the Liverpool to Ashfield pipeline and pump sewage to a new treatment plant located near Prospect reservoir. The treated wastewater will be used to top up Prospect Reservoir. Construction cost is $3.5 billion and operating cost is $4.10/kL and an energy demand of 5529 kWh/ML.

The water resources network also includes transfers from the Shoalhaven River system to the water supply network cost $243/ML and involves an electricity demand of 1624 kWh/ML

These regional water security options are implemented to ensure an acceptable level of annual water restrictions until 2050 for the Greater Sydney region. The trigger for the next level of centralised augmentation is a greater than 10% annual probability of water restrictions in any year.

3.4 Local Augmentation

The Greater Sydney region includes a variety of dwelling types, land uses and distributed water solutions.

Data from the Australian Bureau of Statistics (ABS, 2017), industry suppliers, market surveys and the NSW Government was utilised to determine the distribution and costs of water efficient appliances, rainwater harvesting, greywater, bioretention and urban vegetation solutions. The costs and characteristics of the distributed solutions are presented in Table 2.

Table 2: Installation, operation and renewal costs, and energy use for distributed solutions

Option	Dwelling type	Install ($)	Operate ($/ML)	Renew cost ($) timing (Years)	Energy (kWh)
Greywater	Detached and semi	500	160	500 (10)	0
	Units	2500	5000	1250 (10)	4000
Rainwater	Detached	3400 (3.5 kL) 3600 (5 kL) 4050 (7.5 kL) 4500 (9 kL)	160	750 (10) 950: 3.5 kL (20) 1150: 5 kL (20) 1600: 7.5 kL (20) 2150: 9 kL (20)	1068
	Semi	3100 (2 kL) 3300 (3 kL) 3600 (5 kL) 3800 (6 kL)	160	750 (10) 800: 2 kL (20) 900: 3 kL (20) 1150: 5 kL (20) 1500: 6 kL (20)	1068
	Units	445 (10 kL) 538 (20 kL) 585 (25 kL)	160	75 (10) 210: 10 kL (20) 303: 10 kL (20) 350: 25 kL (20)	1068
Water efficient appliances	All	498	0	498 (10)	-1.9
Rain gardens	All	1000	0	0	0

This information was used to determine the impacts of changing the BASIX policy on the economics of the Greater Sydney region. Note that all costs are presented per dwelling and represent the cost difference from a business as usual solution for a household. For example, it is expected that new dwellings will install 4.5/3 litre flush toilets because less efficient toilet solutions are increasingly difficult to find in the marketplace.

At the detached and semi-detached dwellings, the greywater option involves diversion of greywater to gardens which involves minimal costs and energy profiles. For unit dwellings the greywater solution involves a small treatment plant at a property scale centralised scale that provides treated greywater for outdoor and toilet uses to many units.

3.4 Demographic information

The following median statistics for detached, semi-detached and unit properties underpinned local scale inputs in the Systems analysis (Table 3).

Table 3: Median dimensions of properties per dwelling for Greater Sydney

Dwelling Type	Median dimensions for each dwelling			
	Land area (m^2)	Roof Area (m^2)	Landscaped area (m^2)	Impervious area (%)
Detached	772	210	250	68
Semi-detached	306	100	101	72
Units	45	19	8	83

The values in Table 3 are utilised as inputs to the local scale analysis and these values are varied for each local government area using available local land use attributes.

The demographic information sourced from the NSW Government to create the demographic growth profile used in the systems analysis of the Greater Sydney region.[10] The renovation or redevelopment rate was derived from ABS 8731.0 series "Building Approvals". The values of new dwellings and renovated (or redeveloped) dwellings reported in this document were used to derive the renovation rate for use in this study as a fixed proportion for each LGA of the overall total cost of a new dwelling.

It is important to note that the cost of a single average new dwelling has not been used for all of Greater Sydney – the spatial costs of new dwellings that are vastly different in each zone as derived from real estate databases were used in this study. The renovation or redevelopment rate in each zone was incorporated from ABS data on development approvals. It was assumed that dwellings with significant

[10] ABS, (2016), Census of Population and Housing, Cat No. 2901.0; Household Income and Wealth, Cat No. 6523.0, Australia Bureau of Statistics

NSW government, (2016; 2020), 2016 New South Wales State and Local Government Area Population and Household Projections, and Implied Dwelling Requirements, Department of Planning and Environment.

renovations are included in the BASIX policy. This is dwellings that incur expenses of greater than 50% of the value of an average dwelling and for renovations that are equal or greater than the cost of an average dwelling. The 50% renovation rate, used to include dwellings in the BASIX policy, indicates the proportion of dwellings subject to partial renovation (such as a kitchen, a bathroom or a new extension).

These values were used to define the development rate for each LGA throughout Greater Sydney and to determine the rate in inclusion of BASIX or alterative water management strategies.

3.5 Business as Usual (BAU)

Business as Usual (BAU) is the operation of Sydney's water, sewage and stormwater services based on current practice and planned futures. The BASIX State Environmental Planning Policy continues to be applied to new and redeveloped buildings throughout Greater Sydney. Investigations to establish the BAU Option revealed higher than expected growth in population in some local government areas and increased density of development which was driving increasing demands for utility water supply as shown in Figure 9.

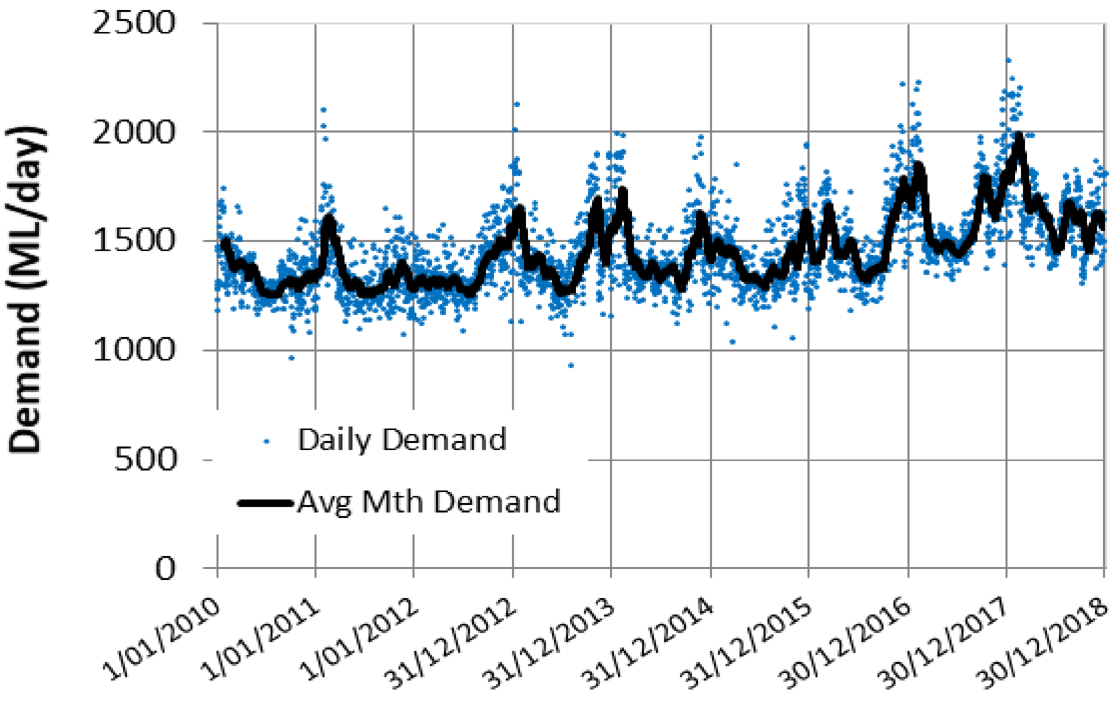


Figure 9: Observed demands for utility water supply from since 2010

We also discovered that there is a reduced focus on water efficiency which was confirmed by the NSW Auditor General.[11] These considerations were included in the

[11] NSW Audit Office, (2020), Water conservation in Greater Sydney, Report by the NSW Auditor General. Parliament of NSW, Sydney.

systems modelling. The BAU option commences in 2010 with about 13.2% of dwellings with rainwater tanks and 42.5% of dwellings with greater than 3 star water efficiency in dwellings.[12]

The number of installed rainwater tanks in the Greater Sydney region was determined from ABS and BASIX data, and from surveys of industry providers. The proportion of households with rainwater supply across increased from 12.8% in 2007 to 13.2% in 2010 to 15.7% in 2013.

The characteristics of buildings in the BAU option are presented in Table 4.

Table 4: Characteristics of the BAU option for Greater Sydney

At approximately 2010
Water efficient (6/3 dual flush) toilets in 82% of dwellings
Low flow showers in 65% of dwellings
Water efficient clothes washer in 24% of dwellings
Rainwater tanks at 13.2% of dwellings
After 2010 rate of installation
60% of renovated dwellings install low flow showers and water efficient clothes washers.
All new dwellings install low flow showers, 4.5/3 litre flush toilets and water efficient clothes washers
8% of renovated detached and semi-detached dwellings install rainwater tanks (100 m^2 roof, 3.5 kL [detached] and 2 kL [semi] tank to supply toilet and outdoor uses)
10% of new (detached and semi-detached) dwellings install rainwater tanks (100 m^2 roof, 5 kL [detached] or 3 kL [semi] tank to supply toilet, laundry and outdoor uses)
79% of new (detached and semi-detached) dwellings install rainwater tanks (100 m^2 roof, 3.5 kL [detached] and 2 kL [semi] tank to supply toilet and outdoor uses)
5% of new units install rainwater tanks (9 m^2 roof and 1 kL per dwelling) for toilet flushing and outdoor uses
0.5% of detached and semi-detached dwellings include local greywater supply for outdoor uses
0.5% of unit dwellings include local greywater supply for toilet and outdoor uses
0.5% of all dwellings also include 5 m^3 of raingardens and 5 m^2 of tree canopy

[12] Coombes P. J., Barry, M. E., Smit, M., (2018), Systems analysis and big data reveals benefit of new economy solutions at multiple scales, 10th International Conference on Water Sensitive Urban Design: Creating water sensitive communities, Engineers Australia, Perth, Australia

The Systems Framework also includes connection to utility recycled water supplies across the local government areas presented in Table 5.

Table 5: Dwellings connected to utility recycled water supplies

Local Government Area	Detached (%)	Attached (%)	Units (%)
Blacktown	2.3	0	1.6
Camden	1.7	8.3	6.6
Campbelltown	12.5	31	3.2
Cumberland	0	0	1.0
Hawkesbury	23.7	0	25
Hills	53.8	12	24.1
Liverpool	8.1	2	8.1
Penrith	0.3	0	0
Sydney	0	0	5.1
Wingecarribee	0.2	0	0
Wollondilly	5.9	0	0

3.5 Greater Sydney Without Basix (NoBasix)

This option assumes that the BASIX policy was not established in 2004 and there is no water efficiency performance requirement on new or renovated buildings. The model assumes that rainwater harvesting and water efficient appliances will continue to be incorporated in dwellings at the rates shown in Table 6.

The NoBasix option commences in 2010 with about 11% of dwellings with rainwater tanks and 34.5% of dwellings with greater than 3 star water efficiency in dwellings. Inclusion of water efficient appliances with greater than 3 star efficiency and rainwater tanks will continue at a lower rate than in the BAU Option that includes the BASIX policy.

Table 6: Characteristics of the No BASIX option for Greater Sydney

After 2004 rate of installation
50% of renovated dwellings install low flow showers and water efficient clothes washers.
80% of new dwellings install low flow showers, 4.5/3 litre flush toilets and water efficient clothes washers
5% of renovated dwellings install rainwater tanks (100 m^2 roof, 5 kL [detached] and 3 kL [semi] tank, supply toilet, laundry and outdoor)
10% of new (detached and semi-detached) dwellings install rainwater tanks (100 m^2 roof, 5 kL [detached] or 3 kL [semi] tank to supply toilet, laundry and outdoor uses)
2.5% of new units install rainwater tanks (9 m^2 roof and 1 kL per dwelling) for toilet flushing and outdoor uses
0.5% of detached and semi-detached dwellings include local greywater supply for outdoor uses
0.5% of unit dwellings include local greywater supply for toilet and outdoor uses
0.5% of all dwellings also include 5 m^3 of raingardens and 5 m^2 of tree canopy

3.6 Increased Water Targets in 2022 (SCN1)

This Option commences with the BAU strategy and incorporates an increase in the BASIX water savings target in 2022 of 10% for detached and semi-detached dwellings, and 5% for units. The water saving target becomes 50% for detached and semi-detached dwellings, and 45% for units.

The model assumes rainwater harvesting and water efficient appliances will continue to be incorporated in dwellings at the rates shown in Table 7.

Table 7: Characteristics of the SCN1 option for Greater Sydney

After 2022 rate of installation
60% of renovated dwellings install low flow showers and water efficient clothes washers.
All new dwellings install low flow showers, 4.5/3 litre flush toilets and water efficient clothes washers
8% of renovated detached and semi-detached dwellings install rainwater tanks (150 m^2 roof, 9 kL [detached] and 100 m^2 roof, 6 kL [semi] tank to supply toilet and outdoor uses
2% of new (detached and semi-detached) dwellings install rainwater tanks (150 m^2 roof, 9 kL [detached] or 100 m^2 roof, 6 kL [semi] tank to supply toilet, laundry and outdoor uses)
1% of new units install rainwater tanks (18 m^2 roof and 2.5 kL storage per dwelling) for toilet, laundry and outdoor uses
79% of new detached and semi-detached dwellings install rainwater tanks (100 m^2 roof, 5 kL [detached], 3 kL [semi] tank to supply toilet, laundry and outdoor uses)
2% of new units install rainwater tanks (9 m^2 roof and 1 kL storage per dwelling) for toilet, laundry and outdoor uses
3% of new detached and semi-detached dwellings install rainwater tanks (100 m^2 roof, 3.5 kL [detached], 2 kL [semi] tank to supply toilet and outdoor uses)
1% of new units install rainwater tanks (9 m^2 roof and 1 kL storage per dwelling) for toilet and outdoor uses
1% of new detached and semi-detached dwellings install rainwater tanks (100 m^2 roof, 7.5 kL [detached], 5 kL [semi] tank to supply toilet, laundry and outdoor uses)
2% of detached and semi-detached dwellings include local greywater supply for outdoor uses
2% of unit dwellings include local greywater supply for toilet and outdoor uses
79% of new dwellings also include 5 m^3 of raingardens and 5 m^2 of tree canopy

3.7 Increased Water Targets and a Stormwater Target in 2022 (SN2)

This Option continues the BAU strategy and includes an increase in the BASIX water savings target in 2022 of 10% for detached and semi-detached dwellings, and 5% for units. The water saving target becomes 50% for detached and semi-detached dwellings, and 45% for units.

A stormwater target is introduced in this Option. The average annual volume of stormwater runoff from the site cannot be greater than twice the average annual volume of stormwater that would be generated from a vacant and landscaped site.

The model assumes rainwater harvesting and water efficient appliances will continue to be incorporated in dwellings at the rates shown in Table 8.

Table 8: Characteristics of the SCN2 option for Greater Sydney

After 2022 rate of installation
60% of renovated dwellings install low flow showers and water efficient clothes washers.
All new dwellings install low flow showers, 4.5/3 litre flush toilets and water efficient clothes washers
8% of renovated detached and semi-detached dwellings install rainwater tanks (150 m^2 roof, 9 kL [detached] and 100 m^2 roof, 6 kL [semi] tank to supply toilet and outdoor uses
2% of new (detached and semi-detached) dwellings install rainwater tanks (150 m^2 roof, 9 kL [detached] or 100 m^2 roof, 6 kL [semi] tank to supply toilet, laundry and outdoor uses)
1% of new units install rainwater tanks (18 m^2 roof and 2.5 kL storage per dwelling) for toilet, laundry and outdoor uses
5% of new detached and semi-detached dwellings install rainwater tanks (100 m^2 roof, 5 kL [detached], 3 kL [semi] tank to supply toilet, laundry and outdoor uses)
2% of new units install rainwater tanks (9 m^2 roof and 1 kL storage per dwelling) for toilet, laundry and outdoor uses
3% of new detached and semi-detached dwellings install rainwater tanks (100 m^2 roof, 3.5 kL [detached], 2 kL [semi] tank to supply toilet and outdoor uses)
1% of new units install rainwater tanks (9 m^2 roof and 1 kL storage per dwelling) for toilet and outdoor uses
79% of new detached and semi-detached dwellings install rainwater tanks (100 m^2 roof, 7.5 kL [detached], 5 kL [semi] tank to supply toilet, laundry and outdoor uses)
2% of detached and semi-detached dwellings include local greywater supply for outdoor uses
2% of unit dwellings include local greywater supply for toilet and outdoor uses
79% of new dwellings also include 5 m^3 of raingardens, 5 m^2 of tree canopy and a 5% reduction in impervious area

3.8 Increased Water Targets in 2025 (SN3)

This Option commences with the BAU strategy and commences Option 2 (SN2) in 2022. In 2025 this Option increases the BASIX water savings target in 2025 of 20%

for detached and semi-detached dwellings, and 10% for units. The water saving target becomes 60% for detached and semi-detached dwellings, and 50% for units.

The stormwater target is also included in this Option. The average annual volume of stormwater runoff from the site cannot be greater than twice the average annual volume of stormwater that would be generated from a vacant and landscaped site.

The model assumes rainwater harvesting and water efficient appliances will continue to be incorporated in dwellings at the rates shown in Table 9.

Table 9: Characteristics of the SCN3 Option for Greater Sydney

After 2025 rate of installation
60% of renovated dwellings install low flow showers and water efficient clothes washers.
All new dwellings install low flow showers, 4.5/3 litre flush toilets and water efficient clothes washers
8% of renovated detached and semi-detached dwellings install rainwater tanks (150 m^2 roof, 9 kL [detached] and 100 m^2 roof, 6 kL [semi] tank to supply toilet and outdoor uses
79% of new (detached and semi-detached) dwellings install rainwater tanks (150 m^2 roof, 9 kL [detached] or 100 m^2 roof, 6 kL [semi] tank to supply toilet, laundry and outdoor uses)
5% of new units install rainwater tanks (18 m^2 roof and 2.5 kL storage per dwelling) for toilet, laundry and outdoor uses
5% of new detached and semi-detached dwellings install rainwater tanks (100 m^2 roof, 5 kL [detached], 3 kL [semi] tank to supply toilet, laundry and outdoor uses)
2% of new units install rainwater tanks (9 m^2 roof and 1 kL storage per dwelling) for toilet, laundry and outdoor uses
2% of new detached and semi-detached dwellings install rainwater tanks (100 m^2 roof, 3.5 kL [detached], 2 kL [semi] tank to supply toilet and outdoor uses)
1% of new units install rainwater tanks (9 m^2 roof and 1 kL storage per dwelling) for toilet and outdoor uses
2% of new detached and semi-detached dwellings install rainwater tanks (100 m^2 roof, 7.5 kL [detached], 5 kL [semi] tank to supply toilet, laundry and outdoor uses)
2% of detached and semi-detached dwellings include local greywater supply for outdoor uses
2% of unit dwellings include local greywater supply for toilet and outdoor uses
79% of new dwellings also include 5 m^3 of raingardens and 5 m^2 of tree canopy

3.9 Tariffs, Costs and Economics

A focus on centralised supply and disposal solutions has defined the urban water sector as a transport industry that moves water and sewage across large distances.[13] This centralised paradigm has substantial impacts on resources (Clarke and Stevie, 1981)[14] and economic outcomes (Coase, 1947).[15]

The water supply transfer distances from reservoirs to local government areas shown in Figure 10 and the wastewater disposal transfer distances from local government areas to nearest wastewater treatment plants presented in Figure 11 are utilised, in combination with financial data from IPART and Sydney Water, to define the distributed costs of utility services.

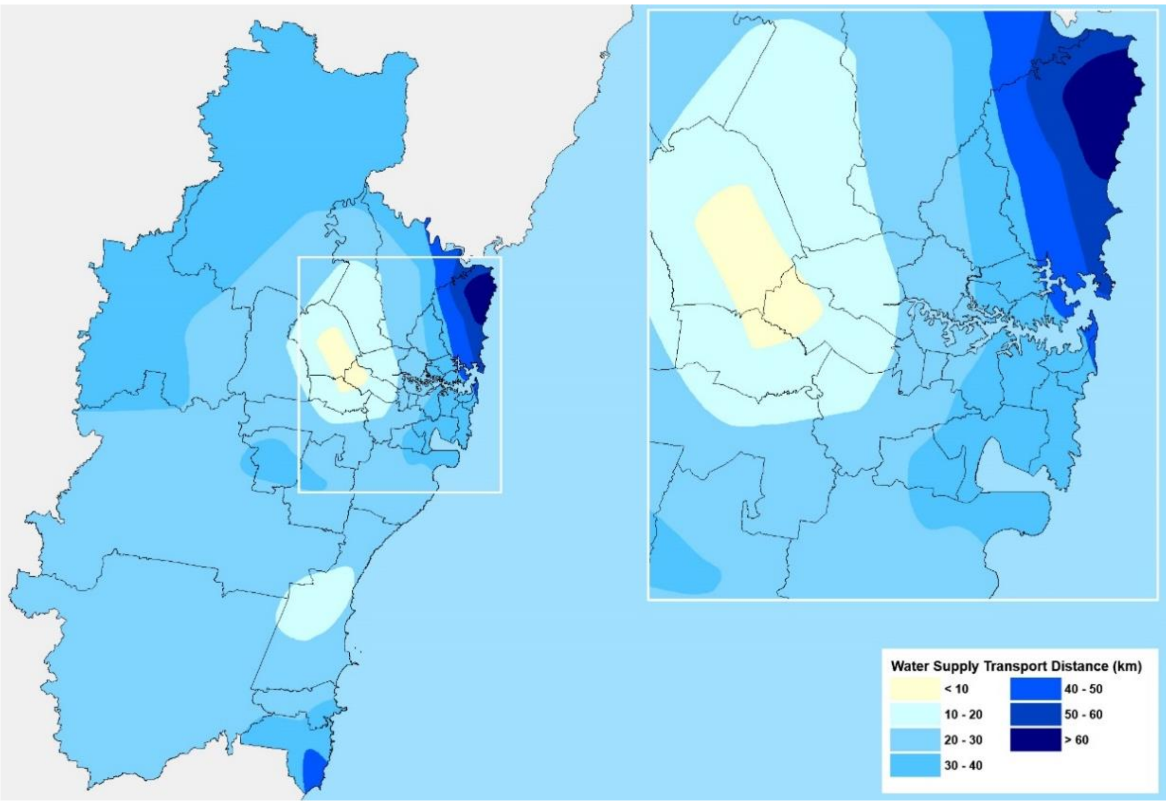


Figure 10: Water supply transfer distances across Greater Sydney

[13] Coombes P.J., and Barry M.E., (2014), A systems framework of big data driving policy making for Melbourne's water future, OzWater14, Australian Water Association, Brisbane.

[14] Clarke R.M., and Stevie R.G., (1981), A water supply cost model incorporating spatial variables, Land Economics, University of Wisconsin Press, 57(2), 18-32.

[15] Coase R.H., (1947), The economics of uniform pricing systems, Manchester School of Economics and Social Studies, 139-156.

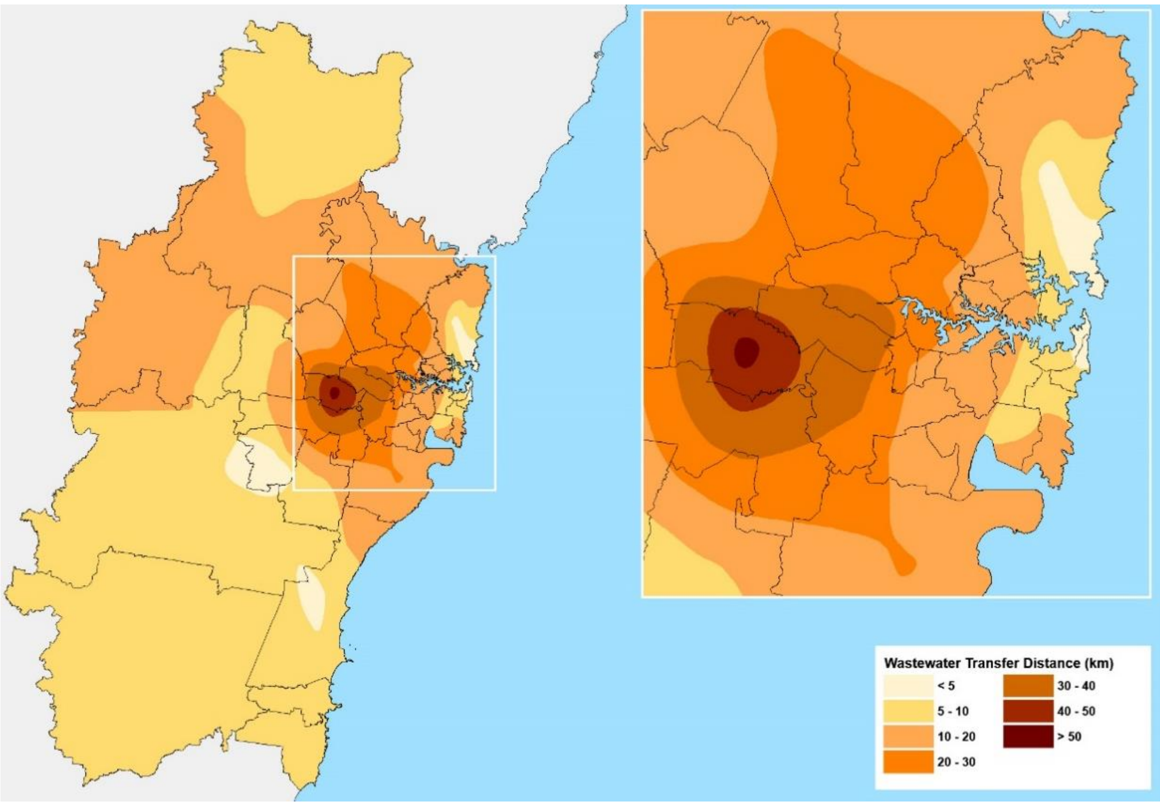


Figure 11: Wastewater disposal transfer distances across Greater Sydney

Figure 10 reveals that the transfer distances from nearest water sources to end users in local government areas ranges from 5 km to 67 km. Figure 11 highlights that wastewater transfer distances from end users in local government areas to treatment plants range from 1 km to 56 km. The spatial costs of water and sewage services for the BAU option were previously derived by Coombes et al (2020) for all costs in the planning horizon from 2010 to 2050 and are shown in Figure 12.

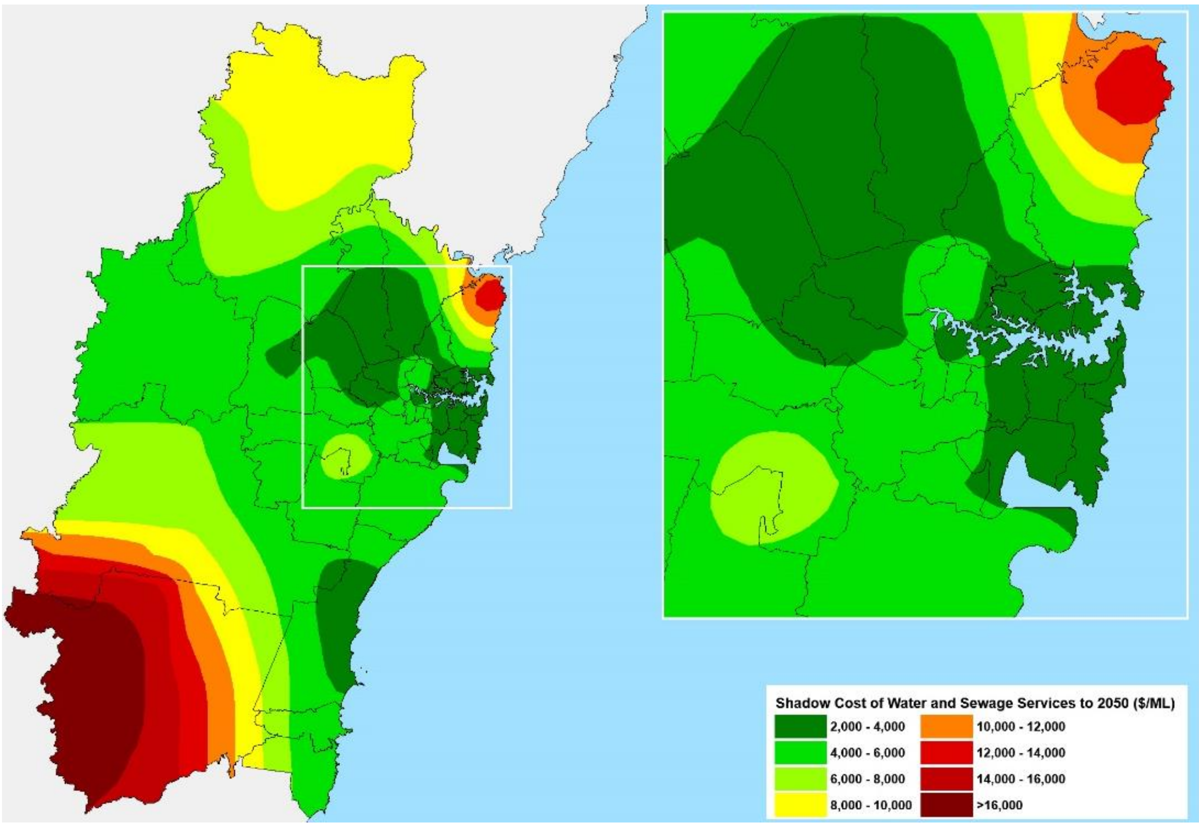


Figure 12: The spatial costs of water and sewage services to 2050 across greater Sydney in the BAU option

Figure 12 reveals that the total spatial costs of water and sewage services ranged from $2/kL to greater than $16/kL. These values represent all operation, renewal, treatment, transfer, augmentation and water security costs divided by the cumulative water supply volumes for the period 2010 to 2050. Given that in the long run all costs are variable, these results represent the long run spatial marginal costs of water and sewage services for Greater Sydney and can be used to evaluate the economic viability of distributed solutions.[16]

These values from previous studies by the author can be considered to be shadow cost maps for evaluation of distributed strategies such as water efficient appliances, rainwater harvesting and alternative water sources. A majority of these spatial long run marginal costs are greater than the values of $1.28/kL in the short run and $2.08 in the long run proposed by Sydney Water Corporation for assessment of water conservation strategies.[17]

The financial inputs to the Systems Framework model were sourced from IPART determinations and associated reports, Sydney Water Annual reports, Bureau of Meteorology National Performance Reports and a range of other sources. The costs

[16] Coombes P.J., Barry M.E., and Smit M., (2020), Revealing the spatial long run marginal costs of water and sewage services for Australian capital Cities, In review

[17] Sydney Water (2018), Water conservation report 2017-2018, Sydney Water

associated with water supply and sewage treatment included in the systems model are presented in Tables 10 and 11 below.

Table 10: Water costs for supply catchments

Water Catchment	Costs ($/ML)			
	Operation	Treatment	Bulk	Transfer
Cascade	2060	667	406	1790
Illawarra	738	826	406	641
Macarthur	502	932	406	436
Nepean	1000	459	406	869
North Richmond	795	380	406	380
Orchard Hills	602	233	406	523
Potts Hill	366	122	412	144
Prospect East	584	111	374	144
Prospect North	672	128	431	144
Prospect South	276	85	286	144
Ryde	428	114	385	233
Warragamba	2511	1742	406	282
Woronora	332	767	406	289

The values in Table 10 for water supply are combined with information about renewals and transfer costs derived from IPART and Sydney Water using spatial information infrastructure networks to derive the full range of water supply costs used in the Systems Framework model.

Table 10 shows that the costs for extensions and transfers were not available for a number of wastewater catchments. These costs were supplemented with values from nearby catchments servicing each LGA.

Table 10: Wastewater treatment costs

Wastewater catchment	Extensions ($/ML)	Transfer ($/ML)	Treatment ($/ML)
Bellambi	-	-	2,012
Blackheath	-	-	631
Bombo	-	835	790
Bondi	21,793	358	203
Brooklyn	-	95	4,379
Castle Hill	-	815	528
Cronulla	-	604	293
Gerringong	-	111	12,619
Glenbrook	-	-	580
Glenfield	-	-	941
Fairfield	-	-	653
Hornsby Heights	-	434	892
Liverpool	-	-	2,614
Malabar	18,322	449	118
Mount Victoria	-	-	701
North Head	11,681	478	129
North Richmond	11,987	1,022	2,750
Penrith	4,598	986	473
Picton	42,353	982	1,328
Port Kembla	-	-	1,025
Quakers Hill	-	418	482
Richmond	-	626	2,069
Riverstone	-	237	2,241
Rouse Hill	17,940	588	1,090
Shellharbour	16,729	679	805
St Marys	15,224	532	604
Warragamba	2,638	1,004	1,693
Warriewood	22,564	567	431
West Camden	44,008	642	1,006
West Hornsby	-	471	568
Winmalee	-	909	387
Wollongong	43,726	514	642

The structure of these inputs for water, sewage and stormwater services were derived as costs per ML of service for a particular scheme within each local government area are:

- **Extensions:** the full cost to implement new infrastructure to cope with increased demand. These costs were evaluated as the cost for each Megalitre of increased transfer capacity for water supply or sewerage or stormwater disposal.
- **Renewals:** the full cost to maintain and renew infrastructure
- **Transfer:** the full costs to transfer water from water source to local government area or the full costs to transfer wastewater from local government areas to treatment plants
- **Treatment:** the costs to operate treatment plants
- **Bulk:** the additional costs of bulk supply from reservoirs or disposal to waterways
- **Energy:** the total energy use to provide water from extraction to treatment to transfer to local government areas. Or the total energy use of transfer, treatment and disposal of wastewater.

This investigation has accounted for the economic transfers within the system from lot scale to regional scale. There are a number of levels of expenses and revenues, or benefits within a system.

The spatial and temporal costs of providing water and wastewater services are included. There are also associated costs with the impact on the environment of activities such as disposal of wastewater in waterways and oceans, or the impact of constructing a new dam or desalination plant. On the other side of the ledger are a series of economic benefits from the provision of water services. These include the generation of utility and amenity to individuals and society though the provision of water and wastewater services. Benefits are also derived by returning water to certain environments and ecosystems. It is important to holistically consider all of these economic costs and benefits.

From a financial perspective, there are a series of financial transactions associated with the provision of water and wastewater services between the entities involved in the process including Governments, the water utility and the community as outlined in Figure 13.

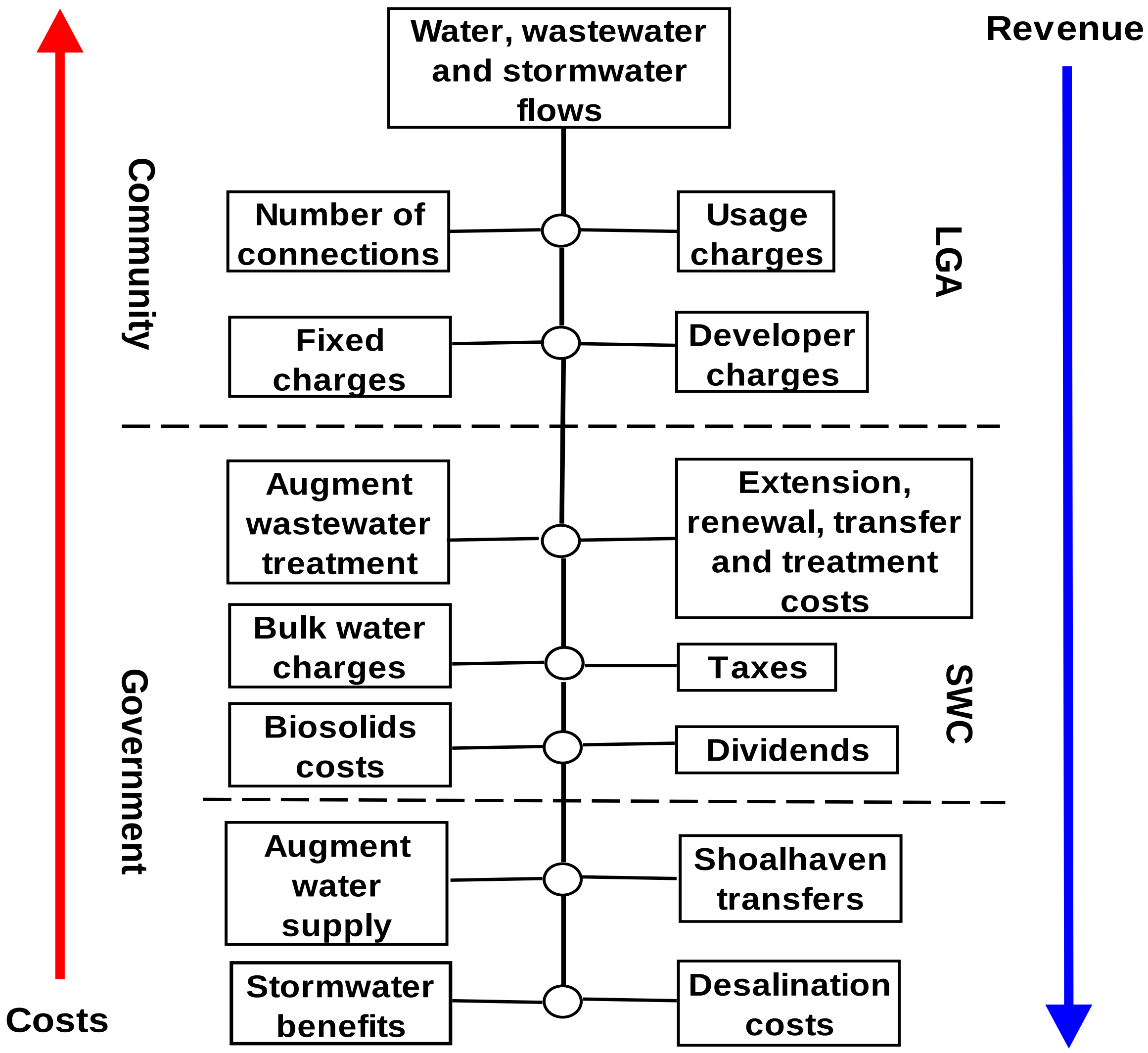


Figure 13: Schematic of the economic analysis

Figure 13 shows that our economic analysis has evaluated the detailed transactions involved in the transfer of services from the bulk water supplier to water utility to Greater Sydney with consequent charges (revenue earned) for these services. In addition, the economic analysis considers the impacts of stormwater runoff and sewage discharges to water quality in waterways, and on urban flooding.

It is important to consider both the economic and financial aspects of the provision of services when undertaking a systems analysis of the provision of water services. The economic analysis includes the revenue earned by the water utility from developer, fixed and variable charges to connected properties in each LGA for water, wastewater and stormwater services.

Delivery of these services has been defined as extension, renewal, transfer and treatment costs of operating the water and wastewater systems. The foundation elements of these expenses and revenues are imbedded in the dynamic analysis of the spatial economics for water and wastewater services as shown in Figures 14 and 15 respectively.

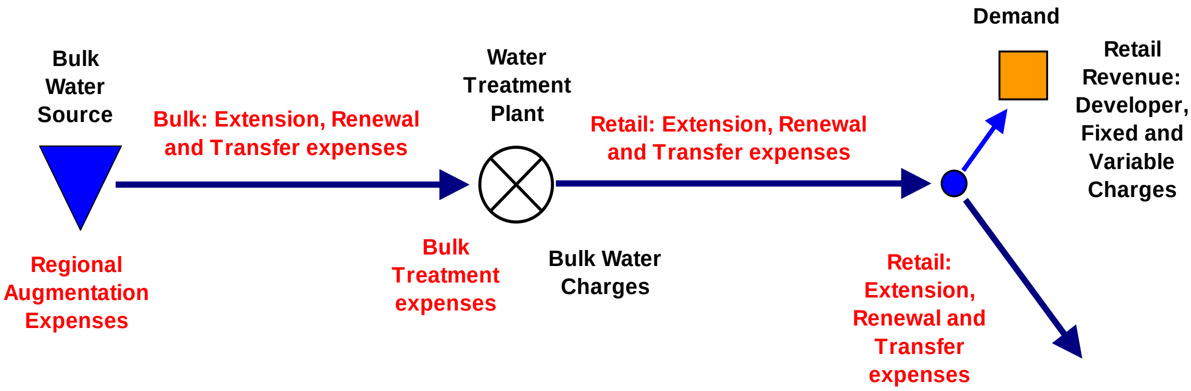


Figure 14: Structure of economic analysis for water resources in the Systems Framework

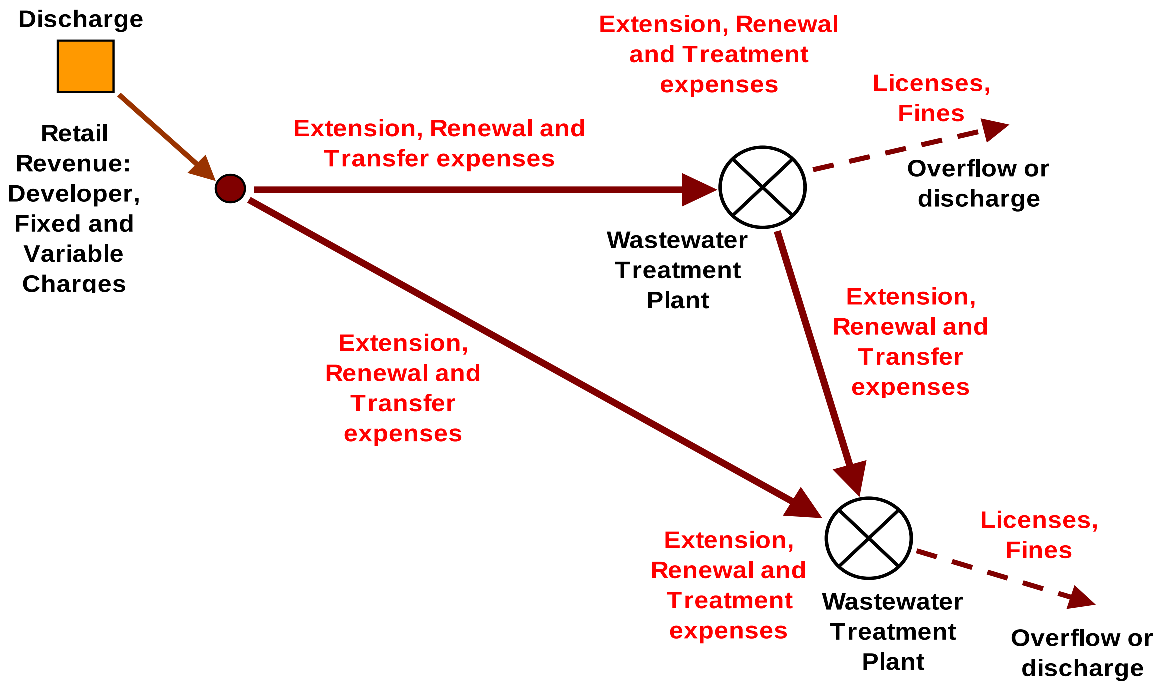


Figure 15: Structure of economic analysis for wastewater disposal networks in the Systems Framework

Figures 14 and 15 demonstrate that extension, renewal, transfer and treatment costs are included in the spatial systems analysis for each of the basic transfer elements in the network. Transfer of water from one location to another requires the use of infrastructure and a range of associated resources that are included using this methodology.

Note that the costs associated with transfer of additional flows in the sewage networks generated by infiltration of stormwater are also included in this method. Moreover, the financial impacts of alternative water strategies that may have some reliance on the existing centralized network are also counted in this method – failure to supply sufficient water from (say) a stormwater harvesting system at a given spatial location will require additional water supply from the centralized system which may generate a requirement to augment the central systems and incur extension costs.

3.10 Cost benefit analysis

The Systems Framework model includes dynamic economic processes that produce detailed Cost-Benefit analysis outputs that are consistent with the requirements of State Government Treasuries, such as the NSW Treasury.[18] This analysis addresses the market failure of water efficiency and distributed water solutions in a government monopoly environment as outlined by the NSW Auditor General.[19]

The performance of the proposed BASIX options were compared to the baseline of the BAU option for water, sewage and stormwater services for Greater Sydney. All available costs and benefits are collated to determine the highest net social benefit that is assessed from the perspective of the NSW society reference group.

Analysis of the society sub-groups Consumers, Producers, Labour and Government are also undertaken using real discount rates of 3%, 7% and 10%. These outputs are expected to address the social welfare of NSW society.

[18] NSW Treasury (2017), NSW Government guide to cost-benefit analysis, TTP 17-03

[19] NSW Audit Office (2020), Water conservation in Greater Sydney, NSW Auditor General's Report

4 Results

The results from the systems analysis of the five options BAU, NoBasix, SN1, SN2 and SN3 are summarised in this section for a range of physical, environmental and economic criteria. The outcomes for the entire Greater Sydney region are provided from a water utility, building and whole of society perspective.

4.1 Water

This Section presents the results for utility water supply, local rainwater supply, water savings from buildings with greater than three-star water efficiency, local greywater supply and water security.

Water Demands

The expected total annual demand of the Greater Sydney region for utility water supply is presented in Figure 16 for the period 2010 to 2050.

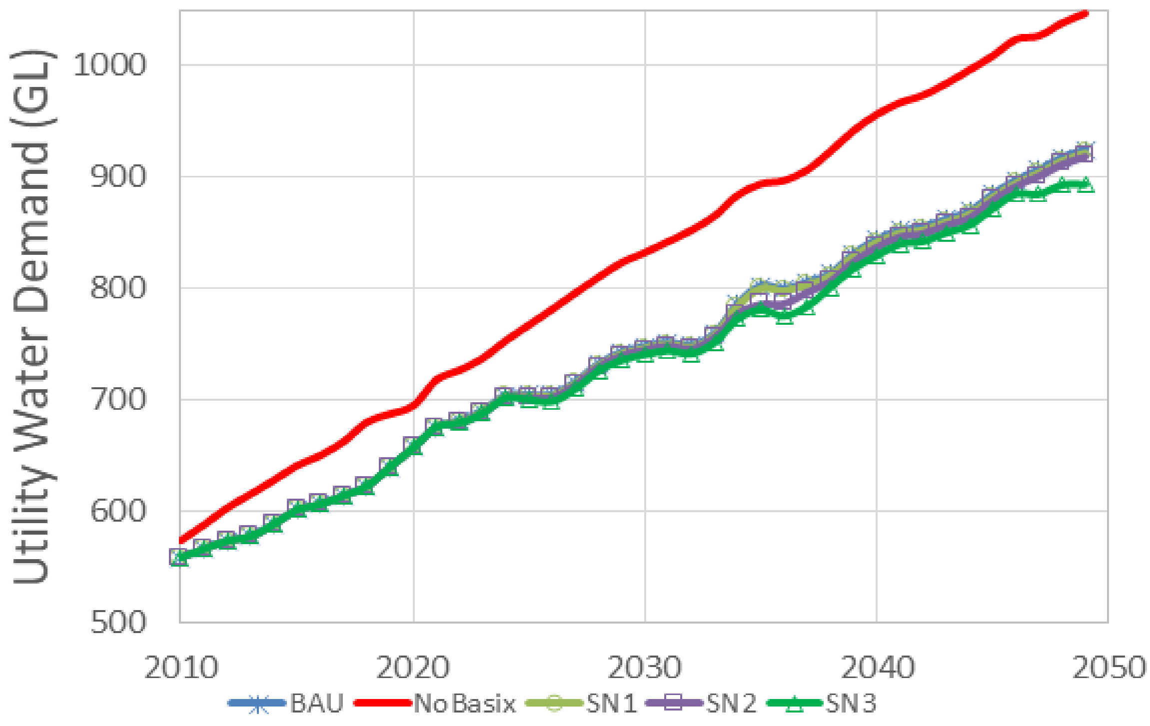


Figure 16: Utility water demands for the Greater Sydney region

Figure 16 shows that the NoBasix option produces highest demands for utility water supply. The options that include variations of BASIX with local water sources and water efficiency generate significant reductions in demands for utility water supply.

The NoBasix Option increases demand for utility water supply by 122 GL (13.2%) in 2050. In contrast, the Options further reduce demand for utility water supply for SN1 by 3 GL (0.3%), for SN2 by 6 GL (0.7%) and for SN3 by 31 GL (3.4%) in 2050.

The distributed solutions for water supply and efficiency mandated by the BASIX policy reduce demands for utility water supply by 144 GL for BAU to 153 GL for SN1 in 2010.

The local use of rainwater in each of the Options is presented in Figure 17.

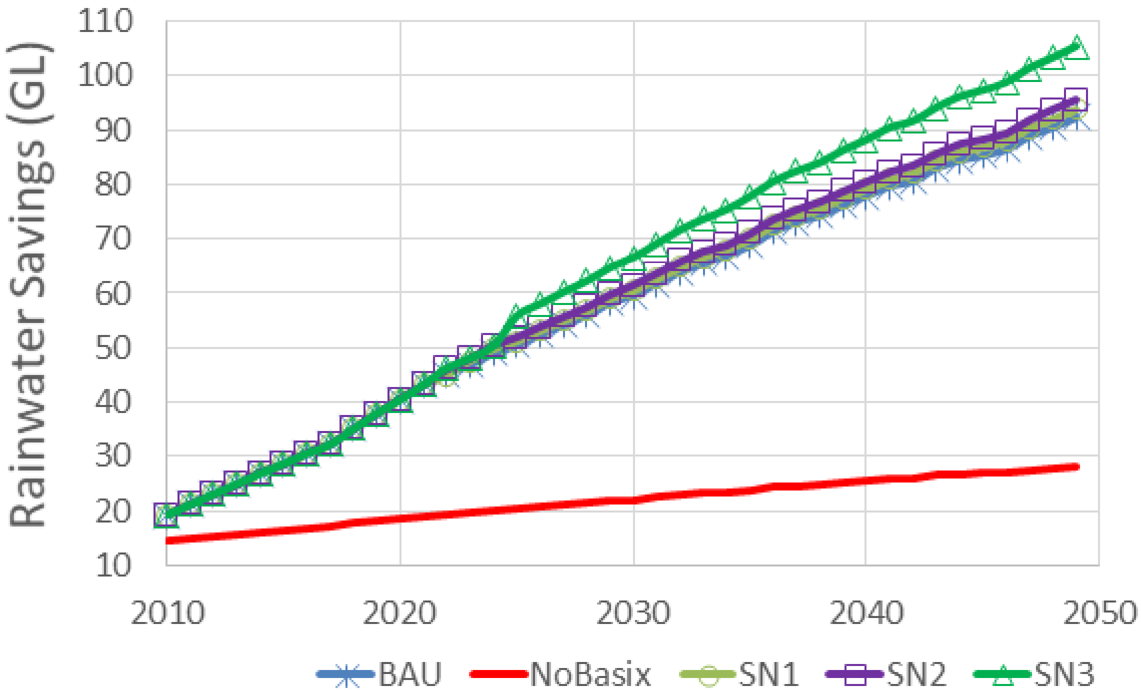


Figure 17: Local harvested rainwater supply for the Greater Sydney region

Figure 17 reveals that the BASIX policy increases building scale rainwater harvesting across Greater Sydney by 64 GL to 77 GL in comparison to the NoBasix Option by 2050. Local rainwater supply in the Greater Sydney region is expected to be 28 GL in 2050 and with the BASIX policy rainwater supply will increase to 92 GL to 105 GL.

The expected regional water savings from buildings with greater than three-star water efficient appliances is provided in Figure 18.

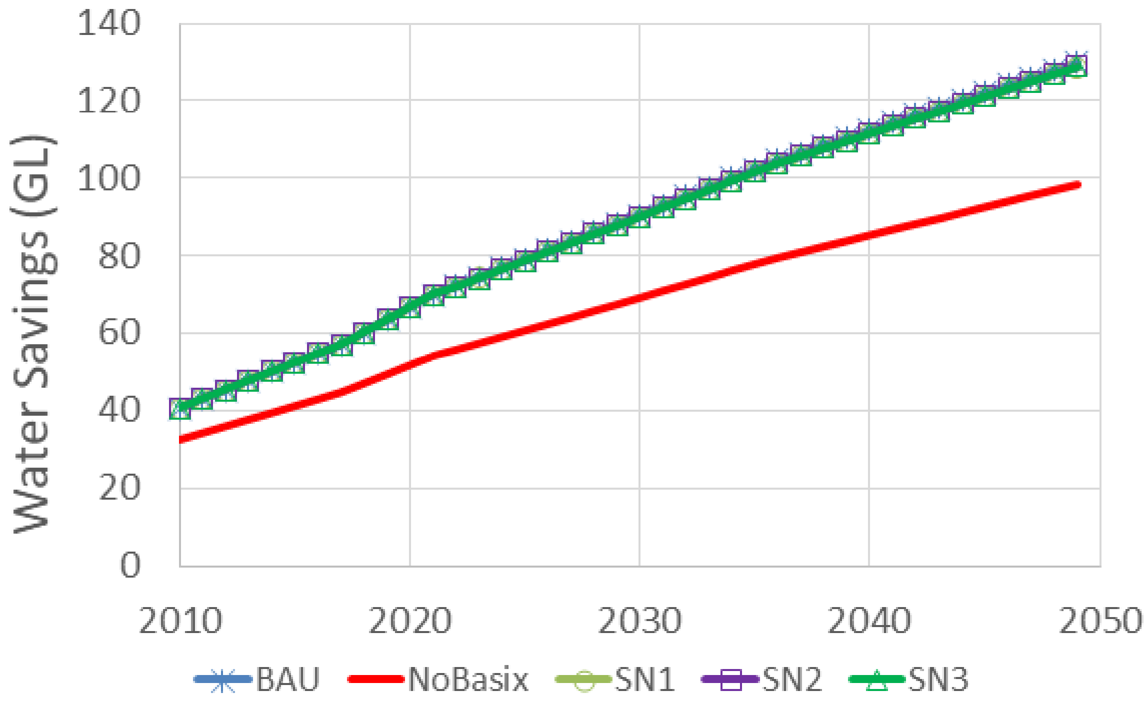


Figure 18: Local water savings from buildings with greater that three-star water efficiency for the Greater Sydney region

Figure 18 reveals that the quantum of local water savings generated by water efficient appliance with greater than three-star water efficiency will increase by 32 GL to 130 GL in response to the BASIX policy by 2050. The local water efficiency savings are similar for the BASIX scenarios.

The expected local greywater supply for the Greater Sydney region is provided in Figure 19.

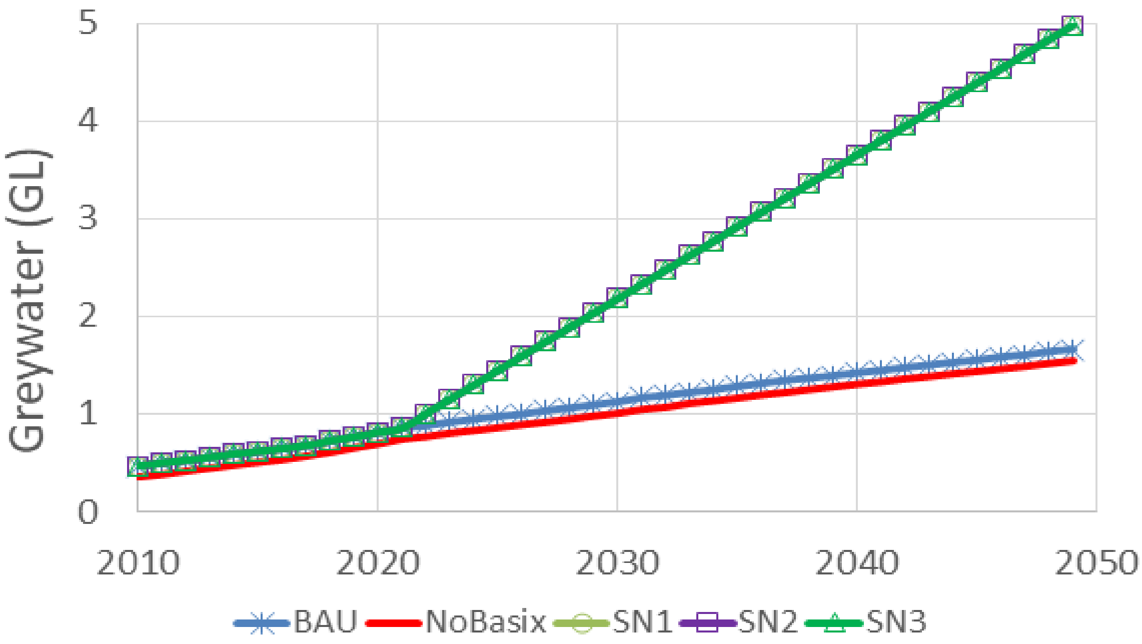


Figure 19: Local greywater supply for the Greater Sydney region

Figure 19 shows that the property scale use of greywater increases to 1.6 GL/annum in the BAU Option and to 1.5 GL/annum in the NoBasix Option. The local supply of greywater increases to 5 GL/annum in the SN1, SN2 and SN3 BASIX options by 2050 which is an increase of 2.6 GL/annum. Note that it was assumed that additional incentives for greywater solutions were assumed to commence in 2022.

Water Security

The water security provided to the Greater Sydney region from each option is represented by the timing of the major augmentation of regional water supplies by the Avon Tunnel or desalination plants or indirect potable reuse from Prospect Reservoir in Table 11.

Table 11: Water security for the Greater Sydney region from each option as defined by timing of requirement to augment with major supply sources

Supply Source	Augmentation timing by year				
	BAU	NoBasix	SN1	SN2	SN3
Avon Tunnel	2026	2019	2026	2026	2028
Desalination stage 2	2026	2019	2026	2026	2028
Desalination to Prospect	2034	2026	2036	2037	2037
South Coast Desalination	2039	2036	2039	2039	2039
Prospect Potable Reuse	2047	2038	2047	2047	-

Table 11 shows that the BAU option requires five major supply augmentations in the period to 2050 – these major supply options are the Fitzroy Falls to Avon tunnel, desalination plants and topping up Prospect Reservoir with treated sewerage.

The BASIX policy delays the timing of the desalination augmentations within central Sydney and the Avon tunnel by 7 and 8 years, and delays the requirement for indirect potable reuse by 11 years. In addition, the requirement for a South Coast desalination plant is delays by 3 years.

Enhancements to the BASIX policy in Options SN1, SN2 and SN3 generate further delays in the need to augment water supply with desalination plants. The SN3 Option eliminates the need for indirect potable reuse at Prospect Reservoir.

Local water supply and building scale water efficiency in the BASIX Options makes a significant contribution to the security of water supply to Greater Sydney.

4.2 Wastewater Discharges

The expected annual wastewater discharges from the Greater Sydney region from utility sewage networks is presented in Figure 20 for the period 2010 to 2050.

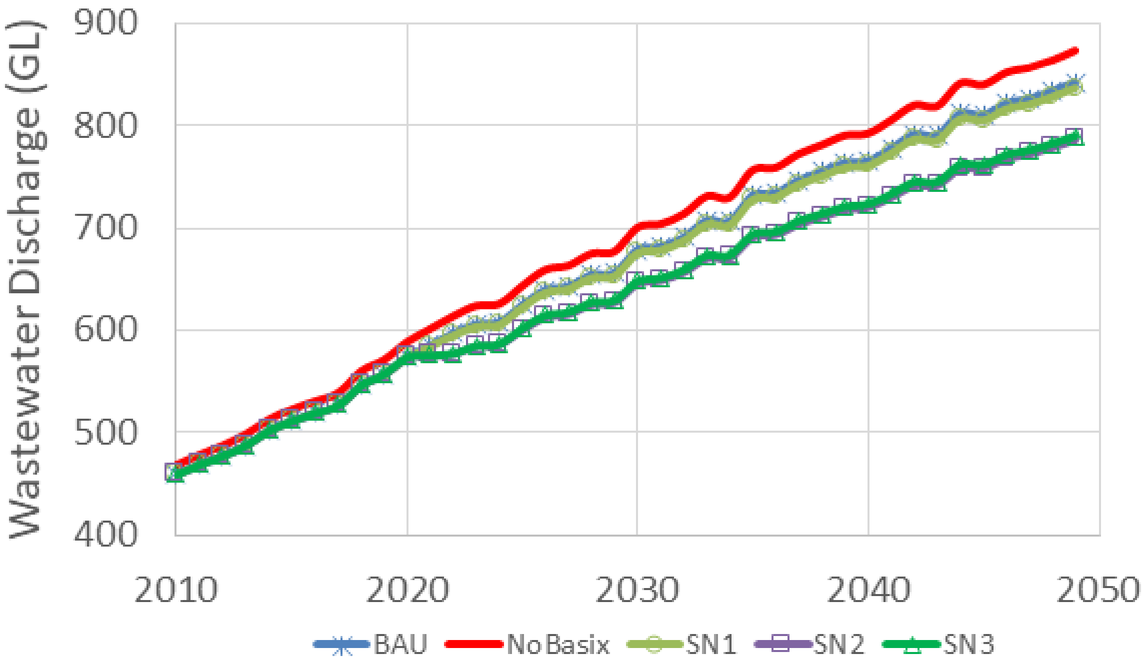


Figure 20: Wastewater discharges for the Greater Sydney region

Figure 20 shows that the NoBasix Option generates increased wastewater discharges of 32 GL (3.7%) by 2050. The SN1 Option further reduces wastewater discharges by 5 GL (0.6%) in comparison to the BAU Option. The reduced stormwater runoff in the SN2 Option provides a 56 GL (6.6%) reduction in wastewater discharges and the SN3 Option decreased wastewater discharges by 53 GL (6.3%).

The reduced indoor water uses and property scale stormwater runoff in the BASIX policy decreases wastewater discharges from 32 GL (BAU) to 87 GL (SN2).

4.3 Stormwater Runoff

The expected stormwater runoff from all urban areas across the Greater Sydney region is presented in Figure 21 for the period 2010 to 2050. Note that these values include stormwater runoff from all land uses in urban areas and does not include inflows from upstream rural areas.

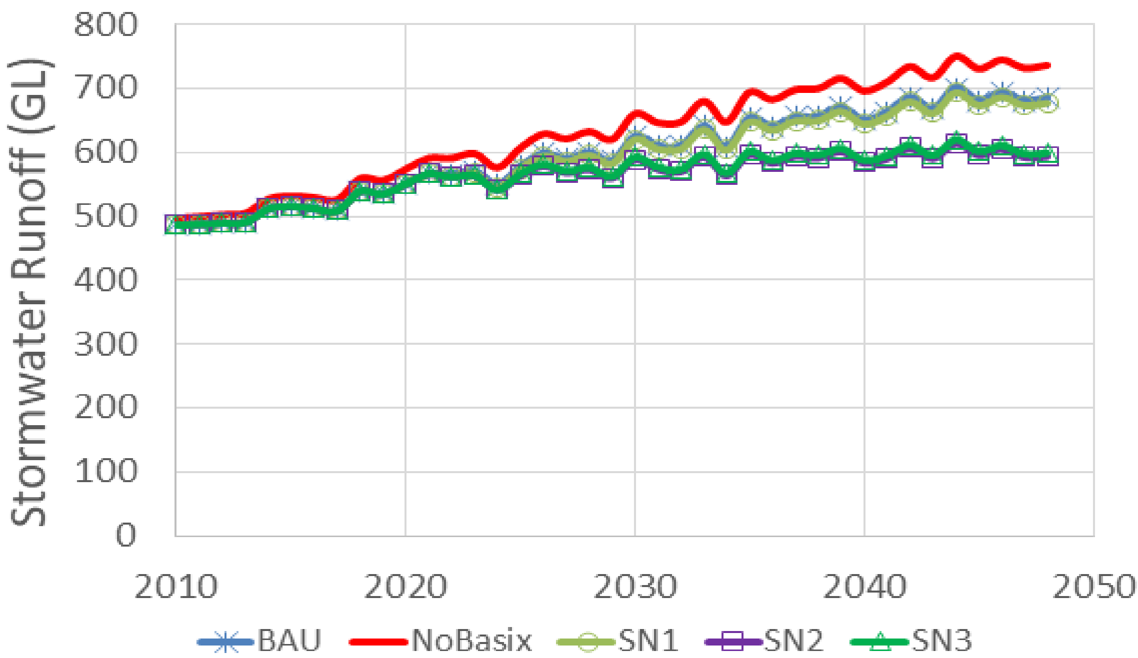


Figure 21: Stormwater runoff from urban areas throughout the Greater Sydney region

Figure 18 reveals that the Greater Sydney region will be subject to increases in urban stormwater runoff that will be generated by greater areas of impervious surfaces. The NoBasix Option displays an increase in stormwater runoff of 144 GL by 2050 and the SN1, SN2 and SN3 Options reduce annual stormwater runoff volumes by 18 GL, 176 GL and 176 GL respectively.

Rainwater harvesting in the BASIX policy reduces stormwater runoff by 64 GL to 77 GL by 2050. The cumulative impact of rainwater harvesting across the Greater Sydney region reduces stormwater runoff by 28 GL (NoBasix) to 105 GL (SN2). The addition of raingardens and green space further diminishes stormwater runoff by 10 GL to 93 GL in 2050.

The disconnection of impervious surfaces from street drainage networks via raingardens and green spaces generates higher reductions in stormwater runoff.

The expected cumulative stormwater runoff volumes and nitrogen loads in urban stormwater runoff across the Greater Sydney region is presented in Table 12 for the period 2010 to 2050.

Table 12: Cumulative stormwater runoff volumes and nitrogen loads from the Greater Sydney region for the period 2010 to 2050

Criteria	BAU	NoBasix	SN1	SN2	SN3
Nitrogen (Tonnes)	60,081	69,059	59,128	43,842	44,341
Runoff (GL)	24,032	27,624	23,651	17,537	17,736
Nitrogen Change (Tonnes)		8979	-952	-16,239	-15,740
Runoff Change (GL)		3592	-382	-6496	-6296
Nitrogen Change (%)		15	-1.5	-27	-26
Runoff Change (%)		15	-1.5	-27	-26

Table 12 reveals that NoBasix Option generates 15% higher runoff volumes (3592 GL) and nitrogen loads (8979 tonnes) during the 2010 to 2050 period. The enhanced BASIX Options provide reductions of 1.5% (SN1) and 26% to 27% (SN3 and SN2) in stormwater runoff and nitrogen loads.

4.4 Greenhouse Gas Emissions

The expected annual Greenhouse Gas Emissions from utility water and sewage services to Greater Sydney region is presented in Figure 22 for the period 2010 to 2050.

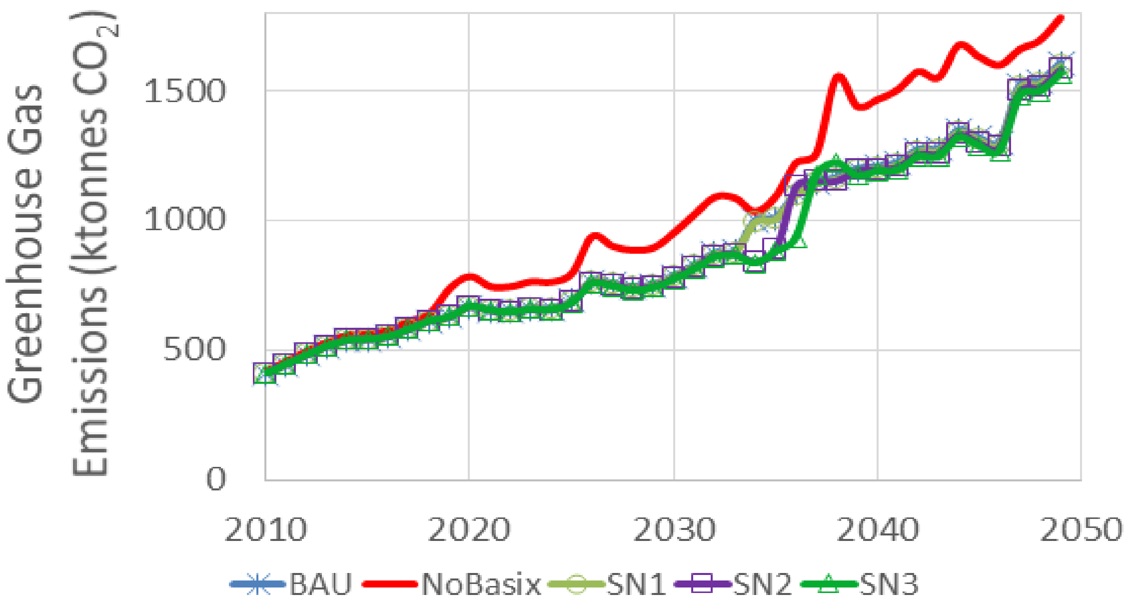


Figure 22: Greenhouse Gas Emissions from utility water and sewage services for each option

Figure 19 reveals that the NoBasix Option increases greenhouse gas emissions generated by utility water and sewage services by up to 178 ktonnes in 2050. The SN1, SN2 and SN3 Options decrease greenhouse gas emissions by 8, 23 and 42 ktonnes respectively.

The current BASIX policy has reduced annual greenhouse gas emissions of utility water and sewage services by 178 ktonnes and the enhanced BASIX Options decrease annual greenhouse gas emissions by up to 220 ktonnes.

The expected Greenhouse Gas Emissions from utility water and sewage services and decentralised water solutions to the Greater Sydney region is presented in Figure 23 for the period 2010 to 2050.

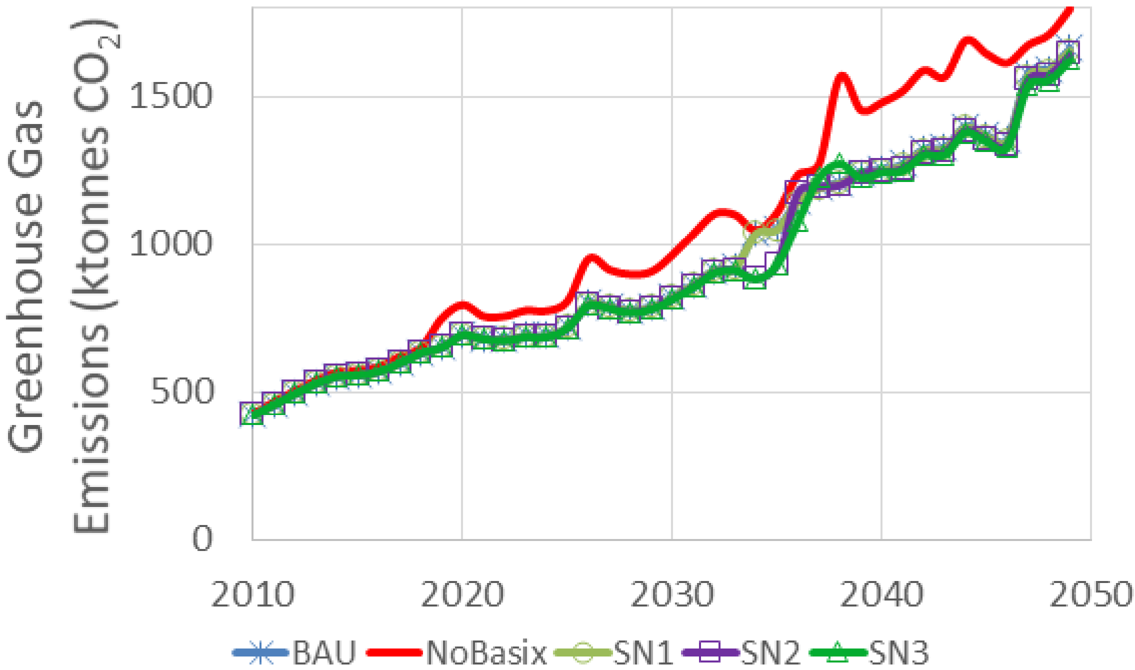


Figure 23: Greenhouse Gas Emissions from utility water and sewage, and decentralised water services for each option

Figure 23 reveals that the current BASIX policy which is a component of the BAU Option decreases greenhouse gas emissions for utility and decentralised water services by 138 ktonnes/annum in 2050. The current BASIX policy has reduced annual greenhouse gas emissions of utility water and sewage services by 138 ktonnes and the enhanced BASIX Options decrease annual greenhouse gas emissions by up to 178 ktonnes for the Greater Sydney region.

This result demonstrates that the small increases in greenhouse emissions from decentralised solutions (57 ktonnes/annum) is overwhelmed by reductions in greenhouse emissions from utility operations and from indoor water efficient appliances. Reduced indoor water demands reduces energy use for heating water in buildings, and for utility water production, transfer and treatment costs.

4.4 Recycled Water

The Greater Sydney region includes 16 recycled water plants with a combined treatment capacity of 233 ML/day. Some of this treated wastewater is used for residential, commercial and industrial uses increasing from 21 GL/annum in 2010 to 32 GL/annum in 2050. The remainder of this treated wastewater supplies agricultural uses and is discharged to waterways.

4.5 Economics

The economics impacts of the proposed options BAU, NoBasix, SN1, SN2 and SN3 are evaluated from the perspective of the water utility and whole of society in this Section.

The Water Utility Perspective

The revenue earned from consumers paying for utility water and sewage services for the Greater Sydney region is presented in Figure 24 for the period 2010 to 2050. This source for revenue for the options includes fixed and variable tariffs for water and sewage services as levied by IPART (2020)[20] and reported in Sydney Water Annual reports (for example; SWC, 2020)[21].

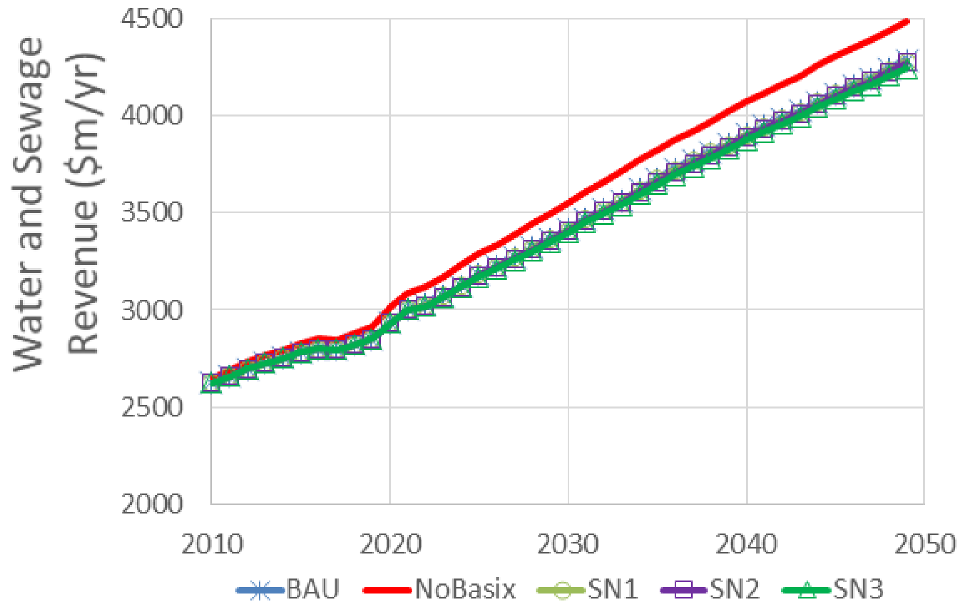


Figure 24: Utility water and sewage revenue earned for each option in 2020 dollars

[20] IPART (2020), Review of prices for Sydney Water Corporation 1 July 2020 to 30 June 2024, Water Final Report, Independent Pricing and Regulatory Tribunal.
[21] SWC (2020), Annual Report, Sydney Water Corporation.

Figure 24 shows that the NoBasix option earns more revenue than the BAU and enhanced BASIX Options. The total annual revenue for water and sewage services earned in the BAU option increased by $1,665 million (63%) to $4287 million by 2050.

The reduced uptake of water efficient appliances and rainwater harvesting in the NoBasix Option results in $198 million/annum additional revenue by 2050. The enhanced BASIX Options SN1, SN2 and SN3 experience small reductions in utility revenue, in comparison to the BAU Option, of $7 million/annum, $14 million/annum and $43 million/annum respectively.

The total capital and operation costs of providing utility water and sewage services throughout the Greater Sydney region are presented in Figure 25 for the period 2010 to 2050 for each option. Note that these costs are based on 2020 dollar values.

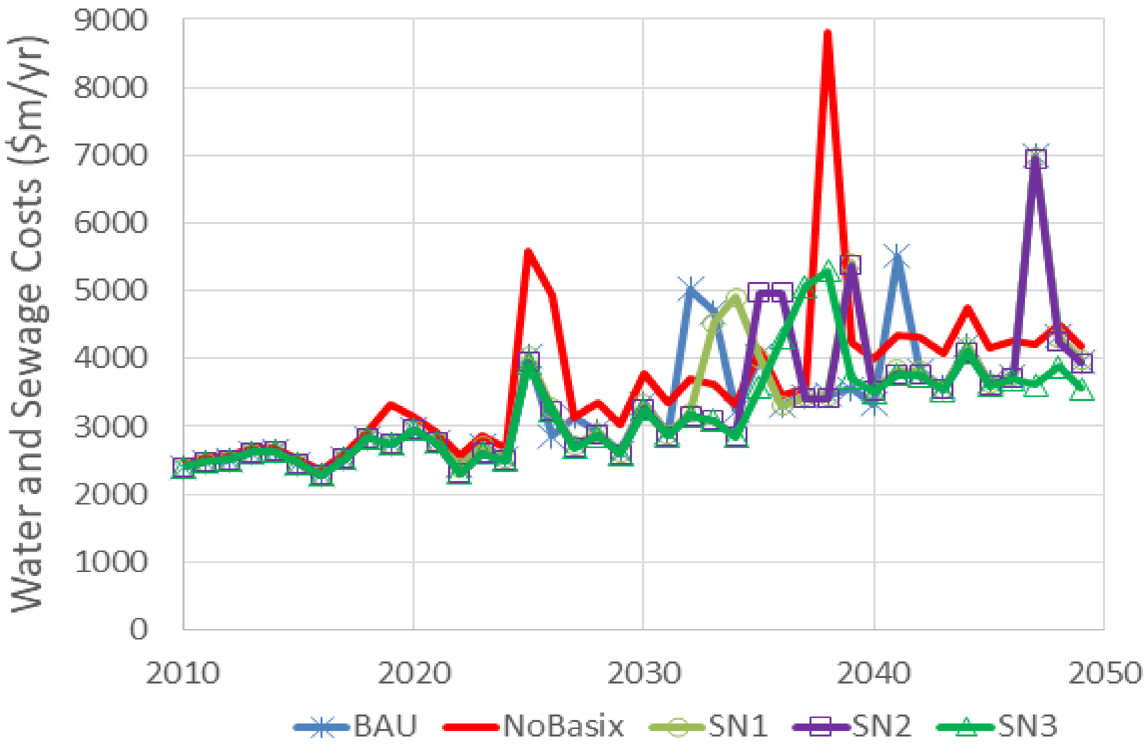


Figure 25: Utility water and sewage costs for each option in 2020 dollars

Figure 25 shows that the annual costs to provide utility water and sewage services in the BAU option increase by $1544 million (64%) to $3945 million/annum by 2050.

The NoBasix option is subject to increases in annual water and sewage costs by $1741 million (71%) to $4193 million/annum by 2050. A reduced uptake of water efficient appliances and rainwater harvesting results in higher annual costs of $186 million by 2050.

Greater uptake of water efficient appliances, rainwater harvesting and local use of greywater in the enhanced BASIX Options SN1, SN2 and SN3 has lowered annual costs in 2050 by $15 million, $83 million and $444 million respectively.

A key insight from these results is that decreased costs overwhelm diminished revenue by a factor of three when distributed solutions reduce demand for utility water and sewage services.

The net present costs, revenues and benefits are summarised for the period 2010 to 2050 using a discount rate of 7% in Table 13.

Table 13: Present economic values for utility water and sewage services to 2050 using a discount rate of 7%

Item	Present value ($m) versus option				
	BAU	NoBasix	SN1	SN2	SN3
Costs ($m)	38,728	41,833	38,659	38,187	37,794
Net costs ($m)		+3,105	-69	-542	-934
Revenue ($m)	40,700	41,801	40,676	40,649	40,596
Net revenue ($m)		+1101	-24	-50	-104
NPV ($m)	1,971	-32	2,016	2,463	2,801
Net Benefit ($m)		-2,003	+45	+491	+830

Table 13 reveals that the net benefit of the BASIX policy in the BAU Option is $2003 million compared to the NoBasix option. This is the net present cost of the NoBasix Option. The enhanced BASIX options SN1, SN2 and SN3 provide net present benefits of $2048 million, $2494 million and $2833 million respectively.

These economic results show that abandoning distributed water savings provided by BASIX in the BAU Option increases utility costs by $3105 million for a gain in revenue of $1101 million. This is an increase in costs of $3 for every additional dollar earned. Similarly, increased distributed water sources and water efficiency provides economic multipliers of benefit ranging from 3:1 to 10:1.

The net present costs, revenues and benefits are summarised for the period 2010 to 2050 using a discount rates of 3% and 10% in Tables 14 and 15.

Table 14: Present economic values for utility water and sewage services to 2050 using a 3% discount rate

Item	Present value ($m) versus option				
	BAU	NoBasix	SN1	SN2	SN3
Costs ($m)	72,556	78,732	72,458	71,405	69,900
Net costs ($m)		+6176	-98	-1151	-2656
Revenue ($m)	74,837	77,224	74,774	74,702	74,547
Net revenue ($m)		+2387	-63	-135	-290
NPV ($m)	2,281	-1,509	2,316	3,296	4,647
Net Benefit ($m)		-3,789	35	1,015	2,366

Table 15: Present economic values for utility water and sewage services to 2050 using a 10% discount rate

Item	Present value ($m) versus option				
	BAU	NoBasix	SN1	SN2	SN3
Costs ($m)	27,212	29,204	27,164	26,894	26,739
Net costs ($m)		1,992	-48	-318	-473
Revenue ($m)	28,886	29,579	28,874	28,860	28,834
Net revenue ($m)		694	-12	-26	-52
NPV ($m)	1,674	375	1,710	1,966	2,095
Net Benefit ($m)		-1,298	36	292	421

Table 14 shows that the net benefit of the BASIX policy in the BAU Option is $3789 million for a discount rate of 3% The enhanced BASIX options SN1, SN2 and SN3 provide net present benefits of $3824 million, $4804 million and $6155 million respectively.

Table 15 shows that the net benefit of the BASIX policy in the BAU Option is $1298 million for a discount rate of 10% The enhanced BASIX options SN1, SN2 and SN3 provide net present benefits of $1334 million, $1590 million and $1719 million respectively. The benefits to the water utility of the BASIX policy in the BAU Option holds across the discount rates of 3% to 10% recommended by the NSW Treasury providing net benefits ranging from $1298 million to $3789 million. Enhanced BASIX options provide net utility benefits ranging from $1334 million to $6155 million.

These results also reveal an economic multiplier for reduced costs over increased revenue of 3 to 10 for the BASIX Options. Increased costs also overwhelm gains in revenue by a ratio of 3:1 in the situation where policies supporting distributed water savings are abandoned in NoBasix.

The Whole of Society Perspective

The net present costs of managing urban stormwater runoff across Greater Sydney is presented for discount rates of 7%, 3% and 10% in Tables 16, 17 and 18.

Table 16: Net present costs of stormwater infrastructure and managing nutrient loads using a 7% discount rate

Item	Net Present Costs ($m)				
	BAU	NoBasix	SN1	SN2	SN3
Nitrogen NPC ($m)	40,562	45,266	40,207	34,538	58,155
Infrastructure NPC ($m)	19,016	20,697	18,829	15,552	26,891
Nitrogen NPV ($m)		-4,704	354	6,024	15,379
Infrastructure NPV ($m)		-1,681	187	3,464	7,601

Table 17: Net present costs of stormwater infrastructure and managing nutrient loads using a 3% discount rate

Item	Net Present Costs ($m)				
	BAU	NoBasix	SN1	SN2	SN3
Nitrogen NPC ($m)	73,536	83,416	72,605	57,683	34,709
Infrastructure NPC ($m)	34,492	37,740	34,072	26,623	15,663
Nitrogen NPV ($m)		-9,880	931	15,853	5,853
Infrastructure NPV ($m)		-3,248	420	7,868	3,354

Table 18: Net present costs of stormwater infrastructure and managing nutrient loads using a 10% discount rate

Item	Net Present Costs ($m)				
	BAU	NoBasix	SN1	SN2	SN3
Nitrogen NPC ($m)	28,988	32,029	28,803	25,838	25,923
Infrastructure NPC ($m)	13,575	14,725	13,464	11,548	11,609
Nitrogen NPV ($m)		-3,041	186	3,150	3,065
Infrastructure NPV ($m)		-1,150	111	2,026	1,965

Tables 16, 17 and 18 reveals that the BASIX policy in the BAU Option reduces stormwater infrastructure costs by $3248 million to $1150 million, and reduced stormwater quality improvements costs by $9880 million to $3041 million. The enhanced BASIX options SN1, SN2 and SN3 provide stormwater quality improvement benefits ranging from $3227 million to $15,733 million and stormwater infrastructure benefits ranging from $1261 million to $6602 million.

The household perspective

The net present costs of the distributed solutions within the Greater Sydney region are provided in Table 19 for discount rates of 3%, 7% and 10%. These costs include installation, renewal and operating costs.

Table 19: Net present costs of the distributed solutions for Greater Sydney

Item	**Net Present Costs ($m)**				
	BAU	**NoBasix**	**SN1**	**SN2**	**SN3**
3% Discount rate	2,627	754	2,620	3,144	3,155
Net Present Value		-1,872	-6	518	528
7% discount rate	1,384	420	1,384	1,688	1,692
Net Present Value		-964	0	305	309
10% discount rate	955	302	957	1,180	1,182
Net Present Value		-652	2	225	227

Table 19 shows that the net present costs of the BASIX policy range from $1872 million to $653 million as demonstrated by the difference between the costs of local solutions in the BAU and NoBasix Options.

The net present costs of enhanced BASIX Options SN1, SN2 and SN3 are $1879 - $655 million, $2390 - $878 million, and $2401 - $880 million respectively.

5 Discussion

The results of the systems analysis are summarised for key physical and economic parameters in Table 20. Note that the economic results are presented as present values at a discount rate of 7%.

Table 20: Summary of results from the systems analysis of Options for the Greater Sydney region

Criteria	**BAU**	**Change from BAU**			
		NoBasix	**SN1**	**SN2**	**SN3**
Utility water supply in 2050 (GL)	925	122	-3	-6	-31
Water Security (number of augmentations) Change in augment timing. See Table 11.	(5)	(5) +7 +7 +8 +3 +9	(5) 0 0 -2 0 0	(5) 0 0 -3 0 0	(4) -2 -2 -2 0 -
Utility sewage discharges (GL) in 2050	842	31	-5	-56	-53
Stormwater Runoff (GL) in 2050	696	53	-8	-95	-90
Nitrogen Loads (tonnes) in 2050	1740	360	-46	-777	-752
Greenhouse gas emissions (kTonnes) in 2050	1665	138	-8	-20	-40
Utility water and sewage NPC ($m)	38,728	3,105	-69	-542	-934
Utility water and sewage net present revenue ($m)	40,700	1101	-24	-50	-104
Total economic value: Utility water and sewage NPV ($m)		**-2,003**	**45**	**491**	**830**
Economic multiplier (Δ costs/Δ revenue)		2.81	2.88	10.84	8.98
Distributed Solutions NPC ($m)	1,384	-964	0	305	309
Stormwater services NPC ($m) to 2050	19,016	1,681	-187	-3,464	-3,354
Nutrient NPC ($m) to 2050	40,562	4,704	-354	-6,024	-5,853
Total economic value: NPV ($m) to whole of society		**-7424**	**586**	**9674**	**9732**

Table 20 reveals that the Options that include variations of the BASIX policy – BAU, SN1, SN2 and SN3 – produce strong net present economic values to the water utility and to whole of society in comparison to the NoBasix Option. These increased total economic values are driven by reduced demands for water, sewage discharges and stormwater runoff throughout the Greater Sydney Region.

Economic impact of BASIX options on the water utility and whole of society

This results in diminished operating and capital expenses, and delayed augmentation costs. The total impact of the BASIX options in comparison to the NoBasix option are presented in Table 21.

Table 21: Summary of the value of BASIX Options for the Greater Sydney region

Criteria	Change in magnitude to 2050			
	BAU	**SN1**	**SN2**	**SN3**
Water demand (GL)	122	125	128	153
Wastewater discharge (GL)	31	36	87	84
Stormwater runoff (GL)	53	61	148	143
Nitrogen load (tonnes)	360	406	1137	1112
Greenhouse emissions (ktonnes)	128	146	158	178
Total economic value to water utility (NPV: $m)	**2003**	**2048**	**2494**	**2833**
Total economic value to society (NPV: $m)	**7424**	**8010**	**17,098**	**17,156**

Table 21 highlights that all BASIX Options provide net physical and economic values to both the water utility and whole of society. The BAU option provides substantial value and the SN3 is the pareto optimum solution as indicated by the highest net present value from the perspective of the water utility and whole of society.

Economic impact of BASIX Options on household welfare

The impact of the BASIX Options on household welfare is provided by the change in costs and benefits to households in Table 22. This analysis is achieved by understanding that the change in revenue to the water utility can be considered to be a transfer to households as a reduction in water and sewage tariffs.

Table 22: Summary of household welfare generated by BASIX Options

Criteria	Change in magnitude by 2050			
	BAU	**SN1**	**SN2**	**SN3**
Household costs ($m/yr)	964	964	1,268	1,272
Household revenue ($m/yr)	1,101	1,125	1,152	1,205
Household welfare (NPV: $m/yr)	**137**	**161**	**-116**	**-67**

It is noteworthy that Table 22 only considers that change in water utility revenue as an increased benefit to households. The reduced costs of managing stormwater were not considered as a transfer benefit to households because a transfer mechanism via price regulation of stormwater tariffs is not directly available. In addition, there are considerable non-market values, such as increased amenity and property values, that are not considered in this investigation.

Table 22 shows that the BASIX Options BAU and SN1 produce net present benefits to household which will have the effect of increasing the disposable income of households. Increases in disposable income improves the overall economic status in society due to increases savings and spending on other goods and services. The SN1 Option is the pareto optimum solutions as it provides the greatest net benefit to households.

The results in this investigation are consistent with the analysis of historical data to understand the impacts of local water efficiency and water sources on utility operating costs and household welfare during the period 2003 to 2016 by Coombes et al. (2018).[22] That study utilised systems analysis and econometric methods to estimate that the BASIX policy has improved annual household welfare by $218 m to $578 m and decreased annual water utility operating costs by $53 m to $810 m using a 4% discount rate. The net present value of decreased water and sewage operating costs in the BAU option for this investigation was $1154 m as compared to the NoBasix Option.

Effect of economic discount rates

To ensure consistency with the guidance provided by the NSW Treasury, this investigation employed 3%, 7% and 10% discount rates in the economic evaluation.[23]

The positive economic benefits of the BASIX Options hold across the selected discount rates for the water utility and whole of society perspective, and the SN3 Option is the Pareto Optimum strategy.

Examination of the results from the perspective of household welfare reveal that the positive economic benefits hold for all BASIX Options subject to the 3% discount rate. However, for the 7% and 10% discount rates, the SN2 and SN3 Options produce a net cost to households. The Pareto Optimum solution from the household perspective is the SN1 Option.

---

[22] Coombes P. J., Barry, M. E., Smit, M., (2018), Systems analysis and big data reveals economic efficiency of solutions at multiple scales, OzWater 2018, Australian Water Association, Brisbane, Australia

[23] NSW Treasury (2017), NSW Government guide to cost-benefit analysis, TTP 17-03

Cost multipliers

One the key findings of this investigation is that the local or distributed solutions provided by the BASIX policies drive beneficial economic multipliers. From the perspective of water and sewage services, local water savings provide $3 reductions in utility costs for each $1 in reduced revenue.

This outcome provides a key insight that a primary focus on increasing utility revenue by reducing local water savings (such as abolishing the BASIX policy) generates utility costs that are three times the potential gains in revenue. This indicates that reducing local water savings will create substantial economic losses to water utilities.

Importantly, the inclusion of stormwater processes in the economic analysis increases these economic multipliers reduced costs to greater than $10 for every $1 in reduced utility revenue. A BASIX policy that includes stormwater targets creates substantial economic multipliers of benefit to the whole of society in the Greater Sydney region. It follows from this discovery that abolishing BASIX to increase revenue to the water utility creates an economic disbenefit of 10:1.

Other considerations

Greater Sydney will need to find 67% more water by 2050 than it currently provides, will need to manage 83% more wastewater discharges and 43% more urban stormwater runoff. Just maintaining the current BASIX policy until 2050 (BAU Option) will save Greater Sydney the annual equivalent of a desalination plant, additional major wastewater treatment plants and substantial stormwater management facilities.

The stormwater management benefits of rainwater harvesting, raingardens and greens spaces that include trees were not part of the original BASIX policy in 2004. This investigation (SN2 and SN3 Options) has revealed that including stormwater targets in BASIX has provided substantial whole of society benefits around reducing urban stormwater runoff volumes and improving the quality of stormwater in urban waterways. Importantly, the systems analysis in the investigation replicates that connectivity of urban stormwater runoff and the centralised hierarchical networks of sewage discharges. Reduce urban stormwater runoff at source also decreases the volumes of sewage discharges and mitigates some of the risk of sewage overflows.

Significant progress in their planning frameworks in implementing a water sensitive urban design (WSUD) approaches and drafting deemed to comply rainwater harvesting provisions for WSUD has been undertaken in South Australia and Victoria. These jurisdictions have identified that their current stormwater management infrastructure is not designed for increased urban densities, the challenges of population growth and more intense rain events associated with climate change.

Incorporating targets for reducing stormwater runoff volumes into BASIX policy is a logical step in response to the evolving challenges facing Greater Sydney. This investigation reveals that the BASIX Options that include stormwater targets provide the highest net benefits to the water utility and whole of society (Options SN2 and SN3). These options do not provide the highest benefits to households because there is currently no mechanism to transfer the benefits of stormwater improvements from utilities, government agencies and whole of society to households.

The price regulation by provided by IPART provides a framework to return benefits to households as a function of setting prices for water utility services. Recent decreases in fixed tariffs and preference for variable tariffs for water services has increased the likelihood of economic transfers to households. Inclusion of a regulated tariff for effective impervious areas on properties and counting reduced stormwater runoff from BASIX solutions in the evaluation of a stormwater tariff would provide a mechanism to recognise local stormwater contributions in economic transfers to households. This insight is consistent with the findings of Coombes (2018) for the Greater Melbourne region.[24] In any event, the additional net present cost of including stormwater targets in BASIX is small, ranging from $15 to $37 per household. This small net increase could be offset using policy and pricing incentives.

[24] Coombes P. J., (2018), Systems Analysis quantifies urban stormwater resources and market mechanisms for pricing stormwater and environmental management, Stormwater 2018, Stormwater Australia, Sydney, Australia

6 Conclusions

This investigation utilised the system framework models developed for the Greater Sydney region over the previous 20 years and incorporated additional information from the NSW government and the rainwater industry. The Systems Framework methodology was recognised in 2018 by Engineers Australia as leading water resources and hydrology research by the award of the GN Alexander Medal (Barry and Coombes, 2018).[25] This analysis methodology was enhanced for this investigation to incorporate more input data and additional analysis methods.

The Systems Framework is used to model and then compare five Options. The Business as Usual (BAU) Option considers current water cycle (water, sewage, stormwater and environment) management practices and BASIX policies across the Greater Sydney region. The second Option (NoBasix) examines the impacts of not implementing the BASIX policy in 2004 to document the benefits of the state planning policy. A third Option includes BASIX (SN1) higher water saving targets and two additional options (SN2 and SN3) include stormwater volume targets and increased water saving targets designed to address key challenges facing Greater Sydney.

The key insight is that a combination of supply and demand management is more efficient than relying entirely on supply solutions when considering utility and whole of society benefits. These demand management solutions include behaviour change, water efficient appliances, greywater reuse, rainwater harvesting and green solutions.

An example of these benefits is significant deferral of the multi-billion dollar centralised augmentation requirements provided by the BASIX policy. Inclusion of rainwater harvesting, rain gardens and vegetated spaces that include trees as a stormwater management solution has both infrastructure and demand management benefits and is an efficient decentralised infrastructure asset that improves the performance of the whole system.

This investigation has highlighted the water and sewage transfer distances of over 50 km across Greater Sydney. Transporting water and sewage across these distances and significant changes in ground elevations represents high capital and operational costs and potential economic inefficiencies. In some parts of Greater Sydney, the shadow cost (medium run marginal cost) of delivering water and sewage services is greater than $16/kL, which is almost 8 times the household water usage tariff, as shown in Figure 12.

[25] Barry M. E., and Coombes P. J., (2018), Planning resilient water resources and communities: the need for a bottom-up systems approach, Australasian Journal of Water Resources, 22(2), 113-136. Canberra, Australia

The variants of the BASIX policy examined in this systems analysis provided substantial benefits to 2050 as follows:

- Reduced annual utility water demands by 122 to 153 GL
- Reduced annual utility wastewater discharges by 31 to 87 GL
- Decreased regional annual stormwater runoff volumes by 53 to 148 GL
- Diminished annual nitrogen loads discharging to urban waterways by 360 to 1137 tonnes
- Lower annual greenhouse gas emissions from water and sewage services by 128 to 178 ktonnes
- Reduced net present costs to operate the water utility by $2003 to $2833 million
- Reduced whole of net present costs to whole of society by $7424 to $17,156 million

It is a key finding of this investigation that the benefits of the current BASIX policy are significantly greater than the costs from the perspective of the water utility and whole of society within the Greater Sydney region. This result holds for discount rates ranging from 3% to 10%.

The current and proposed Scenario 1 versions of BASIX provide significant improvements in household welfare for all households in response to real reductions in utility tariffs to 2050. The local value of water savings at households was not considered. Inclusion of stormwater management and green infrastructure in the BASIX increases household costs by 10% for scenario 2 and 6% for scenario 3 because there is no economic mechanism to transfer catchment scale stormwater benefits to households in council rates.

Enhancement of the BASIX policy to incorporate higher water targets and targets for reduced stormwater volumes provides the highest economic benefits from the perspective of the water utility and whole of society. BASIX with increased water savings target provides the highest economic benefits to households.

Incorporation of mechanisms to transfer some of the regional stormwater benefits to households (about $15 - $27 per household) or also counting non-market benefits (such as amenity and enjoyment of healthy waterways) in the analysis will indicate that the SN3 Option that combines increased water savings and stormwater targets is the Pareto Optimum solution for Greater Sydney from all perspectives.

7 References

ABS, (2017), Environmental Issues: water use and conservation (Mar, 2013), Cat No. 4602.0.55.003: customised report. Australian Bureau of Statistics,

ABS, (2016), Census of Population and Housing, Cat No. 2901.0; Household Income and Wealth, Cat No. 6523.0, Australia Bureau of Statistics

Clarke R.M., and Stevie R.G., (1981), A water supply cost model incorporating spatial variables, Land Economics, University of Wisconsin Press, 57(2), 18-32.

Coase R.H., (1947), The economics of uniform pricing systems, Manchester School of Economics and Social Studies, 139-156.

Coombes, P., and Barry, M. (2014). A systems framework of big data driving policy making for Melbourne's water future. Ozwater14. Australian Water Association.

Coombes, P., Barry, M., and Smit, M. (2020). Revealing the spatial long run marginal costs of water and sewage services for Australian Capital Cities. In Review.

Coombes P. J., and Barry, M. E., (2018), Using surfaces of big data to underpin continuous simulation in systems analysis, 10th International Conference on Water Sensitive Urban Design: Creating water sensitive communities (WSUD 2018 & Hydropolis 2018), Engineers Australia, Perth, Australia

Coombes P. J., Barry, M. E., Smit, M., (2018), Systems analysis and big data reveals benefit of new economy solutions at multiple scales, 10th International Conference on Water Sensitive Urban Design: Creating water sensitive communities, Engineers Australia, Perth, Australia

Coombes P.J., and Barry M.E., (2015). A Systems Framework of Big Data for Analysis of Policy and Strategy. WSUD2015 Conference. Engineers Australia. Sydney. Australia.

Coombes, P., Smit, M., & Macdonald, G. (2016). Resolving boundary conditions in economic analysis of distributed solutions for water cycle management. Australian Journal of Water Resources, Vol 20, 11-29.

Coombes P. J., Kuczera G. A., Kalma J. D., Argue J. R., (2002), An Evaluation of The Benefits Of Source Control Measures At The Regional Scale, Urban Water, 4, 307- 320.

Coombes P. J., (2005), Integrated Water Cycle Management: Analysis of Resource Security, Water, 32, 21-26

IPART (2020), Review of prices for Sydney Water Corporation 1 July 2020 to 30 June 2024, Water Final Report, Independent Pricing and Regulatory Tribunal.

IPART. (2018). Review of prices for Sydney Water Corporation 1 July 2016 to 30 June 2020, Water, Final Report. Independent Pricing and Regulatory Tribunal.

IPART. (2018). Review of the Sydney Water Corporation Operating Licence 2015-2020. Sydney: Independent Pricing and Regulatory Tribunal.

Kuczera, G., (1992), Water supply headworks simulation using network linear programming, Advances in Engineering Software, 14, 55-60

OEH. (2016). Floodplain risk management guidelines. NSW Office of Environment and Heritage.

NSW government, (2016; 2020), 2016 New South Wales State and Local Government Area Population and Household Projections, and Implied Dwelling Requirements, Department of Planning and Environment.

NSW Audit Office, (2020), Water conservation in Greater Sydney, Report by the NSW Auditor General. Parliament of NSW, Sydney.

NSW Treasury (2017), NSW Government guide to cost-benefit analysis, TTP 17-03

Parsons, W. (2015). Nepean River Flood Study. Camden Council.

SWC (2020), Annual Report, Sydney Water Corporation.

Sydney Water (2018), Water conservation report 2017-2018, Sydney Water

Sydney Water. (2010). Annual Report. Sydney Water Corporation.

Sydney Water. (2015). Determining Sydney Water's Economic Level of Water Conservation - Part A. Sydney: Sydney Water.

WaterNSW. (May 2008). Greater Sydney's water supply system yield. WaterNSW.