

Urban water sustainability

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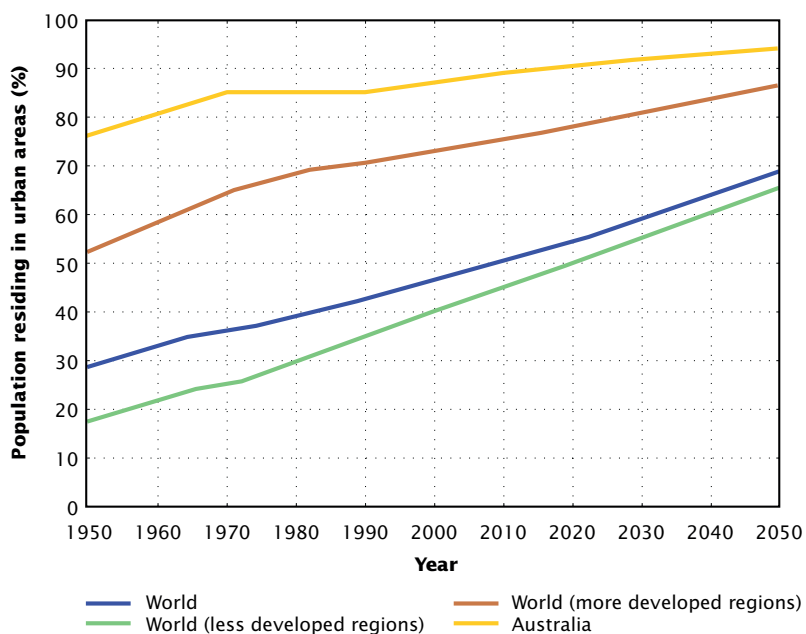
Key messages

- * An extra 10 to 20 million people could be living in Australian cities by 2050, requiring more water supplies, more wastewater disposal, and greater energy use to provide these services.
- * The increasing demands for water, energy, and other resources in cities are leading to new approaches to urban water as part of broader urban sustainability and liveability.
- * There is considerable potential to improve urban sustainability by recovering water, energy, carbon, and nutrients from wastewater and reusing them in the city and as fertiliser for food production.

Growing cities and the need for sustainability

The world's population in the 21st century will become predominantly urban. Half of the world's population is already living in cities and this proportion will increase to about 70% by 2050 (Figure 6.1). Nearly all of the expected growth in the world's population will occur in urban areas by 2050.¹

Demand for urban water supplies will grow across the world and Australia is no different. Australia is already highly urbanised, with almost 90% of the population living in cities, but in the next 50 years 10 to 20 million extra people will live in Australian cities.² The capital cities alone will need to accommodate an additional 10.5 million people by 2050² – the equivalent of the current population of Sydney, Melbourne, Perth, and Adelaide. Not only will more water be needed to supply this population, but more sewage will be produced and treated, and more urban stormwater will be generated from the additional roofs, roads, and paved areas. The impacts of these discharges on the valued rivers, estuaries, coasts, and groundwater systems surrounding our cities is already significant, and this level of urban growth will place waterways under increasing pressure.



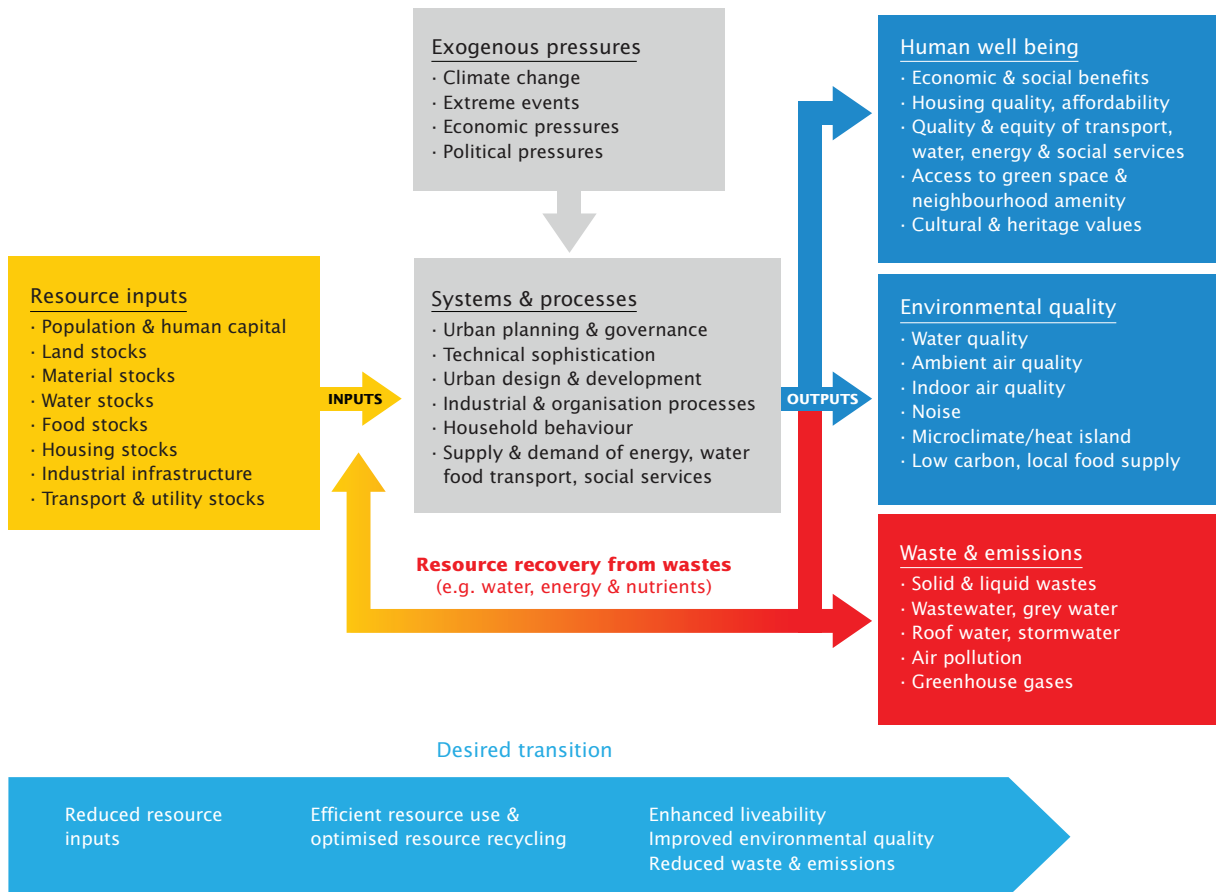
◀ **Figure 6.1:** The percentage of global population living in urban areas is increasing especially in less developed regions. Australia already has a highly urbanised population but it too will become more urbanised.¹

The strong growth of cities and the emergence of mega cities raises questions about their future sustainability, and the way water is managed is central to these concerns. Urban water systems have evolved into large, highly engineered systems in which water is imported from surrounding catchments and aquifers, distributed through extensive pipeline networks, and used just once. Most of the used water is then collected in large sewerage systems, treated to remove contaminants and nutrients, and discharged back to rivers and the sea. These systems provide reliable clean water for residents and industry, and they protect public health, but there are concerns that water systems could be much more efficient, rather than just importing more water, disposing of more wastewater and removing more stormwater. They will need to more efficiently use local sources of water as populations grow, water resources become fully allocated, and climate change reduces the supply of water from catchments and aquifers.

The International Water Association argues that the objectives of urban water management should expand to contribute to the development of more liveable and sustainable cities.³ Urban water systems do not exist and operate in isolation: they have many linkages to other systems within a city and its surrounding regions. For example, population growth and urban density influences water demand, and water use influences wastewater generation and energy use for treatment and transport. Urban design influences stormwater generation and flows, which in turn influences flood risk and water quality. Green space and open water in cities can reduce extreme temperatures, perhaps using more water, but requiring less energy for cooling. There are other direct and indirect connections, some of which will be discussed further in this chapter.

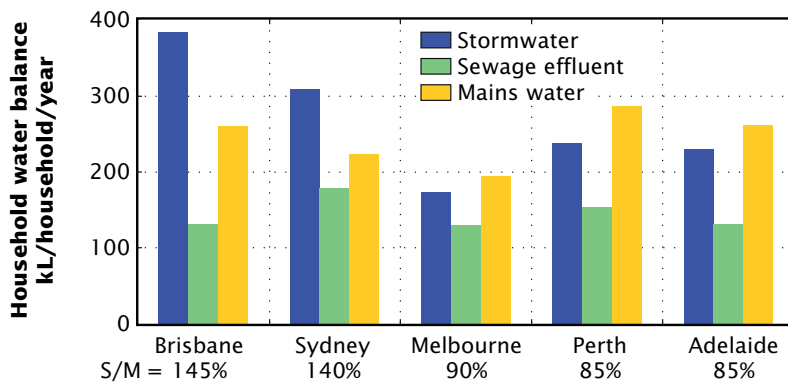
'Urban metabolism' is a useful metaphor to visualise the city as a system, rather like a living organism (Figure 6.2).⁴ Resource inputs, such as water, are translated through a series of connected urban systems and processes into a range of human wellbeing and liveability outcomes, and, in this process, waste streams are generated, which can impact on the local and surrounding natural environment. The system can be made more efficient by improving the benefits from

the resources, such as by reusing them or recycling resources, and reducing impacts on the environment. Resources can potentially be recovered from these wastes to reduce the need for new inputs. By changing the urban system and processes within a city, including the way we design and manage water systems, the ‘metabolic efficiency’ of a city can be enhanced.



▲ **Figure 6.2:** Cities from an urban metabolism perspective: consuming resources, processing them to produce wellbeing, and producing waste products.⁵

An example of the potential for greater efficiency in urban water use is shown in Figure 6.3. Depending on each city’s outdoor water use, up to 75% of water supplied becomes sewage effluent, which could be recycled to offset input of additional water. Urban stormwater is an additional resource that often exceeds the volumes of mains water, but except for Perth, less than 3% of urban stormwater is harvested. Perth recycles an estimated 80% of stormwater for irrigation reuse following recharge to aquifers. Until recently, all household water use was of potable quality even though up to half was used for garden watering and less than a third is used in the kitchen or bathroom.



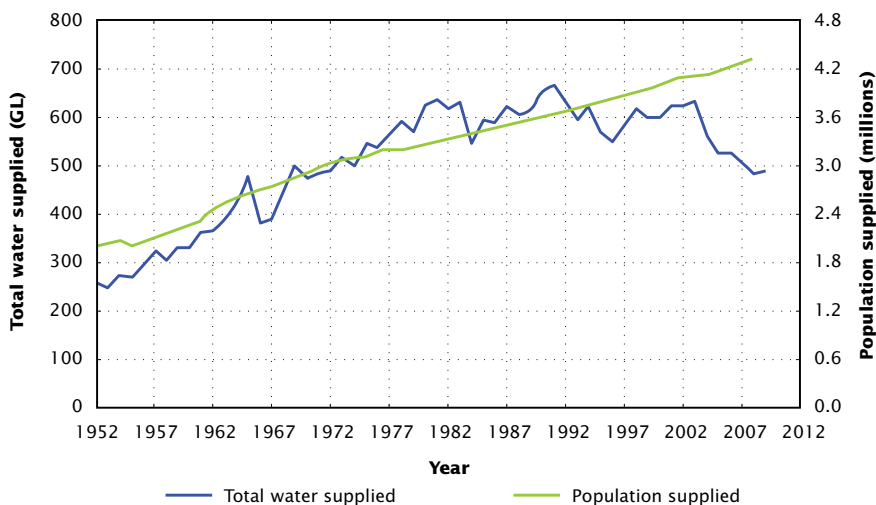
◀ **Figure 6.3:** Water balances per household in Australia's five largest cities. Much mains water ends up as sewage effluent, and stormwater is an even larger waste stream that can exceed the volumes of mains water. S/M refers to stormwater volumes as a percentage of mains water supply.⁶

This chapter examines how urban water management can respond to the challenges of sustainability. Chapter 7 explores in more detail the options for augmenting supplies in Australian cities to meet the growing demand for water.

Managing demand

Households use 70–80% of total urban consumption, so, historically, water use tended to rise in line with population. However, since the early 1990s, per capita water use has declined in most cities as a result of greater water use efficiency in households and industry, higher prices for water, and changing urban design such as increasing multi-unit housing and smaller sizes of household blocks. Figure 6.4 demonstrates the effect of this trend in Sydney, where total water use today is the equivalent of demand in the early 1970s, despite an additional 1.2 million residents.

Consumers do not require a specific volume of water: they want the services that water provides such as clean clothes, pleasant landscapes, or waste removal, in addition to safe water for drinking, cooking, and bathing. These services can be provided while using less water through better system design, technology efficiency, or changed behaviour.



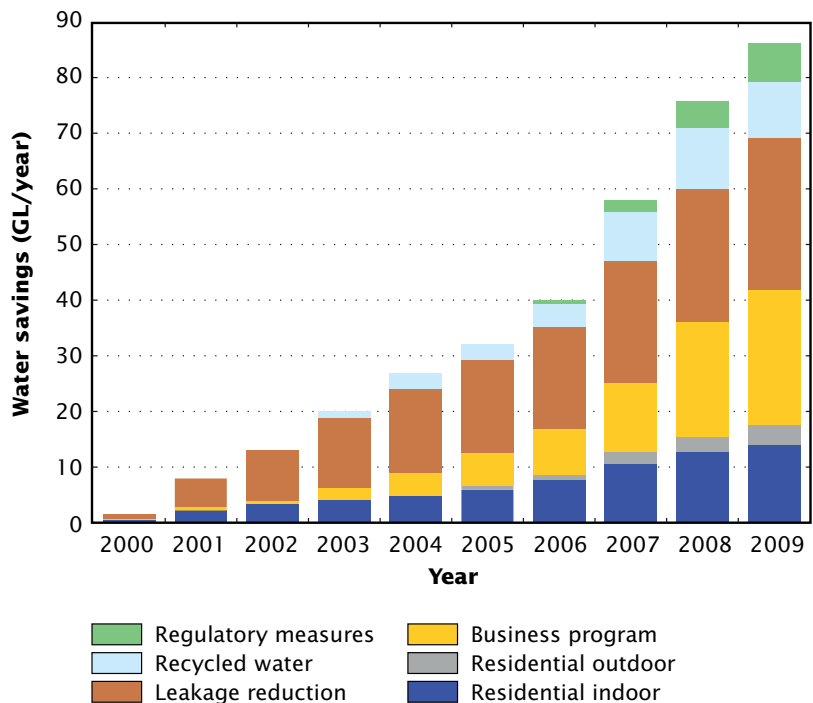
◀ **Figure 6.4:** Long-term trend in Sydney water supply. Water supply used to grow in line with population, but reduced per capita consumption since 1992 enabled more people to be supported from the same total supply.⁷

Efficient water use delays the need for expensive augmentation of supplies, such as from new dams or desalination plants. Reducing per capita use is invariably less expensive than sourcing, processing, and supplying more water. Demand management can also reduce per capita wastewater flows, providing additional capacity in existing sewers to cater for population growth.

Strategies to reduce demand include adoption of appliances that are more water-efficient such as shower nozzles, dishwashers, and washing machines. Garden water use efficiency has improved through the use of drought tolerant species, more efficient irrigation systems, and education on garden watering. For many purposes, drinking water could be substituted by water sourced from rainwater, stormwater, or recycling. The water supply system can also be made more efficient by reducing distribution losses through leakage control and pressure management, using less water to provide the same service.

A prominent Australian example is the potable water savings of 85 GL/year achieved in Sydney over the last decade from sustained demand management and water recycling strategies (Figure 6.5). These water use reductions equate to the volumes that can be provided by the recently constructed Sydney desalination plant, or 15% of annual supply to Sydney.

During the millennium drought in the southern capitals, restrictions were imposed to reduce household water use as supplies dwindled. The most extreme reductions occurred in South East Queensland where the average per person residential consumption dropped from 300 to 130 L/person/day in response to dam storages dropping below 20%. Historically, water restrictions have been an effective temporary response to drought. The longer term use of restrictions required



► **Figure 6.5:** Water saving measures in Sydney, which have made savings equivalent to 15% of supply.⁸ (Adapted from Sydney Water Corporation 2010.)

during the millennium drought highlighted the impact on some services such as the quality of parks and gardens, and the detrimental effects on landscape and garden industries. The drought and associated restrictions did galvanise community action on water conservation through lower water use appliances, use of rainwater tanks, and improved garden design. Since restrictions were lifted, water use has increased slightly,⁹ indicating that there has probably been a permanent change in behaviour that will not see a return to pre-restriction levels of water use.

The density and design of housing will influence residential water use, particularly outdoor water consumption, in the future. In some Australian cities, backyard irrigation is almost half of total household water use. A recent study in Melbourne found that adopting a more compact city design could reduce residential water consumption by 100 GL/year by 2045, compared with more traditional low density urban expansion.¹⁰ Higher housing density brings other benefits of reduced transport and energy costs and is thus a part of urban planning in most cities.

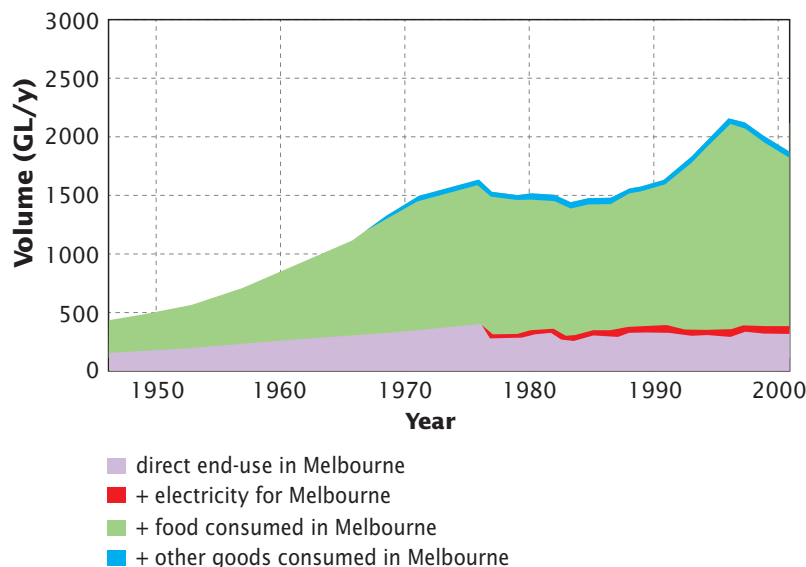
There has been considerable debate over the potential for water pricing to be used as a mechanism to moderate demand.^{11,12} Many utilities charge higher prices for water above a basic supply charge, but the prices do not change over time with the scarcity of water. The price for high rates of domestic consumption could be increased during drought as an alternative to water restrictions.¹³ This would work if demand was sensitive to price, but there is conflicting evidence for that at present. It also requires effective price signals, which are lacking when only a small part of the cost is variable, when the costs are paid 3 months in arrears, and when costs are shared equally across multi-unit apartments.

The water effectively consumed by a city includes not just the water directly supplied but the water used in rural areas to produce food and fibre for city residents and to generate the city's electricity. The fact that the produce from irrigated agriculture is predominantly consumed in cities is often forgotten in polarised conflicts between urban and rural communities. For example, the amount of water used to produce food, fibre, and electricity consumed in Melbourne is



Low water use shower head. Photo: CSIRO.

► **Figure 6.6:** Total effective consumption of water in Melbourne includes not just the direct supply of water to the city but also the water consumed to produce electricity, food, and other goods consumed in the city.¹⁰



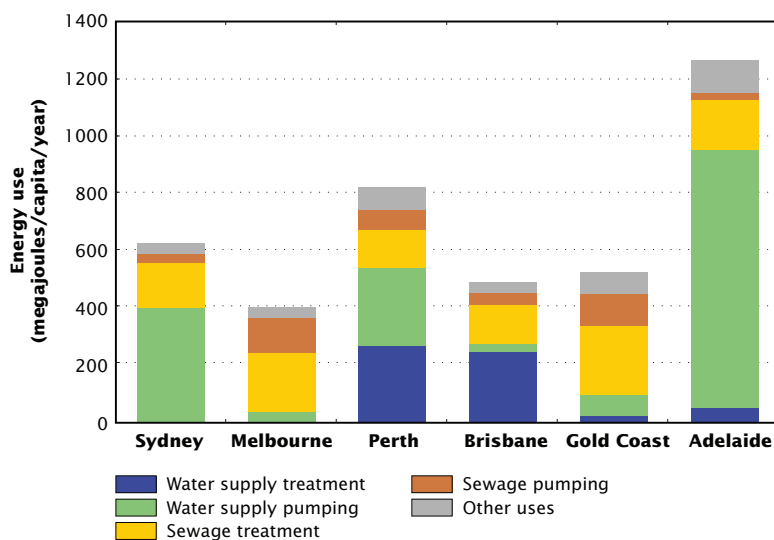
approximately four times the water directly used by city residents and businesses, and has grown faster than direct water use (Figure 6.6). A further significant share of water use is to produce exports, which provide earnings to offset imports that are a large part of consumption of all Australians.

Water and energy

To provide water and wastewater services requires energy for treatment and pumping, and the dominant forms of current energy generation require large volumes of water. The choices made about urban design, water, and energy use, and the sources of both water and energy will influence the future sustainability of cities.

The recent growth in desalination and water recycling has put a focus on energy use in water supply. Direct energy use for the provision of water services in 2007 represented only about 0.2% of total city energy use (about 7 Petajoules (PJ)/ year).¹⁴ By comparison, residential hot water heating uses 46 PJ/year, nearly seven times the amount used to supply water.¹⁴ Even more energy is used in association with commercial and industrial uses of water, mainly for heating and transport processes.¹⁵

A breakdown of energy consumption by water utilities for 2006–07 (a year that precedes desalination and large-scale reuse), shows that each of the major cities differ substantially in their energy use because of differences in topography or system configuration (Figure 6.7). Figure 6.7 clearly shows the energy penalty associated with pumping, where both Sydney and Adelaide were transferring bulk water over long distances to maintain supplies during drought. Water is very heavy at 1 tonne for every kilolitre. Sourcing water close to its end use has definite energy benefits.



◀ **Figure 6.7:** Energy use for water and wastewater services differs markedly among cities (2006–07) depending upon the type and location of their supplies and the location of sewage disposal.¹⁴

Unfortunately, future water supplies are likely to use more energy. Until recent times, most of Australia’s coastal cities were supplied by water fed by gravity from inland dams. Future supplies will have to rely upon piping water over catchment divides or will interconnect systems across regional water grids or entail desalination plants and recycled water schemes, all of which use more energy. A 25% population growth by 2030 is anticipated to increase energy use by water utilities to twice that of 2006–07 levels.¹⁴ Even decentralised supplies, such as rainwater tanks, stormwater harvesting, and local wastewater recycling, can be more energy intensive than existing supplies if poorly designed or maintained.

The largest energy use associated with water though is in heating of water in homes, commercial, and industrial applications, and there are opportunities to reduce this use. Water heating accounts for about 25% of all residential energy use¹⁶ but it could be halved through water-efficient appliances and more efficient water heaters.¹⁴ Even greater energy benefits may be gained in industry, where reductions in steam and hot water losses, reduced pumping in manufacturing, and cooling result in significant energy savings.

There are growing international efforts to reduce greenhouse gas emissions from water use for environmental and economic reasons. Large and increasing energy use combined with rising energy costs provide strong business incentives for water utilities to reduce their energy use. Measures being pursued by Australian utilities include optimising system operations to minimise energy use, generating renewable energy through installing mini-hydro systems in pipeline networks, recovering biogas during wastewater treatment, sequestering carbon through tree farms and woodlots, or offsetting by purchasing renewable energy.¹⁷

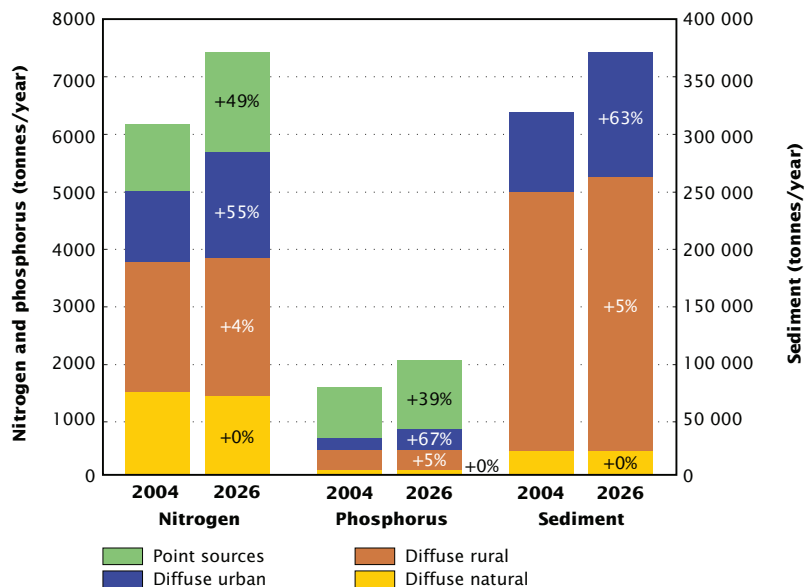
Reducing wastewater and stormwater impacts

The growth of cities will produce an equivalent increase in the amount of human waste that needs to be managed and increased stormwater runoff. Most rivers, estuaries, coastlines, and groundwater systems close to cities and towns have suffered environmental impacts from various forms of pollution. The waterways and coasts are among the most heavily used and valued, placing pressures on water managers to reduce the impacts of stormwater and sewage.

From a wastewater management perspective, the removal of nutrients such as phosphorus and nitrogen contained in human waste is the primary focus for current and future sewage treatment. Strengthening regulation of industrial and commercial pollution at its source over the last 20 years in Australian cities means that the discharge of other contaminants to sewer systems is strictly controlled to avoid waterway pollution. Since the early 1990s, the gradual adoption of load-based environmental regulation across Australia has resulted in upgrade to sewage treatment plants, which use advanced biological treatment processes to improve effluent discharge quality into receiving waters.

Despite these gains, total sewage volumes and nutrient loads will increase over the coming decades because of population growth. Additional measures will be required to constrain nutrient loads to environmentally sustainable levels. The cost of additional treatment to further reduce nutrient concentrations is relatively expensive and energy intensive – a significant problem for fast-growing regions such as South East Queensland which have sensitive aquatic ecosystems. Figure 6.8 shows that the expected increase in phosphorus, nitrogen, and sediment loads to Moreton Bay over the coming decades will be predominantly from point sources such as sewage effluent and diffuse urban sources such as stormwater runoff.

► **Figure 6.8:** Predicted increases in nitrogen, phosphorus and sediment loads to Moreton Bay over the next 20 years showing that urban sources will soon dominate nitrogen loads.¹⁸



Diffuse pollution from stormwater runoff remains a significant problem for cities. Stormwater typically contains litter, sediment, vegetation, nutrients, chemicals, pesticides, metals, and bacteria. Stormwater can also be contaminated with bacteria and nutrients from sewage overflows and animal faeces after rain. Urbanisation increases the volume of and speed of runoff, helping entrain more pollutants and impacting on receiving waterbodies and riparian vegetation.

Water sensitive urban design is an increasingly adopted approach to urban development to minimise the impacts of urbanisation and improve the liveability of cities. It recognises that the way we design buildings, landscapes, and public infrastructure can incorporate water design features that enhance public amenity, cool surfaces and the surrounding air, capture and store stormwater for recycling, improve water quality outcomes in waterways, and protect local biodiversity.

Examples of these approaches include the use of stormwater retention and storage ponds, managed aquifer recharge, constructed wetlands, bio-filtration beds, grassed swales, permeable paving and roadways, and the increased use of water features in public spaces.

Resource recovery

It may be possible to reduce the export of wastewater from a city in a way that recovers resources and substitutes them for inputs into the city. Treated wastewater can be used as a recycled water source for a city, but it can also be a valuable source for nitrogen and phosphorus fertiliser to grow food and fibre, and be a source of energy while reducing greenhouse gas emissions from the treatment process. In essence, some of the inputs and outputs to a city could be internalised into its metabolism, making it more efficient and sustainable.

Growing global populations require increased food and fibre production and increased demand for fertilisers. In Australia, fertiliser use has increased seven fold over the last 40 years.¹⁹ All phosphorus-based fertilisers are sourced from phosphate rock, and it is predicted that high- grade phosphate rock will become depleted over the coming century and lower grade resources will be used instead. Production and energy costs will be greater for these resources and they present other problems such as potential contamination with heavy metals.²⁰ An alternative source for phosphorus could be to recover it from treated wastewater.

Similarly for nitrogen, fertilisers are produced using a very energy-intensive process and then nitrogen is removed during wastewater treatment at a high energy cost. Tertiary wastewater treatment processes can also generate and emit nitrous oxide to the atmosphere: a very potent greenhouse gas. Again there could be many benefits of recovering nitrogen from wastewater as an alternative source of nitrogen fertiliser.

Human waste contributes about 80% of the nitrogen and phosphorus in domestic sewage. The world's population excrete about 25 million tonnes of nitrogen per annum and about 4.4 million tonnes of phosphorus. This is the equivalent of about 17% of the total worldwide production of nitrogen fertiliser and about 22% of that for phosphorus. The amount of nitrogen and phosphorus in agricultural wastes is at least as large, so nutrient recovery from these sources has the potential to supply a significant fraction of the total worldwide fertiliser demand and contribute to more sustainable food production.

Because urban populations provide a concentrated source of nutrient flows in wastewater, sewage treatment plants are an ideal focus for resource recovery in a city. Recent innovations in nutrient recovery from wastewater streams highlight the potential to produce struvite (a slow-release fertiliser of magnesium, ammonium, and phosphate).²¹ Commercial application of this technology is progressing in sewage treatment plants in Canada and the United States of America. Vacuum stripping of ammonia is a new technique and simulation studies on the impact of the ammonia recovery process indicate a reduction in greenhouse gas emissions of between 25% and 48%, compared with current advanced biological treatment.²²

Table 6.1 illustrates the approximate potential value of methane, ammonia, and phosphorus in Melbourne's sewage, based on 2008 prices for these resources. Methane can be used as an energy source to make the treatment plant a net source of energy. The value of water contained in the sewage would be many times the value of the resources. The challenge is to develop and adopt technologies to realise this value in a cost-effective way while protecting environments from pollution.

Table 6.1: Estimate of annual quantities and values of methane, ammonia, and phosphorus available from Melbourne's sewage.²³

	Yearly (tonnes)	Value (\$/year)
Methane	93 200	\$30 million
Ammonia	22 500	\$22.5 million
Phosphorus	3660	\$12 million



Melbourne CBD, Yarra River and urban parkland.
Photo: Robert Kerton, CSIRO.



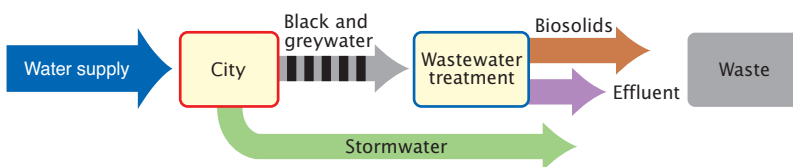
Domestic rainwater tank. Photo: CSIRO.

One way to realise the potential of resource recovery is to separate black water (toilet wastewater) at its source. Current sewers collect black water and grey water flows. However, black water contributes about 20% of residential sewage discharges but contains some 90% of the nitrogen and 60% of the phosphorus discharged.²⁴ Black water separation would concentrate the flows of nutrients and carbon in sewage to enable purpose-built energy and nutrient recovery

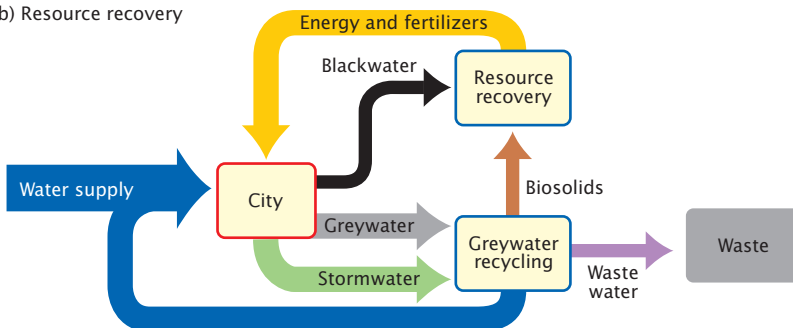
treatment processes. The remaining grey water sewage flows would be significantly lower in nutrients, greatly reducing the need for tertiary treatment based on nitrogen removal, thereby reducing energy use and facilitating simpler and safer grey water recycling (Figure 6.9).

Black water separation is easier to implement in new developments, but a transition to such a system may also be possible in existing areas of a city as wastewater infrastructure and housing stock is renewed over time. The economics of such a transition are complex but should consider the value of all the components and resource flows beyond simply the cost of sewage treatment. Black water separation requires additional collection pipelines (possibly within the existing sewer), as well as a resource recovery treatment processes – both significant investments. These could be offset by new income from the fertilisers and energy produced, a new water source from recycled grey water, lower capacity required for sewage treatment plants, and lower pollutant discharges to the environment.

a) Conventional



b) Resource recovery



◀ **Figure 6.9:** A conventional urban water system compared with one designed to recover resources from black water and recycle grey water.

Transitioning to a sustainable urban water system

Today, society has the advanced technologies and the economic capacity that allow us to manufacture clean drinking water or water fit for other purposes from virtually any source of water, wastewater, or stormwater. Technologies are emerging that will enable more effective recovery of resources from wastewater, that will provide real-time management of water quality and water use, and optimise integrated water system operation for a range of environmental, public health, and service quality outcomes.

Across the globe, water managers are grappling with the challenge of how to use these technologies to evolve to more sustainable water systems. The first step is to define a new vision for urban water management in light of 21st century challenges. With significant input from the Australian water sector, the International Water Association recently endorsed a set of principles that describe the water related characteristics to which cities can aspire. These principles include:³

- * Liveable and sustainable cities that have a compact footprint and use green urban design and green space to cool cities and provide low-impact transport corridors.
- * Cities that generate water, energy, and nutrient by-products in a way that is carbon neutral and recognises resource connections with surrounding regions.
- * In addition to public health and water security, recognise the role that water provides for urban ecosystems, waterways, and a green city.
- * A greater choice of water services and ones that bear the full environmental and social cost of these choices. Choices that are informed by improved access to useful and accurate information about costs and benefits and their own resource usage.
- * City planning that integrates water, energy, and urban design at all scales to enhance sustainability benefits.

The expanded contribution to more liveable, sustainable cities is appropriate where broader social, public health, and environmental benefits and costs are defined or where there is a willingness by water consumers or other urban beneficiaries to pay for the outcomes.¹² This highlights the challenge of effectively valuing the wider social and environmental benefits and costs of alternative water servicing approaches. All major cities in Australia have progressed towards pricing based on the recovery of direct capital and operating costs, although governments have directly subsidised some recent large water projects.¹² The inclusion of indirect costs and benefits or externalities into water prices has generally been limited to cases where these costs are internalised through regulation.

A shift from conventional to more integrated water, wastewater, and stormwater systems often requires an increased level of involvement from the community due to the increasingly decentralised nature of these systems. Recent research highlights the benefits from engaging and educating the community in order to identify acceptable management and ownership of water

sensitive systems and overcome the sometimes poor understanding of water sensitive urban design and inappropriate uses of non-potable water sources. Some plans for potable recycling of water, such as in Toowoomba, have been defeated as a result of the lack of community acceptance.

Conclusions

Over the past 100 years the water sector has expanded its range of functions, evolving from water delivery to wastewater, drainage, and pollution control functions. It has also begun to recover energy and capture nutrients in bio-solids and to implement water-sensitive urban design. Climate change, limited and decreasing catchment water supplies, and the relatively high cost of manufactured water will continue to place pressure on water services, just as waterway health and rising treatment costs will continue to place pressure on wastewater services. Large price increases have already been foreshadowed, but it is perhaps only by considering the full range of values gained from water that the sector will evolve towards sustainability.

Further reading

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