NORTHCONNEX:
OPPORTUNITIES TO REDUCE AND RECYCLE WATER
DURING OPERATION OF THE TUNNEL ASSET

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Executive Summary

This report explores the potential water uses in the operations of the NorthConnex Tunnel in Sydney, Australia in order to identify possible water savings of up to 20%, as well as generate water sustainability interventions to achieve Operations Phase IS Rating under the Infrastructure Sustainability Council of Australia guidelines.

Each sustainability intervention is assessed through a Cost-Benefit Analysis (CBA), where cost data is available, and benefits can be quantified. After which, a two-variable sensitivity analysis is used based on optimal combinations of interventions for a balanced approach. This analysis produced four possible pillars of investment that can save anywhere from 2% to 92% of potable water in tunnel operations.

The report finds that behavioural change and educational components that involve the community can have the greatest benefit for short- and long-term sustainability and value of water as a precious natural resource.

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I. Introduction

Sustainable development requires a holistic approach to the planning, design, construction and operation of the built environment. Infrastructure in our cities, in particular, requires an intensive amount of resources in order to fulfil its function of serving the needs of the community (Sarté 2010, p. 36). With the combination of a growing population, increased urbanisation[1] and severe impacts of climate change, the pressure is increasing to ensure that development is sustainable[2]. There is an opportunity in the provision of infrastructure to find ways to minimise the ecological footprint of today's modern cities.

A. The NorthConnex Tunnel

One of the major transport infrastructure projects currently being constructed in Sydney is the NorthConnex-M2 Link. With a scheduled completion by 2020, the Lendlease Bouygues Joint Venture (LLBJV) NorthConnex tunnel will bridge two major thoroughfares: the Sydney Orbital Network and the National Highway, accomplishing a major milestone in the NSW State Infrastructure Strategy 2018-2038 (Infrastructure NSW 2018). In support of LLBJV's push for sustainability in its projects, NorthConnex has achieved the 'Leading' Design v1.0 IS Rating, the highest rating possible for the certification body (ISCA 2018). While this is a huge feat, LLBJV recognises that there is still more to be done to reduce potable water consumption and improve efficiency across the project (NorthConnex 2016). Building on the NorthConnex Environment Protection License (EPA 2019) and the LLBJV Water Quality Plan and Monitoring Program (2018a), NorthConnex seeks to achieve one of the key Operations Phase IS Ratings that relates to **water efficiency**.

B. Water and Sustainability

The use of natural resources, specifically water, is the focus of this report. Less than 1 percent of the Earth's water can be considered for human consumption and a significant portion of that consumption is in infrastructure (US Green Building Council 2019). Australia is one of the driest continents on earth, and as of 2019, Sydney is facing another drought. In the coming decades, there is likely to be a reduction in the availability of water and security of supply issues for some communities (Infrastructure NSW 2014). This requires using water resources wisely and in infrastructure, promoting integrated-water design principles (Queensland Urban Utilities 2019). As well as this the United Nations Sustainable Development Goals and the Infrastructure Sustainability Council of Australia (ISCA) acknowledge the importance of saving our world's water resources. Road tunnels are complex and expensive and have a life cycle up to and beyond 100 years, and therefore the concept of sustainable development, including the sustainability of water use, is incredibly relevant for all road tunnels around the world (PIARC 2015).

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[1] The United Nations predicts 68% of citizens living in urban areas by 2050 (UNDESA, 2018)

[2] There are varying definitions of Sustainable Development, however the 1992 Rio Summit underscores sustainable development as meeting the needs of the present without compromising the ability of future generations to meet their own needs, underscoring three core pillars: Social, Economic and Environmental development.

LLBJV have an objective to reduce energy and potable water consumption, improve efficiency and prevent pollution across the project. Maximising opportunities for water efficiency and recycling of resources is a core value of the LLBJV Sustainability Policy (2016) that is underscored in the annual sustainability reports (LLBJV 2017b). In addition, commitments to water quality and savings are set out in the NSW Environmental Protection Agency (2019) Environment Protection License and the LLBJV the Water Quality Plan and Monitoring Program (2018a) for the project.

C. Methodology

The report combines a literature review, field research and a cost-benefit-analysis methodology to create a model of water savings in the operations of the NorthConnex Tunnel.

The literature review included national and international case studies that identify relevant challenges and opportunities for large infrastructure projects, specifically tunnels, to reduce water use in operations. Alongside LLBJV and other relevant NorthConnex reports, literature on infrastructure sustainability was consulted to inform a framework for analysis based on mechanical, operational and behavioural categories and various industry documents were consulted to inform interventions and initiatives under these categories. Costs and benefits were assessed to determine all possible water savings options and where the data was available, these costs and benefits were given estimated monetary values. A sensitivity analysis based on costs and potential water savings was used to compare the identified opportunities. Finally, a model built on four possible pillars of water savings was developed for the NorthConnex tunnel.

II. The NorthConnex Tunnel Operational Water Cycle

This report analyses the lifecycle of water collection and use in the operations of the Northconnex tunnel.

A. Sources of Water

Water is captured and processed in two ways:

1. Several rainwater tanks are included in the design of the Southern and Northern operations centres, as well as alongside smaller incident response facilities along the tunnel route.

2. Groundwater, stormwater runoff, deluge and other tunnel service water is collected by open channels and pipes that carry the water to the Water Treatment Plant (WTP); see Appendix 1 for more details on the WTP. Some initial flows of water after a storm may be discharged to the sewer as trade waste, while most of the water is treated by the plant and by current standards, then discharge to the local Council's existing piped drainage system to Blue Gum Creek (LLBJV 2018a). LLBJV estimates that the WTP could discharge 32,000KL of water per year.

The main operations centres include the Motorway Operations Complex (MOC) at the Southern end of the tunnel, the Northern Ventilation facility and two Incident Response Facilities along the tunnel. (More information on the Operations Centres can be found in Appendix 1). The WTP is located along with two buffer tanks for water overflow at the Southern Facility. The deluge testing tanks are located at the Northern Facility. Two incident response facilities are also located along both the northern and southern parts of the tunnel.

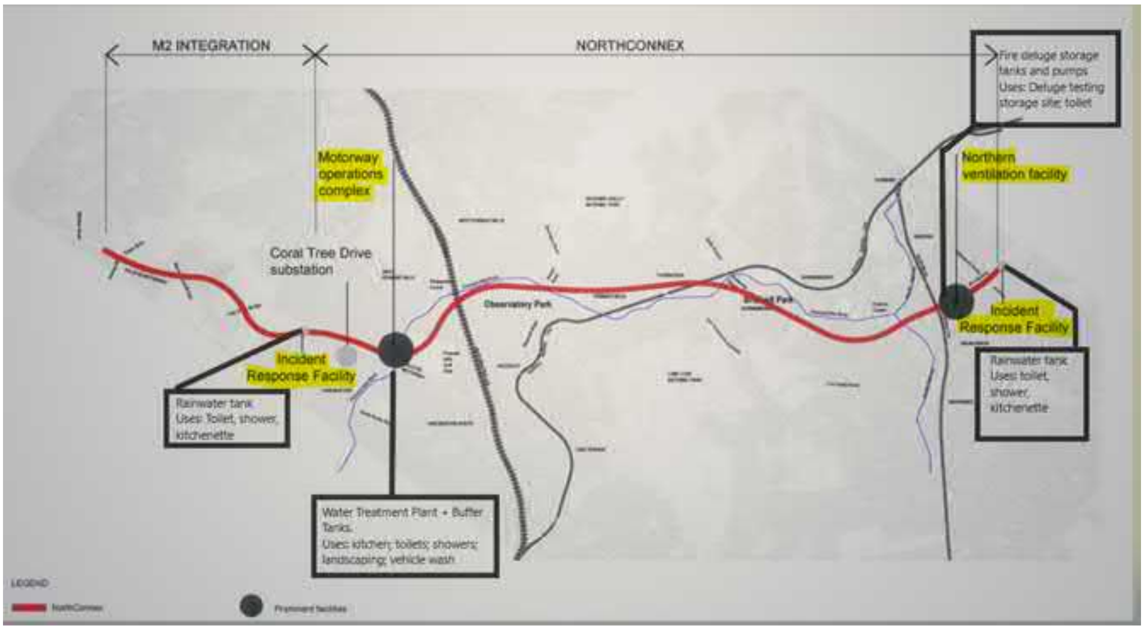

Figure 1. Location of water uses, water storage and treatment plant in NorthConnex
(source: NorthConnex Urban Design and Landscape Plan Stage Two, 2018)

B. Uses of Water

The core activities that use water in the tunnel that are further explored in this report include:

- Deluge testing: water for testing the emergency fire response systems;
- Street sweeping around the main operations centre;
- Day to day use by staff involved in the various operations centres;
- Landscaping around the operations centres.

Table 1 includes estimates of water use by LLBJV and separate calculations for landscaping (see Appendix 5).

Table 1: Estimated water use for NorthConnex Tunnel operations
(Source: LLBJV client estimates; calculations for landscaping based on NorthConnex Urban Design and Landscaping Guide Stage 2, 2018)

Base Case	Potable Water Used Kl/annum	Potable Water as % of total used
Potable water uses for Deluge Testing	40,000	83%
Potable water uses for Street Sweepings	7,955	16%
Potable water uses at Operations Centres	360	1%
Potable water uses for landscaping at Southern, Northern and Coral Tree Drive complexes	164	0.34%
Total	48,479	100%

III. Case Studies of International Best Practice

In order to explore best practice for water-use efficiency and water recycling in tunnel operations, the research considered various international case studies of large infrastructure projects, and in particular focused on those across Japan and Singapore.

A. Japan and Tunnel Infrastructure Quality

In Japan, there are about 10,000 tunnels in the country (MLIT 2017). Since 2015, a development project began in the area around Shibuya Station, and nine new buildings will be built. The station building will be built with a 47-story integrated commercial building as well as a 4,000-ton underground storage tank, which will be built 25 meters below the ground, equivalent to the storage capacity of eight standard swimming pools. This type of reservoir has many uses. When the rainfall exceeds 50 mm per hour, it can store the rainwater around the area, solving the short-term drainage capacity, and connecting with the huge underground drainage system in Tokyo (Kato 2017). More importantly, the reservoir can function as a regulating tank. Usually, a certain amount of rainwater is stored in the pool. After the rainy season, when the ground is short of water, it can be taken out at any time for watering, dust removal, deluge, etc., and after purification it can even be used by the public. This project reflects how Japan handles rainwater, from a simple discharge to an effective combination of supporting sustainable discharge and utilisation.

In addition, as Japan pays close attention to the quality and performance of the ground, many roads are paved with large stones and asphalt. Permeable bricks are also commonly used in the roads, which greatly improves the water permeability (Lin et al. 2006). At the same time, they try to reduce the hardening of the ground and leave more mud.

B. Singapore and Tunnel Infrastructure Safety

In Singapore there are ten tunnels. At the mouth of the Singapore River, the Land Transport Authority (LTA) is building Singapore's first undersea tunnel and the tenth expressway in Singapore. Its name is called Marina Coastal Expressway (MCE) (Thangasamy et al. 2009).

Fires that occur in tunnels can quickly climb temperatures above 1,200 °C in a matter of minutes. If it cannot be contained in time, the high-temperature environment and a large amount of smoke will pose a threat to people, vehicles and tunnel structures. The MCE selected an HDWN device for deluge testing, a specially designed water outlet system that produces water mist within seconds of triggering, which effectively suppress the spread of fire by consuming a lot of energy and dispersing oxygen. Shielding and reflection of heat radiation are beneficial to firefighters entering the fire and as the smoke is washed away, it helps people to inhale the oxygen in the air (Ingason 2008). As Singapore is one of the world's most resource- and recycling-conscious and environmentally friendly countries, it is telling that they have not proposed using recycled water instead of some clean water that people drink.

IV. Proposed Water Efficiency Initiatives

Several potable-water saving initiatives can be considered within the context of the NorthConnex tunnel operations using a variation of the waste hierarchy, see figure 2 (Hansen et al. 2002). This acts as a framework to consider sustainable consumption of natural resources, including water.

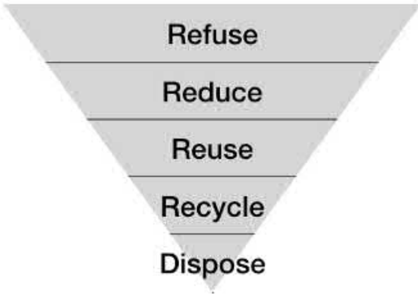

Figure 2. Adaptation of the waste hierarchy pyramid

Water-saving initiatives were assessed using this framework and three core pillars associated with the water use in NorthConnex:

- Mechanical efficiency measures;
- Operational savings opportunities;
- Behavioural change.

A. Mechanical Opportunities: Investing in Smart Water Systems

1. Water Efficiency Fixtures Around Operations Centre

Figure 3. WELS Rating
(Australian Government 2017)

The first step towards water saving initiatives within the operation centres would be to install fixtures and appliances with high Water Efficiency Labelling and Standards (WELS) rating (Department of the Environment and Energy 2019). This rating indicates the level of water efficiency each fixture has, with 6 stars having the top efficiency.

There are two operation centres along the tunnel asset, the larger Southern complex and the smaller Northern complex as well as some toilets and taps at the Incident Response Facilities. The following fixtures and appliances could be upgraded in order to improve the water efficiency in these centres (Department of the Environment and Energy 2019):

- Water efficient shower heads,
- Low-flow taps,
- Dual flush toilets instead of single flush toilets,
- Water efficient dishwashers.

Another potential option is to use rainwater instead of potable water within the operation centres and for the incident response facilities. It is shown on the NorthConnex Stage 2 Urban Design Guide maps (Lendlease Bouygues Joint Venture, 2018), that there are rainwater tanks located near both operation centres and alongside the incident response facilities. Due to the rainwater tanks being in an urban area, NSW Government, Health Department, suggest that rainwater only be used for non-drinking purposes such as toilet flushing (Department of Environmental Health 2018). The process of connecting the rainwater tanks to the plumbing system for the toilets should be relatively simple and cost-effective (for example see Sydney Water Rainwater Tank Connection Plumbing Guidelines, Sydney Water 2019). However, due to lack of data on the specifications of the rainwater tanks around the NorthConnex centres and facilities, this option was excluded from the model.

<u>Costs per type of fixture</u>

4-star WELS rated products were selected for all of the fixtures and appliances, as this rating provided sufficient efficiency in the fixtures at an affordable price. The cost per unit and water use was all obtained from Bunnings Warehouse, as this company provided a range of products at cost-effective prices. A breakdown of the current fixtures in the operation centres has been detailed in Appendix 4.

Table 2: WELS rating and water use for various fixtures and appliances

Description of Product	**WELS Rating and Water Use**	**Cost per unit**	**Number of Units**	**Total Cost**
Shower Head – Methven Maku Satinjet Rail Shower (Bunnings Warehouse 2019a)	4 Star 7.5L/min	$100	6	$600
Tapware – Estilo 35mm Cast Basin Mixer (Bunnings Warehouse 2019b)	4 Star 7.5L/min	$30	12	$360
Toilets – Estilo Dual Flush Toilet (Bunnings Warehouse 2019c)	4 Star 4.5L/flush	$170	18	$3,060

Description of Product	WELS Rating and Water Use	Cost per unit	Number of Units	Total Cost
Dishwasher – Bellini Stainless Steel Dishwasher (Bunnings Warehouse 2019d)	4 Star 11.8L/wash	$350	2	$700
TOTAL				$4,720

For the purpose of this report, we have not included the cost of installation of these new fixtures. This is because it was assumed that there was already a budget in place for plumbing costs and this would be relatively the same for upgrading to the water efficient fixtures.

<u>Water Savings</u>

According to Energy Star Australia, installing water-efficient fixtures such as efficient shower heads, low-flow taps, toilets, and dishwashers can save, on average, approximately 30% of the water used in a household (Energy Star 2017). Appendix 3 details the water efficiencies per fixture, however, given some of the unknowns for the operations centres, for the purpose of this paper, the 30% measure is used as an average estimation on the total amount of water that can be conserved in the operation centres at NorthConnex.

Table 3: Water savings potential of water efficiency fixtures in operation centres

	Water Use (kL/year)
Current Water Use	360
Water Use with Efficiency Measures	252
Water Savings	108

Table 4: Summary for water efficiency fixtures

Estimated Capital Costs	Estimated Benefits
$4,720 for a range of fixtures	108 kL of potable water saved per annum

2. Comprehensive Leak Detection System

With use, the tunnel's water system infrastructure will age, and this prolonged period of use can cause the pipes and joints to deteriorate or shift, which causes leaks in the system. "Water infrastructure such as pipes can be expected to last for between 50 and 100 years depending on conditions, implying replacement rates of at best 2 percent per annum" (Cashman & Ashley 2008). Aside from material deterioration, other potential causes of leaks are: temperature change; moisture in the soil; unregulated water pressure; and clogs (Vedachalam et al. 2016). Bad workmanship during the construction stage can also cause leaks. One preventive measure that can potentially mitigate the effects of ageing infrastructure is the implementation of a smart water system or a comprehensive leak detection program (Auckland Airport 2016).

Costs

Comprehensive leak detection can be done in two ways: first is to ensure that there is an adequate number of sub-meters at each point of water source and water use to make automated or manual measurement of transmission loss possible. The other method is through the use of acoustic leak detection, done through a leak detection meter, which uses acoustics to identify and locate possible leaks. In the latter method, a unit of the measuring device can cost just around $700 per kit, and this can be shared throughout the facility (PQWT 2018).

Water Savings

Anecdotal evidence reveals that a comprehensive leak detection program can save anywhere from 10-20% of water consumption, which translates to about 36kL of savings, at the minimum, in water use for the operations centre of NorthConnex (ADS Environmental Services 2012).

Table 5: Summary for comprehensive leak detection

Estimated Capital Costs	Estimated Benefits
$700 per leak detection kit	36 kL of potable water saved per annum

B. Operational Opportunities: Avoiding Potable Water Use

1. Deluge Testing

To provide fire emergency response, a key component of the NorthConnex tunnel is the deluge system, which would automatically operate in the event of a fire or other emergency. The primary water source for the deluge system would be stored in tanks, and the NorthConnex Phase 2 Urban Design guide indicates two tanks will be stored at the Northern ventilation facility (Lendlease Bouygues Joint Venture 2018). Each tank has a capacity of 1,220 cubic meters and would be supplied by Sydney Water (RMS 2014).

Deluge tests are usually performed four times a year as part of a standard maintenance program. The quality of water produced in deluge testing is considered similar to stormwater runoff (Lendlease Bouygues Joint Venture 2018). A total of 2,440 kL of water from the two deluge tanks will be used up to four hours at a time and as such, nearly 10,000 kL of fire water will be used each year (Lendlease Bouygues Joint Venture 2018). Finding measures of reducing potable water use in this case is significant for reducing the overall water consumption. There are two main water savings options to consider.

Option 1: Recycled Water for Deluge Testing

According to two reports issued by Government of South Australia (2017) and Environmental Health Directorate (2011), recycled water is recommended for use in deluge systems for training, testing, and emergencies. The reports acknowledge that the recycled water meets fire water requirements in terms of cleanliness and quality. For firefighters' health considerations, the use of recycled water in firefighting activities has a medium risk exposure level (Water Services Association of Australia 2008).

Costs for Option 1

Even if recycled water is well suited for fire testing, there are still transportation costs. The deluge water tanks at the Northern Complex are 10-11km away from the WTP at the Southern Complex. There are currently no existing pipelines for conveying water. If a dedicated pipeline is used for transporting the treated water, the cost of labour could, procurement, etc. could be as high as $400,000 (Chee et al. 2018). Using trucks for transportation, the initial investment can be smaller, but there are additional concerns for costs with respect to energy and fossil fuel consumption. Capital costs of a water transportation truck can be up to $204,000 based on TruckWorld (2019) estimates, with additional annual costs of operation, maintenance and greenhouse gas emissions to consider for hundreds of trips that are required to fill the deluge tanks.

As such, one recommendation is to move the position of the deluge testing water tank closer to WTP. If this is difficult to achieve because of existing installations, the auxiliary water tank for deluge testing should be set near the WTP to provide at least part of the water for testing.

Option 2: Dry Deluge Testing

Dry deluge testing uses high pressure smoke or steam to inspect the operation status of the system to ensure proper connections and detect abnormal blockages and dripping. The advantages of such a system include short preparation time, water savings, and reduced internal corrosion of the flow tube and nozzle (Siron 2019). It is usually possible to reduce test time by 50% and operation costs by 60%. Dry deluge testing is also compliant with the NFPA 25 Standards for the Inspection, Testing, and Maintenance of Water-Based Fire Protection Systems (GAPS Guidelines 2009). However, as there is no water in dry deluge testing, according to the requirements of the Fire Safety Guidelines for Road Tunnels (2001), the water supply pump and power supply section should be tested separately.

Costs for Option 2

A dry deluge system can use regular water-based fire safety systems so there is no capital cost assumed, however there is a cost for operating the dry deluge testing estimated at $8,200 per annum (Siron 2019).

Table 6: Summary for dry deluge or recycled water deluge testing

Estimated Costs	Estimated Benefits
Recycled Water Deluge Testing Capital Costs approximately $204,000 and an additional $85,000 per year in operational and maintenance costs. Considerable greenhouse gas emissions through transportation of the water.	10,000 kL of potable water saved per year.
Dry Deluge testing approximately $8,200 per year in operational and maintenance costs.	10,000 kL of potable water saved per year.

2. Street Sweeping

Street sweeping is another large component of water usage in NorthConnex operations, using almost an estimated 8,000 kL per year. New water saving initiatives for street sweeping can therefore vastly reduce the overall water use. There are three options to consider.

Option 1: Use recycled water in the existing street sweeping fleet

By using recycled water instead of potable water in the current street sweeping fleet, the amount of potable water purchased can be reduced while also making use of the recycled water from the NorthConnex Wastewater Treatment Plant.

San Diego County Water Authority released a technical guide for converting street sweepers to use recycled water instead of non-potable water. The conditions for converting to recycled water are detailed in the guide, however, the figure below details the basics for converting a street sweeper fleet (San Diego County Water Authority 2011).

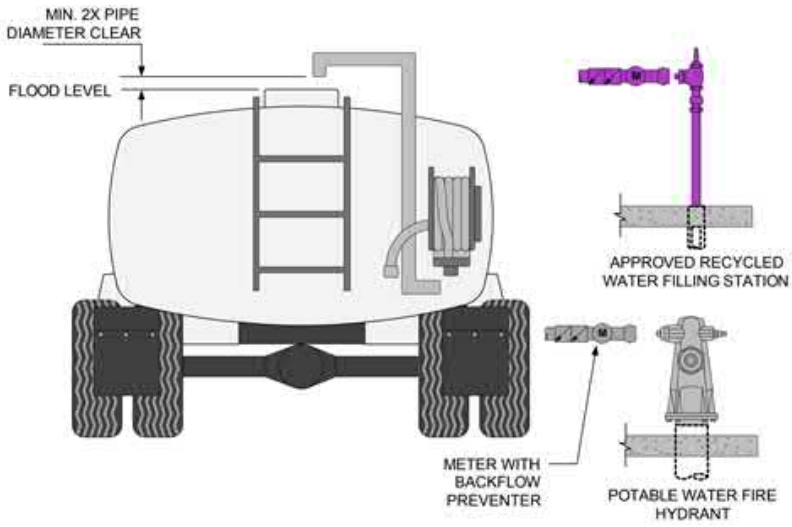

Figure 4. Typical truck and water supply system
(San Diego County Water Authority 2011)

From the figure, it is clear that the only upgrade needed is an approved recycled water filling station and a meter with a back flow preventer. The back flow preventer can be removed if the truck is only filled from recycled water filling stations and never used for potable water purposes.

<u>Option 2: Replace the current fleet with Dual-Tank Potable and Recycled Water Street Sweepers</u>

Option 2 involves investing in a dual-tank street sweeper that will use both potable water and recycled water. In California, USA, this practice is already being implemented. They currently promote using street sweepers with dual-tanks to ensure potable water is only used when recycled water is unavailable (Kidwell-Ross 2019). The dual tanks allow for no cross-contamination between recycled and potable water use. Although a dual-tank system uses more potable water than both option 1 and option 3, the system provides more flexibility to adjust to current conditions and needs. This option may also be more viable that Option 1 if there is no existing street sweeper to retrofit for use of recycled water only.

<u>Option 3: Replace current fleet with Water-Free Street Sweepers</u>

The final option is the investment in a water-free street sweeper. This option completely removes the need for water, dramatically reducing water consumption during the operation of the tunnel asset. A strong option is the Disa-Clean 130, which provides the services of both brushing and vacuuming the street without the need for water or chemicals for cleaning or dust suppression (Arezza 2017). See specifications in Appendix 6. While this product does come with many advantages over traditional street cleaning trucks, it should be noted that there are some disadvantages. The vacuum process produces a significant amount of noise, which can affect surrounding neighbourhoods. Also, the maintenance process is varied and requires a vigorous and regular scheme to ensure trucks are working effectively (Walker & Wong 1999).

Figure 5. Disa-Clean 130, water-free street sweeper (Arezza 2017)

Costs

In order to breakdown the cost of each option for street sweeping, the following categories were incorporated:

- capital costs for purchasing the truck
- installation costs,
- maintenance costs, and
- additional labour costs.

There are no capital costs for option 1, assuming that there are no issues with directly using recycled water in current street sweeper fleet. However, there is an estimated cost for installing a recycled water filling station. Given the unknown conditions for the installation of water filling station at NorthConnex, a proxy value was used based on the cost of installation for a fire hydrant, estimated at approximately $4,500 (South East Water 2019). The capital costs for the dual tank street sweeper in option two was estimated to be $285,000 (How Stuff Works 2009). The cost of a new water-free street sweeper in option 3 can be up to $427,000 (Donovan 2014). For the maintenance costs, it was assumed that the budget originally allocated for maintenance of street sweepers for NorthConnex would be sufficient to cover all relatively comparable maintenance processes.

Water Saving Potential

While options 1 and 3 completely remove the need for potable water use, it was estimated for the dual-tank street sweeper, half the water used per year is from potable water sources and the other half is from the recycled water from the water treatment plant.

Table 7: Summary for dry, dual or recycled water street sweeping

Estimated Costs	Estimated Benefits
Recycled Water Street Sweeping. No capital costs; maintenance and installation costs estimated at $4500	7,955 kL of potable water saved
Dual Tank Street Sweeping. $285,000 of capital costs and $4500 of installation costs.	3,977.5 kL of potable water saved
Dry Street Sweeping, $427,000 in capital costs.	7,955 kL of potable water saved

3. Reuse of Water from Treatment Plant

Another important consideration is the potential to offset potable water use through the WTP. LLBJV identify 32 000 kL of water that can potentially be treated through the WTP per year. According to the NorthConnex Water Quality Management Plant, the treated water quality meets ANZECC/ARMCANZ (2000) standards and is comparable to high quality recycled water (Lendlease Bouygues Joint Venture 2018). See Appendix 1 for further details.

Using treated water is not a new concept. PIARC (2017) identify that treated water from tunnel drainage systems and runoff can be used for construction and fire-fighting purposes in European infrastructure, and this can be seen in Sweden's E4 Stockholm bypass tunnel for example (Trafikverket 2019). In Australia, collected, treated water is already being used in large infrastructure projects such as toilets at Sydney Airport (Sydney Airport, 2018) as well as for irrigation of various large water-consuming landscapes, including universities and golf courses (Sydney Water 2013; 2018).

There are various stakeholders within a 6km radius of Northconnex that have high water use demands. Figure 5 below and Appendix 2 have a full list of options which include:

- Community sports fields and parks (North Rocks Park; Murray Farm Reserve; Rainbow Farm Reserve; George Thornton Reserve and Ted Horwood Reserve);
- Community centres (Roselea Community Centre)
- School ovals (Carlingford High School);
- Golf courses (Pennant Hills or Muirfield Golf Course) and
- Car Washes (Scooters Hand Car Wash; Skyblue; Crazy Car Wash; etc).

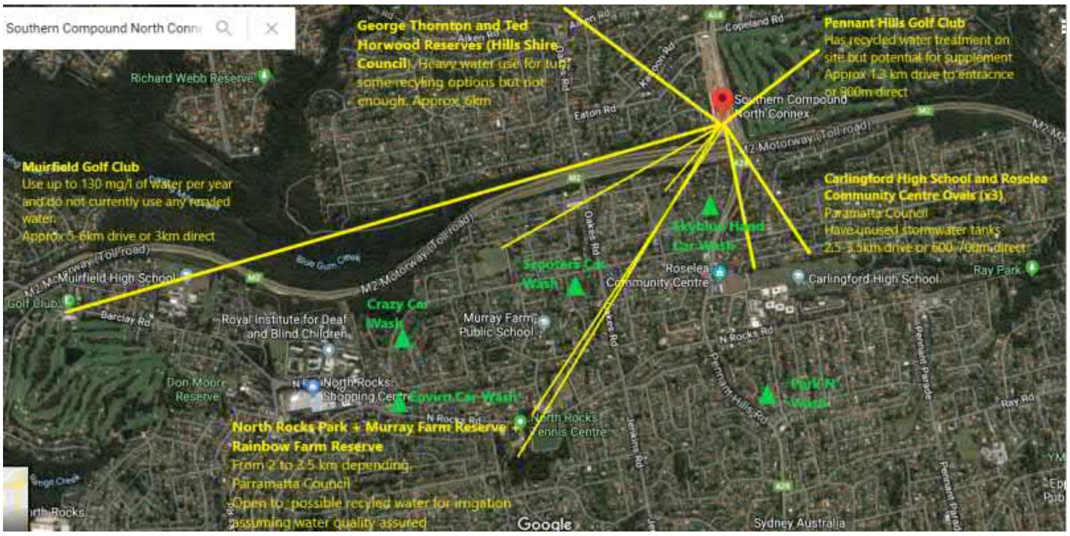

Figure 6. Options for reusing treated water from the NorthConnex WTP in a 6km radius including parks, schools, golf courses, community centres and car washes

A full list of opportunities is available in Appendix 2, but this research suggests that the optimal opportunities for engaging in a discussion on use of the treated water are:

- Local parks and sports fields: particularly Roselea Community Centre and Carlingford High School under Parramatta Council or Ted Howard and George Thorton Reserves under Hills Shire Council. These Councils both have significant targets for potable water savings (City of Parramatta, 2017; Hills Shire Council interview, 2019) and have to use significant amounts of water, particularly for turf maintenance.

- Muirfield Golf Club: although approximately 6km drive from the WTP, it has high water demand (130 ML per year) and no recycled water system in place yet though they are open to it (Muirfield Golf Club interview, 2019).

Costs

The core costs to consider are transportation of the water; maintenance and operation of any water transportation systems; potential additional pumps at the WTP and potential additional storage requirements.

The assumption is that a 15,000 L water transportation truck would cost approximately $204,000 based on TruckWorld (2019) and Machines4U (2019) prices, including a pump. Using the FreightMetrics Calculator (2019), operating costs are primarily assumed as fuel for roughly 12km per day of travel as well as labour costs based on one trip per week and insurance and maintenance costs for the truck over the course of the year.

Another important consideration is the quality of the recycled water and the impact on public health. Any reuse of water with public contact will need to meet the criteria for recycled water management in line with the NSW Department of Industry Guidelines for Water Recycling: Managing Health and Environmental Risks (2015). Without more testing to understand quality of the treated water and its interaction with the various proposed landscapes, it is difficult to fully assess its applicability against the legislation. However, in comparing the WTP specifications with others in NSW such as Central Park (CRC for Water Sensitive Cities 2018) it would seem that it has a high enough quality to meet the relevant standards.

Water Savings

The core benefit would be captured in the offsetting of potable water use elsewhere in the community, approximately 32,000KL per year. There are additional benefits with respect to sustainability marketing and reputational benefit. For the community, there is the added benefit of financial savings in potable water but most importantly, there are benefits from greener landscapes (greener parks, more diverse outdoor spaces and opportunities for other landscape uses) and longer-term education on water as a previous resource.

Any reuse of water also should include community engagement and consultation where possible and NorthConnex should work with relevant stakeholders to inform and engage the community on a decision for how the water should be used. This can be strengthened through behavioural and education components (see Chapter IV-C).

Table 8: Summary for reusing treated water for social or commercial offset

Estimated Costs	**Estimated Benefits**
Capital costs for a water transportation tank approximately $204,000 with ongoing operation and maintenance costs of $69,000.	• Offsetting 32,000 KL of potable water use in the community through treated water. • Greener areas for the community. • Education and awareness raising for water sustainability. • Sustainability marketing and reputational benefit. • Lower risks through ongoing stakeholder engagement.

4. Landscaping

Another opportunity to save water is in the landscaping around the NorthConnex complexes. There are several options, including around the Southern, Northern and Coral Tree Drive complexes. The LLBJV Urban Design and Landscape Plan Stage 2 (2018) states that there will be active measures to support landscape planting and vegetation, and the Plan already encourages water sensitive design. However, the Plan currently does not give any indication about where water is sourced. This can be an option for using the WTP water. A rough calculation based on the Plan suggests a potential use of 24.7 kL of water per week for landscaping across the complexes (see Appendix 5 for details).

Costs

There are no major costs under the assumption that the existing systems used by the contractor can be fitted for treated water, and the core cost to NorthConnex would therefore be the capital costs of a pump to deliver that water to a truck.

Another key considerations for using treated water in landscaping is the interaction with health and environment, which is dependent on the type of plant and grass species along with the specific soil type and the range of native species in the area (Environment Protection and Heritage Council et al. 2006). This may require regular monitoring.

Water Savings

The core benefit is a potential savings of 12,000 kL of potable water use per year. There are additional benefits for the community, as a better maintained landscape promotes greener, healthier and more aesthetically pleasing areas for the neighbours.

Table 9: Summary for reusing treated water for operations centre landscaping

Estimated Costs	Estimated Benefits
Negligible additional costs in comparison the business as usual approach.	Potential 12,000 kL of potable water use per year.

C. Behavioural Opportunities: Beyond Engaging Communities

Field trips conducted by the group to the Sydney Water Treatment Plant and the NorthConnex construction site revealed the importance of behaviour change in cultivating a sustainability mindset in any infrastructure project. Various authors support this, such as Barr et al. (2003), who acknowledge that from a sustainability policy perspective, behavioural changes are a valuable tool, with the authors going into a discussion of the concept of 'social marketing' as a means of affecting behaviour, towards fulfilling sustainability interventions. Indeed, "the importance of defining behaviour as the end-point of a behavioural intervention cannot be overstated," in science and elsewhere (Michie & Johnston 2012).

This research proposes to recycle a few temporary site facilities in the NorthConnex construction site and convert these into a visitor centre that doubles as a site administration office during the operations phase of the infrastructure project. This interim facility, which can also be redeveloped in the future into a more permanent one depending on its effectiveness as a sustainability intervention, will be called the InvoLiving Centre. Aside from recycling construction materials, InvoLiving Centre will also showcase water efficiency and water use reduction methods, processes and technologies, such as rainwater harvesting, efficient water fixtures, and other initiatives discussed in this report.

Figure 7. Illustration of the InvoLiving Centre

1. Envision

Behavioural opportunities must begin at the corporate level, via the development of a Water Use Mission Statement, attached to Water Conservation Guidelines. These two documents will set targets and a roadmap toward achieving water sustainability outcomes (US Office of Water 2000).

2. Empower

To ensure that there is oversight and leadership (Lozano 2006) for the implementation of all water sustainability efforts during the NorthConnex operations, a Sustainability Champion, a role that is critical in any corporate social responsibility (CSR) strategy (Schaefer 2004), has to be appointed from within the workforce. The Sustainability Champion has to be present during the period of transition from construction to operations.

3. Educate

Stakeholder engagement, that is, forming relationships with the immediate community, depends on effective communication of sustainability efforts (Gill et al. 2008), and NorthConnex must do the same. This can be accomplished by working with local schools and communities through education drives that are, as examples, geared toward dispelling negative notions about toilet-to-tap technologies, which are known to generate safe and almost tasteless water (Harmon et al. 2018), and mitigating the effects of nature deficit disorder or NDD (Louv 2008).

4. Engage

Within the NorthConnex operations, engagement is also important, in that "structuring rewards and competitions to optimise water use helps in changing the user behaviour" (Danielsson & Spuhler 2018).

The benefits of the InvoLiving Centre can be quantified in different ways; however, they are better seen from the lens of social and human-oriented benefits. In terms of the ISCA rating, this intervention touches on eight (8) categories: 1) Green infrastructure, 2) Energy and carbon, 3) Water, 4) Leadership and management, 5) Innovation, 6) Stakeholder engagement, 7) Legacy and 8) Workforce sustainability.

Table 10: Summary for InvoLiving Centre

Estimated Costs	**Estimated Benefits**
Costs of staff time and potential repurposing of existing site facilities.	• Community benefit for awareness raising and education for water. • Reputational benefit through promoting green infrastructure and sustainability. • Lower risks through ongoing stakeholder engagement. • Trickle down benefits for potable water savings in the organisation and community.

V. Proposed Water Savings Summary of Options

The table below summarises the core costs and benefits considered under each option for enabling water savings in the operations of the NorthConnex Tunnel:

Table 11: Summary of proposed potable water saving initiatives (costs and benefits)

Water Savings and Reuse Options	Costs	Benefits
Mechanical		
Smart water fixtures and leakage detection systems	Initial capital costs: • Efficient taps; shower fixtures and other mechanisms • Water efficient labelling • Replacement or new leakage detection systems and sub-meters Ongoing costs: • Maintenance	• Potable water saved • Reduction in the costs of purchasing of potable water
Operational – Internal		
Deluge testing: Option 1 – Use of treated water (from WTP) for deluge testing Option 2 – Dry deluge testing	Initial Capital Costs: Option 1: • Transportation of treated water from WTP to deluge tanks Option 2: • System installation Lifetime maintenance costs for both options	• Potable water saved • Reduction in the costs of purchasing of potable water.
Street sweeping: Option 1 – Use of recycled water for street sweeping Option 2 – Dual tank street sweeping Option 3 - Dry street sweeping	Initial Capital Costs: Option 1: • Pump for WTP to supply street sweeping truck Option 2: • Dual Tank Street Sweeper Option 3: • Dry Street Sweeper Ongoing costs: Maintenance (assumed similar to base case)	• Potable water saved. • Reduction in the costs of purchasing of potable water

Water Savings and Reuse Options	Costs	Benefits
Operational - External		
Parks, fields, community centres, school ovals etc. under Paramatta or Hills Shire Council	Initial capital costs: • Truck with water tank for transportation Ongoing costs: • Transportation (fuel) for 1km to 4km drive one way • Truck maintenance • Tank cleaning	• Reduced potable water consumption for parks and fields in the community Community and reputational benefit: • Helping to create nicer parks and fields for the neighbouring communities (*particularly with community consultation component)
Landscaping around the NorthConnex complexes	Initial capital costs: • Pump for WTP to supply truck Ongoing costs: • Monitoring and testing (assumed to be similar to base case)	• Potable water saved • Reduction in the costs of purchasing of potable water • Reduced urban excess flow into waterways Community and reputational benefit: • Creating green spaces, promoting greener visual amenity for the neighbouring communities
Golf courses Option 1 – Pennant Hills Golf Course (less viable) Option 2 – Muirfield Golf Course (more viable)	Initial capital costs: • Truck with water tank for transportation + pump Ongoing costs: • Transportation (fuel) for 1km to 6km drive one way • Truck maintenance • Tank cleaning	• Potable water saved • Reduced urban excess flow into waterways • Reduced potable water consumption for parks and fields in the community Income: • Potential depending on choice to sell treated water at a discount price

Water Savings and Reuse Options	Costs	Benefits
Behavioural		
Involving Centre	• Staff time to develop sustainability champions; training; awards systems and education • Capital costs for repurposing existing materials as a water recycling education facility	• Enabling short and long term behaviour change that values water as a precious resource • Promoting green infrastructure • Promoting sustainable consumption • Leadership and management of sustainability in the organisation • Reputational benefits • Legacy benefits for the community

VI. Cost Benefit Analysis of Options

There are two key measures of analysis to consider. First, the opportunity to save potable water in the operations of the NorthConnex tunnel in comparison to the business as usual scenario (see Tables 12 and 13). Second, monetising the various water-savings initiatives in order to compare the potential costs of each option (see tables 14 and 15). For the purposes of this study, costs and benefits are examined based on a current year snapshot and are not calculated for net present value with consideration of changes over time as there are still many unknown variables and proxies used for calculation. Though the costs and benefits cannot be compared in the same sense as a traditional CBA, they are helpful in demonstrating the scale of potential water savings and costs associated with various initiatives.

Table 12: Summary of proposed potable water saving initiatives (potable water saved)

Potable Water Efficiency Measures	Potable Water Saved kL/annum	Potable water saved as percentage of base case
(A) Water efficiency fixtures for showers, kitchens, etc. at MOC	108	30%
(B) Comprehensive Leak Detection Monitoring	36	10%
(C)Treated Water use for deluge testing	10,000	100%
(D) Dry Deluge Testing	10,000	100%
(E) Dual Treated/Potable Tank for Street Sweeping	3,978	50%
(F) Treated Water for Street Sweeping	7,955	100%
(G) Dry Street Sweeping	7,955	100%
(H) Treated water use for landscaping at Northern, Southern and Coral Tree Drive Complexes	1,286	100%

(A) Assumption that 30% of savings possible at MoC based on best practice (see section X)

(B) Assumption that a savings of 20% is possible on old pipes. Adjusted for newer technology and products to a 10% savings of the water use at MOC

(C) Assumption 100% treated water can be used

(D) Assumption no water used

(E) Assumption that a 50% savings is possible with a 50:50 split of the tanks

(F) Assumption 100% treated water can be used

(G) Assumption no water used

(H) Assumption 100% treated water can be used

Table 13: Possible savings (kL, %) from recycling treated water from the WTP

Water Treatment Plant Uses	Treated Water Discharged kL/ annum	Recycled Use of Treated Water kL/ annum	Percentage of water recycled / annum in comparison to base case
Base Case (discharged into Sydney stormwater receivers)	32,000		0%
Water Efficiency measures:			
Treated Water Use for Deluge Testing	22,000	10,000	31%
Treated Water use for Street Sweeping	24,045	7,955	25%
Treated Water use landscaping around northern, southern and Coral Tree Drive complexes	30,714	1,286	4%
Treated Water use/ commercial (golf courses/car wash)	0	32,000	100%
Treated Water use community donation /social	0	32,000	100%

Table 14: Possible savings ($) from recycling treated water from the WTP

Benefits as compared to base case (assumptions and estimations; all figures AUD) ^											
Water efficiency initiatives	(A) Water Efficiency fixtures at MoC	(B) Rainwater for toilets at MoC	(C) Comprehensive leak detection at MoC	(D) Treated Water for Deluge Testing*	(E) Dry Deluge Testing	(F) Dual Treated/ Potable Tank Street Sweeping	(G) Recycled/ Treated Water for Street Sweeping	(H) Dry Street Sweeping	(I) Recycled water for landscaping	(J) WTP Water Donated for Community Parks, Fields*	(K) WTP Water Sold to Golf Courses, CarWash*
Potable Water Savings / annum	$225		$75	$20,800	$20,800	$8,273	$16,546	$16,546	$2,675		
Offsetting potable water use elsewhere / annum										$66,560	$66,560
Reputational / community benefit^^	$112		$37	$10,400	$10,400	$4,137	$8,273	$8,273	$1338	$33,280	$33,280
Total annual benefit	$337	$0	$112	$31,200	$31,200	$12,410	$24,820	$24,820	$4013	$99,840	$99,840

^ Assumption of cost of potable water based on Sydney Water prices for business use at $2.08/KL (Sydney Water 2019)

^^ There are no simple formulas for calculating sustainability benefits or community benefits, though some suggest that there is a corporate reputational benefit of about 3 to 5 % of total corporate value for sustainability branding (UK GBC, 2018). Without having more of this information from LLBJV, this project assumes that this could be

Table 15: Summarising monetised costs for the various water efficiency options

Water efficiency initiatives	(A) Water Efficiency fixtures at MoC	(B) Comprehensive leak detection at MoC	(C) Treated Water for Deluge Testing*	(D) Dry Deluge Testing	(E) Dual Treated/ Potable Tank Street Sweeping	(F) Recycled/ Treated Water for Street Sweeping	(G) Dry Street Sweeping	(H) Recycled water for landscaping	(I) WTP Water Donated for Community Parks, Fields*	(J) WTP Water Sold to Golf Courses, CarWash*
Capital Costs	$4720	$712	$204,000	$0.00	$289,500	$4500	$427,000	$4500	$204,000	$204,000
Operating Costs (+ labour)	$0	$0	$70,456	$8200	$0	$0	$0	$0	$69,166	$69,166
Maintenance Costs	$0	$0	$14,091	Included above	$0	$0	$0	$0	$15,000	$15,000
Total	**$4720**	**$712**	**$288,547**	**$8200.00**	**$289,500**	**$4,500**	**$427,000**	**$4,500**	**$288,166**	**$288,166**

See Chapter IV for assumptions

* For any options that include a truck to transport treated water from the WTP, the capital cost would only be incurred once. For example, a truck could be used to transport treated water for parks and community; for gold courses; and up to the northern complex tanks for deluge testing.

VII. Sensitivity Analysis of Options

The paper acknowledges that primarily due to capital outlay considerations, not all of the interventions proposed can be implemented at the same time. To this end, sensitivity testing was conducted by grouping the sustainability interventions based on a plotting across two variables: estimated costs and potential potable water savings. In determining the optimal combinations for each option, a variation of the waste hierarchy was used (refer to Figure 2), with priority given to Refuse and Reduce initiatives.

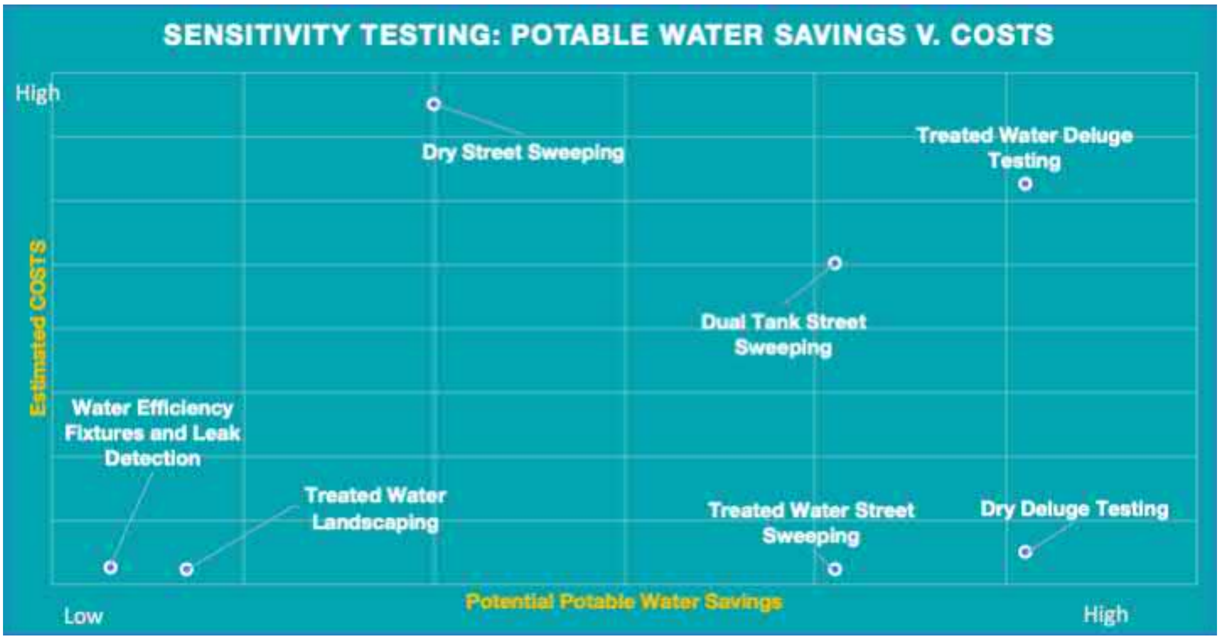

Figure 8. Plot of sustainability options across two variables

Based on the sensitivity testing, four options were developed that combine various water saving initiatives:

Option 1 (Refuse) showed 92% of potable water saved given the emphasis on dry-technology, but capital costs were highest for this group.

Options 2 (Reduce) combines the treated water deluge testing system and dual system street sweeping, which shows high potable water savings but also higher costs. It is also important to consider the whole of system costs, which could include higher greenhouse gas emissions as the result of transportation of the treated water via truck.

Option 3 (Reduce) combines efficiencies in the operations centre alongside treated water use for street sweeping and landscaping. Though potable water savings are not as high as options 1 and 2, the savings are significant, the costs are medium and this option provides an opportunity to explore community and behavioural benefits of offsetting through the WTP.

Option 4 (Minimum) only included the installation of water efficiency fixtures intervention, and the water saved was minimal, since there is only a small amount of water use in the operations centre as compared with the overall water use. Though these measures are important, they are not enough to demonstrate greater savings.

Table 16: Sensitivity testing using four options

	Option 1 (REFUSE)	**Option 2 (REDUCE High$)**	**Option 3 (REDUCE Low$)**	**Option 4 (Minimum)**
	Dry Deluge + Dry Street Sweeping	Treated Water Deluge testing + Dual System Street Sweeping	Water Efficiencies in MOC + Treated Water Sweeping + Treated Water Landscape	Water efficiency fixtures in MOC
Potable Water Saved	92%	71%	48%	<2%
Costs	$$$$	$$$	$$	$
Considerations	Ground-breaking model for Australia	Potential high costs of energy & emissions for transportation of water for deluge testing	Costs could be offset through partnership with other companies/ communities for landscape + street sweeping	Bare minimum (but important behavioural change)

VIII. NorthConnex Water Savings Model

The four options reveal that potable water savings increase as a function of capital expenditure, which is a key consideration on timing the implementation of these interventions.

As a result, the report suggests that if capital resources are available for NorthConnex operations, then Option 1 would be the strongest water savings model to pursue. It combines dry-systems which are innovative and state-of-the-art for Australia, while also promoting significant water savings. This could also be paired with a community consultation on possible uses of the WTP water for parks and fields and therefore include additional benefits for community greening. It would significantly exceed the 20% ISCA savings criteria.

If capital resources are constrained for NorthConnex operations, then Option 3 would be the strongest to consider, given that it can combine several opportunities for water efficiencies, including in the operations centre, street sweeping and landscaping. It also offers the potential for some of the WTP water to be reused in the community. This combination encompasses: potable water savings; moderate capital costs; greening-the-community benefits; reputational benefit and most importantly, can include behavioural change components for longer-term sustainability within the organisation and the broader community. Depending on how these various levers are used year by year, this option can offer anywhere from 20% to 48% savings on potable water use in response to the ISCA criteria.

IX. Conclusion

This report has demonstrated that there are numerous opportunities for NorthConnex to enable potable water savings in the operation of the tunnel including mechanical and technical fixes, system changes in the operational structure, and organisation behavioural changes. Various costs and benefits were monetised in this report to compare and consider the relationship between capital investment and water saving potential. Depending on the combination of opportunities explored, potential water savings can range from 2% to 92%.

Depending on the capital resources, optimal models can either transition to state of the art dry-systems or explore a combination of water-use adjustments across the whole tunnel system. Regardless of which of these models are pursued, this report suggests that NorthConnex should invest in behavioural strategies. Changing water-use practices throughout the NorthConnex organisation, and including education for the community at large, can generate greater respect and value for water as a precious resource in Australia both now and into the future.

Appendices

Appendix 1. Description of the individual NorthConnex facilities

Sources: Lendlease Bouygues Joint Venture 2017, NorthConnex and M2 Integration Project Sustainability plan, Revision 04, ALL-LLB-01-001-QA-PL-0071; Lendlease Bouygues Joint Venture 2018, Urban Design and Landscape Plan - Stage Two, Prepared by Conybeare Morrison International Pty Ltd November 2018; Lendlease Bouygues Joint Venture 2018, NorthConnex M1-M2 Water Quality Plan and Monitoring Program, Revision 10, ALL-LLB-01-001-QA-PL-0062.

There are two main points for operations management for the NorthConnex Tunnel.
The first is the Motorway operations complex (MOC) located at the Southern end of the tunnel. It includes the Motorway Control Centre (MCC), the Southern Ventilation Facility; the maintenance centre; and miscellaneous parking and surface facilities. The southern ventilation facility includes the Water Treatment Plant along with two buffer tanks for water overflow for the treatment plant. The maintenance centre design also includes two rainwater tanks.

The second, Northern Ventilation Facility, includes ventilation buildings as well as fire deluge storage tanks. The facility includes office space alongside the mechanical ventilation and other structures, but the only identifiable water uses in the facility are toilets and landscaping.

There are two "incident response facilities" located along the southern and northern parts of the tunnel. These are stand-alone buildings that contain facilitated for incident response personal. They include a rainwater tank. The main water uses in the facilities are: toilet, shower and kitchenette as well as some minor landscaping.

The Water Treatment Plant

Stormwater and groundwater is collected and pipes carry the water to the Treatment Plant. Groundwater entering the tunnel is collected by open channels placed at the side walls of the tunnel. The collected water is directed via pipes to the roadway drainage system. The roadway drainage system also collects stormwater from relevant portals, as well as tunnel service water (for deluge testing, etc). Groundwater and stormwater will be collected and sent to a Low Point Sump, located at the deepest part of the tunnel, with two sets of pumps. One pump for low flow groundwater and one for high flow stormwater. They will pump the water to two buffer tanks located on the surface that will the release that to a Water Treatment Plant. The two buffer tanks are there to store water in excess of the WTP. (See schematic on the next page from the NorthConnex Water Quality Plan and Monitoring Program, p.102)

All components of the water treatment system are sized to be capable of managing the maximum potential groundwater flow of 22.5 L/s. This includes periods of drought, low intensity rainfall and high intensity rainfall.

Water Quality

The WTP includes flocculation to remove suspended solids; dissolved air flotation and micro-filtration to remove particulates; carbon filtration to remove volatile organic compounds; reverse osmosis to reduce salinity and dissolved solid concentrations; correction of pH level through addition of lime or acid. The quality of treated water is in accordance with ANZECC guidelines (ANZECC and ARMCANZ 2000).

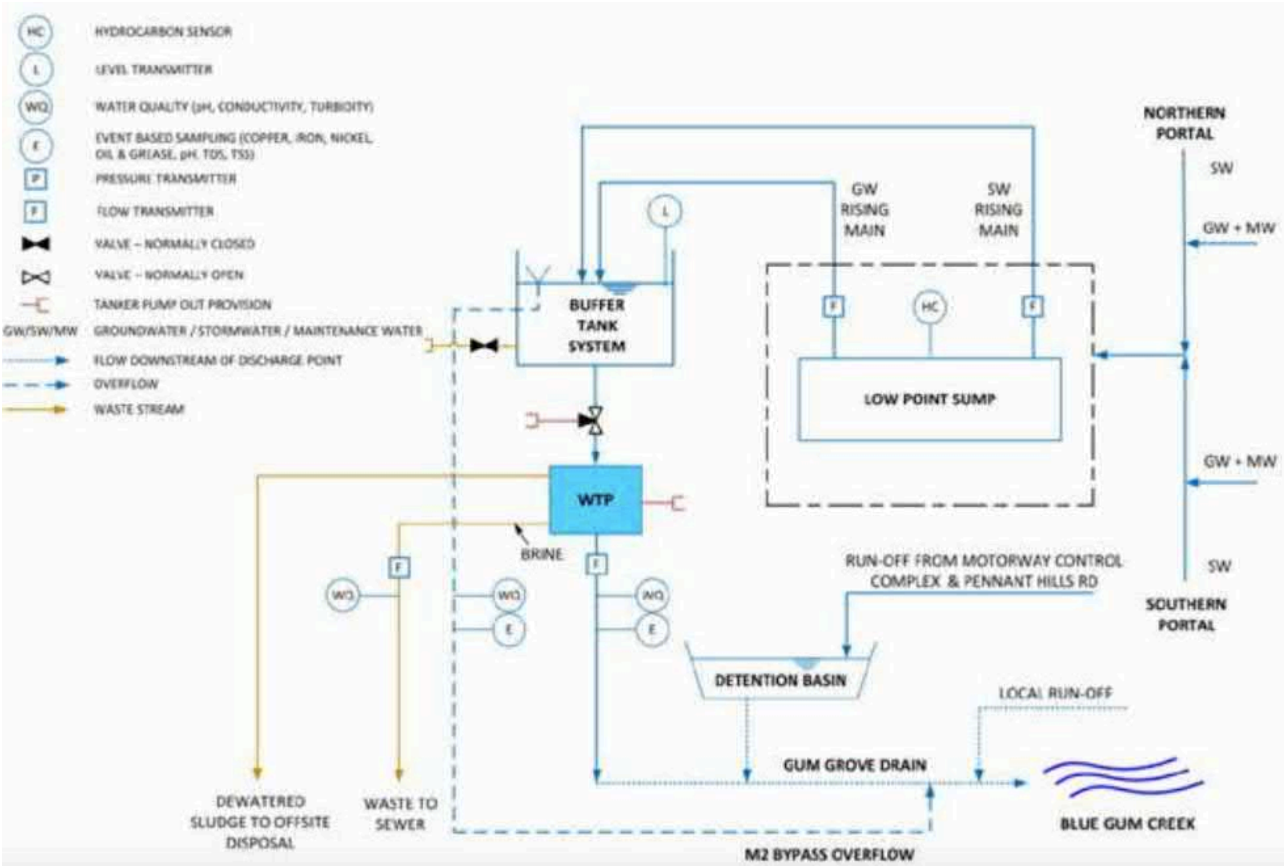

Figure 9. Schematic of the operational phase water management

Appendix 2. Possible external uses of the treated water from the NorthConnex WTP

The table below summarises possible uses of the treated water for the NorthConnex Water Treatment Plant outside of the tunnel operations.

Table 17: Possible external uses of the treated water

Who/What	Key Details	Reference
Pennant Hills Golf Club	• Approx. 1.3km drive or 500 meters direct from the WTP. • Golf club already has recycled water treatment (specifically sewer mining treatment plant) that is on site.	Pennant Hills Golf club website, as well as calls to the club and emails from Superintendent and Manager of the Water Treatment plant. 27.3.19; 1.4.19; 9.4.19
Muirfield Golf Club	• Approx. 5-6km drive or 3km direct from the WTP. • Golf club does not use recycled water, obtains water by pumping from creek. Uses 100 – 130 mega litres per year. • Interested in recycled or treated water use if salinity is right. There are different ranges, greenway water and fairway water therefore high potential to match quality.	Call with Muirfield Golf Club with Course Superintendent. 4.4.19
Roselea Community Centre and Carlingford High School Ovals	• There are three adjacent ovals used by the Roselea community centre, Carlingford High School and Roselea Primary School. These are 2.5-3.5km drive or 600 to 700m direct from the WTP. • A rainwater and stormwater runoff tank exist underground at Roselea community centre for use in the centre itself but it's not currently being used. • In high sport-peak seasons, for cricket for example, Hornsby Shire Council will bring in trucks with water to maintain the turf for the Carlingford High School oval. • There is currently no other irrigation of the fields. There is a generally positive attitude toward recycled water use for irrigation and landscaping if it is of good quality and regularly available.	Call with Roselea Community Centre 29. 03.19. Call with Carlingford High School Grounds Administrator 12.04.19. Email correspondence with Paramatta Council 5.4.19.

Who/What	Key Details	Reference
Parks under Parramatta Council: North Rocks Park + Murray Farm Reserve + Rainbow Farm Reserve	• Parramatta Council is exploring alternative water uses for assets such as parks approximately 2 – 4km away from the WTP. • They already have stormwater harvesting and recycled water use in several parks, including North Rocks Park and several across Epping. However, other parks in the area including Murray Farm Reserve and Rainbow Farm Reserve could be an option for using treated water from the WTP. • They respond positively to the idea of using treated water and are considering collecting water from carpark runoff but would want to make sure it meets quality needs for the type of grass and landscape they have.	Email with Parramatta City Council 3.4.19 and 5.4.19
Parks under the Hills Shire Parks: Ted Horwood Reserve + George Thornton Reserve	• Several parks within a 6km range of the WTP site fall under Hills Shire Council which has policy commitments to limiting potable water use. • They use significant water for turf management which they are keen to maintain as replacing turf can cost up to $90,000. • They have 31 reuse water tanks throughout the Shire, conduct regular water quality testing and have processes in place of dealing with sediment in the tanks. Ted Horwood Reserve already includes 2 water storage tanks and George Thornton includes 1 drainage and 3 irrigation tanks on site for their own water recycling systems. • The council are interested in using recycled and treated water. Have previously made requests to Castle Hill Recycled Water Plant to use treated water.	Calls and Emails with Hills Shire Council, 11.04.19; 20.04.19; 1.5.19

Who/What	Key Details	Reference
Scooters Hand Car Wash Skyblue Hand Car Wash Crazy Car Wash Enviro Car Wash	• A commercial option: to sell treated water to local car washes for cheaper price. Distances are anywhere from 3.2km to 5km drive. • The Australian Car Wash Association encourages businesses to adopt recycled water systems to save approximately 200L per car (Car Wash World, 2019) and car wash businesses respond positively to using recycled and treated water in early rinses and to mix with detergents given it meets quality standards and low levels of metals (EnviroConcepts, 2015).	Calls attempted 4.4.19; 9.4.19; 12.4.19. Articles from CarWashWorld consulted.

Appendix 3. Water efficiencies per fixture

The data for the water usage of standard fixtures and appliances were based on water efficiency in fixtures in households provided by the Department of the Environment and Energy, Australian Government (2019). The water usage for each water efficient fixture or appliance was obtained from Table 3.

Table 18: Water savings efficiency of each fixture type

	Water Usage of Standard Fixture	**Water Usage of Efficient Fixture (4 Star WELS Rating)**	**Water Saving %**
Shower Heads	15L/min	7.5L/min	50%
Taps	15L/min	7.5L/min	50%
Toilets	12L/flush	4.5L/flush	37.5%
Dishwashers	19L/flush	11.8L/flush	62.1%

The table above shows that there is an average water saving of approximately 50%, which is larger than the expected 30%. However, for our model, it was decided to use the more conservative 30% water saving potential, as there were various variable and assumptions that were unknown in these calculations.

Appendix 4. Breakdown of current fixtures in operations centres

It should be noted that these figures are an estimate from the NorthConnex Stage 2 Urban Design Guide maps (Lendlease Bouygues Joint Venture, 2018), and therefore the actual numbers will be different.

The table below shows the breakdown of current operation centre fixtures based on NorthConnex Urban Design and Landscape Guideline Stage 2, 2018.

Table 19: Estimated number of fixtures in the operations centre

	Southern Operation Centre	Northern Operation Centre	Total
Office density	20	10	30
Number of Showers	4	2	6
Number of Toilets	12	6	18
Number of Taps	8	4	12

Appendix 5. Landscaping calculations

Based on Northconnex Urban and Landscape Design Guide Stage 2 (2018), rough calculations in conversations with landscape experts suggest that trees identified in the design will use approximately 20 to 25% of water per weight, so for a 400 L tree we assume 100L of water per watering. Across the NorthConnex complexes, there are over 70 of the 75 L trees, 9 of the 400 L trees, and 84 of the 25 L trees. The assumption is that these are watered once per week. The calculation also assumes that the native turfs, grasses and shrubs will use approximately ¼ of their surface area in water once a week. All together a rough estimate is approximately 24.7 kL of potable water per week.

Appendix 6. Dry street sweeper product details

DISA-CLEAN 130

The DISAB Group offers the broadest product range on the market, giving you the opportunity to choose a vacuum unit that suits your needs. With our wide range of options and long experience, we will optimize the unit to your daily work.

Dust-Free High-Vacuum Dry Street & Area Cleaner Sweeper

Developed to help meet EU environmental requirements to reduce hazardous PM_{10} and $PM_{2.5}$ particulate matter in cities and industries. Awarded 4-star PM-Certificate.

DISA-CLEAN vacuum sweeper combines brushing and high-powered vacuuming in a single-operation <u>without</u> the use of water.

DISA-CLEAN operates without water and removes virtually all PM-material, while dispersing virtually no dust into the air, in the EUnited PM-tests, receiving the highest level of certification - 4 stars. DISA-CLEAN offers superior dust-control - it will not blow particles back out in the air again, as the air is filtered through a unique and efficient 4-step separation and filtering process.

Another reason for the superior dust-control when operating a DISA-CLEAN, is the vacuum-evacuated encapsulated brushes in combination with a unique vacuum nozzle that removes both dirt and even the finest material from the surface.

The high-performance vacuum pump forces the airflow through the container and filters at maximum capacity and efficiency during the entire operation, allowing a considerably high working speed, giving DISA-CLEAN a uniquely high capacity, also when surfaces are dirty and wet.

Vacuum sweeping without water with DISA-CLEAN brings several advantages and improved results:

- Operating without water saves >100,000 litres annually/unit
- With **superior high-vacuum (-0,45 bar)** and **high suction force (1600 kgs)**, much less dust and particles are left on ground and in asphalt cavities
- Brushes are virtually **dust-free** due to rubber protection and vacuum evacuation
- **No hazardous particles** are passing through the system and emitted back into the air due to unique 4-step PM_{10} and $PM_{2.5}$ separation system

This unit is equipped with options

- No dust & hazardous particles will be wet-smeared and left as wet slurry to dry on the ground
- No dust & hazardous particles will be flushed into water drains and further
- Immediately and constantly less free particles even after surfaces have dried out
- Operational in **both dry and wet** conditions with brushes and high-vacuum suction
- Operational **below 0°C** as no water is used – sweeping also possible wintertime
- Operational up to **20 km/h – high productivity**

A user-friendly visual touch-screen based control system allows the operator to focus on the road and safety.

And as a true DISAB product, it is versatile - it can be transformed into a **Vacloader with wanderhose** and nozzle, or for **cleaning tramways.**

TECHNICAL SPECIFICATIONS- DISA-CLEAN 130

Touch-screen CanBus control system

- All system controls user-friendly and graphic
- Pre-programmed settings
- Simple programme controls & settings
- Displaying auxiliary engine, vacuum pump, filter status etc.
- ...

Item/Model	**DISA-CLEAN 130**
Truck chassis	Volvo FE 240, 4x2
Engine	Euro6, 168 kW
Wheel base	4,30 m
Real axle	13 ton
Front axle	7,1 ton

Auxiliary engine for high-vacuum pump	
Model	Turbo, 4-cylinder (Stage III or IV)
Output	160 kW
Vacuum capacity	Down to -450 mBar
Vacuum power	Up to 1600 kgs
Air flow	Up to 8,000 m3/hr

Air control system	
Main filters	Class $PM_{2.5}$ PE Teflon
Safety filters	Class $PM_{2.5}$ PE
Vacuum nozzle and brushes	
Main brushes & vacuum nozzles	2500 mm
Optional: side brush left and side brush right	+300 mm each when deployed
Total swept width	2800 mm
Function	Hydraulic and pneumatic
Operational speed	0-20 km/h
Pay-load volume	Approx 5000 liters

Specifications may be changed without prior notice.

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www.disab.com

Appendix 7. List of interviews conducted

Carlingford High School
Call with Brian Truscott (brian.truscott@det.nsw.edu.au)
GA for Carlingford High School
11 April 2019

City of Parramatta:
Email correspondence with Kyle O'Brien (kyle.obrien@cityofparramatta.nsw.gov.au)
Business Support Officer, City Strategy, City of Parramatta Council
1 April 2019, 3 April 2019, 5 April 2019

Hills Shire Council
Call with Don Higginbotham (dhigginbotham@thehills.nsw.gov.au)
Parks Asset Officer, Hills Shire Council
1 May 2019

Muirfield Golf Course
Call with Peter Watts (gm@muirfieldgolf.com.au)
Course Superintendent at Muirfield Golf Course
4 April 2019

Pennant Hills Golf Club
Email correspondence with Richard Kirby (richard@pennanthillsgolfclub.com.au)
Course Superintendent, Pennant Hills Golf Club
9 April 2019

Permeate Partners
Email correspondence with Kurt Dahl (kurt@permeate.com.au)
Managing Director of Permeate Partners
9 April 2019

Roselea Community Centre:
Call with general response line
28 March 2019

Scooters Hand Car Wash
Call with general response line
9 April 2019, 11 April 2019

Other unsuccessful outreach included:
Hornsby Shire Council (email)
Crazy Car Wash (call)
Enviro Car Wash (call)
Skyblue Hand Car Wash (call)

References

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Built Environment

SUSD0016	**Sustainable Infrastructure**	6 May 2019
Course ID	*Course Name*	*Date*
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Dr. Sarath Mataraarachchi

Convener

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