Department of Planning and Environment

Review of water sensitive urban design strategies for Wianamatta–South Creek

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Cover photo: Wetland and playground at Blacktown Showground. Blacktown City Council

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1. Protected to the most insignificant jet

‘On 28 August 1826 a truly remarkable public meeting was held in Windsor Courthouse attended by notable local Aboriginal figures of the day. In this remarkable meeting it was resolved “that the rivers be protected to the most insignificant jet”, a poignant resolution still pertinent for the waters of the Wianamatta system.

Water resources have important cultural, spiritual, and practical values for First Peoples. Waterways are crucial for cultural practices and knowledge transfers as part of a healthy, flowing, connected system.

The Cannemegal and Wianamattagal peoples of the Dharug nation still care for the Country of Wianamatta and carry the stories and knowledges of that landscape. Dharug Elders describe Wianamatta as an interconnected system, formed through the Dreaming, this cultural landscape connects from beyond the mountains out to the sea. It is a particularly important place for pregnant women as the place of the mother creek – a female landscape relating to motherhood and creation.

The floodplains of Wianamatta remain a significant place for Aboriginal communities. South, Ropes, Badgerys, and Thompsons Creeks form a major part of the Aboriginal infrastructure which has provided resources such as food, medicine, and recreation over thousands of generations of people. It is imperative to respect these waterways and their dynamic movements, and to learn from their capacity to find the path of least resistance. Allowing one part to become ill through pollution, mismanagement or overuse will cause the whole system to suffer. All the waters must be protected to ensure the health of the whole system – to the most insignificant jet.’

Dr Danièle Hromek is a Budawang woman of the Yuin nation – she has spent some time yarning with the Aboriginal Elders in Wianamatta to help translate cultural values into land-use planning

2. About this document

This document describes the feasibility of a range of water sensitive urban design (WSUD) strategies for achieving new stormwater management targets that protect and restore the blue grid in the Wianamatta–South Creek catchment. The new targets are presented as standard planning requirements for stormwater infrastructure in both the Western Sydney Aerotropolis Development Control Plan – Phase 2 (WSPP 2021), and Mamre Road Precinct Development Control Plan (DPIE 2021d).

The findings of the feasibility assessment are intended to support decisions on developing robust and cost-effective institutional arrangements for urban development in the Wianamatta–South Creek catchment. This document presents optimal WSUD strategies (solutions) for large format industrial (LFI) and high density residential (HDR) typologies, based on comparisons of overall capital, operating, and land costs associated with each of the WSUD strategies.

This document is technical in nature, but should be considered by a wide range of stakeholders involved in land-use planning, and managing stormwater and waterways in the Wianamatta–South Creek, including:

- policy and planning practitioners (including development assessors) involved in land-use planning and policy development
- infrastructure planners and engineers involved in water management cycle planning
- proponents and associated consultants involved in the planning, design, delivery and operation of stormwater infrastructure.

This document provides background for the NSW Government *Technical guidance for achieving Wianamatta–South Creek stormwater management targets* (DPE 2022a). It is part of a series of technical documents that have been released by the NSW Government to support precinct planning in Western Sydney, including:

- *Mapping the natural blue grid elements of Wianamatta–South Creek: High ecological value waterways, riparian vegetation communities and other water dependent ecosystems* (DPE 2022b)
- *Performance criteria for protecting and improving the blue grid in Wianamatta–South Creek: Water quality and flow related objectives for use as environmental standards in land-use planning* (DPE 2022c)
- *Wianamatta–South Creek stormwater management targets* (DPE 2022d).

3. Background

The Wianamatta–South Creek catchment is part of the Hawkesbury–Nepean River system and lies ~50 km west of Sydney. It is the central location for the Western Parkland City, and Sydney's second international airport. Strategic land-use planning for the area has been landscape led (WSPP 2020; DPIE 2021a), predominantly achieved through the creation of a Blue and Green Infrastructure Framework to provide a range of benefits related to liveability, building resilience to city hazards like urban heat and flooding, and protecting the iconic and/or endangered ecological communities that characterise the area (GSC 2018a; DPIE 2021a; WSPP 2021).

This landscape led approach has changed almost all aspects of land-use planning for the airport and surrounding precincts that make up the Western Sydney Aerotropolis. This includes changes to planning controls for stormwater infrastructure delivery, which have shifted from long standing post-development load reductions targets to new outcomes-based targets designed to protect and restore the blue grid (see Section 3.1). The targets now include requirements for managing stormwater flow volumes and rates to specifically mitigate risks of stream erosion, riparian and instream habitat loss, and changes to life cycles of flora and fauna (DPE 2022c). The targets were developed by the NSW Government via a risk-based framework (DPE 2022d), in accordance with the NSW Government policy for managing waterways, the Western City District Plan (GSC 2018b), Western Sydney Aerotropolis Plan (WSPP 2020) and State Environmental Planning Policy (Precincts – Western Parkland City) 2021.

The NSW Government *Risk-based framework for considering waterway health outcomes in strategic land-use planning decisions* (Risk-based Framework; Dela-Cruz et al. 2017) outlines a process for developing management targets, in consideration of their feasibility of being achieved. As outlined in Step 4 of the Risk-based Framework, feasibility could include aspects of costs of delivery, benefits achieved, site constraints/characteristics, operational requirements, and/or social considerations.

In this document, we present the results of the feasibility of achieving the new (outcomes-based) stormwater management targets for Wianamatta–South Creek by comparing a range of WSUD strategies. Feasibility is based on capital, operating and land costs in context of site constraints and the vision set out by the Greater Sydney Commission to deliver a cool parkland city. The site constraints/ characteristics determined the stormwater treatment measures that are viable in the Wianamatta–South Creek catchment. The vision determined the range of WSUD strategies investigated, which themselves were based on consultation with local and state governments, and Sydney Water, who delivered integrated water cycle management plans for the Western Sydney Aerotropolis and Mamre Road precincts (Sydney Water 2020, 2021).

3.1 Stormwater management targets

Table 1 to Table 4 present the new (outcomes-based) stormwater management targets that need to be achieved at the outlet of a development site during the operational phase; that is, once the site has been developed. A development must demonstrate compliance with both the stormwater quality and quantity (flow) targets.

There are 2 options for targets provided for stormwater quality and 2 for stormwater quantity (flow). The 2 options are intended to provide flexibility in demonstrating compliance with the targets (see DPE 2022a, d), and were a direct request of the water professionals or practitioners who were representing large landowners in Wianamatta–South Creek at the time of this study.

For stormwater quality targets, most development will likely adopt Option 1, which is based on annual load reduction targets (Table 1). If a development incorporates significant areas of pervious space (e.g. by adopting green roofs), then a proponent may prefer to use Option 2, which is based on allowable loads (Table 2).

Differences between the 2 options for the stormwater quantity (flow) targets are mainly related to the extent of post-processing of results generated from the industry standard model MUSIC (DPE 2022a, d). Option 1 allows results to be directly extracted from MUSIC and compared with the targets (Table 3). Option 2 requires flow data to be extracted from MUSIC and a flow duration curve to be developed (Table 4). The proponent is free to select whichever option suits their WSUD strategy best, noting that:

- Option 1 stormwater quantity (flow) targets are based around limiting the mean annual runoff volume (MARV) from a development site as well as ensuring there is suitable low flow regime in the streams
- Option 2 stormwater quantity (flow) targets are based on preserving key percentiles of a flow duration curve (see DPE 2022d).

Table 1 Operational phase stormwater quality targets Option 1 – annual load reduction

Parameter	Target – reduction in mean annual load from unmitigated development
Gross pollutants (anthropogenic litter >5 mm and coarse sediment >1 mm)	90%
Total suspended solids (TSS)	90%
Total phosphorus (TP)	80%
Total nitrogen (TN)	65%

Table 2 Operational phase stormwater quality targets Option 2 – allowable loads

Parameter	Target – allowable mean annual load from development
Gross pollutants (anthropogenic litter >5 mm and coarse sediment >1 mm)	<16 kg/ha/y
Total suspended solids (TSS)	<80 kg/ha/y
Total phosphorus (TP)	<0.3 kg/ha/y
Total nitrogen (TN)	<3.5 kg/ha/y

Table 3 Operational phase stormwater quantity (flow) targets Option 1 – MARV

Parameter	Target
Mean annual runoff volume (MARV)	≤2 ML/ha/y at the point of discharge to the local waterway
90%ile flow	1,000–5,000 L/ha/day at the point of discharge to the local waterway
50%ile flow	5–100 L/ha/day at the point of discharge to the local waterway
10%ile flow	0 L/ha/day at the point of discharge to the local waterway

Table 4 Operational phase stormwater quantity (flow) targets Option 2 – flow percentiles

Parameter	Target
95%ile flow	3,000–15,000 L/ha/day at the point of discharge to the local waterway
90%ile flow	1,000–5,000 L/ha/day at the point of discharge to the local waterway
75%ile flow	100–1,000 L/ha/day at the point of discharge to the local waterway
50%ile flow	5–100 L/ha/day at the point of discharge to the local waterway
Cease to flow	Cease to flow to be between 10% and 30% of the time

4. Developing WSUD strategies

A total of 16 different WSUD strategies are presented in this document, all demonstrating how the new (outcomes-based) stormwater management targets can be achieved. The WSUD strategies account for the site and development characteristics and associated design principles, reliability of stormwater treatment measures during operation, and apply to different scales of delivery (allotment, precinct, regional).

4.1 Site and development characteristics

The precincts of the Western Sydney Aerotropolis and Mamre Road contain a mix of employment zones of various characters (e.g. town centre and enterprise areas), as well as some medium and high density residential areas. The greatest portion of the land use will be industrial (large format and strata) and logistics operations, which are characterised by high site coverage with impervious surfaces. Hence, while the vision for the Western Parkland City requires lower impervious cover than 'business-as-usual', site coverage and imperviousness will still be relatively high for these industrial areas to be commercially viable and provide the envisaged employment opportunities.

Impacts of site coverage and imperviousness on the hydrology are significant, producing much more runoff and mobilising many more pollutants than undeveloped catchments. As shown in a companion study, these impacts have a flow-on effect on the ecology of the waterways, riparian corridors and other water dependent ecosystems that make up the blue grid in Wianamatta–South Creek (DPE 2022c). There is a 'tipping point' at which the ecological health of the blue grid is significantly impacted by flows. The tipping point occurs at a level of imperviousness (~10%), consistent with previous findings for the Greater Sydney Region (Tippler et al. 2012) and diagnostic of the urban stream syndrome (Walsh et al. 2005; Walsh et al. 2012).

Mitigating excess runoff from industrial areas is considered the most challenging aspect of stormwater management in Wianamatta–South Creek because of several compounding factors. The presence of saline and sodic soils (DPIE 2021b, c) means that stormwater treatment measures like infiltration and permeable paving should not be applied without appropriate soil testing to confirm soil capabilities. Highly variable water demands between allotments in industrial, logistics and agri-business areas/typologies are also a critical consideration when developing WSUD strategies. Predicting allotment water demands (especially for non-potable water) are highly dependent on the activities of a particular tenant. At development planning stages, individual tenants and their types of activities are generally unknown, and therefore predicting lot-scale water demands is not feasible in these industrial areas. However, it is feasible to grossly predict water demand at the development precinct scale.

This varying nature of (non-potable) water demands between lots for industrial land use highlight the potential benefit of a regional reticulated stormwater reuse system. This system can deliver harvested stormwater to all allotments in a region to ensure water is supplied to large users of non-potable water such as a glasshouse horticultural business (compared to a big-box distribution centre). This provides a significant opportunity for conservation of drinking water by allowing all lots to use recycled water for non-potable uses. The supply for the recycled water could be treated wastewater, treated stormwater or a blend of the 2 sources, depending on the design of the reticulated system.

4.2 WSUD design principles

With consideration of site characteristics and the vision for the Western Parkland City, a set of WSUD design principles was developed to inform the WSUD strategies. Input was sought from key science and operations groups within the NSW Government, particularly those with in-depth local knowledge and data on the soil characteristics of Wianamatta–South Creek (DPIE 2021b, c) and/or those with responsibilities for guiding waterway management, riparian corridors and/or flood impacts. The following list provides the main WSUD design principles derived from the expert input, and therefore used when selecting stormwater treatment measures for a particular WSUD strategy:

1. Preference is for vegetated treatment systems as they provide hydrologic and green infrastructure benefits.
2. Infiltration measures (including unlined porous pavements) are unlikely to be feasible because of saline and sodic soils, unless detailed site analysis is done to confirm feasibility.
3. Stormwater treatment systems should be arranged in parallel as much as possible, to minimise double treating of stormwater.
4. Stormwater harvesting is likely to be a fundamental part of the strategy for protecting waterways. Preference is for a regional reticulated scheme that delivers harvested water to all lots and for all non-potable demands.
5. Irrigation rates should be managed to avoid over irrigation and exacerbating saline and sodic soil issues.
6. Stormwater management systems should be lined to minimise infiltration (e.g. engineered clays or a synthetic liner).
7. Stormwater treatment and harvesting systems can be located within 1% AEP (annual exceedance probability). They are to be avoided in flood conveyance areas (i.e. 1% AEP floodways and high floodways) and critical flood storage areas unless a flood impact and risk assessment for the development demonstrated that their impacts on flood behaviour and on the community can be managed. Refer to principles set out in an accompanying technical guidance (DPE 2022a).
8. Stormwater treatments and harvesting storages can be located within the vegetated riparian zone (VRZ), provided the function of the VRZ is preserved (DPI – Office of Water 2012) and design principle 7 (above) and those set out in our accompanying technical guidance (DPE 2022a) are satisfied.

Figure 1 Dead trees in low lying areas is an indicator of salinity in the landscape
Photo: Rob Muller/DPE

4.3 Stormwater treatment measures

Although there are growing numbers of stormwater treatment measures, a limited number were selected to be suitable for Wianamatta–South Creek catchment based on the WSUD design principles (Section 4.2) and the outcomes of consultation with the local governments and stormwater engineers/contractors operating within the catchment. Table 5 provides a list of stormwater treatment measures, together with an outline of an assumed configuration for each measure. The measures were considered to be both practical and reliable, and therefore used in the example WSUD strategies presented in this document.

Table 5 Description of stormwater measures adopted in the WSUD strategies

Measure	Description
Green roofs	Roof areas that are covered with soil and vegetation. They act to capture rainwater, promote evaporation, reduce runoff volumes and cool the buildings
Gross pollutant trap (GPT)	GPTs filter litter and debris from stormwater and act to contain oil spills
Roof water tanks	Tanks that collect roof water that is then pumped to supply indoor uses (e.g. toilet and laundries) and/or outdoor uses (irrigation)
On-site detention	Sunken landscaped areas that provide stormwater storage during infrequent flooding events
Lot bioretention	Bioretention basins that collect and filter stormwater within a lot, typically targeting roads, carparks and hardstand areas
Lot wetlands	Constructed wetlands for the purpose of stormwater treatment – treated water commonly pumped to storages for reuse
Lot storages	Lot storage can be either tanks (e.g. above ground) or open storages (e.g. dam) and are used to supply pumps for reuse systems (e.g. irrigation)
Street bioretention	Bioretention basins located in road verges that collect and filter stormwater from the road, located within the verges (assumed earth batters and no grate covers)
Passively irrigated street trees	Stormwater diverters installed in kerbs to direct small amounts of stormwater into soils around street trees for irrigation (not bioretention)
Precinct wetland	Constructed wetlands for the purpose of stormwater treatment – treated water can be directed to storages for reuse, could be located above or below 1% AEP levels (refer to Section 4.2)
Precinct bioretention	Bioretention basins that collect and filter stormwater. They are typically located in public open space, and could be located above or below 1% AEP levels (refer to Section 4.2)
Combined wetland/ bioretention	Wetlands in combination with bioretention, where wetlands treat baseflows and then overflow into bioretention basins during storm events – both share extended detention volumes
Public open space (POS) storage tank and reuse	Treated water storage in POS can be either tanks (in smaller parks) or open water storage (e.g. lakes or dams)
Regional reuse storage	Treated water storage in open water dams or lakes, could be located above or below 1% AEP levels (within policy and/or legislative requirements)
Reticulated reuse pipe	A dedicated reticulated water pipe to supply recycled stormwater to allotment and open space. Can be combined with recycled wastewater

4.4 Scales of delivery

Development control plans for the Western Sydney Aerotropolis and Mamre Road precincts specify that stormwater management systems can be delivered at a range of scales (i.e. allotment, street, estate, or sub-precinct scale) to treat stormwater, integrate with the landscape and maximise evaporative losses to comply with the new (outcomes-based) stormwater management targets.

For this feasibility assessment, 3 scales of delivery are considered:

- allotment (on the lot) – WSUD is located entirely within the boundaries of a development site, and compliance with stormwater management targets is demonstrated at an outlet from a development site
- allotment and precinct – WSUD is delivered on lots, in streets and at precinct scale (i.e. open space) to enable full development of each lot (up to 85% impervious, as per development control plans) and still comply with the stormwater management targets
- regional – WSUD includes a reticulated stormwater reuse system that provides stormwater treatments and storages at precinct or regional scales, and requires a trunk drainage manager.

Allotment-scale WSUD strategies are presented to reflect smaller-scale developments where POS is not available for stormwater management.

Combined allotment and precinct scale delivery is the strategy presented in the Western Sydney Aerotropolis Stormwater and Water Cycle Management Study (Sydney Water 2021). It is based on WSUD delivered on lots and in public open spaces (parks), using captured rain and stormwater for irrigation.

Regional and reticulated reuse strategies rely on the establishment of a trunk drainage manager. Sydney Water’s proposal for an Advanced Water Recycling Centre within the Aerotropolis presents an opportunity for regional treatment and reticulated reuse of stormwater. Extensive consultation with Sydney Water and the NSW Government indicated that this specific WSUD strategy was under consideration at the time of this study, and therefore is included in the feasibility assessment.

To support delivery of any future regional WSUD strategy, a staged WSUD strategy is included to allow early development to occur while arrangements for a trunk drainage manager are being developed. This staged WSUD strategy includes:

- ‘interim’ solutions that can comply with the targets without trunk drainage manager measures being implemented (typically these include partial development of an area)
- ‘ultimate’ solutions that enable interim solutions to transition to final (i.e. full) development that incorporate trunk drainage manager infrastructure such as precinct/ regional treatment and a reticulated stormwater harvesting system.

The above range of scales for delivery (and hence example WSUD strategies) were based on the needs/questions raised by relevant local and state governments ahead of the decision to adopt the stormwater management targets for Wianamatta–South Creek. To further support the delivery of the new stormwater targets and WSUD strategies, the NSW Government commissioned the *Technical guidance for achieving Wianamatta–South Creek stormwater management targets* (DPE 2022a). This guidance provides schematics and further technical details for WSUD strategies described in this document.

5. WSUD strategies for large format industrial development

WSUD strategies were assessed for LFI developments, given that this typology makes up the greatest proportion of the land use in the priority release precincts. This typology also represents the greatest challenge in terms of achieving the stormwater management targets. This is because LFI areas are traditionally characterised by large expanses of roof and ground level impervious areas with limited landscape. Hence, if a WSUD strategy that achieves the stormwater management targets can be developed for an LFI typology, it can also be replicated more easily for other typologies with lower intensity land use.

Table 6 provides a range of possible WSUD strategies for achieving the stormwater management targets for LFI typologies. It is not intended as an exhaustive list of strategies, but rather to provide a range of examples to demonstrate possibilities to comply with the stormwater targets.

Some of the WSUD strategies presented in Table 6 do not include streetscape measures such as street trees for stormwater management, but it should be noted that the strategies do not preclude tree canopy coverage targets being met in different ways. This may include passive irrigation of street tree systems (that divert low flows of stormwater to trees) or irrigation from reticulated recycled stormwater. Where streetscape systems are not required to achieve the stormwater management targets, they have not been included in the WSUD strategies (i.e. their function is not related to stormwater management but rather landscape and cooling). This is because converting a street tree or passively irrigated street tree to a stormwater treatment system (i.e. bioretention tree) is an expensive stormwater solution and should only be considered if necessary.

Table 7 shows the sizes of different stormwater treatment measures contributing to each WSUD strategy, along with the impervious coverage. Sizes were determined in MUSIC, using the model assumptions described in the companion study *Wianamatta–South Creek stormwater management targets* (DPE 2022d). Other key model assumptions such as those adopted for rainwater harvesting, irrigation and water demands are also available in the companion study. Note that other on-site pollution control systems such as gross pollutant traps (GPTs) and oil spill containment systems are not listed but will be required for most allotments.

Table 6 Example WSUD strategies for LFI development

WSUD strategy – LFI		Stormwater infrastructure requirements								
		Reduced site coverage	Tanks	Lot WSUD	Streetscape WSUD	Precinct WSUD (above 1% AEP)	Regional WSUD (maximise below 1% AEP)	Stormwater quantity detention	POS stormwater harvesting	Reticulated regional stormwater harvesting
A	Current targets adopted by local government		✓	✓		✓		✓		
B1	Lot and streetscape	✓	✓	✓	✓			✓		
B2	Lot, streetscape and local irrigation	✓	✓	✓	✓			✓		
C1-a	Lot, local POS and regional treatment (above 1% AEP)	✓	✓	✓	✓	✓		✓		
C1-b	Lot, local POS and regional treatment (above 1% AEP)	✓	✓	✓	✓	✓		✓		
C2-a	Lot, local POS and regional treatment (below 1% AEP)	✓	✓	✓	✓		✓	✓		
C2-b	Lot, local POS and regional treatment (below 1% AEP)	✓	✓	✓	✓		✓	✓		
C3-a	Lot, local POS and regional treatment, and POS irrigation (below 1% AEP)	✓	✓	✓	✓		✓	✓	✓	
C3-b	Lot, local POS and regional treatment, and POS irrigation (below 1% AEP)	✓	✓	✓	✓		✓	✓	✓	
C4	Lot, local POS and regional treatment, and POS irrigation (below 1% AEP)		✓	✓	✓		✓	✓	✓	
D1-a	Lot and regional treatment, and reticulated stormwater reuse		✓	✓			✓	✓		✓
D1-b	Lot and regional treatment, and reticulated stormwater reuse		✓				✓	✓		✓
D2-a	Regional treatment and reticulated stormwater reuse (no tanks)						✓	✓		✓
D2-b	Regional treatment and reticulated stormwater reuse (no tanks)						✓	✓		✓
D3-a	Lots and streetscape with regional treatment and reticulated stormwater reuse		✓	✓	✓		✓	✓		✓
D3-b	Lots and streetscape with regional treatment and reticulated stormwater reuse		✓	✓	✓		✓	✓		✓

*Differences between the 'a' and 'b' options are different mixes of wetlands and bioretention systems for treatment – as shown in Table 7.

Table 7 Infrastructure sizes and impervious (imperv.) cover for LFI development WSUD strategies

WSUD strategy – LFI		Stormwater treatment measures												% open space		% imperv.	
		Tanks (kL/ha)	Lot bioretention (m^2/ha)	Street bioretention (m^2/ha)	Lot/ precinct wetland (m^2/ha)	Regional wetland (m^2/ha)	Regional bioretention (m^2/ha)	Stormwater harvesting on lot storage (m^3/ha)	Stormwater harvesting on lot to irrigation (ML/y/ha)	Stormwater harvesting to POS storage (m^3/ha)	Stormwater harvesting (local) to POS irrigation (ML/y/ha)	Regional stormwater harvesting storage (m^3/ha)	Reticulated regional stormwater harvesting (ML/y/ha)	Local	Regional	Lot	Total
A	Current targets adopted by local government	31	42				40							7.4	7.0	85	72
B1	Lot & streetscape	140	10	35	550									0	0	50	48
B2	Lot, streetscape & local irrigation	14	10	35	550			300	0.7					0	0	60	53
C1-a	Lot, local POS & regional treatment (above 1% AEP)	104	69	25	500									7.4	7.0	70	62
C1-b	Lot, local POS & regional treatment (above 1% AEP)	47	56	20	600									5.6	30	85	54
C2-a	Lot, local POS & regional treatment (below 1% AEP)	104	69	25		500								7.4	7.0	70	62
C2-b	Lot, local POS & regional treatment (below 1% AEP)	47	56	20		600								5.6	30	85	54
C3-a	Lot, local POS and regional treatment & POS irrigation (below 1% AEP)	75	69	24		500				200	0.3			7.4	7.0	75	65
C3-b	Lot, local POS and regional treatment & POS irrigation (below 1% AEP)	47	60	14		350				200	0.6			6	20	85	62
C4	Lot, local POS & regional treatment & POS irrigation (below 1% AEP)	60	69	24		350				200	0.8			7.4	7.0	85	72
D1-a	Lot & regional treatment & reticulated stormwater reuse	55	24			500						300	1.3	7.4	7.0	85	72
D1-b	Lot & regional treatment & reticulated stormwater reuse	14				200	60					300	1.9	7.4	7.0	85	72
D2-a	Regional treatment & reticulated stormwater reuse (no tanks)					375	60					380	1.6	7.4	7.0	85	72

WSUD strategy – LFI		Stormwater treatment measures												% open space		% imperv.	
		Tanks (kL/ha)	Lot bioretention (m^2/ha)	Street bioretention (m^2/ha)	Lot/ precinct wetland (m^2/ha)	Regional wetland (m^2/ha)	Regional bioretention (m^2/ha)	Stormwater harvesting on lot storage (m^3/ha)	Stormwater harvesting on lot to irrigation (ML/y/ha)	Stormwater harvesting to POS storage (m^3/ha)	Stormwater harvesting (local) to POS irrigation (ML/y/ha)	Regional stormwater harvesting storage (m^3/ha)	Reticulated regional stormwater harvesting (ML/y/ha)	Local	Regional	Lot	Total
D2-b	Regional treatment & reticulated stormwater reuse (no tanks)					200	60					380	2.0	7.4	7.0	85	72
D3-a	Lots and streetscape with regional treatment & reticulated stormwater reuse	55	69			300						300	1.4	7.4	7.0	85	72
D3-b	Lots and streetscape with regional treatment & reticulated stormwater reuse	55	69	24		150	40					300	1.6	7.4	7.0	85	72

Note that Option B has a 0% open space proportion because it considers a development of only allotments and streets (not POS).

Options B and C, which represent WSUD strategies that include stormwater treatment measures on allotments, in streetscapes and local parks result in reduced impervious coverage in development areas. The extent varies within a range of 50% to the maximum allowable (85%) impervious cover specified in development control plans for the Western Sydney Aerotropolis and Mamre Road precincts. The extent depends on the specific type and size of stormwater treatment measure selected. Option C4 for example, provides for 85% impervious cover, incorporates allotment, streetscape and local POS stormwater treatment measures but requires that 100% of (15%) pervious spaces are irrigated by allotment and POS reuse systems (which would need to be confirmed with local authorities).

If a regional treatment and reticulated stormwater reuse system is assumed, WSUD strategies can adopt a variety of stormwater measures along with maximum allowed site imperviousness and achieve the stormwater targets (i.e. the D options). Generally, the precinct/regional treatment and reticulated stormwater treatment options rely less on WSUD on allotment and within streets. WSUD infrastructure at the precinct/regional scale is typically less expensive to construct, has more certainty over ongoing maintenance and is less expensive to maintain than distributed small WSUD systems (see Section 7).

Option D3 is presented as an interim or staged approach to meeting the stormwater management targets until such time as a regional WSUD strategy is available that proponents can connect to. At that time, the full development allowance for a site can be delivered.

Figure 2 Rainwater tanks at Bungarribee
Photo: Blacktown City Council

6. WSUD strategies for high density residential development

HDR developments are characterised by relatively large populations (e.g. 125 people per hectare) with multistorey dwellings set amongst landscaped areas. The non-potable water demands of these typologies provide an opportunity to supply harvested stormwater, and the landscaped surrounds offer a potential to integrate WSUD elements with multiple functions including treatment, harvesting, cooling and amenity improvements. Local parks in HDR areas also provide opportunities to integrate water into the urban fabric and increase the blue-green network that is central to the vision for the Western Parkland City.

Careful management of stormwater quantity and quantity is still required to ensure the performance criteria (water quality and flow objectives) for protecting and restoring the blue grid are met. Similar to LFI developments, a challenge for HDR developments is intercepting and using sufficient stormwater to limit the quantity of discharges to meet the stormwater flow targets.

A range of possible WSUD strategies is provided in the following tables (Table 8, Table 9), which apply depending on the scale of development and whether there is a regional stormwater treatment, harvesting and reticulation system. Two WSUD strategies adopt allotment and streetscape measures only, 2 strategies use local parks in addition to lots and streetscape measures, and 2 have regional stormwater treatment combined with a reticulated stormwater reuse system as part of the strategy.

Allotment and streetscape strategies rely on green roofs being implemented to reduce site impervious cover (for at least 70% of the roof area). This also improves amenity and would also contribute to green infrastructure, offering other benefits such as urban cooling and increased biodiversity. HDR developments would not be required to implement green roofs for stormwater management purposes where there is a regional treatment and reticulated stormwater reuse system. Green roofs may however, still be adopted to achieve the other liveability and amenity objectives for the Western Parkland City.

The performance of green roofs is modelled in MUSIC as reduced impervious cover of the source node. Similar to the work undertaken for LFI developments, all MUSIC model assumptions for this (HDR) work are provided in the companion study (DPE 2022d).

Table 8 Example WSUD strategies for HDR development

WSUD strategy – HDR		Stormwater infrastructure requirements								
		Reduced site coverage (green roof)	Tanks	Lot WSUD	Streetscape WSUD	Precinct WSUD (above 1% AEP)	Stormwater harvesting (local)	Stormwater quantity detention	Regional WSUD (maximise below 1% AEP)	Reticulated regional stormwater harvesting
A	Current targets adopted by local government					✓		✓		
B1	Lot (wetlands) and streetscape	✓	✓	✓	✓			✓		
B2	Lot (bioretention) and streetscape	✓	✓	✓	✓			✓		
C1	Lot, streetscape and POS wetland and reuse		✓	✓	✓	✓	✓	✓		
C2	Lot, streetscape and POS bioretention and reuse		✓	✓	✓	✓	✓	✓		
D1	Lot, street and regional treatment and reticulated stormwater reuse			✓	✓			✓	✓	✓
D2	Regional treatment (bioretention) and reticulated stormwater reuse							✓	✓	✓

Table 9 Infrastructure sizes and impervious (imperv.) cover for HDR development WSUD strategies

WSUD strategy – HDR		Stormwater treatment measures													% open space		% imperv.	
		Green roof (m^2/ha)	Tanks (kL/ha)	Lot bioretention (m^2/ha)	Street bioretention (m^2/ha)	Lot/ precinct wetland (m^2/ha)	Regional wetland (m^2/ha)	Regional bioretention (m^2/ha)	Stormwater harvesting on lot (m^3/ha)	Stormwater harvesting on lot to irrigation (ML/y/ha)	Stormwater harvesting to POS (m^3/ha)	Stormwater harvesting (local) to POS irrigation (ML/y/ha)	Reticulated regional stormwater harvesting (m^3/ha)	Reticulated regional stormwater harvesting (ML/y/ha)	Local	Regional	Lot	Total
A	Current targets adopted by local government							80							10	5	70	62
B1	Lot (wetlands) & streetscape	2,600	94		41	100			52	0.2					10	5	32	41
B2	Lot (bioretention) & streetscape	2,200	94	200	55				52	0.3					10	5	32	41
C1	Lot, streetscape & POS wetland & reuse		125	5	9	400					60	0.2			10	5	70	62
C2	Lot, streetscape & POS bioretention & reuse		125	5		150		30			60	0.3			10	5	70	62
D1	Lot, street & regional treatment & reticulated stormwater reuse			5	13		500						200	1.2	10	5	70	62
D2	Regional treatment (bioretention) & reticulated stormwater reuse						150	30					200	1.6	10	5	70	62

7. Costs of delivering WSUD strategies

Costs for delivering the WSUD strategies are based on:

- CAPEX – capital (expenditure) infrastructure costs to construct the stormwater treatment measures, including restoration and stabilisation works within waterways and riparian corridors
- OPEX – operating (expenditure) and maintenance costs for stormwater treatment and harvesting measures
- land (take) costs associated with the installation of stormwater treatment and harvesting measures
- recoverable costs that would apply to the regional treatment and reticulated reuse strategy (e.g. from recycled stormwater sales).

Costs have not been attributed to any entity but are a statement of the costs involved across the development life. The purpose of providing cost estimates is to enable a systematic and clear comparison between different strategies. Cost estimates do not include (co-)beneficial costs of protecting and restoring the blue grid, as the decision to deliver the Western Parkland City via a landscape led approach is well established in the Western City District Plan, Western Sydney Aerotropolis Plan and associated Western Sydney Aerotropolis Precinct Plan. It is worth noting however, that previous economic valuation studies show the net benefits of protecting and restoring the natural blue grid is over $1 billion (Bennett et al. 2015; INSW 2019). These net benefits include those for communities within the Wianamatta–South Creek catchment (e.g. bass fishing, riparian vegetation habitat for birds) and those for communities downstream in the Nepean River and out towards the ocean (e.g. swimming, no infestation of water weeds).

7.1 Cost assumptions

The stormwater treatment measures considered, and their capital cost unit rates are presented in Table 10. The unit rates relate to the wetted footprint of a stormwater treatment measure and these cover all associated costs (including access tracks, batter treatments) except for land costs. The rates have been estimated by using the most recent adopted cost rates by several local authorities, recent industry installations/construction including within Western Sydney, and industry best practice guidelines (Melbourne Water 2013; eWater 2021; Sydney Water 2021). The unit cost rates were also confirmed with the independent reviewers of this work, who represent local water and stormwater (engineer) practitioners and professionals from the urban development industry.

Land (take) costs associated with the installation of each stormwater treatment measure are based on the total area needed to construct, access and maintain an asset (not just the wetted footprint). Total land required is assumed to be double the area of the wetted footprint.

Land costs associated with a reduction in impervious area (i.e. reduction in development yield) are also included at the rate identified as ‘Land and opportunity above 1% AEP’ in Table 10. It is assumed that this land would otherwise be developed if it were not required to comply with the new stormwater management targets. Also shown in Table 10 are the cost rates that were assumed for areas below and above a 1% AEP flood level to recognise different land values.

Table 10 CAPEX unit rates assumed for different components of the WSUD strategies

Stormwater treatment measure	Unit	CAPEX
WSUD costs		
Rainwater tanks	kL	$1,000
Green roofs	m^2	$150
Allotment bioretention	m^2	$1,000
Streetscape bioretention* (or 'biopod') – excludes normal tree costs	m^2	$1,350
Passively irrigated trees – excludes tree costs	each	$300
Precinct/regional bioretention (>200 m^2)	m^2	$500
Wetland (>2,000 m^2)	m^2	$175
Local stormwater reuse system (e.g. in POS including above ground storages)	ML/y supplied	$100,000
Reticulated stormwater harvesting reuse system (including open storages)	ML/y supplied	$30,000
Reticulation pipe network	ha of development	$25,000
Waterway Rehabilitation Costs – full waterway	ha of development	$64,600
Waterway rehabilitation costs – part waterway	ha of development	$36,500
Land costs		
Land below 1% AEP	m^2	$90
Land and opportunity above 1% AEP	m^2	$600

* Streetscape bioretention costs do not cover hard edges and grated covers but are assumed to be located in verges with vegetated batters.

Streetscape bioretention systems in Table 10 are systems that are constructed in verges with vegetated batters (and can include street trees). These differ from streetscape bioretention systems in more space constrained areas that incorporate vertical sides, structural soils or permanent covers around trees, which are not included because they are much more expensive and generally are not required for greenfield installations.

Passively irrigated street trees are shown as a comparison with streetscape bioretention. The costs per tree include the 'plumbing' (kerb diverter, transfer pipe and sump) but not the cost of the tree or soil.

Reticulation pipe network costs are included as a stormwater cost in the regional treatment and reticulated reuse scheme (Option D) strategies. It is noted that a reticulated pipe may be installed as part of a recycled wastewater network separately, and therefore costs may not necessarily be incurred for the pipe. The pipe costs are however, included here for completeness of a WSUD strategy in the event there is no recycled wastewater system or there is a separate reticulated stormwater reuse network.

Rehabilitation costs for the waterways and riparian corridors were adopted from the Western Sydney Aerotropolis Riparian Corridors Assessment (Sydney Water 2021), which is largely based on the costs provided for the Western Sydney Place Infrastructure Compact (GSC 2020). The 'full waterway' works relate to restoration and stabilisation associated with business-as-usual stormwater management, where the hydrologic regime is significantly altered and would not preserve the ecological values of Wianamatta–South Creek. The 'part waterway' works are mainly associated with riparian plantings and some minor armouring, and assume that the flow targets are already being met (resulting in less impact on streams).

Costs for green roofs only account for the 'stormwater components' such as soil, vegetation and drainage pipes. They do not include the building costs such as structural elements.

Land costs for developable land (above 1% AEP) were estimated from Atlas Urban Economics (2020), and those for flood prone land (i.e. below 1% AEP) were estimated from the work of Frontier Economics (2021). It is recognised that property prices are volatile and are subject to change with market forces; however, these estimates provide a realistic interpretation of the impact of required land for stormwater measures on landowners at the time of writing and should be considered as relative.

As indicated above, the footprint of the total land required for stormwater infrastructure is assumed to be double the wetted footprint of a stormwater system (harvesting storages are assumed to be 2 m deep). Total land costs are a sum of the footprints required for stormwater treatment systems (excluding allotment and street measures because WSUD systems are integrated without requiring additional land), harvesting storage systems as well as reduced yield on the development site (i.e. any decrease in impervious area compared to a base case of 72% imperviousness for the total development area).

Note that the costs in Table 10 focus on stormwater treatment measures that manage flows, nutrients and sediments. They do not include costs for on lot spill control systems, oil separators or GPTs. Costs for GPTs are excluded as there is such a wide range of proprietary products available with hugely varying treatment performances, and few with industry endorsed performance criteria.

Table 11 OPEX unit rates assumed for different components of the WSUD strategies

Stormwater treatment measure	Unit	Annual cost
WSUD costs		
Rainwater tanks	KL/y	$10
Allotment bioretention	m^2/y	$5
Streetscape bioretention (or ‘biopod’) – excludes normal tree costs	m^2/y	$50
Precinct/regional bioretention (>200 m^2)	m^2/y	$3
Wetland (>2,000 m^2)	m^2/y	$2
Local stormwater reuse system (e.g. in POS including above ground storages)	ML/y	$2,250
Reticulated stormwater harvesting reuse system (including storages)	ML/y	$1,250
Water reuse revenue		
Sold water	KL	$2.20

The operating costs shown in Table 11 are based on operating stormwater systems in Australia from commercial (in confidence) projects undertaken by the document authors (Design Flow Consulting Pty Ltd) and then cross checked with rates quoted in industry best practice guidelines (Melbourne Water 2013; eWater 2021; Sydney Water 2021). The unit rates are expressed as dollar figures per unit (as opposed to percentages of CAPEX) to enable direct derivation of operating costs from the scale of the stormwater treatment measures. Operating costs for stormwater harvesting schemes have been derived from a review of operating costs for local-scale schemes (e.g. 5–20 ML/year) and then dividing by a typical scale for an oval irrigation scheme (i.e. 10 ML/year).

Costs to operate reticulated stormwater harvesting schemes have been based on the City of Salisbury (South Australia) scheme because it is of similar scale to that proposed (by Sydney Water) for Wianamatta–South Creek. The costs reported by previous studies (e.g. Dillon et al. 2013; Radcliffe et al. 2017) have been factored up (approximately doubled) to account for uncertainties and because it is unlikely to be a managed aquifer scheme.

Stormwater reuse revenue rates were estimated from discussions with City of Salisbury. The unit rates are conservative because the configuration of a reticulated stormwater reuse scheme in Wianamatta–South Creek is unknown.

Figure 3 shows a bioretention system in the City of Salisbury at a site (Unity Park) that harvests more than 600 ML of stormwater each year for reuse.

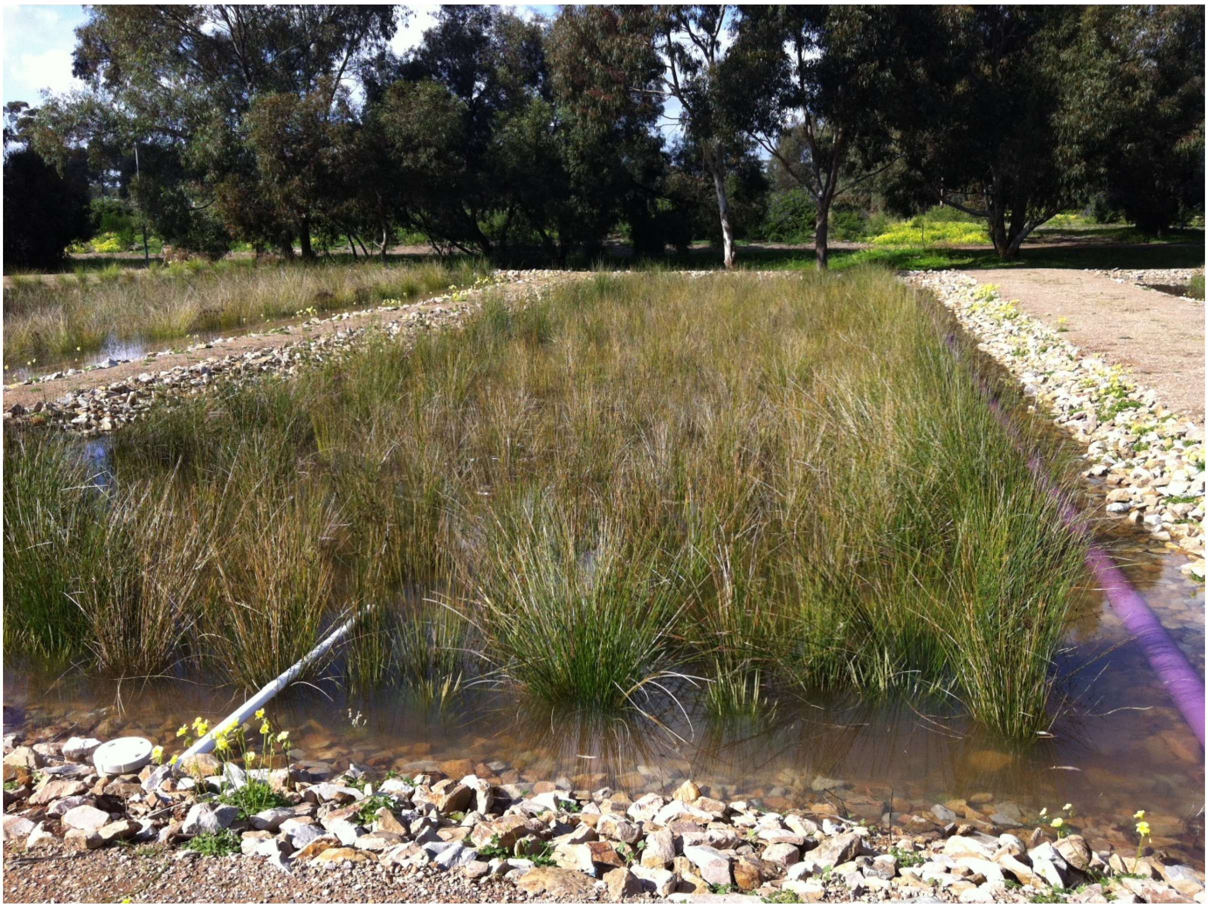

Figure 3 Salisbury Water harvesting bioretention system (Unity Park)
Photo: Design Flow Consulting

7.2 Cost comparisons

Using the unit rates shown in Table 10 and Table 11, cost estimates are calculated for each strategy using the infrastructure sizes outlined in Table 7 (LFI) and Table 9 (HDR). Note that Option A does not achieve the stormwater management targets and will result in waterway degradation and is only included for information and transparency. Example layouts of selected WSUD strategies are illustrated in the companion study (DPE 2022a) to demonstrate how the stormwater infrastructure may interact with other elements of a development.

It is quite evident from the plots (e.g. Figure 4, Figure 5) that regional treatment and reticulated stormwater reuse strategies (i.e. Option D) represent the most cost-effective approach for delivering the stormwater management targets. Connecting harvested stormwater to high water users via a reticulated stormwater reuse scheme is the most cost-effective method of losing excess stormwater to protect the waterways and achieving the Western Parkland City vision, with the added benefit of conserving potable water for potable uses.

The benefit of the regional treatment and reticulated reuse strategy is emphasised further when land costs (Figure 5) are compared. The cost of land associated with the reduced imperviousness is significant in Options B and C (except Option C4).

Option C4 (i.e. using lot, local POS and regional treatment within the 1% AEP area) is also shown as a potentially viable option in Figure 5. However, it is worth noting this option requires 100% of the pervious area of allotments and 100% of POS pervious areas to be irrigated (i.e. to create a sufficiently large irrigation demand). The viability and ongoing commitment to such an extensive irrigation scheme would need to be thoroughly investigated and agreed upon with a local authority for POS, and conditioned as part of approval for private allotments.

Operational costs are presented in Table 14 and Table 15, and show the benefit of revenue from the sale of harvested stormwater in the reticulated stormwater schemes (Option D). In fact, this revenue outweighs the operational costs for several of the D options for LFI development and Option D2 for HDR development.

Table 12 Capital cost estimates of WSUD and land for LFI developments

WSUD strategy – LFI		Stormwater treatment measures										Land costs			WSUD + land total ($/ha)
		Tanks ($/ha)	Lot bioretention ($/ha)	Street bioretention ($/ha)	Regional wetland ($/ha)	Regional bioretention ($/ha)	Stormwater harvesting on lot ($/ha)	Stormwater harvesting for POS ($/ha)	Regional harvesting & reticulation ($/ha)	Waterway rehabilitation ($/ha)	WSUD cost total ($/ha)	Above 1% AEP ($/ha)	Below 1% AEP ($/ha)	Total land cost ($/ha)	
A	Current targets adopted by local government	$31,000	$42,000			$20,000				$64,600	$157,600	$48,000		$48,000	$205,600
B1	Lot and streetscape	$140,000	$10,200	$47,250	$96,250					$36,500	$330,200	$1,440,000		$1,440,000	$1,770,200
B2	Lot, streetscape and local irrigation	$14,000	$10,200	$47,250	$96,250		$70,000			$36,500	$274,200	$1,140,000		$1,140,000	$1,414,200
C1-a	Lot, local POS and regional treatment (above 1% AEP)	$103,700	$69,300	$33,075	$87,500					$36,500	$330,075	$1,200,000		$1,200,000	$1,530,075
C1-b	Lot, local POS and regional treatment (above 1% AEP)	$47,000	$55,800	$26,595	$105,000					$36,500	$270,895	$1,800,000		$1,800,000	$2,070,895
C2-a	Lot, local POS and regional treatment (below 1% AEP)	$103,700	$69,300	$33,750	$87,500					$36,500	$330,750	$600,000	$90,000	$690,000	$1,020,750
C2-b	Lot, local POS and regional treatment (below 1% AEP)	$47,000	$55,800	$26,595	$105,000					$36,500	$270,895	$1,080,000	$108,000	$1,188,000	$1,458,895
C3-a	Lot, local POS and regional treatment and POS irrigation (below 1% AEP)	$75,000	$69,300	$32,940	$87,500			$30,000		$36,500	$331,240	$420,000	$108,000	$528,000	$859,240
C3-b	Lot, local POS and regional treatment and POS irrigation (below 1% AEP)	$47,000	$59,600	$18,900	$61,250			$60,000		$36,500	$283,250	$600,000	$81,000	$681,000	$964,250
C4	Lot, local POS and regional treatment and POS irrigation (below 1% AEP)	$60,000	$69,300	$32,940	$61,250			$76,000		$36,500	$335,990		$81,000	$81,000	$416,990
D1-a	Lots, regional treatment and reticulated stormwater reuse	$55,300	$24,300		$87,500				$64,600	$36,500	$268,200		$117,000	$117,000	$385,200
D1-b	Lots, regional treatment and reticulated stormwater reuse	$14,000			$35,000	$30,000			$80,500	$36,500	$196,000		$73,800	$73,800	$269,800
D2-a	Regional treatment and reticulated stormwater reuse (no tanks)				$65,625	$30,000			$73,000	$36,500	$205,125		$112,500	$112,500	$317,625
D2-b	Regional treatment and reticulated stormwater reuse (no tanks)				$35,000	$30,000			$84,100	$36,500	$185,600		$81,000	$81,000	$266,600
D3-a	Lots and streetscape with regional treatment and reticulated stormwater reuse	$55,300	$69,300		$52,500				$66,700	$36,500	$280,300		$81,000	$81,000	$361,300
D3-b	Lots and streetscape with regional treatment and reticulated stormwater reuse	$55,300	$69,300	$32,940	$26,250	$20,000			$71,500	$36,500	$311,790		$61,200	$61,200	$372,990

Table 13 Capital cost estimates for WSUD and land for HDR development WSUD strategies

WSUD strategy – HDR		Stormwater treatment measures												Land costs			WSUD + land total ($/ha)
		Green roof ($/ha)	Tanks ($/ha)	Lot bioretention ($/ha)	Lot wetland ($/ha)	Street bioretention ($/ha)	Regional wetland ($/ha)	Regional bioretention ($/ha)	Stormwater harvesting on lot ($/ha)	Stormwater harvesting for POS ($/ha)	Regional harvesting & reticulation ($/ha)	Waterway rehabilitation ($/ha)	WSUD cost total ($/ha)	Above 1% AEP ($/ha)	Below 1% AEP ($/ha)	Total land cost ($/ha)	
A	Current targets adopted by local government							$40,000				$64,600	$104,600	$96,000		$96,000	$200,600
B1	Lot (wetlands) & streetscape	$390,000	$94,000		$30,000	$55,350			$52,000			$36,500	$657,850				$657,850
B2	Lot (bioretention) & streetscape	$330,000	$94,000	$200,000		$73,575			$52,000			$36,500	$786,075				$786,075
C1	Lot, streetscape & POS wetland & reuse		$125,000	$5,000		$12,150	$70,000			$22,000		$36,500	$270,650	$516,000		$516,000	$786,650
C2	Lot, streetscape & POS bioretention & reuse		$125,000	$5,000			$26,250	$15,000		$27,000		$36,500	$234,750	$252,000		$252,000	$486,750
D1	Lot, street & regional treatment & reticulated stormwater reuse			$5,000		$16,875	$87,500				$61,000	$36,500	$206,875		$108,000	$108,000	$314,875
D2	Regional treatment (bioretention) & reticulated stormwater reuse						$26,250	$15,000			$73,000	$36,500	$150,750		$50,400	$50,400	$201,150

Table 14 Operating cost estimates of WSUD for LFI developments (* POS denotes public open space)

WSUD strategy – LFI		Maintenance costs ($/ha/y)									Water sales ($/ha/y)	Net total ($/ha/y)
		Tanks	Lot bioretention	Street bioretention	Wetland	Regional bioretention	Stormwater harvesting for lot irrigation	Stormwater harvesting for POS irrigation	Reticulated regional stormwater harvesting	Total ($/ha/y)		
A	Current targets adopted by local government	$310	$210			$120				$640		$640
B1	Lot and streetscape	$1,400	$51	$1,750	$1,100					$4,301		$4,301
B2	Lot, streetscape and local irrigation	$140	$51	$1,750	$1,100		$1,575			$4,616		$4,616
C1-a	Lot, local POS and regional treatment (above 1% AEP)	$1,037	$347	$1,225	$1,000					$3,609		$3,609
C1-b	Lot, local POS and regional treatment (above 1% AEP)	$470	$279	$985	$1,200					$2,934		$2,934
C2-a	Lot, local POS open space and regional treatment (below 1% AEP)	$1,037	$347	$1,250	$1,000					$3,634		$3,634
C2-b	Lot, local POS and regional treatment (below 1% AEP)	$470	$279	$985	$1,200					$2,934		$2,934
C3-a	Lot, local POS and regional treatment & POS irrigation (below 1% AEP)	$750	$347	$1,220	$1,000			$675		$3,992		$3,992
C3-b	Lot, local POS and regional treatment & POS irrigation (below 1% AEP)	$470	$298	$700	$700			$1,350		$3,518		$3,518
C4	Lot, local POS and regional treatment & POS irrigation (below 1% AEP)	$600	$347	$1,220	$700			$1,710		$4,577		$4,577
D1-a	Lots, regional treatment and reticulated stormwater reuse	$553	$122		$1,000				$1,650	$3,325	–$2,904	$421
D1-b	Lots, regional treatment and reticulated stormwater reuse	$140			$400	$180			$2,313	$3,033	–$4,070	–$1,038
D2-a	Regional treatment and reticulated stormwater reuse (no tanks)				$750	$180			$2,000	$2,930	–$3,520	–$590
D2-b	Regional treatment and reticulated stormwater reuse (no tanks)				$400	$180			$2,463	$3,043	–$4,334	–$1,292
D3-a	Lots and streetscape with regional treatment and reticulated stormwater reuse	$553	$347		$600				$1,738	$3,237	–$3,058	$179
D3-b	Lots and streetscape with regional treatment and reticulated stormwater reuse	$553	$347	$1,220	$300	$120			$1,938	$4,477	–$3,410	$1,067

Table 15 Operating cost estimates for WSUD for HDR development WSUD strategies

WSUD strategy – HDR		Maintenance costs ($/ha/y)									Water sales ($/ha/y)	Net total ($/ha/y)
		Tanks	Lot bioretention	Street bioretention	Wetland	Regional bioretention	Stormwater harvesting for lot irrigation	Stormwater harvesting for POS irrigation	Reticulated regional stormwater harvesting	Total ($/ha/y)		
A	Current targets adopted by local government					$240				$240		$240
B1	Lot (wetlands) & streetscape	$940		$2,050	$200		$405			$3,595		$3,595
B2	Lot (bioretention) & streetscape	$940	$1,000	$2,725			$698			$5,363		$5,363
C1	Lot, streetscape & POS wetland & reuse	$1,250	$25	$450	$800			$495		$3,020		$3,020
C2	Lot, streetscape & POS bioretention & reuse	$1,250	$25		$300	$90		$608		$2,273		$2,273
D1	Lot, street & regional treatment & reticulated stormwater reuse		$25	$625	$1,000				$1,500	$3,150	–$2,640	$510
D2	Regional treatment (bioretention) & reticulated stormwater reuse				$300	$90			$2,000	$2,390	–$3,520	–$1,130

Note that operating costs for green roofs are assumed to be included with landscape maintenance (not included here).

Figure 4 shows plots of the CAPEX for the LFI development WSUD strategies, and Figure 5 includes the OPEX and land costs. OPEX represents the net present value by assuming a 35-year life cycle and 2% discount rate. The distinct differences among the approaches is evident; in particular, the land costs associated with reducing the site coverage in Options B and C.

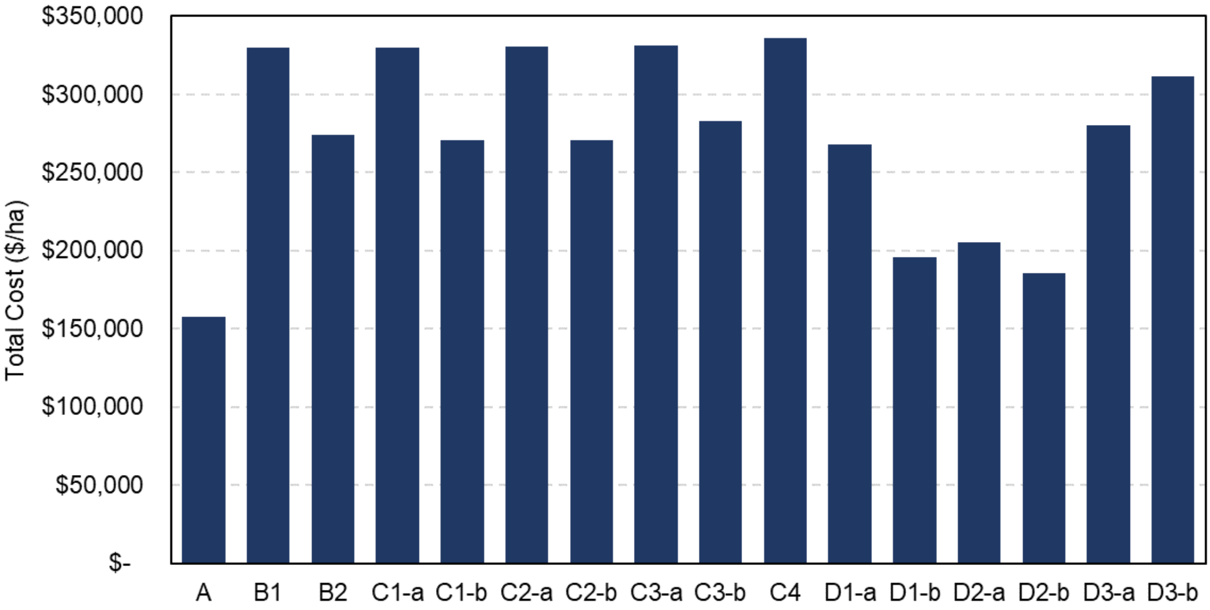

Figure 4 Capital (CAPEX) cost of WSUD strategies for LFI development

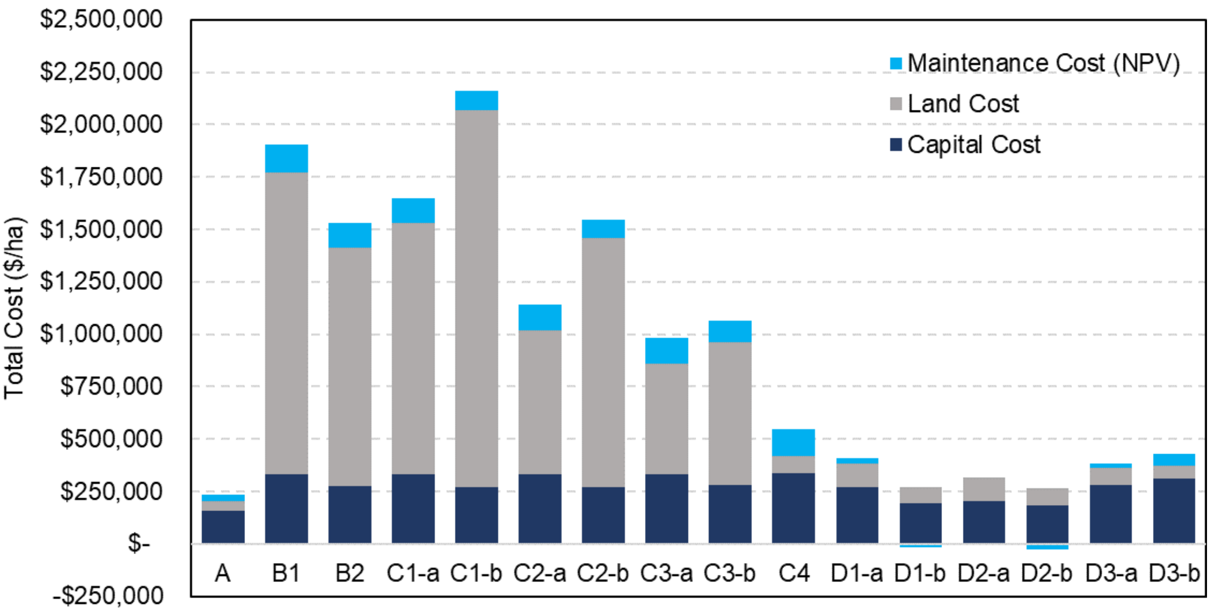

Figure 5 Capital (CAPEX), maintenance (OPEX) and land costs of WSUD strategies for LFI development

Figure 6 shows plots of the CAPEX for the HDR development WSUD strategies, and Figure 7 includes the OPEX and land costs. Note there are no land costs associated with Options B1 and B2 because green roofs are adopted, and therefore the lots can be fully developed. The plots show that Option D has the lowest combined costs, noting that Option A does not meet the stormwater management targets and will not protect and restore the blue grid.

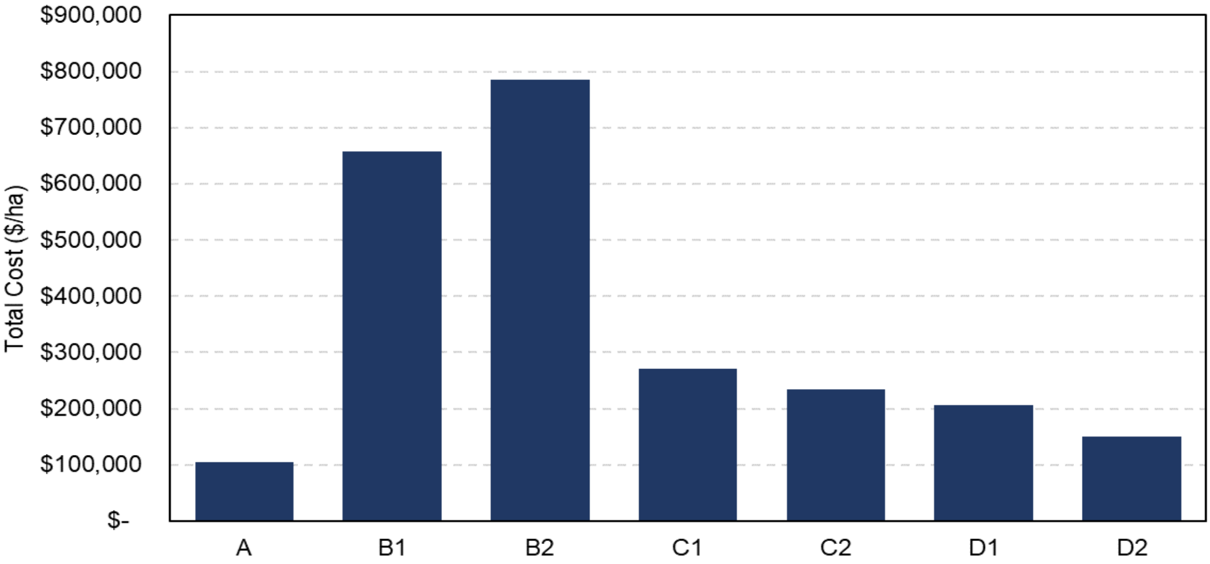

Figure 6 Capital (CAPEX) cost of WSUD strategies for HDR development

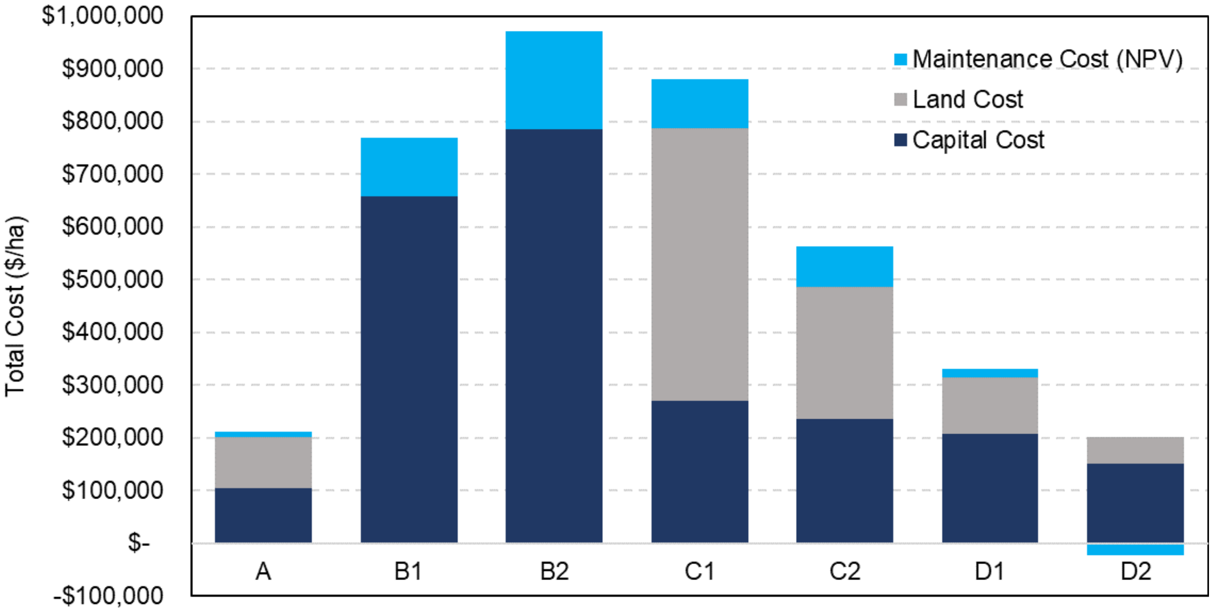

Figure 7 Capital (CAPEX), maintenance (OPEX) and land costs of WSUD strategies for HDR development

7.3 Operational risks

Table 16 and Table 17 describe some of the operation and management risks associated with the different WSUD strategies. The risks relate to implementation and operation of the WSUD systems discussed in this document and the resulting potential impact to the blue grid. It is noted again that land uses will also have other on-lot measures, such as GPTs and oil capture systems (particularly for LFI land uses); however, these do not relate to the comparison between the stormwater schemes discussed here.

In general, the more WSUD assets that are used, particularly in private ownership, the higher the risk for the long-term delivery of stormwater management outcomes. A strategy that relies on many distributed/decentralised WSUD assets will require all proponents to design and deliver the WSUD infrastructure, and then owners to manage the assets effectively. This includes a need for auditing and compliance checks of the WSUD assets.

WSUD strategies that have fewer assets and a defined owner (e.g. a trunk drainage manager) are considered to have fewer long-term risks of failure and consequential negative impacts on the blue grid. Indeed, the qualitative assessment of risks shown in Table 16 and Table 17 is consistent with the lowest cost strategies that incorporate a trunk drainage manager to operate a regional treatment and reticulated stormwater reuse system that is plumbed throughout the development area to all allotments.

Human health risks associated with any stormwater reuse scheme are important considerations for the design and operation of the system. It is assumed that any stormwater reuse scheme in a public domain would follow the requirements of the Australian Stormwater Recycling Guidelines (NRMMC et al. 2009), which outline requirements to adequately manage health risks. A similar conclusion could be drawn when assessing human health risks among between schemes; that is, fewer (larger) systems with defined owners and operators present fewer risks than many distributed/decentralised systems.

Table 16 Risks of impacting the blue grid as a result of operation and maintenance requirements for LFI developments – the blue grid is made up of waterways, riparian corridors and other water dependent ecosystems

WSUD strategy – LFI		Stormwater infrastructure requirements									Risk	Description of risk
		Reduced site coverage	Tanks	Lot WSUD	Streetscape WSUD	Precinct WSUD (above 1% AEP)	Regional WSUD (maximise below 1% AEP)	On-site stormwater quantity detention	POS stormwater harvesting	Reticulated regional stormwater harvesting		
A	Current targets adopted by local government		✓	✓		✓		✓			High	Performance criteria (water quality and flow objectives) for blue grid not met, resulting in negative impacts
B1	Lot and streetscape	✓	✓	✓	✓	✓		✓			High	Relies on allotment WSUD requiring comprehensive compliance and regulation, and maintenance of distributed street bioretention
B2	Lot, streetscape and local irrigation	✓	✓	✓	✓	✓		✓			High	Relies on allotment WSUD requiring comprehensive compliance and regulation, and maintenance of distributed street bioretention
C1-a, b	Lot, local POS and regional treatment (above 1% AEP)	✓	✓	✓	✓	✓		✓			High	Relies on allotment WSUD requiring comprehensive compliance and regulation, and maintenance of distributed street bioretention and local stormwater harvesting scheme
C2-a, b	Lot, local POS and regional treatment (below 1% AEP)	✓	✓	✓	✓		✓	✓			High	Relies on allotment WSUD requiring comprehensive compliance and regulation, and maintenance of distributed street bioretention and local stormwater harvesting scheme
C3-a, b	Lot, local POS and regional treatment and POS irrigation (below 1% AEP)	✓	✓	✓	✓		✓	✓	✓		High	Relies on allotment WSUD, and maintenance of distributed street bioretention and POS reuse schemes
C4	Lot, local POS and regional treatment and POS irrigation (below 1% AEP)		✓	✓	✓		✓	✓	✓		High	Less reliant on allotment measures and lot harvesting, but relies on and maintenance of streetscape bioretention, POS reuse systems and very high proportions of irrigated area
D1-a	Lots, regional treatment and reticulated stormwater reuse		✓	✓			✓	✓		✓	Low	Minimal allotment WSUD, no streetscape WSUD, trunk drainage manager for regional systems and reticulated reuse
D1-b	Lots, regional treatment and reticulated stormwater reuse		✓				✓	✓		✓	Low	Tanks on allotments, no streetscape WSUD, trunk drainage manager for regional systems and reticulated reuse
D2-a, b	Regional treatment and reticulated stormwater reuse (no tanks)		✓				✓	✓		✓	Low	No allotment or streetscape WSUD, trunk drainage manager for regional systems and reticulated reuse
D3-a, b	Lots and streetscape with regional treatment and reticulated stormwater reuse		✓	✓	✓		✓	✓		✓	Low – moderate	Relies on some allotment and streetscape WSUD, trunk drainage manager for regional systems and reticulated reuse

Table 17 Example WSUD strategies for HDR development

WSUD strategy – HDR		Stormwater infrastructure requirements									Risk	Description of risk
		Reduced site coverage (green roof)	Tanks	Lot WSUD	Streetscape WSUD	Precinct WSUD (above 1% AEP)	Stormwater harvesting (local)	On-site stormwater quantity detention	Regional WSUD (maximise below 1% AEP)	Reticulated regional stormwater harvesting		
A	Current targets adopted by local government		✓	✓	✓	✓		✓			High	Performance criteria (water quality and flow objectives) for blue grid not met, resulting in negative impacts
B1	Lot (wetlands) and streetscape	✓	✓	✓	✓			✓			High	Relies on allotment WSUD (including reuse) requiring comprehensive compliance and regulation and maintenance of distributed street bioretention
B2	Lot (bioretention) and streetscape	✓	✓	✓	✓			✓			High	Relies on allotment WSUD (including reuse) requiring comprehensive compliance and regulation and maintenance of distributed street bioretention
C1	Lot, streetscape and POS wetland and reuse		✓	✓	✓	✓	✓	✓			High	Relies on allotment WSUD, distributed street bioretention and maintenance of local POS reuse schemes
C2	Lot, streetscape and POS bioretention and reuse		✓	✓	✓	✓	✓	✓			High	Relies on allotment WSUD, distributed street bioretention and maintenance of local POS reuse schemes
D1	Lot, street and regional treatment and reticulated stormwater reuse			✓	✓			✓	✓	✓	Low – moderate	Relies on some allotment and streetscape WSUD, trunk drainage manager for regional systems and reticulated reuse
D2	Regional treatment (bioretention) and reticulated stormwater reuse							✓	✓	✓	Low	No allotment or streetscape WSUD, trunk drainage manager for regional systems and reticulated reuse

8. Case study – regional WSUD strategy

To illustrate the potential implementation of a WSUD strategy in the Wianamatta–South Creek catchment, a hypothetical case study was developed for the Mamre Road Precinct. The case study assumes that a regional treatment and reticulated stormwater reuse scheme is implemented (i.e. Option D). The case study provides a high-level concept layout for required treatment systems and reuse storages distributed across the precinct, for illustrative purposes only.

The approach makes use of the multifunctional intention of the Blue and Green Infrastructure Framework along Wianamatta–South Creek and Ropes Creek (i.e. outside significant vegetation areas). The stormwater treatment measures are located within the 1% AEP flood extents, while ensuring flood behaviour is not compromised (see the ‘Flood Risk Management Manual Package’, and principles in our technical guide – DPE 2022a).

8.1 Site description

The Mamre Road Precinct and approximate stormwater catchment is shown in Figure 8. The precinct site has a ridge running roughly north–south, meaning that stormwater will flow either westwards into Wianamatta–South Creek or eastwards into Ropes Creek.

The dominant typology in the Mamre Road Precinct is LFI development. The MUSIC model assumptions relating to this typology are outlined in our companion study (DPE 2022a), and were adopted for the case study. The most significant characteristic of the assumptions is the 85% impervious cover in the allotments, consistent with the Mamre Road Precinct Development Control Plan.

8.2 Proposed treatment and reuse system description

The WSUD strategy adopted for the case study is based on the Option D1-b for LFI areas (Table 6), and water demand and irrigation rates from Department of Planning and Environment (2022a). This WSUD strategy assumes:

- tanks on individual allotments to capture 50% of roof areas and supply water for toilet flushing (14 KL tanks with 375 L/day demands per hectare of development)
- regional wetland systems that are 2% of the catchment areas, with a small rate of treated flow released to meet environmental flow needs of the waterways
- regional bioretention systems at 0.6% of the catchment area that share extended detention with the wetland system
- the regional treatment systems are located in POS (managed by a trunk drainage manager) and in the 1% AEP area where possible
- treated water from the treatment system is directed to a storage, as part of a broader stormwater harvesting scheme
- the regional water storage systems are sized to be 300 m^3 per hectare and have a constant daily demand of 6.25 KL/day per hectare, as part of a regional reticulated reuse system.

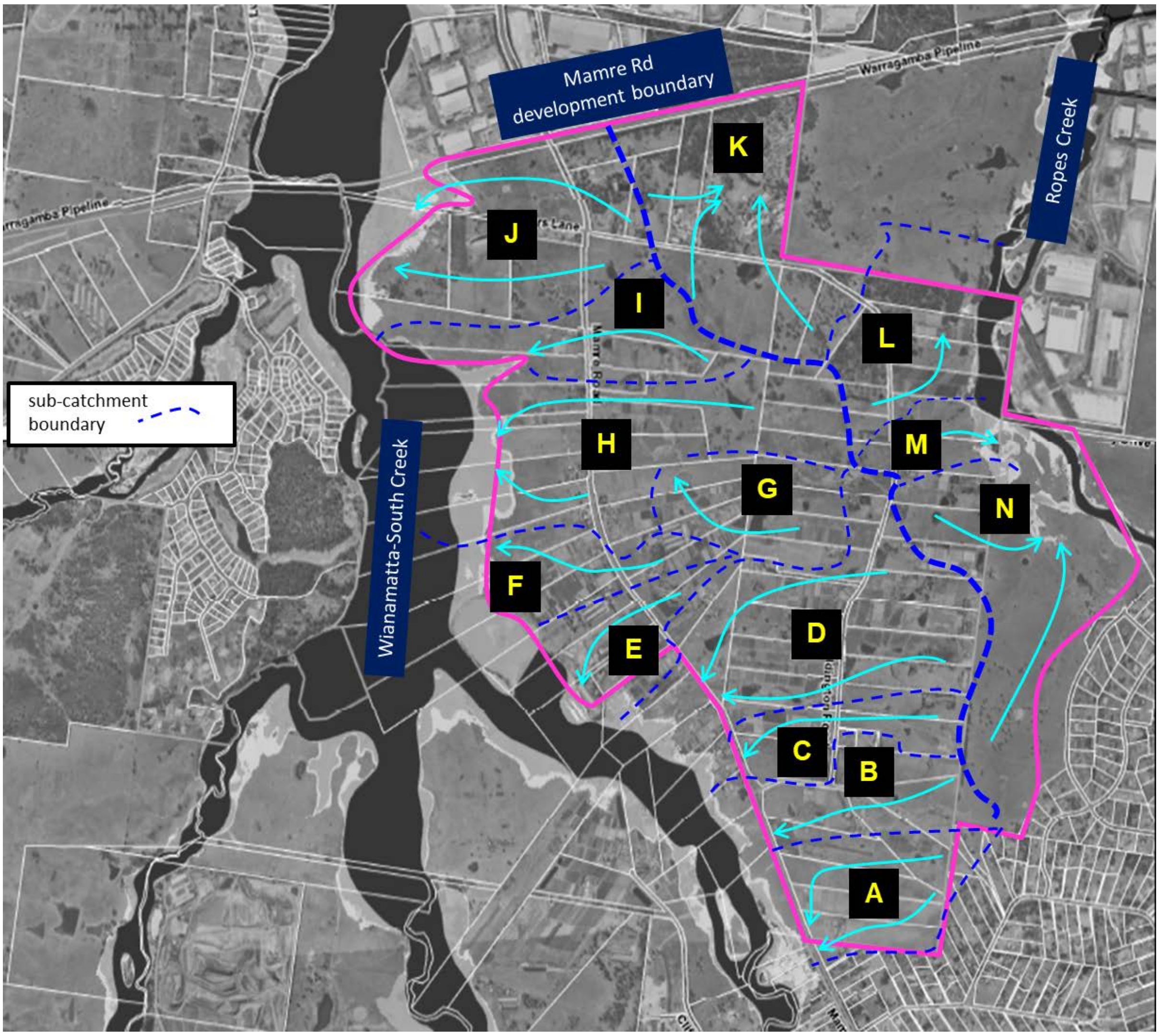

Figure 8 Mamre Road Precinct and stormwater catchment

The intent is that the treatment systems and storages are located within the 1% AEP areas if there is sufficient available space. Another design approach is to limit the sub-catchment areas to each treatment system to approximately 150 ha so the size of each system is not too large and the risk of damage caused from spills is spread, so if one treatment system is off-line it will not significantly affect the overall treatment and reuse system. This approach results in some treatment systems being located above the 1% AEP in the development area.

In addition to the above requirements, each lot would be required to meet on-site detention requirements as well as gross pollutant capture and possibly oil spill containment, depending on the land-use type.

Table 18 provides a list of sub-catchments and sizes of respective stormwater treatment measures.

Table 18 Sub-catchments making up the Mamre Road Precinct, and sizes of respective stormwater treatment measures

Sub-catchment	Area (ha)	Wetland (m^2)	Bioretention (m^2)
A	100	20,000	6,000
B	50	10,000	3,000
C	40	8,000	2,400
D	160	32,000	9,600
E	35	7,000	2,100
F	50	10,000	3,000
G	90	18,000	5,400
H	120	24,000	7,200
I	50	10,000	3,000
J	115	23,000	6,900
K	100	20,000	6,000
L	25	5,000	1,500
M	30	6,000	1,800
N	100	20,000	6,000
Total	1,065	213,000	63,900

The storages have been consolidated to have one storage in the west (Wianamatta–South Creek – 243 ML) and one in the east (Ropes Creek – 77 ML). Treated stormwater would be pumped or gravity fed from the treatment systems to these storages, which would then connect to a broader reuse scheme and potentially be combined with treated wastewater. This means each storage in this example would not require its own treatment plant as it would transfer flows to separate storages (and a treatment plant) as part of a broader scheme.

An indicative layout of the regional treatment and reuse storages is shown in Figure 9. It shows how most of the treatment and storage systems are located along the edge of the development and are within the 1% AEP areas.

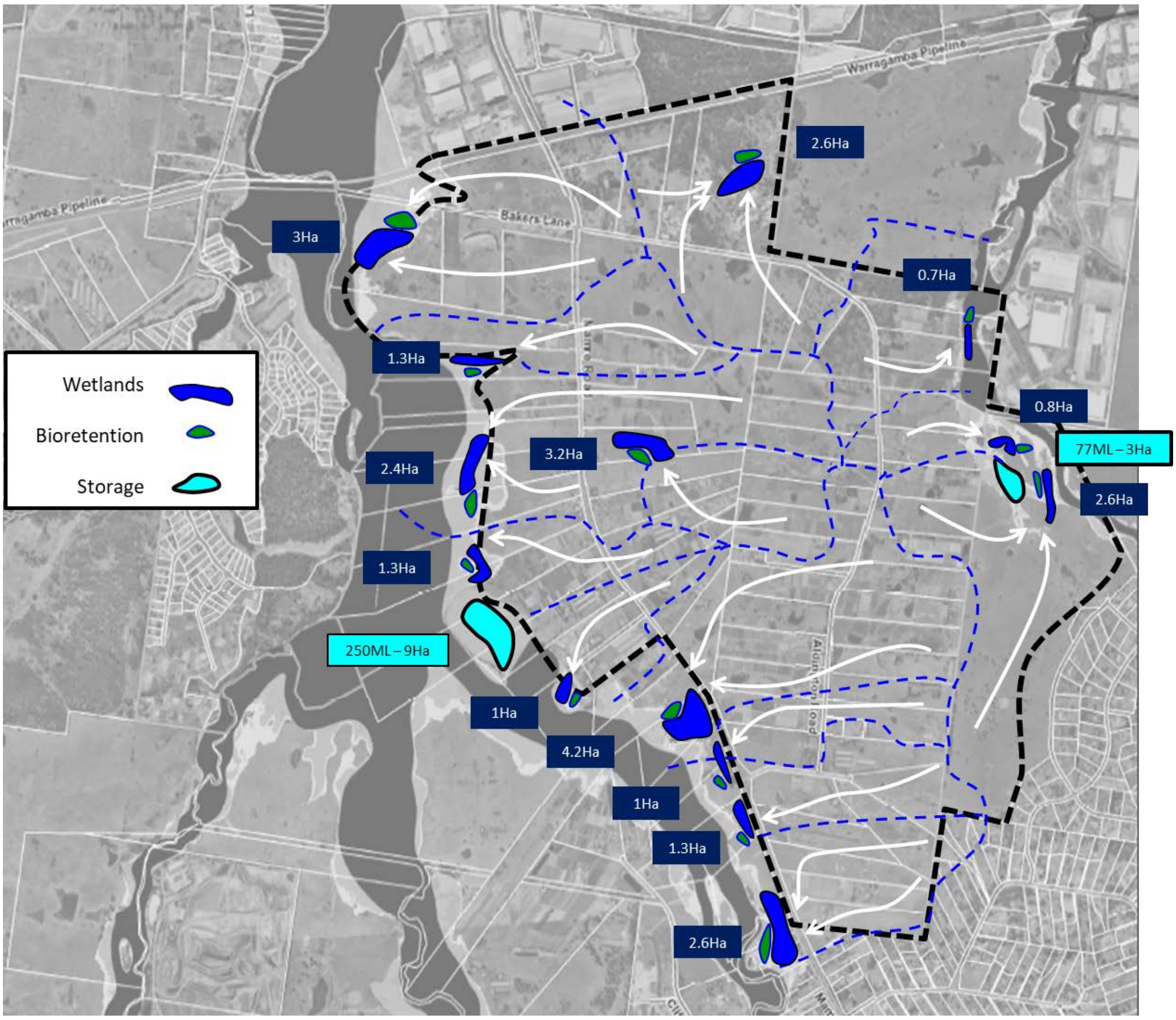

Figure 9 Indicative layout for the case study showing the sub-catchments, treatments and reuse storages

8.3 System performance

The system performance of the above WSUD strategy was modelled and analysed using the calibrated MUSIC file and post processing Excel spreadsheet provided with our companion study (i.e. technical guide – DPE 2022a). Specifically, the model is used to generate daily flows, and the spreadsheet to develop flow duration curves and assess compliance with the targets. Table 19 and Table 20 were produced directly from the spreadsheet. They show the modelled results of stormwater quality and quantity, compared against the respective targets. These results indicate that the WSUD strategy achieves both targets. Figure 10 shows the flow duration curve, which was also directly produced from the spreadsheet.

Table 19 Modelled stormwater quality compared against target

Water quality targets alternative 1			
Parameter	**Result**	**Complies?**	**Target**
TSS	94	Yes	>90% load reduction
TP	85	Yes	>80% load reduction
TN	74	Yes	>65% load reduction

Table 20 Modelled stormwater quantity (flow) compared against target

Flow targets alternative 1			
Parameter	**Result**	**Complies?**	**Target**
95%ile	13,196	Yes	3,000–15,000 L/ha/day
90%ile	1,769	Yes	1,000–5,000 L/ha/day
75%ile	916	Yes	100–1,000 L/ha/day
50%ile	32	Yes	5–100 L/ha/day
Cease to flow	12%	No	10–30%

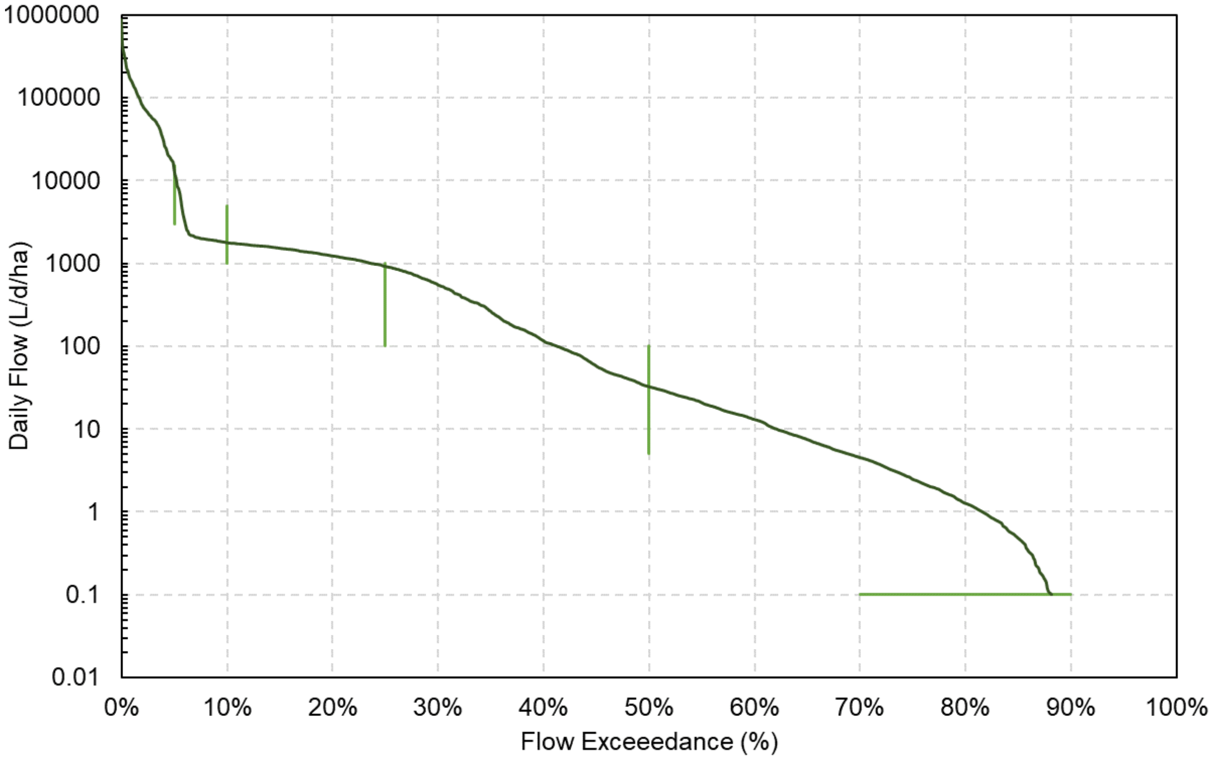

Figure 10 Flow duration curve for proposed WSUD strategy

Overall, the modelling results indicate the following water balance estimates:

- 4,800 ML/year of runoff is generated
- 135 ML/year is used for toilet flushing
- 645 ML/year is lost to evaporation from wetlands, bioretention and storages
- 25 ML/year is lost to seepage
- 1,785 ML/year is used through the reticulated stormwater reuse system
- 2,210 ML/year is released back to Wianamatta–South Creek.

It is also worth noting that while approximately 1,800 ML/year will be reused through the reticulated stormwater reuse system, this could be increased to up to 2,400 ML/year if further demands are found outside of the case study area or larger storages were used. In the current scenario the storages overflow approximately 600 ML/year to the waterways, which could be reduced if the storages were made larger or if there were more demands on the reuse system.

8.4 WSUD cost estimates

The costs for this WSUD strategy were estimated using the unit rates shown Table 10. Construction cost estimates are presented in Table 21 for the type and scale of infrastructure needed to meet the targets.

Table 22 presents an estimate of the land costs associated with the WSUD infrastructure. The land required was estimated by doubling the water surface area to account for other land requirements such as batters, bunds and access tracks. The water storages were assumed to have an average depth of 2 m.

Land costs are estimated for infrastructure located above and below the 1% AEP as it will have different values, as indicated in Table 10.

Table 21 Cost estimates for the stormwater treatment measures

Stormwater treatment measure	Unit	Rate	Quantity	Costs ($million)
Rainwater tanks	kL	1,000	14,910	14.9
Regional wetlands	m^2	175	213,000	37.3
Regional bioretention	m^2	500	63,900	32.0
Reuse storage and treatment	ML	30,000	1,800	54.0
Reticulation	ha	25,000	1,065	26.6
Waterway rehabilitation	ha	36,500	1,065	38.9
			Total CAPEX	**$204 million**
			CAPEX per ha	**$191,204**

Table 22 Estimated land (take) costs associated with the installation of stormwater treatment measures

Land take area	Wetted area (m^2)	Total area required (m^2)	Rate ($/$m^2$)	Costs ($million)
Treatment areas below 1% AEP	253,500	507,000	90	45.6
Treatment areas above 1% AEP	23,400	46,800	600	28.1
Storage areas below 1% AEP	319,500	319,500	90	28.8
			Total land cost	**$102 million**
			Land cost per ha	**$96,211**

Operation costs for the WSUD are shown in Table 23. The costs to operate and maintain the stormwater treatment and reuse systems is approximately $2,800 per hectare each year. This cost is outweighed by the revenue from stormwater sales so that the net operation costs are a revenue of approximately $900 per hectare each year, equivalent to $940,000 per year for the total case study area.

Table 23 Estimated operation costs and stormwater sales revenue

Stormwater treatment measure	Unit	Rate	Quantity	Costs ($/y)
Rainwater tanks	$/kL	10	14,910	149,100
Regional wetlands	$/m^2/y	2	213,000	426,000
Regional bioretention	$/m^2/y	3	63,900	191,700
Reuse storage and treatment	$/ML/y	1,250	1,800	2,250,000
Stormwater reuse sales	$/ML/y	–2,200	1,800	–3,960,000
			Total OPEX per year	**–$943,200**
			OPEX per ha per year	**–$886**

8.5 Case study outcomes

This case study indicates that a combined cost of WSUD infrastructure and waterway rehabilitation is $191,000 per hectare if a regional treatment and reticulated reuse system is implemented. This cost includes $14,000 per hectare for on allotment rainwater tanks with the remainder of the costs being subdivision-scale works. This is very similar to the rates presented for Option D1-b (Table 12).

The treatment and storage systems would require approximately 87 ha of land and costs associated with land acquisition equate approximately to an additional $96,000 per hectare. This rate is higher than Option D1-b ($76,000/ha) because some of the treatment systems are in areas above 1% AEP, which have significantly higher land costs (Option D1-b assumed all areas were below the 1% AEP).

The overall WSUD and land capital cost is $276,000 per hectare. Revenue from harvested stormwater sales is estimated to exceed annual operation costs, providing a revenue of approximately $900 per hectare per year.

The success of a regional treatment and reticulation system relies on available land for infrastructure and this will need to be carefully planned and implemented through precinct/master planning.

9. Conclusion

The work presented in this document has focused on a range of WSUD strategies to achieve new (outcome-based) stormwater management targets for the Wianamatta–South Creek catchment. The new stormwater management targets are inclusive of flow volumes and flow rates, consistent with best practice to protect the waterways and other components of the blue grid that help deliver the vision for the Western Parkland City.

This work shows that a variety of WSUD strategies are available depending on the scale and typologies proposed. The strategies considered include allotment, streetscape and POS treatment and reuse systems. Significantly, the feasibility assessment shows that if stormwater treatment measures are restricted to allotments and streetscapes only, a reduced level of imperviousness on the allotment (compared to typical development) is required to meet the stormwater management targets. This translates into reduced development yield unless stormwater treatment measures such as green roofs can be adopted. The overall cost impacts of the reduced development yields (land costs) significantly determine/affect the total costs of the different WSUD strategies, compared to the cost of the stormwater treatment measure (CAPEX and OPEX).

It is clear from the feasibility assessment that the most cost-effective WSUD strategy incorporates a regional approach to treatment and a reticulated stormwater reuse system that provides non-potable water to all allotments. This approach enables full development yield (up to 85% impervious coverage) to be achieved as well as achieving the stormwater management targets.

The most critical component to achieve the stormwater management targets is to intercept and divert stormwater from receiving waterways. This can generally be done either through generating less runoff, promoting evapotranspiration and/or with a reuse system, especially given that infiltration is generally limited because of a high salinity risk of the soils in the area.

WSUD strategies that incorporate a reticulated stormwater reuse system enable treated stormwater to be delivered to all allotments so the high demands for non-potable water can be met with recycled stormwater. Another advantage of this approach is an ability to recover costs through the sale of the reused stormwater. This system requires a trunk drainage manager to plan, construct, manage and administer the system.

The hypothetical case study for the Mamre Road Precinct demonstrates that if a regional treatment and reticulated reuse system is implemented, the cost of WSUD infrastructure is in the order of $191,000 per hectare. The treatment and storage systems would require approximately 87 ha of land and costs associated with land acquisition equate approximately to an additional $96,000 per hectare. The case study includes a reticulated stormwater reuse system and the revenue from harvested stormwater sales is estimated to exceed annual operation costs, providing a revenue of approximately $900 per hectare each year.

The overall findings of this work demonstrate that financially viable solutions to achieve the stormwater targets can be developed if a trunk drainage manager is established. The findings form Step 4 of the NSW Government Risk-based Framework (Dela-Cruz et al. 2017), and will assist decisions on institutional arrangements for development and delivery of water infrastructure in the Wianamatta–South Creek catchment.

10. Acknowledgements

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- Design Flow Consulting Pty Ltd – Robin Allison and Shaun Leinster undertook the feasibility assessment, including extensive consultation with stakeholders, developing WSUD strategies, MUSIC modelling and associated life cycle costings, and prepared the draft versions of this document
- Environment and Heritage Group of the Department of Planning and Environment (the department) – Marnie Stewart, Susan Harrison, Trish Harrup and Jocelyn Dela-Cruz were involved in extensive consultation with stakeholders, including responding to industry queries and state significant development submissions. Jocelyn was responsible for the overall management and delivery of the project, and helped with finalising the document
- Fluvial Consulting – Richard MacManus was instrumental in strategically aligning the findings of this work with related state initiatives for regional infrastructure delivery for the Western Parkland City.

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12. More information

- Blacktown City Council WSUD photo gallery
- Design Flow Consulting Pty Ltd
- Flood Risk Management Manual Package
- State Environmental Planning Policy (Precincts – Western Parkland City) 2021