CRC for
Water Sensitive Cities

Salisbury case study final report: water sensitive outcomes for infill development

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Salisbury case study final report: water sensitive outcomes for infill development
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Water sensitive outcomes for infill developments
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Glossary

amenity	A desirable or useful feature or facility of a building or place
Aquacycle	Aquacycle is a daily urban water balance model for simulating the total urban water cycle and especially suited to investigating supplementary water sources (rain and stormwater harvesting and grey and wastewater recycling) in urban catchments. Refer to Mitchell et al. (2001) and Mitchell (2005) for more information.
aquifer	In this report, aquifer refers to a shallow groundwater resource, as distinct from a deep groundwater resource.
aquifer storage and recovery (ASR)	Aquifer storage and recovery is a technique of managed aquifer recharge (MAR). Aquifer storage and recovery is the process of withdrawing the stored water from the aquifer for use. This term has been adopted from the Aquacycle tool of Mitchell et al. (2001, p.33), citing (Digney and Gillies, 1995).
BAU	Business as usual. Also referred to as standard industry practice
BOM	Bureau of Meteorology
built form	The human-made surroundings that provide the setting for human activity, ranging in scale from buildings to cities including buildings, streets, parks, etc.
catchment	This work uses the hydrological meaning of catchment, which is an area of land where surface water converges to a single point (drainage basin).
community title	A community title is the division of land into at least two lots and an area of common property. Common property relates to those parts that do not form part of a lot and usually includes the service infrastructure and shared driveways. A community title is issued for each lot and the common property (Government of South Australia, 2020).
daylighting	Daylighting refers to removing piped waterways to restore to a more natural open channel condition in order to directly or indirectly achieve more ecological, economic, or socio-cultural benefits (Khirfan et al., 2020).
efficiency	Efficiency is considered in terms of resource efficiency, which is the amount of resource input per unit of service, function, product. In this work it refers to water efficiency, and more specifically to the water efficiency of the urban area being evaluated. Also see ‘urban water efficiency’.
evaluation framework	A structure used to collate, organise and link evaluation questions, outcomes or outputs, indicators, data sources, and data collection methods.
Existing/ EX scenario	EX refers to the current prevailing state of the precinct as in 2019. This essentially means the state before infill with/without intervention. This is also known as pre-urban (pre-European) development. This is an acceptable reference case for a highly urbanised infill development.

field capacity	The amount of soil moisture or water content held in the soil after excess water has drained away and the rate of downward movement has decreased.
forcing values	Forcing value/radiative forcing is the difference between adsorbed sunlight energy by the earth and the energy radiated back to the space. The balance is a function of a climate factor that could change due to natural or anthropogenic cause.
Framework	In this report, the Framework refers to the CRC for Water Sensitive Cities' Infill Performance Evaluation Framework.
green street	A green street is a water sensitive intervention that incorporates vegetation (perennials, shrubs, trees), soil, and engineered systems (e.g. permeable pavements) to slow, filter, and cleanse stormwater runoff from impervious surfaces (e.g. streets, sidewalks). Green streets are designed to capture rainwater at its source, where rain falls. Whereas, a traditional street is designed to direct stormwater runoff from impervious surfaces into storm sewer systems (gutters, drains, pipes) that discharge directly into surface waters, rivers, and streams.
greyfield land	Greyfield describes occupied but economically and technologically obsolescent, failing and under-capitalised housing.
ha	A hectare is a unit of area equal to 10,000 square metres.
heat modelling approach	Based on the distribution of typologies over the study area, to create heat maps at the precinct-scale for each of the four development scenarios.
imported water	Water sourced from outside the urban system, such as centralised supplies from dams, groundwater reserves, seawater, etc.. It is distinct from water sourced from within the urban system, such as harvested rainwater and stormwater, recycled wastewaters etc.
infill/infill development	An urban planning term for the process of redevelopment within established urban areas, typically using previously undeveloped or undersed parcels of land (greyfield), or redeploying previously developed land (brownfield). Infill generally has an emphasis on residential dwellings, but it does not exclude other building types.
infiltration (I)	For this report, infiltration is water that enters the soil, percolates through the soil, and passes out of the urban area boundary, 1 m below the surface. This process can also represent groundwater recharge if it is assumed that the infiltrated water continues to make its way to sub-surface aquifers. Infiltration can be defined differently in other places. For example, in the Aquacycle tool infiltration is the water seeping below the surface and entering the sewer system.
internal water	Internal water is water generated within the urban system (harvested rainwater, stormwater, recycled wastewater).

managed aquifer recharge (MAR)	Managed aquifer recharge (MAR) is the process of transferring surface water to the groundwater system to (i) increase the yield of an aquifer that is already exploited, or (ii) take advantage of its natural storage capacity instead of relying on surface storage.
mass balance	A type of material flow analysis that generates a comprehensive account of the flows of a resource into and out of an urban entity/system (sum of the inflow equals sum of the outflows and the change in storage), with the change in storage acting as a check for the conservation of mass. See also ‘water mass balance’.
MUSIC	MUSIC (Model for Urban Stormwater Improvement Conceptualisation) is designed to help urban stormwater professionals visualise possible strategies to tackle urban stormwater hydrology and pollution impacts.
planning	Planning refers to urban and regional planning—the technical and political processes concerned with the use of land and design of the urban environment, including air, water, and the infrastructure passing into and out of urban areas.
pre-urbanisation/ PRE	This refers to the catchment/area before any development; it is also known as ‘natural condition’. For the Australian context, it is the pre-European settlement (1825) covered with native vegetation. The typical features of PRE are increased evapotranspiration (ET), infiltration (I) and a smaller proportion of stormwater discharge (SW). It is an acceptable reference for hydrological performance of a less urbanised area or greenfield development.
pre-urban development	See ‘Existing’ (EX)
precinct	The scale at which infill is planned and managed by the local authority (e.g. as a development zone or through a planning scheme. It may be as small as a suburban block or as large as a small suburb). A precinct can be: • hundreds of parcels of land each with at least one building • a large number of 'lots' and multi-building complexes combined • several neighbourhoods (e.g. a small suburb covering an area of 100 hectares (Coombes and Roso, 2019, Table 9.6.3).
RBAU	Business-as-usual residential dwelling typologies
recharge	Water that infiltrates through the soil beyond the urban area boundary (i.e., 1 m below the surface) into a shallow aquifer. Referred to as deep percolation in MUSIC and BOM.
REH	Residential high cover category; have smaller lot sizes of around 550 m^2 with 60–100% built cover

REL	Residential low cover category; have the older style larger lots of around 1,500 m^2 with 20–40% built cover, which were assumed to be most prone to redevelopment
REM	Residential medium cover category; have lot sizes of around 625 m^2 with 40–60% built cover
RWS	Water sensitive residential dwelling typologies
site	Site refers to an individual infill development site (e.g. single or multiple residential dwellings on a piece of private land). It may also be a large parcel of land with multiple buildings. Sometimes a small number of 'lots' combined
site plan	Refers to a landscape architectural document or a detailed engineering drawing of a proposed development of a lot. In this context, site plans are generated using the typologies as template.
stormwater (SW)	Stormwater is the runoff from the study area, which may be a fraction of the original amount of runoff, considering that some may drain to pervious surfaces and infiltrate. See also 'stormwater runoff'.
stormwater runoff	Rainfall that flows over the ground surface. It is created when rain falls on roads, driveways, parking lots, rooftops and other paved surfaces that do not allow water to soak into the soil (infiltrate).
supplementary water	In this work, supplementary water refers to locally sourced water supplementing the need for imported water. It could be a combination of rainwater and stormwater (purple pipe scheme) harvest.
SUWMBA	The Site-scale Urban Water Mass Balance Assessment (SUWMB) Tool is a daily urban water balance model that simulates the urban water cycle specifically for urban developments at the site scale. It concurrently examines the influence of both the built form design and water servicing features. Refer to Moravej et al. (2020a) for more information.
Torrens title	Torrens title is a land title that provides the owner the utmost independence and autonomy. The owner is responsible for the entire land allotted to them. It is also the most common type of title in South Australia.
typology	In architecture, typology is a particular set of characteristics of a building and helps in identifying and categorising buildings into different groups of forms. Examples of typologies are courtyard, terrace, townhouse, apartment etc.
UMEP model	Urban Multi-scale Environmental Predictor (UMEP) model used to evaluate urban heat
urban	A location characterised as population clusters of 1,000 or more people, with a density of at least 200/km^2 (Australian Standard Geographical Classification, 2001).

urban entity	The three-dimensional ‘system’ being evaluated for performance. The physical boundary of an urban entity consists of (i) a horizontal boundary related to the precinct/site boundary, and (ii) vertical boundary ranges from 1 m below the ground level to the height of the tallest building or trees in the chosen location. Some of the components of an urban entity are building (water appliances), water infrastructure (piped and natural flows and related treatment systems), landscape (to 1 m depth of soil) and associated land surfaces and vegetation, and related water storage//s. In this report, the term is used interchangeably with ‘urban area’ because the authors believe consideration of the water performance of a three-dimensional ‘urban entity’ is a critically important new concept, but many find this takes time, and believe ‘urban area’ is more readily understandable.
urban design	The design and shape of the physical features of cities, towns and villages, and their associated municipal services.
urban thermal comfort	In this work, urban thermal comfort refers to climate sensitive urban design involving creating thermally comfortable, attractive and sustainable urban environments by enhancing positive natural and human-made features through architecture, planning and landscape design. This report focuses on the ‘thermal comfort’ component of urban design, and the role of water sensitive urban design (WSUD) in achieving climate sensitive streets, neighbourhoods and cities. Thermal comfort (as an outcome) means the ‘feels like’ properties of climate (i.e., human experience). Thermal comfort as an architectural design principle is a process principle to achieve this outcome.
urban water cycle	The movement and use of water within an urban area, which is managed by urban water infrastructure, including (water supply and use, wastewater collection, treatment, recycling and disposal), as distinct from the natural water cycle.
urban water mass balance	A water mass balance in the context of an urban area. See ‘water mass balance’.
UTCI	Universal Thermal Climate Index or the ‘feels like’ temperature
water efficiency	In this work, water efficiency is considered in terms of an urban area, and how efficient is the freshwater consumption of the urban area. Hence, it is the volume of fresh water (sourced from outside the urban system) consumed in the urban area, per capita of population living in the urban area. To distinguish it from other uses of the term water efficiency, it is referred to here as ‘urban water efficiency’.
water mass balance	An equation that describes the flow of water in and out of an entity/system (sum of the inflow equals sum of the outflows and the change in storage), with the change in storage acting as a check for the conservation of mass.
water performance	In this work, water performance describes a set of performance objectives related to the protection and functionality of water in the urban landscape. It includes the maintenance of natural water flows, water resource management, and water-related amenity. It captures the biophysical qualities of a water sensitive city.

water sensitive	Having the attributes of a water sensitive city
water sensitive city	A vision for urban water management that requires the transformation of urban water systems from a focus on water supply and wastewater disposal to more complex, flexible systems that integrate various sources of water; operates through both centralised and decentralised systems, delivers a wider range of services to communities, and integrates into urban design (Wong and Brown, 2009).
water servicing	The supply of water for urban uses (potable water and fit-for-purpose water), and the collection, treatment and disposal (or reuse) of the resulting wastewaters
WS-Cons	Water Sensitive Conservative
WS-Max	Water Sensitive Maximised
WSUD	Water sensitive urban design

Executive summary

This report documents an integrated assessment of greyfield development scenarios for an urban precinct. We used a suburban precinct of approximately 1,900 residents (2019) in the City of Salisbury (Greater Adelaide, South Australia) to identify, quantify and mitigate the adverse effects of infill development on water, urban heat and architectural space quality.

Specifically, this report demonstrates an application of the Infill Performance Evaluation Framework to first understand the context-specific water-related and urban heat impacts and, second, to test how water sensitive design typologies and water servicing variables can improve the performance of the urban precinct in terms of liveability, water security, and resilience. It should be read in conjunction with the Infill Performance Evaluation Framework and the Infill Typologies Catalogue. We developed a second case study for an urban precinct in Western Australia, Knutsford case study, which used the same Site-scale Urban Water Mass Balance Assessment Tool (SUWMBA) and methodology as this case study. Learnings from both case studies are integrated in the Water sensitive outcomes for infill development final report.

Salisbury case study

The area of the Salisbury East case study is about 130 ha. The site is bounded by Main North Road, Saints Road, Brian Street, Commercial Road, Park Terrace and Fenden Road. It is representative of a small scale, low-to-medium density infill development on scattered sites that are predominantly residential with individual privately owned lots and a public housing site, along with some industrial, commercial, and vacant land.

The precinct is located on the edge of the Little Para River, a section of which is currently privately owned. The Riverits corridor is a great community natural asset, with vegetation along its edge including eucalyptus woodland and native golden wattle, as well as olive, almond and orange trees that are remnants of earlier fruit tree groves.

The CRCWSC's Integrated Research Project 4 (IRP4) team collaborated with urban planners and water practitioners to understand the local context, and the needs and aspirations of the stakeholders of the case study application.

The process of applying the Infill Performance Evaluation Framework (referred to hereafer as the Framework) included:

1. Developing scenarios representing the existing or basecase situation (EX), future infill development without watersensitive interventions (BAU – business-as-usual) and future infill development with water sensitive interventions (WS-Con (conservative) and WS-Max (maximised) water sensitive outcome)

2. Designing site plans for residential lots and streets using the Infill Typologies Catalogue as a template for the three future scenarios (BAU, WS-Con, WS-Max). This included defining site-specific parameters related to architectural design and water servicing. A single BAU site plan is generated from a single typology. Four WS site plans are generated using a combination of three typologies, namely apartments, terraces and townhouses. This is an iterative process involving assessing the site plans using the CRCWSC's SUWMBA Tool and readjusting the site plan to attain the desired performance (noting in most developments desired 'water performance' is not currently specified; however, this project and the associated tools enable a performance to be much more clearly defined and, consequently, water performance outcomes achieved)

3. Creating a precinct plan for the study area for each scenario by applying the site plans developed in phase 2 to selected greyfield sites in BAU and WS-Con scenarios and to all the lots, except the parks in WS-Max scenario. This included defining water servicing assumptions at the lot and precinct scale and design of roads, verges and public open space

4. Assessing the proposed precinct plans (phase 3) in terms of urban water flows, urban heat (modelled at site scale and scaled up to represent precinct-scale outcomes) and the architectural and urban space quality, using the performance indicators described in the Framework. The indicators were compared with the context-specific targets where available. When targets (sourced in planning or government documentation) were not available, the project team estimated notional/illustrative targets, guided by our analysis, to help communicate how cumulative indicators at precinct scale can be achieved. Water performance was assessed at precinct-scale using daily water balance using ‘Aquacycle’. Urban heat was evaluated using the Urban Multi-scale Environmental Predictor (UMEP) model.

In this case study, the Existing (EX) and Pre-urbanisation (PRE) scenarios form the baseline against which three alternative urban renewal futures are compared. These alternatives are BAU (without planning intervention), WS-Con and WS-Max (with water sensitive intervention). Table ES 1 describes these scenarios. It also provides the number of residents that a scenario can support and the developable area needed to support the increased population. The role of the PRE scenario is to quantify a second baseline (i.e., the ‘natural state’). While most current development is likely to want to benchmark with the EX state, our view is that innovative urban development would also consider performance against the PRE state which represents very strong water sensitive performance.

Table ES 1: Description of the baseline and alternative scenarios applied

Scenarios		**Description**	**No. of people**	**Change in area**	**Effects of the scenario**
Baseline	Pre-urbanisation (PRE)	PRE is the pre-European settlement scenario and assumes the precinct consisted of a mix of native vegetation including low shrubland, grassland, woodland and mangrove along the water edge.	–		
	Existing (EX)	EX development case represents the 2019 state of development. It is the reference case against which the impacts of the infill scenarios are compared.	1,900		
Infill – without planning intervention	Business-As-Usual (BAU)	BAU typology represents the typical higher-density infill development happening around the Salisbury area that could be expected in the current housing market and without changed planning interventions. Some of the common features are increased paved area, limited canopy cover, unimproved and unintegrated streetscapes.	5,000	40 ha	Increased runoff, larger peak and high volumes of stormwater discharge, unusable common space on extreme hot days

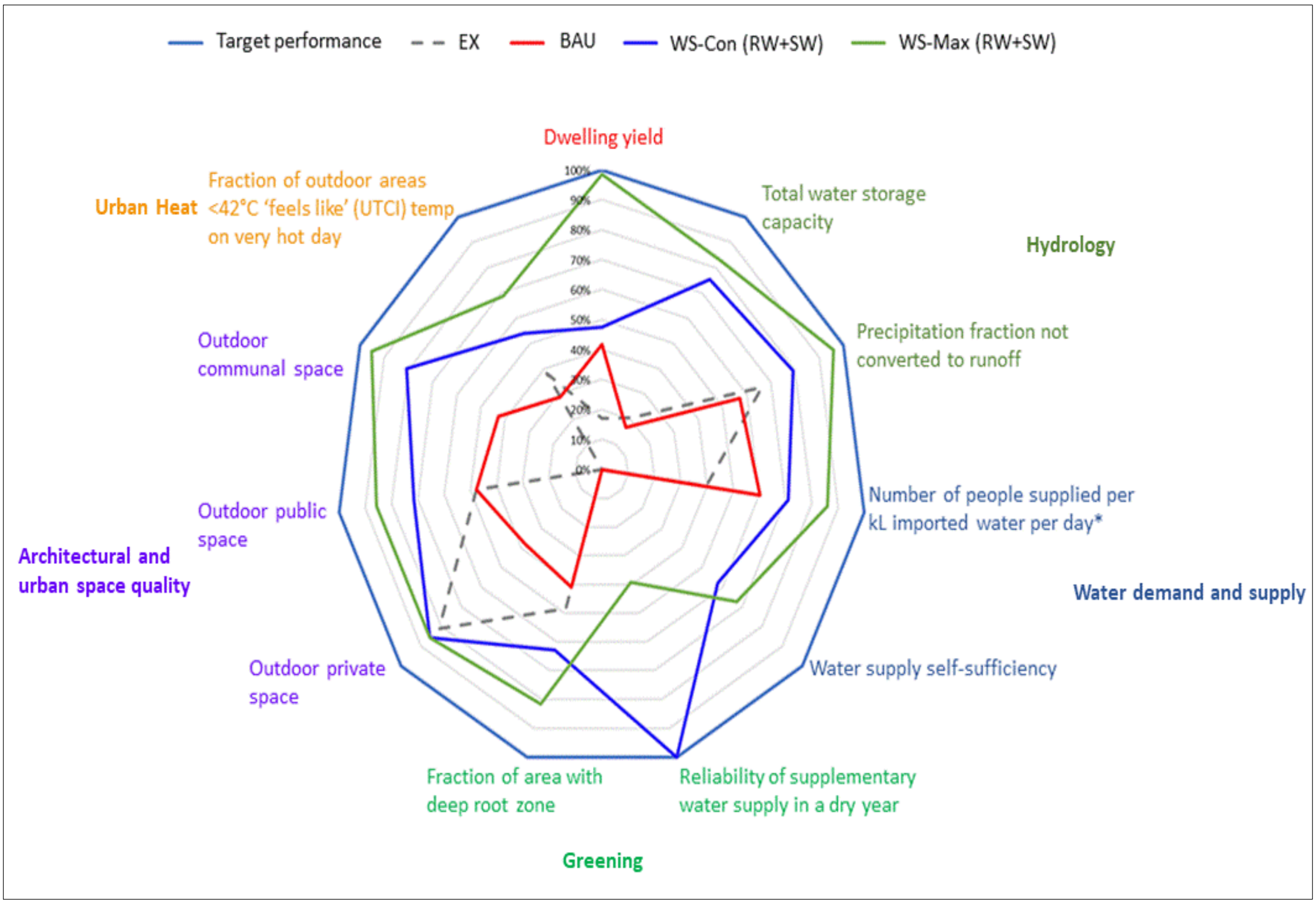
Infill – water sensitive intervention	Conservative (WS-Con)	The water sensitive scenario proposes four infill typologies. The typical features are increased pervious area, vegetation and multiple water servicing options. The impervious fraction is similar to EX scenario but the number of people is substantially higher. In this scenario, the WS typologies are applied to only the few residential sites in the study area, based on the State Planning Commission (2019) Draft Planning and Design Code Phase 3.	5,000	26 ha	Restoration of hydrological flow towards natural, reducing the water imported into the catchment by instead using locally harvested or recycled water sources, improved thermal comfort
	Maximised (WS-Max)	The maximised scenario employs typology similar to WS-Con, and applies this change to all residential sites with WS typologies	11,000	78 ha	

Overall, the case study demonstrated that choices of infill development design can significantly change the water-related performance of a development. Alternative designs that integrate water sensitive principles can lead to considerable influence on stormwater runoff, infiltration, evapotranspiration, and urban heat thus improving liveability, resilience, and water security. The overview effect on water performance is shown in Figure ES1, noting perceived 'good' performance or 'target performance' is the outer circle or 100% score. We found that WS-Con and WS-Max outperformed BAU and also EX in all evaluated areas, with particular improvement made in some key performance indicators (Table ES 2).

Table ES 2: Key performance analysis

Indicator	Target		(Percentage of target)*		
		EX	BAU	WS-Con	WS-Max
Total water storage capacity	150ML	20%	17%	75%	83%
Water supply self-sufficiency	50%	0%	0%	58%	67%
Fraction of outdoor areas with temperature below 42^{o}C (UTCI)	60%	38%	29%	54%	69%
Quality of outdoor communal (qualitative)	21	81%	38%	86%	86%
Quality of public space (qualitative)	21	0%	43%	81%	95%

**Note targets are 'notional/illustrative' and estimated by the project team to help with communicating how different levels of performance can support the achievement of cumulative targets.*



*Note to clarify: This indicator is the inverse of the more familiar water use efficiency indicator of litres/person/day. It is represented this way on the graph such that the higher the number the better the performance.

Figure ES 1: Overview of performance analysis of the Existing (EX), Business as Usual (BAU) and Water Sensitive Conservative (WS-Con) and Maximised (WS-Max) scenarios

The analysis produced several insights in areas of water performance, urban heat and their relationship with architectural design. Below we present several key results.

Water performance (hydrology and water demand and supply)

- **Precipitation fraction converted to runoff**: In the PRE case, 13% of rainfall would run off. In contrast, in the EX case, 42% of rainfall is converted to runoff. BAU would increase this to 50% while WS-Con would have only 31–39% rainfall converted to runoff depending on the extent of stormwater and rainwater harvesting. Under WS-Max conditions, only 16–30% rainfall would be converted to runoff.

- **Total water storage**: In the EX case, 31ML of storage exists primarily as soil moisture holding capacity. In the BAU scenario, this reduces slightly to 25ML but in the WS-Con and WS-Max scenarios the total water storage increases significantly, primarily due to the use of around 80ML of storage capacity in a local aquifer (e.g. used with managed aquifer recharge (MAR)), but also with contributions from surface storages and additional rainwater tanks. In the WS scenarios, in addition to the soil moisture, water stored in rainwater tanks and stormwater storage increases the water storage capacity to 75% and 83% respectively of amounts considered as 'good' water storage, which was decided based on experts' opinion (150ML). As noted above, illustrative 'targets' or 'good performance levels' were estimated by the project team specific to the context of the sites/precincts and guided by both the analysis and discussion with key stakeholders.

- **Water supply self-sufficiency**: In the EX and BAU cases there is no harvesting of rainfall and consequently self-sufficiency is 0%. The precinct is 29% and 34% self-sufficient in WS-Con and WS-Max scenarios due to rainwater harvesting and MAR.

- **Water efficiency**: The number of people supplied per kL of imported water per day indicator is complementary to the most widely used water efficiency indicator ‘Per capita demand of imported (centralised) water’. The per capita demand of imported water is 251 L/p/day in EX, 166 L/p/day in BAU and 141 L/p/day for WS-Con and 116 L/p/day for WS-Max. Similarly, the number of people supplied per kL of imported water is four people in EX, six in BAU, seven in WS-Con and nine in WS-Max. The slight reduction in per capita use and the small increase in number of people supplied per kL of imported water in BAU in contrast to EX is due to no outdoor irrigation and use of water efficient appliances. This may appear to favour BAU in water performance, but it negatively impacts urban heat performance.

- **Reliability of supplementary (local sourced) water**: WS-Con demonstrated 100% reliability, while WS-Max had only 40% reliability attributed to the extensive irrigation of garden and public spaces in WS-Max compared to WS-Con. Further analysis of irrigation scheduling and vegetation selection could improve this performance aspect.

- **Fraction of total case study area with deep root zone**: There is 24% space available in the EX case and 20% in BAU, whereas WS-Con and WS-Max have 31% and 41% respectively. This performance indicator is aimed at supporting healthy vegetation providing cooling and amenity.

Urban heat

- **Fraction of outdoor areas that are less than 42°C UTCI**: The UTCI (Universal Thermal Climate Index) provides the ‘feels like’ temperature. This study uses radiant temperature to derive the UTCI. On a very hot day, 23% of the outdoor areas in EX are below the threshold level (42°C UTCI). Meanwhile, only 17% of the outdoor areas in BAU is below the threshold, and 32% and 42% of the outdoor areas are below the threshold in WS-Con and WS-Max respectively. The small drop in the percentage of outdoor fraction below the threshold in WS-Max is due to the slight increase in built cover (i.e., impervious surfaces).

Architectural design and outdoor space quality (including greening)

- **Quality of outdoor communal space and quality of outdoor public space**: The quality of outdoor communal space was not assessed in EX. For a target score of 21 (based on qualitative 3-point likert scoring of seven parameters; refer to section 3.6), BAU scores poorly with 43%. As expected, both the WS scenarios perform well with a score of 81% in WS-Con and 95% in WS-Max. In terms of outdoor public space, EX, BAU, WS-Con and WS-Max score 48%, 48%, 71% and 86% respectively for a target score of 21. The WS scenarios perform better than the existing scenario despite catering for nearly three times the population.

This case study demonstrates that it is possible to mitigate negative consequences of infill BAU development that has limited planning for hydrological impacts, while simultaneously providing housing for additional (beyond target) population growth.

A range of design variables were observed to strongly influence hydrological outcomes. For example, the overall pervious/impervious fraction, coupled with on-site water storage, and the degree of local use of water, had a substantial influence on most outcomes such as stormwater runoff, infiltration and evapotranspiration. Water storage was highly influential on the water servicing options considered, and particularly affected the degree of self-sufficiency enabled from each different scenario.

The work provides a foundation around which future performance objectives and targets (e.g. for hydrological performance or infill self-sufficiency of supply) could be considered for this development area, noting that performance can also be influenced by annual shifts in rainfall, as well as local conditions such as soil types.

The work provides a significant foundation for developing a more quantified business case for water sensitive designs. Specifically, the work provides design alternatives to BAU approaches, and uses water mass balance to quantify all water inputs and outputs from the site under a range of conditions (of those designs) and potential future heat implications. Using these inputs, we are able to quantify positive (or negative) shifts such as reduced dependence on centralised systems, reduced reliance on air conditioning due to the shift in urban heat, and mitigating downstream flooding by reduced and controlled stormwater discharge. These designs and quantified flows could be used with additional information (such as the cost of the designs and the costs of BAU designs) in a cost–benefit analysis as part of a business case.

There are multiple pathways for the performance evaluation presented in this report to be used to influence governance and planning mechanisms that will lead to water sensitive outcomes on the ground. Principal among these is the South Australian Planning and Design Code and the Salisbury City Council planning mechanisms. A strong business case for water sensitive urban design (WSUD) could be firmly embedded in these processes.

Collaboration across design and performance analysis was critical in developing both the performance analysis approach and the resultant designs, particularly for water servicing options. While this case study did not evaluate a wide range of water servicing options, this is suggested as a next phase because higher levels of development (potentially enabled by WSUD) would potentially lead to greater demand for centralised (externally supplied) water and wastewater. We note that in undertaking the case study, even the language of 'performance analysis' and 'design' had to develop and evolve so that consistent understanding was found across the different disciplines involved (e.g. engineering, architecture, hydrology, climate). This is best represented in the Framework. By comparing across multiple case study sites, we will continue to elicit principles that are emerging for the effective design, water servicing and performance of infill (refer to the Framework).

1. Introduction

This document reports the findings from the Salisbury case study undertaken as part of the CRC for Water Sensitive Cities' Water Sensitive Outcomes for Infill Development project (Integrated Research Project (IRP) 4). The IRP4 project aimed to develop and apply an Infill Performance Evaluation Framework to understand the water-related impacts of infill development, develop new dwelling typologies and create design options and processes that can mitigate impacts, and identify improved governance opportunities for facilitating these. The Infill Performance Evaluation Framework was applied to a selection of case studies, including Salisbury, to contribute to answering the following research questions:

- What are the water-related impacts of infill, and how do these impacts vary in different Australian contexts?
- What are the urban heat impacts of infill, and what role can water play in heat mitigation?
- How do alternative water servicing options influence performance in different contexts?
- Which design and water servicing variables should guide design solutions?
- What performance objectives or targets might be appropriate for infill development?
- What design typologies give good performance in different Australian contexts?
- How might performance evaluation influence governance and planning mechanisms?

The following key outputs have been published under IRP4:

1. Infill Performance Evaluation Framework – an evaluation framework used to understand and manage infill development impacts. The Framework focuses primarily on quantifying hydrological performance of infill and related design. It allows identification of opportunities specific to different developments.

2. Infill Typologies Catalogue – a catalogue containing design options for water sensitive housing typologies to inform better residential infill practice.

3. Two case studies – applications of the Infill Development Evaluation Framework and design options, including Salisbury case study in South Australia (this report) and the Knutsford case study in Western Australia.

4. SUWMBA Tool and methodology – the Site-scale Urban Water Mass Balance Assessment Tool was developed and applied to both the Salisbury and Knutsford case studies to examine the influence of both the built form design and water servicing features, and guide the redesign of each site plan.

5. Water sensitive outcomes for infill development final report – a summary of all the research, publications, and results, and how the outcomes can contribute towards achieving water sensitive, liveable and resilient cities.

Access to these publications is available for free from the IRP4 web page or by contacting the CRC for Water Sensitive Cities (CRCWSC) at info@crcwsc.org.au.

We applied the Infill Performance Evaluation Framework (referred to as the Framework in this report) to an urban precinct in the City of Salisbury north of Adelaide in South Australia. The case study aimed to answer the above questions in the context of Salisbury, and to translate the findings into responses to infill challenges across Australia more generally.

The mode of infill predicted to occur in the Salisbury study area is ‘small scale infill’ (occurring on small to medium sized lots) and ‘block scale infill’ (occurring on medium sized sites), as defined in the Framework. These modes are representative of a large proportion of infill occurring in many capital cities of Australia.

The Salisbury case study area represents a lower socio-economic context present in many outer suburbs and satellite cities of Australia’s larger metropolitan regions. The case study was developed in consultation with the Salisbury City Council, a major developer of residential subdivisions in their local government area and uniquely placed to influence the character of urban growth in one of the fastest growing regions in metropolitan Adelaide. Other stakeholders who contributed to the study were Water Sensitive SA and Housing SA.

1.1 Case study area

Location, landscape, environment, and social context

The study area, including the four infill development sites (Figure 1), is located in the City of Salisbury (Appendix, Figure A 1). It is a 130 ha precinct on the eastern perimeter of the Salisbury City Centre (Salisbury Centre East), incorporating parts of the suburbs of Salisbury and Salisbury Plains (see Appendix, Figure A 2). This area is one of the first stages of an urban renewal strategy under the City of Salisbury Growth Action Plan (City of Salisbury, 2008), which aims to increase the population and workforce in Salisbury to sustain economic prosperity and maximise opportunities for the city.

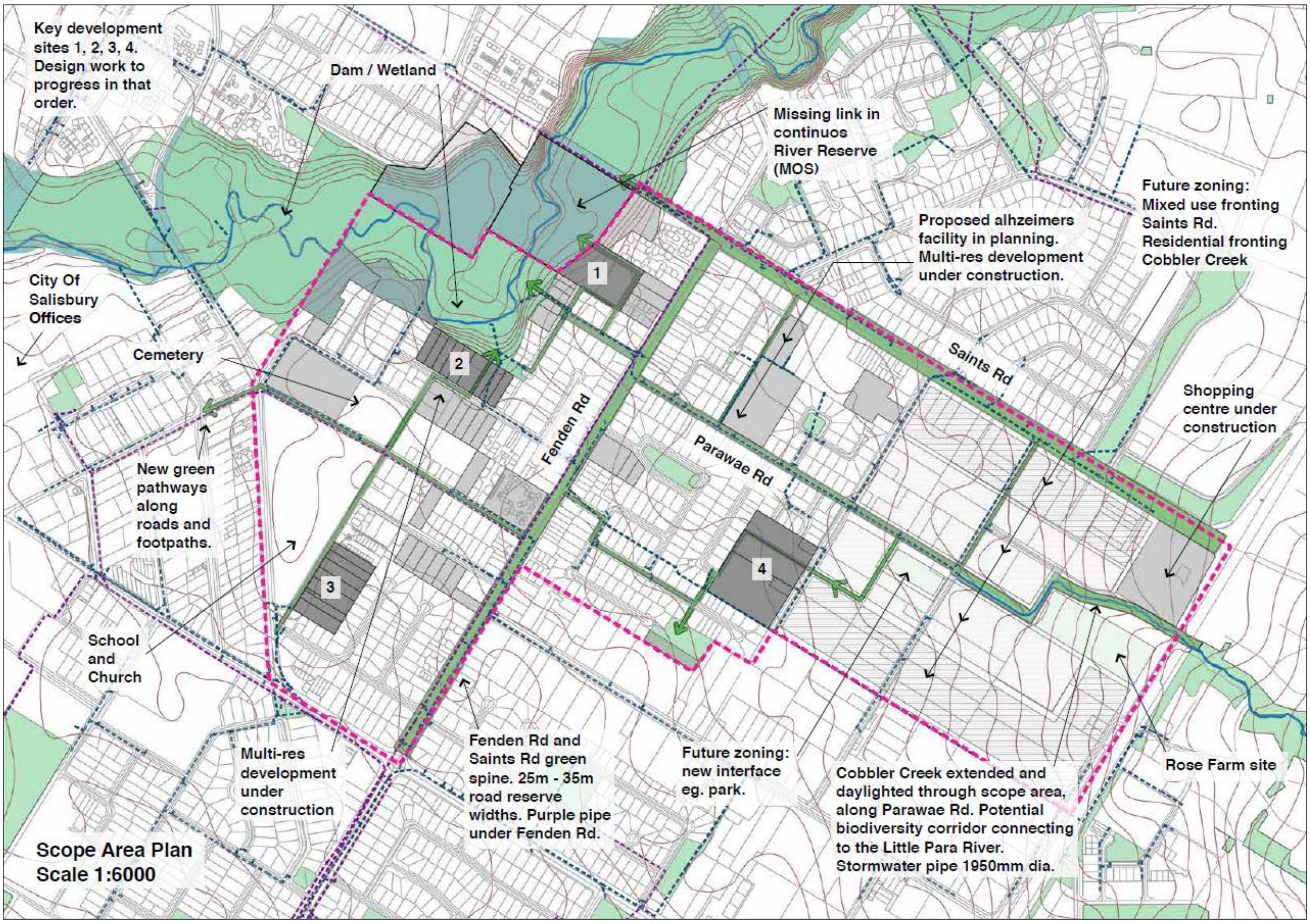


Figure 1: Identified infill development sites (1,2,3,4) within the study area

The study area is in a Mediterranean climate zone, with cool to mild winters with moderate rainfall, and warm to hot and long dry summers (up to 14–16 weeks without rain), and most rain falling in the winter. The annual rainfall and potential evapotranspiration of the area, based on the Adelaide-Kent Town rainfall station (23090), is shown in Figure 2. The soils in the study area are predominantly clay, which limits recharge by infiltration of rainwater into the unconfined aquifer (Clark et al., 2015). These environmental characteristics influence the hydrology of the study area and provide context for the hydrological performance evaluation.

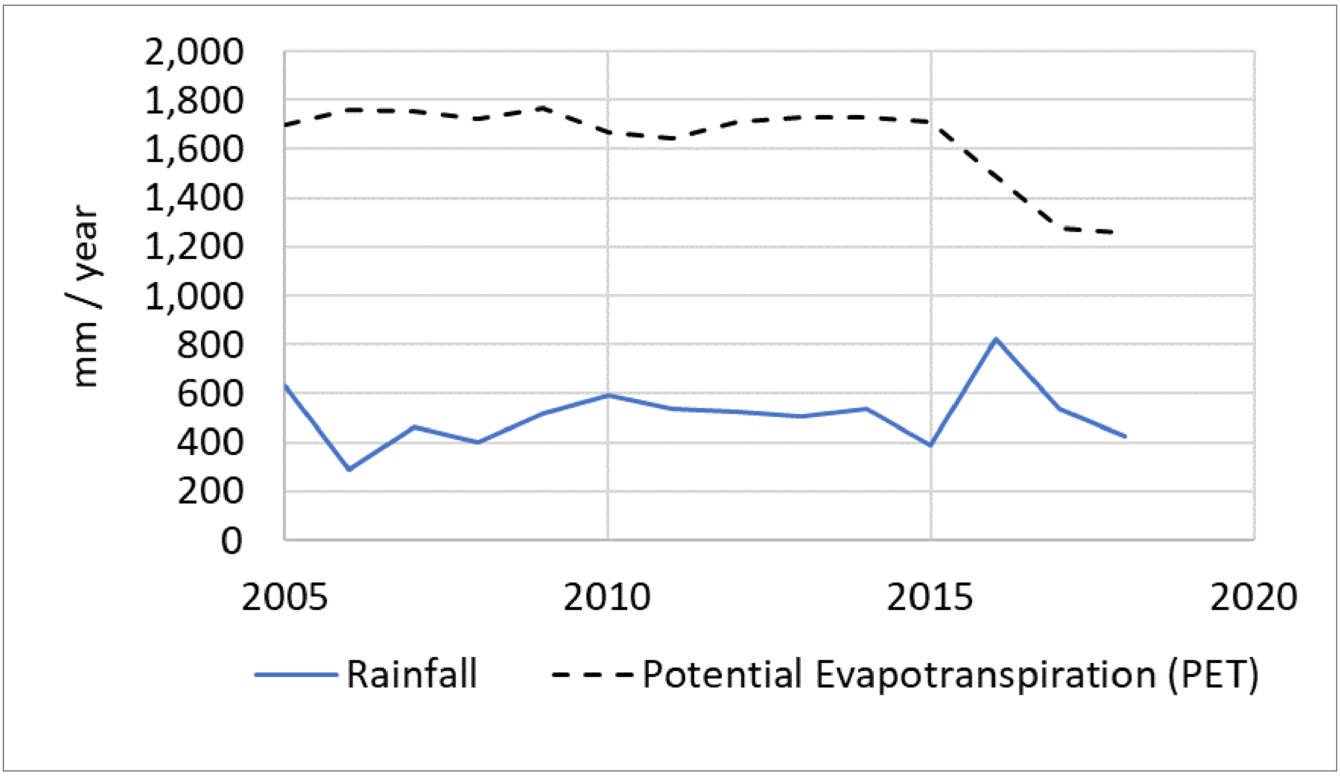


Figure 2: Rainfall and potential evapotranspiration for study area, derived from BOM (2015)

The study area is largely within the Parafield/Dry Creek hydrological catchment (Myers et al., 2013), and sections of the seasonal Little Para River and Cobbler Creek are within the study area. Cobbler Creek originally flowed naturally across the Parafield plains into Dry Creek, but was diverted and piped underground to the Little Para River when the suburb was developed in the 1950–60 period. In the past 10 years, a significant water volume has been diverted back to the plains specifically for harvesting in constructed wetlands on the Parafield Airport.

At the time of this study (2019), around 50% of the study area was residential, with the remainder made up of retail, light industrial, a parish school, a cemetery, and many vacant lots. The study area is bounded at the north-west corner by the Little Para River, which provides some green space with potential recreational opportunities, and there are three small pocket parks. But there is poor connectivity between these green open spaces and residential areas. There are many large vacant lots in the eastern part of the study area. The existing housing stock is predominantly modest homes on large blocks on streets with generous verge widths containing established native trees. The average number of people per dwelling in the City of Salisbury is 2.3, which is lower than the Australian average of 2.6 (ABS, 2016).

The median household income in the City of Salisbury is $837/week (~$44,000/year), which is 30% lower than the Australian median (ABS, 2016). It is ranked in the 'most disadvantaged' category of 1 (on a scale of 1–5) in the 2016 Index of Relative Socio-economic Advantage and Disadvantage (IRSAD) (ABS, 2018). Therefore, it is representative of a low socio-economic residential context.

Water supplies

SA Water supplies some potable water from a water reservoir upstream in the Little Para River, which collects water originating from runoff from the Adelaide hills. The majority of imported water (typically >80%), however, is imported from the River Murray and more recently from a seawater desalination plant. Future development is not constrained by water supply and wastewater treatment, because there is extra capacity in the water system. The study area is not flood prone, and infrastructure is well-sized with large drainage works.

Salisbury Water, a business unit of City of Salisbury, also operates a regional MAR scheme, which harvests stormwater runoff from the urban catchment, treats it in constructed wetlands and biofilters and then stores it in natural underground sandy limestone aquifers (Clark et al., 2015; Dillon et al., 2014; Dandy et al., 2014). The water is recovered from the aquifers and distributed to community customers via a ‘purple pipe’ network, and can be used for irrigation, toilet flushing and a growing number of commercial uses.

Salisbury Water can harvest more stormwater than it can currently sell, due to competition with recycled wastewater (from SA Water) which is understood to be cheaper due to subsidies and a current exemption from full cost recovery pricing principles (personal communication, Salisbury Water). Salisbury Water would like to expand the distribution of the ‘purple pipe’ water supply, and infill development provides an opportunity to do that. They would also like to modulate stormwater flows (i.e., even out the flows through water retention/detention) so that more stormwater can be harvested. Stormwater can only be harvested, treated and pumped into the aquifer storage when streams are flowing. If the peak flows can be reduced and run-time prolonged, then the pumps could run longer and harvest more water.

1.2 Future development projections

Under the City of Salisbury Growth Action Plan (City of Salisbury, 2008), there are plans to attract and increase the population to the suburbs surrounding the study area (Salisbury, Salisbury Plains, Salisbury Downs and Parafield Gardens) by taking advantage of the proximity to public transport nodes (railway stations) that provide good access to Adelaide. The Plan projects that infill development is likely to yield around 100 dwellings per year over 20 years (2008 to 2028) across the city. Infill activity has already commenced within the study area, including single dwelling replacement, dual occupancies, unit and townhouse developments. Around 2,500 new dwellings (approximately 5,000 additional people) are anticipated to be added in the study area through urban consolidation (personal communication, City of Salisbury).

There is currently a mismatch between existing housing stock and household demographics. An overwhelming majority of existing houses are three- and four-bedroom detached houses, but with a significant and growing proportion of single and two-person households. This trend is expected to continue. Many residential owners are at retirement age signalling a generational change of ownership that may force changes. This suggests an increased demand for a wider variety of housing, including smaller houses and/or fewer bedroom houses in the future.

Trends towards smaller allotments, driven by affordability, is also noted. For example, delivery of two- and three-bedroom houses on allotments of less than 150 square metres, such as those available in new Council projects at Paralowie, are popular and reflect the city’s changing demographic. Market demand for apartment development in general is subdued; however, there is recognition that enhancing the quality of public realm in localities such as the adjacent Salisbury City Centre could help stimulate investment. Recent infill within the study area is characterised by developments with high impervious fraction such as townhouse developments, which are devoid of any green space in both common and private areas. There is a strong market preference for Torrens Title properties over Community Title (see definitions in glossary).

1.3 Opportunities and aspirations

Consultation with the case study partners (Salisbury City Council, Salisbury Water and Water Sensitive SA) identified the following aspirations for urban renewal in the study area:

- Amenity/liveability/health benefits that could be derived from:
  - better dwelling design in terms of access, orientation, interface with the landscape, affordability, and meeting the needs of changing demographics of future populations. Identification of priority areas for infill could feed into strategic land acquisitions for strategic renewal
  - water sensitive urban design in the public realm, specifically better connectivity for walkability, improved access to open space, new parks and linkages (Schebella et al., 2014). Recommendations for street upgrades can inform future budget bids and infrastructure renewal
  - urban heat mitigation through increasing street tree canopies, keeping old trees and more grassed areas.
- Improved water security and productivity from water through:
  - greater use of the ample supplementary water available in Salisbury from the 'purple pipe' recycled stormwater supply, particularly for irrigation for urban greening
  - further harnessing of supplementary water supplies, including modulating peak stormwater runoff so more can be harvested, communal harvesting and use of rainwater and greywater, and innovative rainwater storage opportunities (e.g. tanks integrated into fences)
  - enhanced infiltration of rainwater into soils to further support urban greening and improve river health
  - reduced demand for potable water through the end-use water efficiencies from higher densities.

2. Method

2.1 Method overview

We used to Framework to evaluate the performance of alternative infill scenarios for the study area at the precinct scale relative to the existing state.

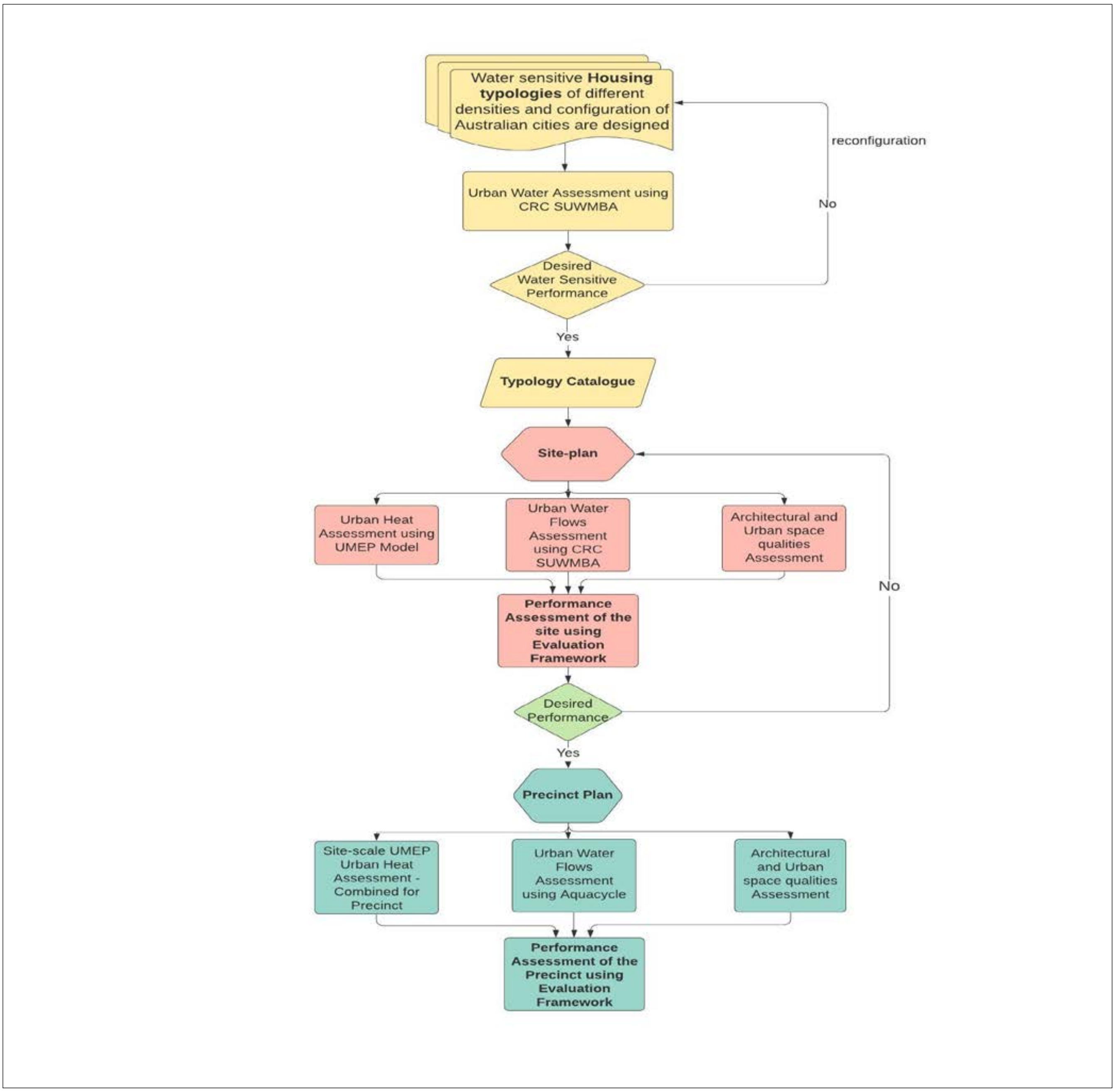


Figure 3: Visual representation of the method used in the case study

The steps/phases we followed are summarised here:

1. creating site plans for residential lots and streets using the Infill Typologies Catalogue as a template for the existing and three future scenarios (Appendix, Figure A 3 and Figure A 4). Three site plans are generated for the EX scenario, a single site plan for BAU and four site plans for both the WS scenarios. This phase is an iterative process which involved assessing the site plans using the SUWMBA Tool and re-adjusting the site plans to attain the desired performance

2. creating precinct plans for four development scenarios in the study area, including the EX development case (at 2019) (Appendix Figure A 9), expected infill development under BAU (Appendix Figure A 10), and alternative infill development based on WS principles (Appendix Figure A 11 and Figure A 12). These plans were developed by the IRP4 project team in consultation with project stakeholders. They were created by applying the site plans developed in phase 1 to selected greyfield sites in BAU and WS-Con scenarios and all the residential sites in WS-Max scenario. Land uses within the study area under each development scenario were categorised into land use clusters (residential, commercial, green space, vacant land, streets, etc) (Appendix Table A 1)

3. defining water servicing assumptions for each development scenario

4. evaluating the following aspects for each of the development scenarios:

    - Urban water flows were estimated for each development scenario using the Aquacycle model (Mitchell et al., 2001), and compiled into urban water mass balances based on the approach described in the Framework.

    - Urban heat of the case study area under each development scenario was modelled using the UMEP model (Lindberg et al., 2018).

    - Architectural and urban space qualities of each development scenario were evaluated using a new qualitative rating scheme developed for this project.

5. generating multiple performance indicators to rate and compare the performance of the BAU and WS infill scenarios against the EX case

6. giving preliminary consideration to governance mechanisms relevant to South Australia and Adelaide (undertaken by IRP4 project team, with additional consideration in related projects such as IRP3).

Box 1: Urban entity

The site and precinct being assessed for performance is an ‘urban entity’; i.e., the composite of the architecture, water infrastructure and key natural landscape elements (such as soil and vegetation) within a ‘three-dimensional volume’ clarified by the system boundary. The physical boundary of urban entity consists of (i) a horizontal boundary relating to the precinct/site boundary, and (ii) vertical boundary ranges from 1 m below the ground level to the height of the tallest building or trees in the chosen location.

Some of the components of an urban entity are buildings (water appliances), water infrastructure (piped and natural flows and related treatment systems), landscape (to 1 m depth of soil) and associated land surfaces and vegetation, and related water storage(s).

Refer to the Framework for more information.

2.2 Site scale dwelling and road typologies

The existing residential dwelling typologies aim to represent dwellings currently present in the study area before infill development. Most are single detached houses on lot sizes ranging from 550 m^2 to 1,500 m^2. These existing dwellings were divided into three categories based on their built cover (fraction of the lot covered by built surfaces) and measured using aerial images (Appendix, Figure A 3). The residential low cover (REL) category has the older style larger lots of around 1,500 m^2 with 20–40% built cover, which were assumed to be most likely to be redeveloped. The residential medium cover (REM) category has lot sizes of around 625 m^2 with 40–60% built cover, and are typical of dwellings west of Fenden Road. The residential high cover (REH) category has smaller lot sizes of around 550 m^2 with 60–100% built cover, and are typical of dwellings east of Fenden Road.

Two road typologies were also defined: minor roads within residential areas and major connection roads (Appendix, Figure A 5).

Business-as-usual residential dwelling typologies (RBAU) were identified to represent the type of higher density development that could be expected in the current housing market and without changed planning interventions (Appendix, Figure A 3). The housing development market in Salisbury generally prefers single storey dwellings, with enclosed garages and with a traditional appearance. They are typical of new dwellings being constructed in Adelaide suburbs at the time of the study (2019). A development at Sullivan Road, Ingle Farm, Adelaide (Figure 4) was used as a template. Roads associated with the RBAU typologies were assumed to be the same as the existing case.

Figure 4: RBAU design adopted from a current infill development in Adelaide

Water sensitive residential dwelling typologies (RWS) were developed to represent alternative dwelling typologies that can achieve similar or higher dwelling densities as the RBAU typology. These were developed in consultation with Salisbury City Council and a real estate professional with consideration of Salisbury's socio-economic context. They were guided by principles for improving the quality, diversity and performance of redevelopment outcomes (Murray et al., 2011), which encourage two-storey instead of single-storey structures to reduce the amount of built cover. Four different site plans (RWS 1, 2, 3 and 4) were developed to provide a range of dwelling densities to suit different contexts, including apartments, townhouses, terraces and combinations of these two (Appendix, Figure A 4). The cross-section and 3D view of RWS 1 can be seen in Appendix, Figure A 7 and Figure A 8. Water sensitive road typologies were also developed (Appendix, Figure A 6).

Site plans for all the above dwellings and street typologies were prepared in the context of likely development sites (Figure 1). Design parameters (surface cover characteristics, etc.) were derived from the site plans (Appendix, Table A 1). Population and density of each typology is given in Appendix, Table A 2. Site plans were not prepared for other land use clusters (commercial, schools), and the parameters for these were instead derived directly from aerial images (Nearmap, 2019). Further details of the typologies can be found in the Infill Typologies Catalogue (London et al., 2020).

2.3 Precinct-scale infill scenarios

The EX and PRE scenarios form the baseline of the study along with three alternative urban renewal futures, namely BAU (without planning intervention) and WS-Con and WS-Max (with WS intervention). Table ES 1 describes these scenarios. It also outlines the number of people each scenario can support and the area that undergoes development to support the increased population.

The EX development case represents the current state of development, at 2019 (Appendix, Figure A 9). It is the reference case against which the impacts of the infill scenarios were compared. The land uses within the study area were categorised into the following land use clusters—residential, commercial, parks and green space, vacant land and streets. Residential clusters were further sub-categorised into the REL, REM, and REH typologies, to model preferential infill on residential lots with lower built cover. The average net dwelling density across all residential areas was estimated to be 16 dwellings/ha, and the average dwelling occupancy was assumed to be 2.5 people/dwelling (ABS, 2016), leading to a population estimate of 1,900. The area (ha) and surface cover characteristics of each land use cluster in the EX case were measured from aerial images and are detailed in Appendix, Table A 1. The overall impervious fraction of the study area was estimated to be 0.41 (Figure 8).

Three infill development scenarios were proposed to achieve increased population through increased dwelling density—BAU, WS-Con and WS-Max. The BAU and WS-Con cases assumed the redevelopment fills vacant lots, displaces exiting residential dwellings on lots with lower site capital ratios, and displaces some commercial uses (redevelopment sites) (Appendix, Figure A 10 and Figure A 11). WS-Max represents an extreme case where the whole study area is redeveloped with WS dwelling and street typologies to understand the upper limit of performance improvements that might be achieved (Appendix, Figure A 12). The areas (ha) and surface cover characteristics of each land use cluster in the infill scenarios are detailed in Appendix Table A 1.

The BAU infill scenario represents the extent of infill development likely to occur over a mid-term horizon (10 years to 2030), based on projected rates of population growth. It was assumed that 1,100 additional dwellings would be built in the study area, increasing the population from 1,900 to 5,000. The type of dwelling assumed to be constructed is the RBAU typology. To achieve the projected population of 5,000, 40 ha of residential areas would be redeveloped based on a dwelling density of 30 dwellings/ha and dwelling occupancy of 2.5 people/dwelling (Figure 5 and Figure 6). This increases the average net dwelling density of the residential areas from 16 to 23 dwellings/ha. Minor roads within redeveloped sites were assumed to be replaced by the internal roads of the RBAU site plan. Other roads were assumed to remain unchanged. The overall impervious fraction of the study area would increase from 0.41 to 0.52 (Figure 7).

The WS-Con infill scenario represents an alternative path for achieving the same population increase as BAU (i.e., from 1,900 to 5,000 people), with the construction of an additional 1,300 dwellings. The type of infill dwellings assumed to be constructed were the four WS residential dwelling typologies. The four WS site plans were distributed over the study area such that the higher density typology (apartments) was located towards the business district and the lower density typologies in other areas. To achieve the projected population of 5,000 a total of 26 ha would need to be redeveloped, based on net dwelling densities ranging from 36–87 dwellings/ha and dwelling occupancies ranging from 2.0–2.5 people/dwelling. This results in an increase in the average net dwelling density of residential areas from 16 to 31 dwellings/ha. Minor roads within redeveloped clusters of lots were replaced by the internal roads of the WS site plans. Two major roads (Fenden Road and Saints Road) and a number of minor roads were proposed to be converted to ‘green streets’. Other roads were assumed to be the same as the existing case. Streets running along Cobbler Creek (Boolcunda Avenue to Kirby Avenue) were assumed to be redeveloped into a ‘green street’ in conjunction with the daylighting of Cobblers Creek. Under this scenario, the overall impervious fraction would be 0.42, which is similar to the EX state (Figure 8) despite an approximate doubling of population. This is achieved by constraining the dwellings’ ‘footprints’ using two-storey rather than single-story structures, and using permeable paving wherever feasible.

The WS-Max case assumes all existing residential, vacant and commercial sites are redeveloped with the four WS site plans. The total area of 78 ha was assumed to be redeveloped to residential land use, with the same dwelling densities and dwelling occupancies as the WS-Con scenario. This resulted in a population around 11,000 people with an average net dwelling density of 58 dwellings/ha, which is a more than doubling of dwelling density. Changes to roads is as per the WS-Con scenario, except that more minor roads are converted to ‘green streets’ and a few more sites are converted into parks. The overall impervious fraction of this scenario is also around 0.4.

A summary of how the area of each land use cluster will change under each scenarios is shown in Figure 7. The resulting imperviousness for each scenario (Figure 8) was calculated from the areas of each land use cluster and the assumed effective impervious factors of the constituent surfaces. Roof and road surfaces were assumed to be 100% effective impervious, non-permeable paved surfaces were assumed to be 70% effective impervious, and permeable paving surfaces were assumed to be 40% effective impervious. The estimated overall imperviousness of the existing case (0.41) compares well with that of Clark et al., 2015, who estimated it to be 0.38 for the wider Parafield catchment in 2015 and predicted it could feasibly increase to 0.41 due to infill densification.

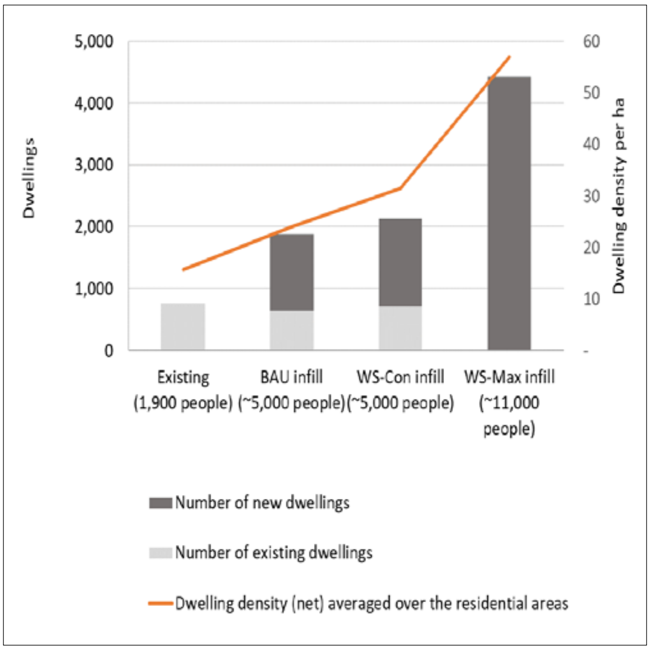


Figure 5: Assumed changes in dwellings

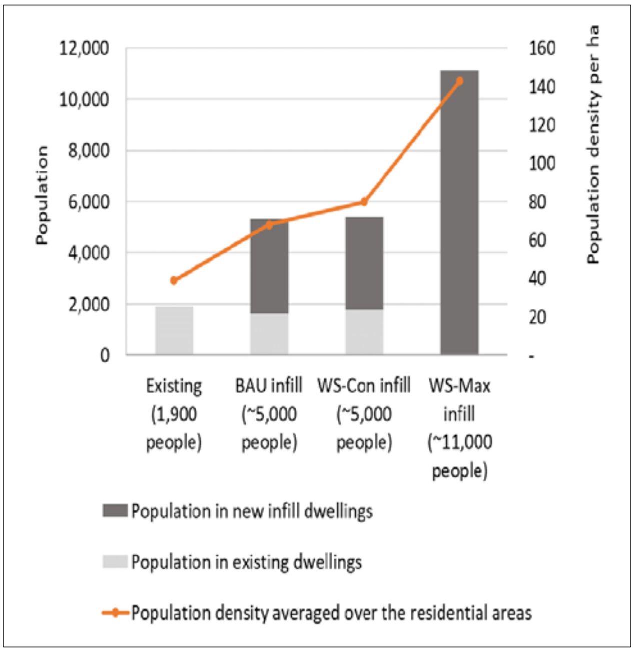


Figure 6: Assumed changes in population

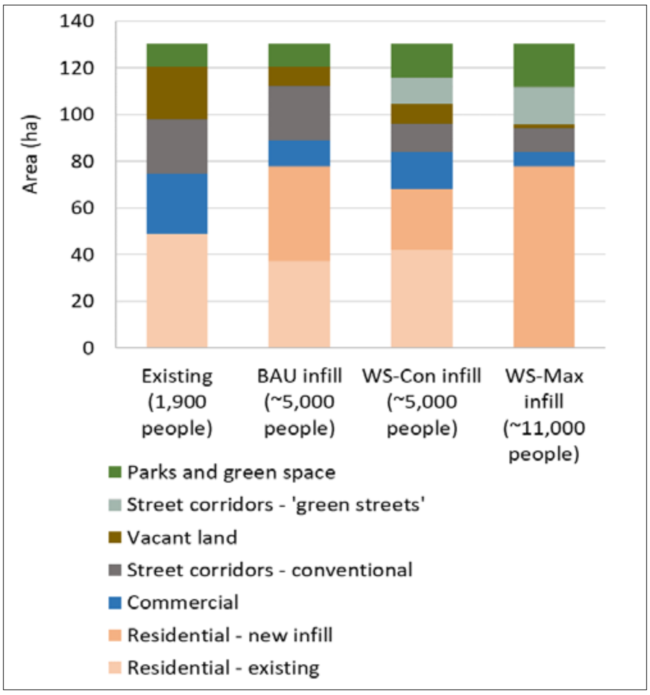


Figure 7: Assumed changes in land use

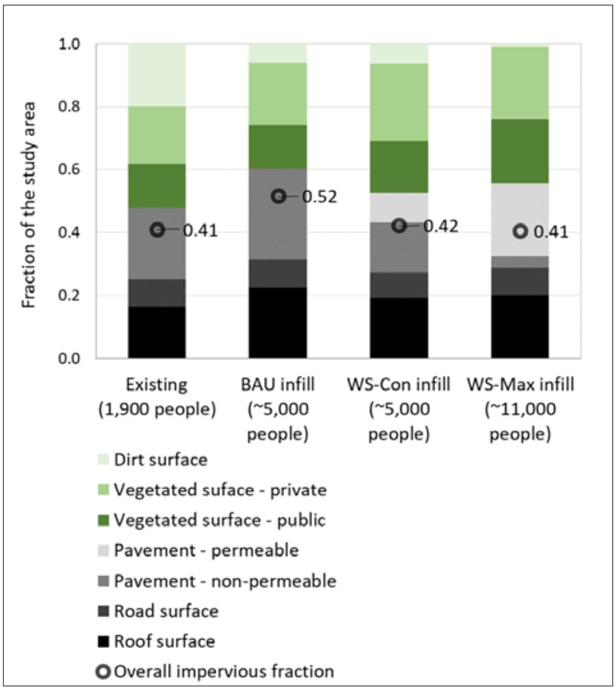


Figure 8: Assumed changes in imperviousness of surfaces

2.4 Water servicing assumptions

Water servicing options for the development scenarios were informed by consultation with Salisbury Water and a review of supplementary water supply technologies (Pype, 2020).

For the EX and BAU infill cases, it was assumed that:

1) Gardens of residential dwellings are partially irrigated (50% of garden area), using imported (mains) water.
2) The green reserve areas on Little Para River are not irrigated.
3) Road verges are not irrigated.
4) Only the school's gardens and sports fields, and the cemetery, are irrigated, using imported (mains) water.
5) Salisbury Water's stormwater harvesting and use scheme is not used in the study area for the EX and BAU cases. It is used in the WS cases.
6) All indoor and outdoor water demand is met by imported (mains) water.
7) There is no significant rainwater harvesting at residential dwellings.[1]
8) Indoor and outdoor water use for commercial areas and swimming pools was not considered.

Even though recycled stormwater (purple pipe) is currently available in the study area (within the Fenden Road reserve) from the aquifer storage and recovery (ASR) scheme, it was assumed to not be in use in the EX case due to the absence of a distribution network. Potential users in the study area (school gardens and sports fields, the cemetery, and three pocket parks) are either not being irrigated (as a carryover from past water restrictions) or are using imported water (because it is subsidised and cheaper) (personal communication, Salisbury Water). The assumption that Salisbury's ASR scheme is not present in the EX case also makes the findings more translatable to other areas, which would not have a major stormwater harvesting scheme as occurs in the base case.

For the WS-Con and WS-Max scenarios, it was assumed that:

1) New infill dwellings have the following water supply options:
    a. rainwater harvested and used by each dwelling, for garden irrigation and non-potable indoor uses (toilets and clothes washers), or
    b. connection to harvested stormwater (purple pipe) supply, for garden irrigation and non-potable indoor uses (toilets only), or
    c. combination of (a) and (b)
    d. demand not met by the above supplementary supplies is met by imported (mains) water.
2) Existing dwellings remain the same as the existing case without being redeveloped.
3) The green reserve areas on Little Para River are not irrigated.
4) Other green spaces and parks (the school's gardens and sports fields, the cemetery, three pocket parks) are irrigated using recycled stormwater (purple pipe).

[1] We note there appears to be approximately 20% of households with aboveground rainwater tanks within the studied precinct. But the modelling method adopted at the time of the case study did not allow this to be considered (i.e., a fraction of total households with tanks). The case study was more focused on understanding the influence of household design typologies on water performance rather than detailed water servicing options. For more detailed analysis of the contribution of water technologies (as well as household design typologies), please refer to the Knutsford case study undertaken as a component of the IRP4 project (case study 2).

5) Gardens of the new residential dwelling are fully irrigated (100% of garden area) using supplementary water (as above).
6) Green streets are irrigated using stormwater (purple pipe).
7) Road verges not converted into green streets are not irrigated.
8) Indoor and outdoor water use for commercial areas and swimming pools was not considered.

For the WS-Con and WS-Max scenarios, three water harvesting variants were considered (see Table 1).

Table 1: Water harvesting variants for the WS infill scenarios

Type	WS-Con infill	WS-Max infill
RW	2,000 L retention rainwater tank for each dwelling, based on the State Planning Commission (2019) Draft Planning and Design Code Phase 3 (Urban areas), resulting in a total rainwater storage capacity for the study area of 3ML	3,000 L of rainwater storage capacity for each dwelling, provided by a 2,000 L retention rainwater tank plus other innovative storages integrated into fences and under driveways, resulting in a total rainwater storage capacity for the study area of 9ML
SW	Conservative use of stormwater (purple pipe) to irrigate 100% of new residential garden areas, 50% of existing residential and 50% new green street area, and 100% of parks	Maximised use of recycled stormwater (purple pipe) to irrigate 100% of new residential garden areas, 50% of new green street area, and 100% of parks
RW+SW	Combination of the above RW and SW harvesting and use	Combination of the above RW and SW harvesting and use

RW = rainwater harvesting and use.
SW = stormwater harvesting and use (via Salisbury Water's ARS and purple pipe scheme).

In all cases where irrigation occurs, the application rate of irrigation water was assumed to be conservative. It was estimated in the water balance model using a 'trigger-to-irrigate' factor of 0.4. This means that the irrigation was assumed to occur (be triggered) when the field capacity of the soil (i.e., the amount of water in the soil profile) dropped to 40% of capacity.

Salisbury's ASR scheme can provide large volumes of recycled stormwater via the purple pipe network for outdoor irrigation and toilet flushing. But it is currently under-utilised in the study area, since it is only used on a small area of parks. For the purpose of the modelling it was assumed that this supplementary water supply is unavailable in the EX and BAU scenarios, but is used more extensively in the WS-Con and WS-Max scenarios.

It was assumed that the ASR scheme was modelled as a small individual aquifer of a size that would service the 130 ha study area, with the following specifications (personal communication, Salisbury Water) (Table 2):

Table 2: MAR storage capacity

Aboveground stormwater storage capacity	10,000 m^3 (10ML)
Aboveground stormwater storage exposed surface	2,000 m^2
Aquifer storage capacity	80,000 m^3 (80ML)
Maximum recharge from stormwater store to aquifer	800 m^3/day (10 L/s), which would recharge 80ML/yr based on 100 days/yr of recharge run time
Maximum recovery rate from aquifer	960 m^3/day (12 L/s) based on the T1 extraction pumps

The rainwater harvesting model within Aquacycle estimated an annual yield of rainwater of around 22 KL/yr per household for a 2,000 L tank. This concurs with the estimate of Marchi et al. (2014) that 2,000 L tanks in the Salisbury context yield 17–32 kLyr for outdoor and indoor use. The rainwater tanks, aboveground stormwater storage and ASR storage were assumed to be half full at the start of the modelling period.

2.5 Modelling urban water flows with Aquacycle

The Aquacycle model was used to estimate annual urban water flows for the study area (Mitchell et al., 2001). Aquacycle was selected because it is more suited than other models to analysis at the precinct scale and for investigating the use of locally generated stormwater and wastewater as supplementary water supplies. The flows of interest are precipitation, evapotranspiration, infiltration, stormwater discharge, supply of mains water (imported water), supplies of supplementary water (harvested rainwater or stormwater and recycled greywater or wastewater), and wastewater discharged.

These flows were estimated with Aquacycle for each of the development scenario (EX, BAU, WS-Con and WS-Max), and also for PRE, which is a point of reference for the hydrology indicators. The water flow data were compiled into a water mass balance (Appendix, Table A 3) as per the Framework, from which the water performance indicators were generated (see Renouf et al. (2020) for details).

We note that each scenario (EX, BAU, WS-Con and WS-Max) is comprised of different site plan designs (individual sites). The IRP4 project developed and applied a new model called 'SUWMBA' (Moravej et al., 2020a, Moravej et al., 2020b) which was used to evaluate and guide the redesign of each site plan.

The calibration parameters used in the hydrological model within Aquacycle for the Adelaide context were derived from parameters used in MUSIC modelling recommended by Myers et al. (2015, p.79) (Table 3). Stormwater runoff from all land use clusters in the study area was assumed to be discharged from the study area to the Little Para River.

Aquacycle also requires per person indoor water use for various household sizes to be specified. These data were derived from a regression algorithm developed by Makki et al. (2015), which is based on the key determinants of household demographics, appliance efficiencies and use habits. These were calibrated against a survey of household water use in Adelaide (Arbon et al., 2014).

The outdoor irrigation demand estimated by Aquacycle was calibrated against the observations of Clark et al. (2015), that public open space irrigation demand is 362 mm/year, with no irrigation requirement over the five months from May to September, and a peak demand of 84 mm in January.

Water flows were estimated with Aquacycle for individual years between 2005 and 2018. This range of years was selected because comprehensive data for both rainfall and potential evapotranspiration were available from the

Bureau of Meteorology (BOM, 2015). Most performance indicators were generated from the water mass balance for an average rainfall year, which was taken to be 2010 (see Figure 2). Some indicators were also generated from the water mass balance of a dry year (2006) and a wet year (2016).

Table 3: Parameters used in Aquacycle for the Adelaide context

Parameter name in Aquacycle	Equivalent parameter name in MUSIC	Value	Comment
Area of previous store 1 (%)		50	Assumed store 1 and 2 in equal amounts
Capacity of pervious store 1 (mm)	Soil moisture storage capacity (SMSC)	40	Assumed the same for both stores
Capacity of pervious store 2 (mm)	SMSC	40	Assumed the same for both stores
Roof area maximum initial loss (mm)	Rainfall threshold	1	
Effective roof area (%)		100	
Paved area maximum initial loss (mm)	Rainfall threshold	1	
Effective paved area (%)		70/40	Paved surfaces (driveways, footpaths) in the EX and BAU scenarios were assumed to be 70% effective impervious. Permeable paving used for driveways, internal roads, and footpaths in the WS scenarios were assumed to be 40% effective impervious.
Road area maximum initial loss (mm)	Rainfall threshold	1	
Effective road area (%)		100	
Base flow index, ratio		0.25	
Base flow recession constant, ratio		0	No
Infiltration index, ratio	NA	0	No infiltration into sewer
Infiltration store recession constant, ratio	NA	0	
Trigger-to-irrigate	NA	0.4	

2.6 Modelling urban heat

Modelling of urban heat was also a component of the case study. The Solar Long Wave Environmental Irradiance Geometry (SOLWEIG) module from the Urban Multi-scale Environmental Predictor (UMEP) model (Lindberg et al., 2018) was used to calculate the mean radiant temperature experienced by a human body (T_{mrt}) at each modelled point in site-scale dwelling typologies. The modelling was performed for 2:00 pm on 12 February 2004 (a typical hot summer day), using the radiant forcing values in Table 4. The radiant temperature values were then used to calculate UTCI (Universal Thermal Comfort Index) values, which were used to derive an urban heat performance indicator in this case study guided by the Framework. This is the first time a heat performance indicator has been applied in a case study.

UTCI values represent the subjective experience and thermal stress of heat on a person in an outdoor area, calculated from the radiant heat (T_{mrt}) values for each point at ground level (1.5 m). It uses the formula of Brode et al. (2009), which generates a categorised equivalent temperature derived from a thermo-physiological model coupled with a behavioural clothing mode (Figure 9). More simply, UTCI values represent the equivalent temperatures of heat stress, which are often referred to as the 'feels like' temperature.

The UTCI values reported in this Framework do not represent actual air temperatures or surface temperatures; however, radiant temperatures are used to derive the UTCI values.

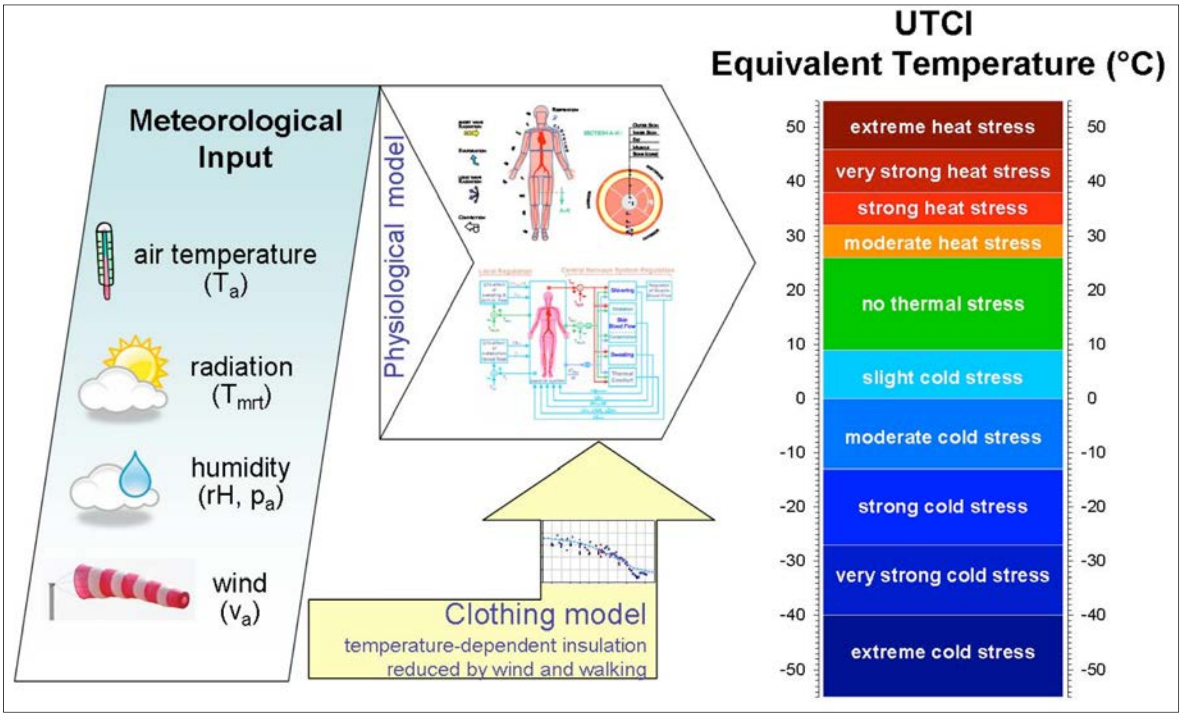


Figure 9: Universal Thermal Climate Index (UTCI) from Brode et al. (2011)

The modelling assumed the vegetation of the garden areas (grass and trees) were in good health and are well irrigated. Since we assumed all water demand, both indoor and outdoor, is met either by supplementary water or imported water, this assumption is valid (see section 2.4 for water servicing assumptions). Sparse tree canopies and struggling lawns will not provide the required shading benefits and cooling benefits. The analysis aimed to capture the heat performance of the different infill designs and that irrigation indirectly contributes to cooling by supporting vegetation vigour.

Irrigation can also provide an additional direct cooling effect at the micro scale through heat exchange with the air when water is sprinkled or misted above ground. There is research that sprinkled irrigation can deliver reductions in air temperature of 2°C with applications of 20 L/m^2/day (Broadbent et al., 2017), and that watering the roads during a heatwave can deliver a substantial cooling benefit (Hendel et al., 2014). But direct cooling strategies are independent of the urban form, reflecting decisions about how the urban design scenario is maintained rather than how it is designed. Further, irrigation is commonly applied to the sub-surface to reduce evaporative losses for water efficiency, and this irrigation design has been assumed in the water sensitive scenario. Consequently, direct cooling effects were not modelled in this work, since the aim was to quantify the performance of passive cooling designs rather than the role of sprinkling water for active cooling. The additional direct cooling benefits of irrigation could be added to the performance evaluation, if irrigation was proposed to be above ground.

Table 4: Forcing values for scenario modelling

Parameter	**Value**
Air temperature	37.4°C
Relative humidity	29.6%
Global radiation	833.0 W/m^2
Di_use radiation	92.0 W/m^2
Direct radiation	925.0 W/m^2
Wind speed	2.5 m/s

Note: W/m^2 = Watt per square metre

The heat modelling was first performed at the site scale to generate heat maps for each of the dwelling and street typology site plans (Appendix, Figure A 13 and Table A 5). These were then combined together, based on the distribution of the typologies over the study area, to create heat maps at the precinct scale for each of the four development scenarios (EX, BAU, WS-Cons and WS-Max) (Appendix, Table A 6).

The visual precinct-scale heat maps were next translated into quantitative distributions of the UTCI ('feels like') temperatures for each development scenario. This distribution plots the number of locations within the precinct expected to have UTCI temperatures in each of the heat stress ranges shown in Figure 9.

The performance indicator for urban heat is the fraction of areas in the precinct that have a 'feels like' (UTCI equivalent) temperature on a very hot summer day that is less than a certain threshold. For this case study the threshold was 42°C UTCI.

2.7 Analysis of architectural and urban space qualities

Available outdoor space plays an important part in both stormwater and urban heat management, creating areas suitable for large canopy trees, infiltration and permeable surfaces. But larger outdoor space may result in increased water and energy demand for irrigation and maintenance. One typical example would be large outdoor areas covered with lawn with high upkeep demands that make little contribution to the reduction of urban heat, especially in drier and hotter climates. The effective performance of available outdoor space is an outcome of design strategies increasing its usability/functionality. The overall quality of both indoor and outdoor spaces depends on their ability to be used, which in turn depends on spatial organisation and design strategies that afford favourable use. The infill dwelling typologies used for the WS scenarios have both internal and external spaces that are:

- multi-functional, adaptable to different uses and living arrangements
- appropriately proportioned, connected and positioned.

Even though many aspects of the design could be quantified, analysis of urban and architectural characteristics is essentially a qualitative evaluation. As such, an 'appropriately proportioned' courtyard could be defined by the ratio of its boundary lengths, where a square-shaped space supports more diverse uses and may be deemed more functional than a long narrow courtyard. An elongated space such as a linear park may also be evaluated as 'appropriately proportioned' if it supports its intended uses.

Here, we give an account of the main principles and criteria used to assess quality of architectural and urban space contributing to liveability, along with high water and thermal performance. Architectural and urban space qualities are assessed on a 10-point scale against the criteria derived from the following principles:

Key design principles

1. Access to quality outdoor public space

Under the pressures of urban intensification and the requirements for more compact living at higher densities, provision and access to quality public realm, such as parks, reserves and plazas, becomes essential. With more public and shared amenity, activated street frontages increase the sense of safety and neighbourliness and encourage walkability, reducing the dependence on cars so prevalent in Australian suburbs.

Considered design strategies for residential precincts, with a range of suitable dwelling typologies allowing a diversity of household types, can complement and encourage use of nearby public open spaces. Higher densities and mixed-use typologies, with home/work options, can generate additional services and functions over time. This can include cafes, grocery shops, pharmacies and other small businesses, increasing use and passive surveillance of public spaces.

Public spaces designed to allow for different ranges of activities maximise their use: for example, 'slow' streets may be used as access to residences, for bicycle connectivity and as linear parks with generous tree canopy cover, allowing communal recreational activities in a pleasant and comfortable environment able to be occupied at different times of the day and year.

Pedestrian and cyclist-friendly infrastructure, including designated paths, bicycle racks, and rest and recreational areas, further reduce car dependence and carbon footprint while encouraging connectivity and use of public open spaces.

2. **Access to quality outdoor communal space**

Consideration of shared amenity becomes significant in higher density infill development. To increase overall site amenity and reduce individual water and energy demands necessary for upkeep, shared BBQ, vegetable garden, play area, and grouped car and bicycle parking areas may be included.

Efficient design strategies, including compact design and organisation of buildings on site, allow provision of quality communal spaces that are functional, accessible to all residents, and adaptable to multiple uses. Certain common spaces, when well-designed, could serve multiple purposes: for example, shared driveways may be used for play and other recreational activities.

To maintain a sense of privacy and individuality, while ensuring adequate sound and visual barriers, it is important to achieve a balanced transition between private and communal spaces. Having adequate setbacks, properly positioning balconies and windows, and selecting the right type of screens and fences will help minimise overlooking from more activated street frontages.

3. **Access to quality outdoor private space**

This refers to the provision of courtyards, terraces, rooftop terraces, balconies and similar, providing good solar access, ventilation, outlook and sufficient soil and space for large canopy trees.

High quality outdoor private space is flexible and adaptable, designed to facilitate a variety of uses. Multiple use is supported when such spaces are considered in terms of their length and width, and the height of surrounding walls with their effect on sun and ventilation throughout the year. Courtyards adjacent to living and dining areas may be used as an extended living room, guest entertainment area, garden, and transitionary space between different house zones. An open carport may also be used as an outdoor space.

Landscaping solutions, including well positioned large canopy shade trees, pergolas and trellises offer shade for better thermal comfort, and can provide sound and visual privacy barriers when private areas face communal and public spaces.

4. **Dwelling amenity and function**

Water sensitive design strategies are used to deliver quality higher density living solutions, without compromising on amenity and function. Building footprints are reduced and the number of floors increased to yield sufficient well considered space for both private and communal outdoor areas on site, allowing more deep soil space to accommodate large canopy trees. Reduction in parking space from the usual two car bays to one per dwelling makes additional usable space available. Further space is gained by grouping parking on site, and open carports allow for permeable paving areas.

Flexibility in internal spatial arrangements is a crucial aspect in increasing usability, supporting a range of occupancies and adapting to changing requirements over time. Flexible internal space is designed to support a diversity of uses—for example, a room with separate services adjacent to a street could be used as a home office, games room or additional bedroom. Internal spatial amenity and functionality are enhanced by direct physical and visual connection to quality outdoor spaces, achieved by designing living areas adjacent to courtyards, terraces and other outdoor areas.

The position and orientation of a dwelling on the site can improve overall site usability, thermal comfort and energy efficiency. Facing windows to the north and north-east will provide favourable solar orientation, and windows in two walls of a room will allow good cross-ventilation and light quality. Adequate shading from the direct sun on the east and west sides is achieved with well positioned greenery or by using various shading systems. On unfavourably positioned sites, lightwells may be considered for access to natural light and breeze.

2.8 Performance indicators used for analysis

Performance indicators communicate the performance of each scenario relative to the reference case. The performance criteria relate to hydrology, water demand and supply, greening, urban heat, and architectural and urban space qualities.

Figure 10 summarises the cause-and-effect relationships between urban design parameters (on the left of the diagram) and performance criteria (on the right). It also shows the indicators that can be used to quantify performance, either at the end-point (actual performance) or at a mid-point (key determinants of performance) in the cause–effect chain. The performance indicators reported for Salisbury are those highlighted in red in Figure 10. Refer to the [Framework]for a more detailed explanation of these indicators, and how they were derived from the urban water balance data (Appendix, Table A 3).

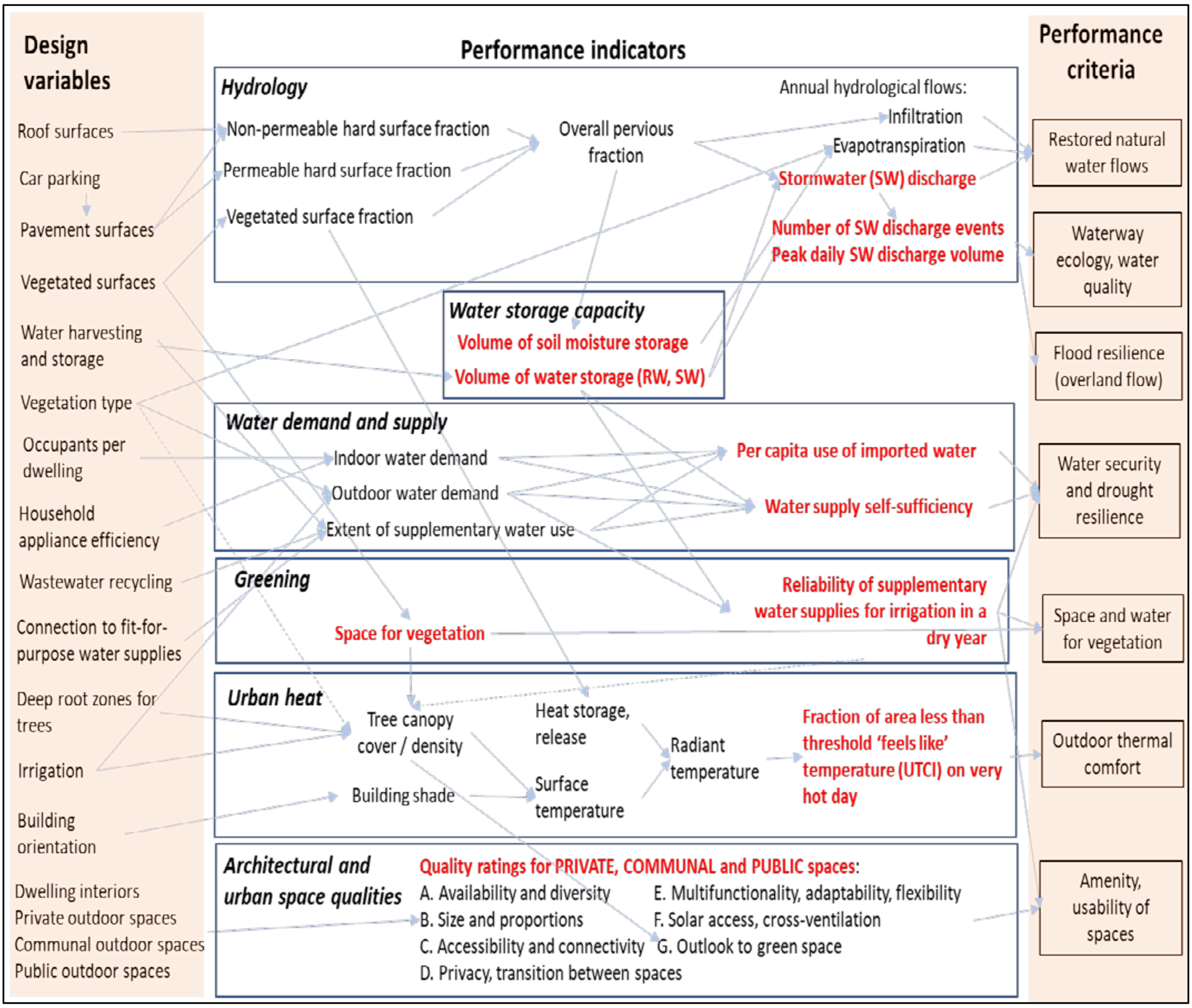


Figure 10: Cause-and-effect relationships between design parameters and performance criteria

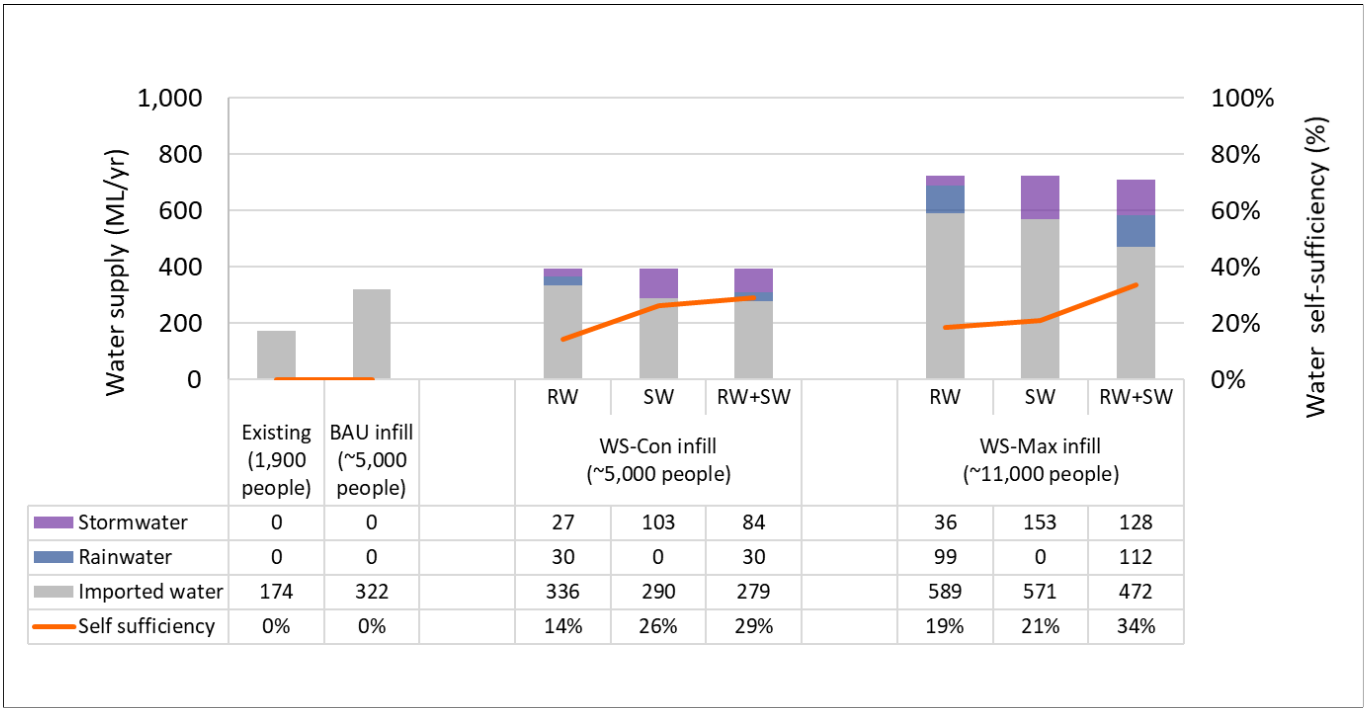
3. Performance evaluation

3.1 Hydrology

The performance principle for hydrology is that ‘infill design aims to mimic the natural hydrology (infiltration, evapotranspiration and stormwater discharge) of the area’ (Renouf et al., 2020). In other words, this principle recognises that in the EX scenario, hydrology of many urban areas is significantly changed. Water sensitive urban infill development aims to maintain or improve hydrology as areas densify.

Changes to hydrological flows — infiltration (I), evapotranspiration (ET), and stormwater discharge (SW) — can be observed by comparing the annual volumes for the infill scenarios (BAU, WS-Con, WS-Max) with those of the EX and PRE cases in Figure 11. Changes in storage are also included, which show how water accumulates in the system (in rainwater and stormwater storages and in the soil) between the start and the end of the reported year (January to December 2010).

For the PRE reference state (i.e., the natural landscape), the total amount of water accounted for, excluding change in storage, equals the annual rainfall onto the study area (593 mm/yr or 773ML/yr in 2010). For some scenarios, the totals are higher than rainfall due to the input of additional imported water for irrigation, which converts to ET. This is a transfer of water from the urban water cycle into the natural hydrological cycle. For other development scenarios, the totals are lower than rainfall due to some rainfall being harvested and used for internal potable uses which ends up flowing to wastewater.



	Existing (1,900 people)	BAU infill (~5,000 people)	WS-Con infill (~5,000 people) RW	WS-Con infill SW	WS-Con infill RW+SW	WS-Max infill (~11,000 people) RW	WS-Max infill SW	WS-Max infill RW+SW
Stormwater	0	0	27	103	84	36	153	128
Rainwater	0	0	30	0	30	99	0	112
Imported water	174	322	336	290	279	589	571	472
Self sufficiency	0%	0%	14%	26%	29%	19%	21%	34%

Figure 11: Hydrological flows in an average rainfall year (2010 with rainfall of 593 mm)

The naturally impervious clay soils at Salisbury mean that infiltration of rainfall into soils is naturally very low, and changes to infiltration volumes due to the changes in imperviousness are only slight (Clark et al., 2015). Changes in hydrology are instead driven by reduced ET as a result of there being less vegetation and fewer pervious surfaces in the developed cases. The consequence of reduced ET and reduced infiltration is increased SW.

Rainfall that does not evaporate, transpire through vegetation, or soak into the ground must go somewhere, and it drains away as runoff.

Therefore, the annual volume of SW discharge is a useful indicator of hydrological performance (blue bar in Figure 11), and refers to the maintenance or restoration of SW towards the more PRE state and better than EX state. This aligns with SA's WSUD policy which 'aims to manage runoff discharged from a site so it does not exceed the existing development state (EX)' (Government of South Australia, 2019). The indicators for representing SW (Table 5) are the fraction of annual rainfall that converts to SW (%) and stormwater 'naturalness' (ratio of post- to pre-urbanised SW).

Table 5: Indicators of hydrological performance

Indicators of hydrological performance	**Reference case**		**Infill scenarios**						
	PRE (natural)	EX (2019)	BAU (~5,000 people)	WS-Con (~5,000 people)			WS-Max (~11,000 people)		
				RW	SW	RW+SW	RW	SW	RW+SW
Fraction of annual rainfall that converts to SW (%)	13	42	50	39	32	31	30	27	16
Stormwater 'naturalness' (SW relative to PRE SW) (%)	NA	3.2	3.8	3.0	2.5	2.4	2.3	2.1	1.3
Stormwater 'naturalness (SW relative to EX SW) (%)	0.3	NA	1.2	0.9	0.8	0.7	0.7	0.6	0.4

RW = rainwater harvesting and use.
SW = stormwater harvesting and use (via Salisbury Water's ARS and purple pipe scheme).

For the EX reference state, the annual volume of SW discharge was estimated to be 42% of the rainfall in an average rainfall year. Interestingly, only 13% of rainfall is converted to SW in the PRE scenario. In BAU infill development, it is estimated that 50% of the rainfall is converted into SW in an average rainfall year, which is 1.2 times that of the EX state. This increase is due to the 1.27 times increase in impervious surfaces in the BAU state when compared with the EX scenario.

The WS-Con infill scenario is expected to produce volumes of SW discharge that are less than the BAU scenario, and also less than the EX case—between 31% and 40% of rainfall, depending on the extent of rainwater and/or stormwater harvesting and use. The performance of the WS-Con scenarios can be directly compared with the BAU infill scenario because they provide equivalent functionality in terms of the populations they accommodate (~5,000 people). The WS-Con scenario can increase the population of the study area to 5,000 while decreasing the annual volumes of SW discharge in comparison to EX state (0.7 to 0.9 times EX). In contrast, BAU will increase the annual volumes of SW discharge by 1.2 times of EX state to achieve the same population increase as WS-Con.

The favourable performance of WS-Con over BAU is due to two factors. The first is the purposeful design of the built form to include as much permeable and vegetated surfaces as possible to promote evapotranspiration, and some infiltration (although limited in the Salisbury context). The second is the integration of rainwater and stormwater harvesting and use into the design, which not only provides supplementary water supply, but also holds back runoff.

The harvesting and use of recycled stormwater alone (for irrigation and toilet flushing) leads to less SW discharge than rainwater harvesting alone (for irrigation, toilet flushing and laundry). This is because the ASR infrastructure can harvest and store more runoff (Figure 14). In this case the benefits of the combined use of both (as modelled[2]) are not additive. This is because the ample availability of the recycled stormwater for garden irrigation and toilet flushing reduces the need for the households with tanks (less than 50% of dwellings) to use rainwater for these purposes, and hence reduces the freeboard in the rainwater tanks for holding back runoff.

The WS-Max scenario represents the best case performance that could be achieved. Volumes of SW discharge for this scenario were estimated to be considerably less than the BAU and EX cases. Harvesting and use of either rainwater or recycled stormwater alone over the whole study area can reduce SW discharge to around 30% of rainfall. Interestingly, combined use of both (rainwater and stormwater) can reduce SW discharge to 16% of rainfall, which is close to the PRE state.

If implemented to their full extent in the WS-Max scenario, the water sensitive design principles could significantly increase the population to around 11,000, while also reducing the annual volumes of SW discharge lower than EX (0.4 to 0.7 times EX). We also note that WS-Max is closer to PRE (1.3 times PRE) in terms of percentage of rainfall converted to SW.

The amount of effective pervious area for WS-Max is similar to that for WS-Con (Figure 8), discounting it as a factor contributing to this performance. The change is instead due to the combined effect of the larger scale of vegetation irrigation which maximises the use of recycled stormwater, and the increased use of harvested rainwater, which has the net effect of making more storage volume available, and more often, to hold back runoff.

Two other indicators of hydrological performance relate to peak daily SW discharge events in a wet year (Figure 12). These are proxy indicators for waterway ecology and water quality, because the number and volume of peak runoff flows contribute to the integrity of waterway structure and the mobilisation of sediment and pollutants. As for the SW discharge indicator, it is typical to make comparisons with the EX state to show that the development has not made things worse (e.g. a deterioration in downstream flooding or changes to groundwater or reduction in evapotranspiration and urban heat). However, comparision with the PRE-state provides a universal point of reference, because a natural condition is the logical aspirational end point for all systems regardless of their current state.

[2] The Aquacycle model makes assumptions about the hierarchy of water use when more than one water source is available. For example, for garden irrigation and toilet flushing, recycled stormwater is used before rainwater.

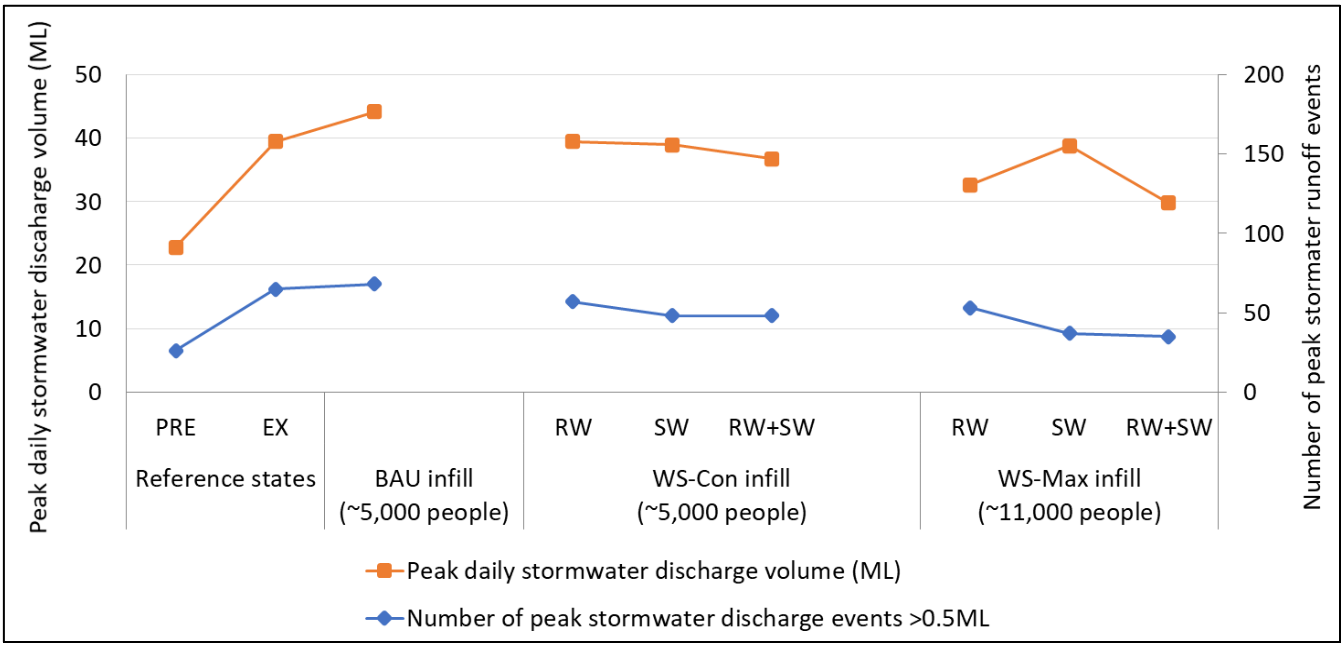


Figure 12: Number and volume of peak daily stormwater discharge events in a wet year (2016)

We estimated that the number and volume of peak SW discharge in the EX state are around double those of the PRE state, and that BAU development will further exacerbate this impact. The WS-Con scenario mitigates this by reducing the number and volume of peak flows to be similar to, or less than, the EX state (Figure 12) for the reasons previously described. Further mitigation is possible in the WS-Max case. The extent of mitigation relies on having enough storage capacity to provide freeboard to hold back peak flows in wet periods.

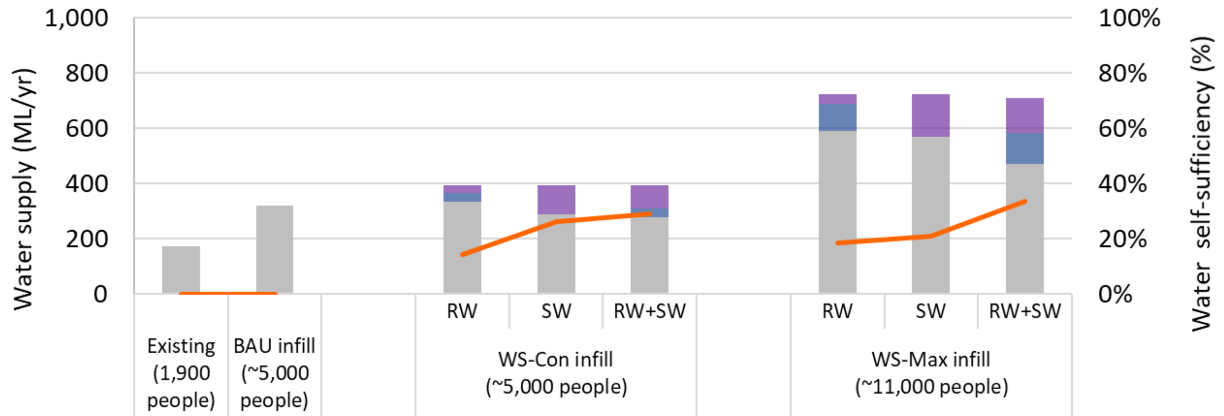
It was estimated that the number and volume of peak SW discharge in the EX state are 65ML and 40ML in an average rainfall year. In the BAU scenario, the volume of peak SW discharge is exacerbated by 1.2 times that of EX. Meanwhile, WS-Con maintains or lowers the number of peak SW discharge, at the same time reducing the volume of peak SW discharge by 0.7 to 0.8 times of EX.

3.2 Water demand and supply

In relation to water supply, the Framework distinguishes between water sourced from within the urban system (in this case harvested rainwater and stormwater), and water imported from outside the urban system (in this case mains water supplied by SA Water). The performance principle for this aspect is that 'infill designs reduce reliance on imported water through use of supplementary water supplies' (Renouf et al., 2020). The degree of water self-sufficiency is the indicator for this, and represents the percentage of water demand that is met by water sourced from within the urban system. The impacts of the infill scenarios on water demand and supply, and on water self-sufficiency in an average rainfall year compared with the EX state, are shown in Figure 13.

The increased population in the study area from 1,900 in the EX case to 5,000 in the BAU will increase water demand by a factor of 1.8 compared with EX demand. Since no supplementary water supplies are assumed for either case, there is no water self-sufficiency for the EX and BAU cases.

The same population increase in the WS-Con case will increase water demand by a factor of 2.3 from EX, which is higher than for the BAU case because a greater amount of irrigation is assumed to occur to promote greening. But supplementary supplies of rainwater and/or recycled stormwater enable a reduction in the use of imported water to various degrees. The harvesting and use of rainwater alone provide 14% self-sufficiency, which is not enough to meet the additional water demand for irrigation, so overall amount of imported water is higher than for BAU infill. The use of harvested stormwater, either on its own or in combination with rainwater use, provides 26–29% self-sufficiency, which more than meets the additional irrigation demand and reduces the amount of imported water to be less than BAU infill.



	Existing	BAU infill		WS-Con RW	WS-Con SW	WS-Con RW+SW		WS-Max RW	WS-Max SW	WS-Max RW+SW
Stormwater	0	0		27	103	84		36	153	128
Rainwater	0	0		30	0	30		99	0	112
Imported water	174	322		336	290	279		589	571	472
Self sufficiency	0%	0%		14%	26%	29%		19%	21%	34%

Figure 13: Water supply and self-sufficiency, in an average rainfall year (2010)

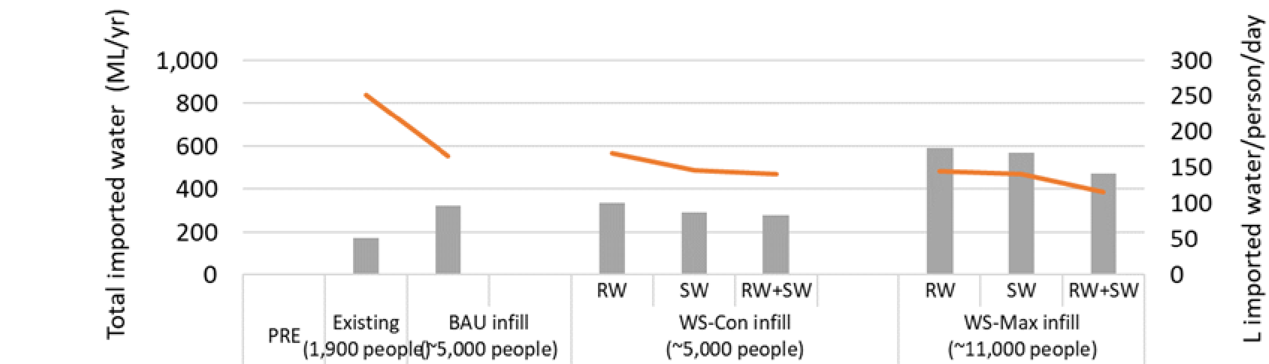
For the WS-Max infill scenario, the population increase to 11,000 people substantially increases water demand in the study area. In the best case, the combined use of recycled stormwater and rainwater harvesting and use by residential dwellings over the whole study area will provide around 34% self-sufficiency. This will constrain the increase in imported water supply by a factor of 2.7 from EX.

The resulting efficiency of the infill scenarios in terms of imported water use per person can be seen in Figure 14. Per person imported water efficiency for the EX case was estimated to be 233 L/p/day, which compares reasonably well with a household water demand study by Arbon et al. (2014), which reported 289 L/p/day.

For the BAU infill scenario, imported water use per person (averaged over the whole study area) was estimated to reduce relative to EX to 159 L/p/day. This comes from there being substantially less garden irrigation as a result of very little garden available to irrigate in the RBAU typology. Consequently, this scenario could be interpreted as being more water efficient than EX, but no greening value is obtained.

For the WS-Con infill scenario with an equivalent population to BAU, imported water use will reduce relative to EX to between 141–170 L/p/day, depending on the available supplementary water supply. If only household rainwater was available (from 2,000 L tanks in the new infill dwellings) it would be 170 L/p/day, which is higher than the BAU scenario, but there will be more greening through irrigation. In the best case, with the combined use of recycled stormwater and rainwater, a WS-Con infill design could provide irrigation-supported greening to about 50% of the study area with an imported water use efficiency of 141 L/p/day. The authors are not aware of any existing target against which this can be compared.

If WS-Max was implemented across the whole study area with the combined use of recycled water and rainwater, it could provide significant greening with an imported water use of around 116 L/p/day.



	PRE	Existing (1,900 people)	BAU infill (~5,000 people)		WS-Con infill RW	WS-Con infill SW	WS-Con infill RW+SW		WS-Max infill RW	WS-Max infill SW	WS-Max infill RW+SW
Total imported water (ML/yr)		174	322		336	290	279		589	571	472
Per capita use of imported water (L/person/day)		251	166		170	146	141		145	141	116

Figure 14: Per capita use of imported water, in an average rainfall year (2010)

3.3 Water storage capacity

As observed in the previous sections, performance in terms of hydrology and water demand and supply are both influenced by the amount of storage capacity in the urban system. This includes not only reservoir stores but also the capacity to store moisture in the soil profile.

The performance principles for this aspect are that ‘infill designs incorporate water storages to facilitate the availability of supplementary water supply, and slow/retain/detain runoff for reducing flooding and facilitate soil moisture storage through permeable surfaces that promote infiltration’ (Renouf et al., 2020). The total water storage capacity of the urban system is a useful indicator for this performance aspect (Figure 15).

Tank storage capacity was taken to be the total combined volume of rainwater tanks and stormwater harvesting reservoirs (including in this case aquifer storage) in the study area. The soil moisture storage capacity was taken to be the volume of water that can potentially be held by the soil. It was calculated from the amount of pervious surface that allows rainfall to infiltrate into the soil profile, the soil’s pervious store (mm), which is one of the calibration parameters for the hydrological modelling (Table 3), and the assumed depth of the soil profile within the urban system boundary (1 m).

In relation to soil moisture storage capacity, the increased surface imperviousness that will occur with BAU infill will continue to reduce the amount of soil moisture that can infiltrate into and be held by the soil profile and available for vegetation (Figure 15). In contrast, both the WS infill scenarios enable densification while maintaining the impervious fraction and the soil moisture storage capacity at similar to the EX state. Figure 15 demonstrates how WS-Con infill provides an extra 12 ha of permeable surfaces compared with BAU. Further, more water will be held in this additional soil profile (30ML) than the total rainwater tank capacity in the WS-Con (2,000 L retention tank per household or 3ML total). This confirms the importance of maintaining pervious urban catchments. Protecting the precinct from increased hard surfaces will be fundamental to good hydrological performance.

Salisbury Water's ASR scheme provides a very large aquifer storage capacity (10ML in aboveground stormwater stores and 80ML in aquifer store), which is a rather unique feature of this case study. The greater use of this storage capacity in the WS infill scenarios has a significant and favourable influence on the water performance that can potentially be achieved. In other regions where a storage aquifer is not available, the storage capacity provided by the aboveground stormwater stores would be more typical.

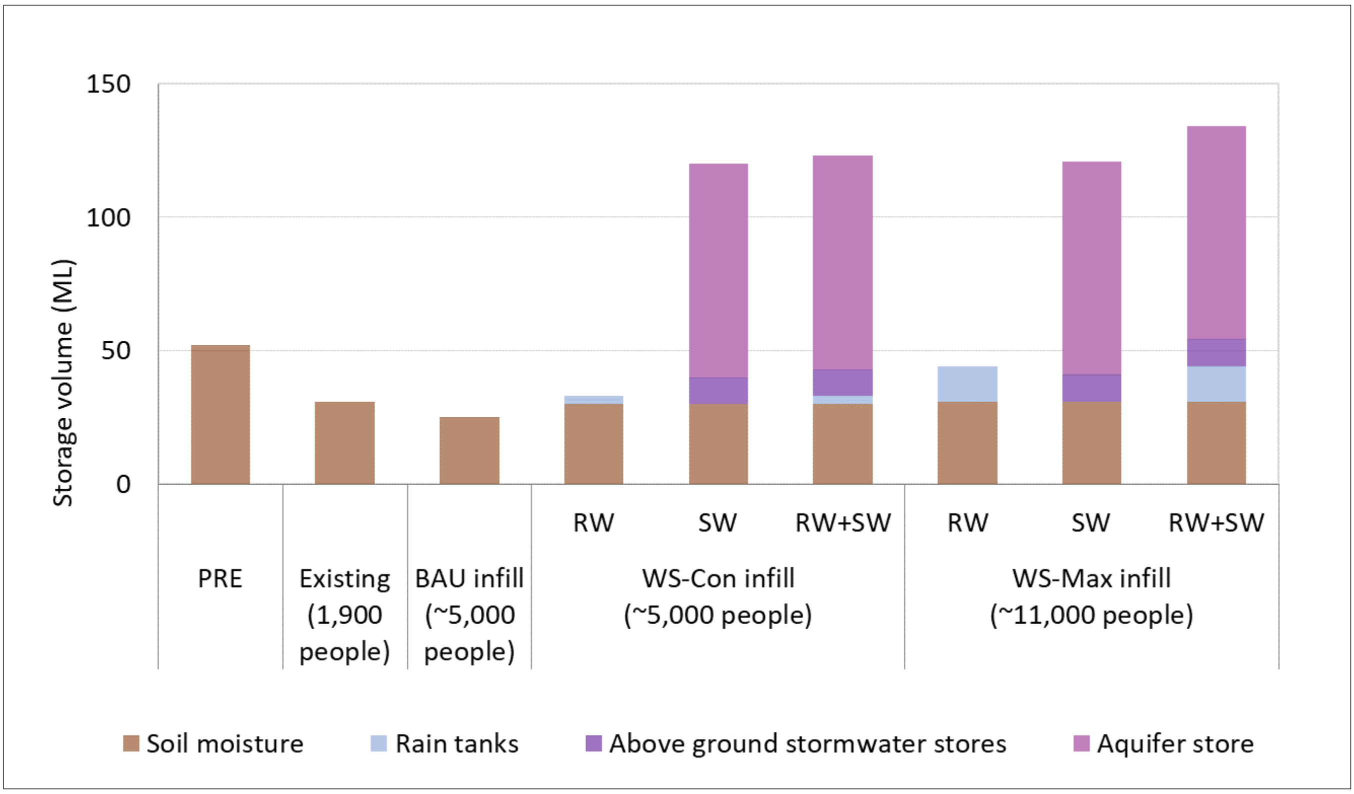


Figure 15: Water storage capacity in the study area (tank storage and soil moisture storage)

3.4 Water and space for greening

This aspect of performance recognises the importance of space and water for greening, cooling, and amenity. Outdoor water use for irrigation is often the first to be restricted during drought periods. But the value for greening challenges such restrictions on irrigation. The performance principle is that 'infill designs include space and deep root zones for vegetation and large trees, and also enable their irrigation with supplementary water supplies, to provide greening for cooling and amenity even in dry years' (Renouf et al., 2020).

Space and water for greening are represented together in Figure 16. Space for greening is represented by the fraction of the study area that is vegetated and the fraction of the study area that provides a deep root zone to support large trees. The vegetated area of verges of typical roads (as in the EX and BAU cases) were assumed to have 80% deep root zone; the vegetated areas of road verges which also incorporate parking bays were assumed to have 50% deep root zone. Public open space areas were assumed to have 100% deep root zone. Water for greening is represented by the volumetric reliability of supplementary water supplies for meeting irrigation demands in a dry year (2006), which is the amount of irrigation demand that can be met by supplementary water supply.

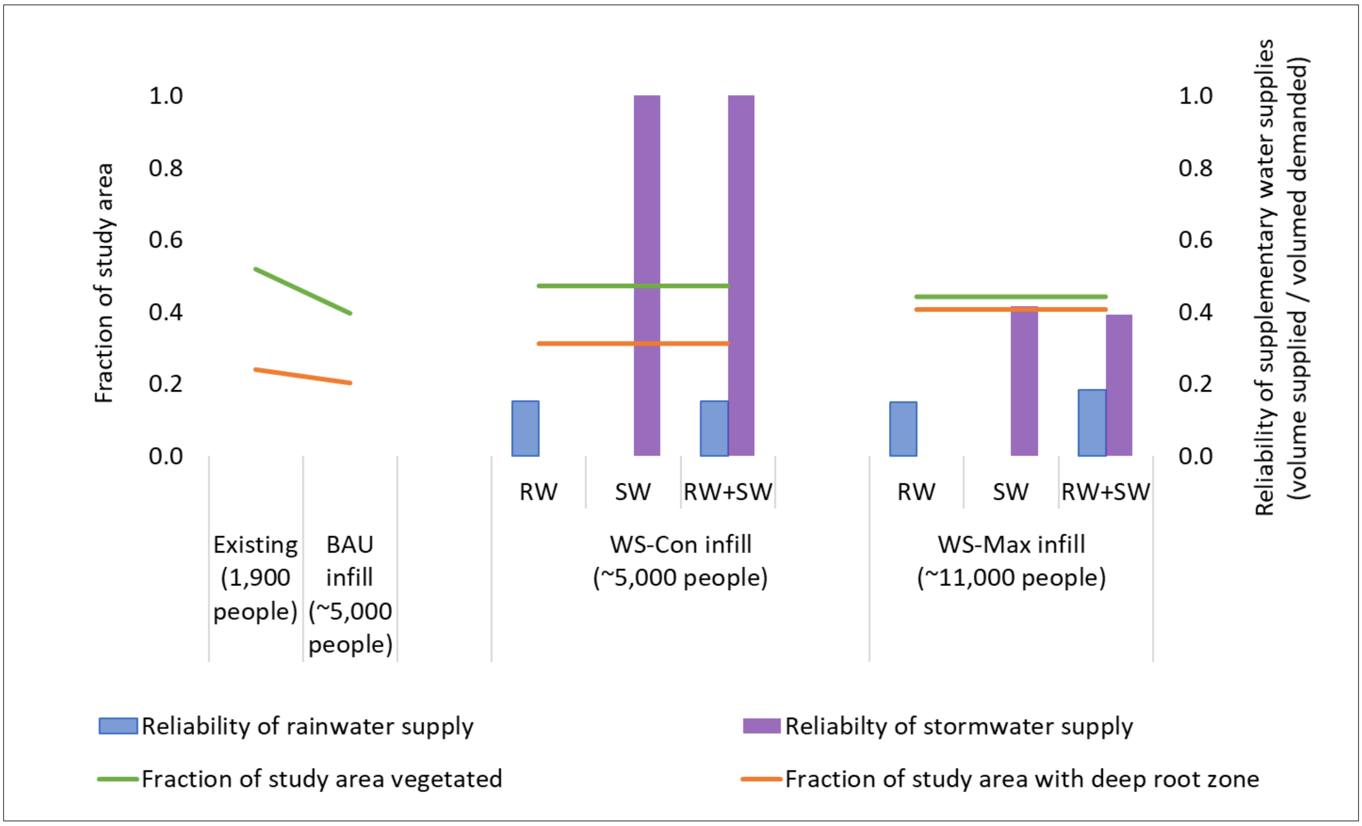


Figure 16: Space for greening and water for irrigation in a dry year (2006)

Compared with the EX case with 52% vegetated area, BAU infill will reduce this to 40%, and the WS infill scenarios will maintain it at 44–47% of the study area.

More important is the fraction of the study area that has deep root zones to support large trees with substantial tree canopies, which is a key contributor to the mitigation of urban heat (see next section). For the EX scenario, this fraction was estimated to be 24%. For the BAU scenario, this reduces to 20% and all of it is present in the gardens of existing dwellings and on public land, and none in the gardens of the new infill dwellings. South Australia's '30 Year Plan for Greater Adelaide' includes a target for an approximate 20% increase in the canopy cover on both private and public land by 2045 (Government of South Australia, 2010a). A reduction in deep root zones in the BAU infill development will make it difficult to achieve this. In comparison, the WS-Con scenario provides 30% of the study area with deep root zones, which increases to 40% in the WS-Max scenario. Achieving the canopy cover target would be easier to achieve under these scenarios.

In the WS scenarios that use recycled stormwater, there is also a greater likelihood of establishing and maintaining the quality and density of vegetation and canopy cover, as a result of the reliability of this water supply even in a dry year. The volumetric reliability of the recycled stormwater supply was estimated to be 100% in the WS-Con scenario, which concurs with the findings of Clark et al. (2015). In the WS-Max case, the reliability was estimated to drop to around 40% because there is a much larger area assumed to be irrigated. The reliability of rainwater supply is much lower, estimated to be only 15% in a dry year, and not viable on its own for supporting vegetation. For BAU there is assumed to be no supplementary water supply, so irrigation would need to use imported water which is more likely to be restricted for irrigation in dry periods. South Australia's 'Water for Good' plan (Government of South Australia, 2010b) seeks to increase the harvesting of stormwater and recycling of wastewater across the state's urban areas, which will be important for reliable supplementary water supplies to support greening targets.

3.5 Urban heat

The performance principle for urban heat is that 'infill designs enable passive mitigation of outdoor urban heat through building orientation and tree canopy shading' (Renouf et al., 2020). The performance indicator is the fraction of outdoor areas that are less than 42°C UTCI (a 'feels like' temperature) on a very hot day.

The distributions of outdoor UTCI temperatures for each of the dwelling and street typologies are provided in Figure 18, and the heat distribution over the whole study area is summarised in Figure 17. To show more granularity, the normal UTCI heat stress categories (see Figure 9) are split into four sub-categories, as shown in Table 6. The distribution of these UTCI heat stress categories for the site scenarios and precinct scenarios are shown in Appendix, Table A 5 and Table A 6.

Table 6: Universal Thermal Climate Index (UTCI) – heat categories

Temperature range	UTCI heat categories	Abbreviation	Relative category
>48°C	Extreme heat – high	EH-max	Higher heat stress
46–48°C	Extreme heat – low	EH-min	
42–46°C	Very strong heat – high	SH-max	Lower heat stress
38–42°C	Very strong heat – low	SH-min	

In the EX case, 77% of the study area exhibits temperatures above 42 UTCI on a high heat day. With BAU this increases to 83%, while the water sensitive designs reduce this to 68% for WS-Con or 59% for WS-Max. Shifts in the distributions of heat stress due to the different types of urban form can be seen in the movement from higher stress categories into lower stress ones across the four precinct scenarios.

In the EX scenario, there is a shift towards the lower heat stress with a distribution of 72.3% in SH-max, and 22.9% in SH-min and only 4% of area in EH-min. The BAU scenario shows a redistribution of heat stress towards the higher heat stress categories, showing distributions of 1% in EH-max and 14% in EH-min followed by 67% in SH-max and 23% in SH-min.

In the WS-Con scenario, the distributions shift towards the lower heat stress categories with distributions of 32.4% in SH-min, 59.6% in SH-max and remaining 7.3% in EH-min and a meagre 0.7% in EH-max. The WS-Max scenario maximises the percentage of the precinct that is in the lowest stress category but also shows a slight increase in the higher stress categories with a distribution of 10.3% in EH-min, 47.6% in SH-max, and 41.2% in SH-min.

It was observed that the areas of greatest cooling on the site-scale heat maps (Appendix, Figure A 13) align with shade trees that were assumed to be included in the site plans. Therefore, it appears that shading from dense canopies may be the most important factor influencing cooling. In examining the surface type breakdowns for each infill scenario, EX shows the highest percentage of garden/green space while BAU shows the smallest amount. The slight increase in higher stress temperatures from WS-Con to WS-Max can likely be attributed to the slight increase in total impervious surfaces in the maximised scenario (from 60.3% to 64.7%). Across all the scenarios, the impervious surfaces were consistently the areas of highest heat stress, showing the importance of minimising those features.

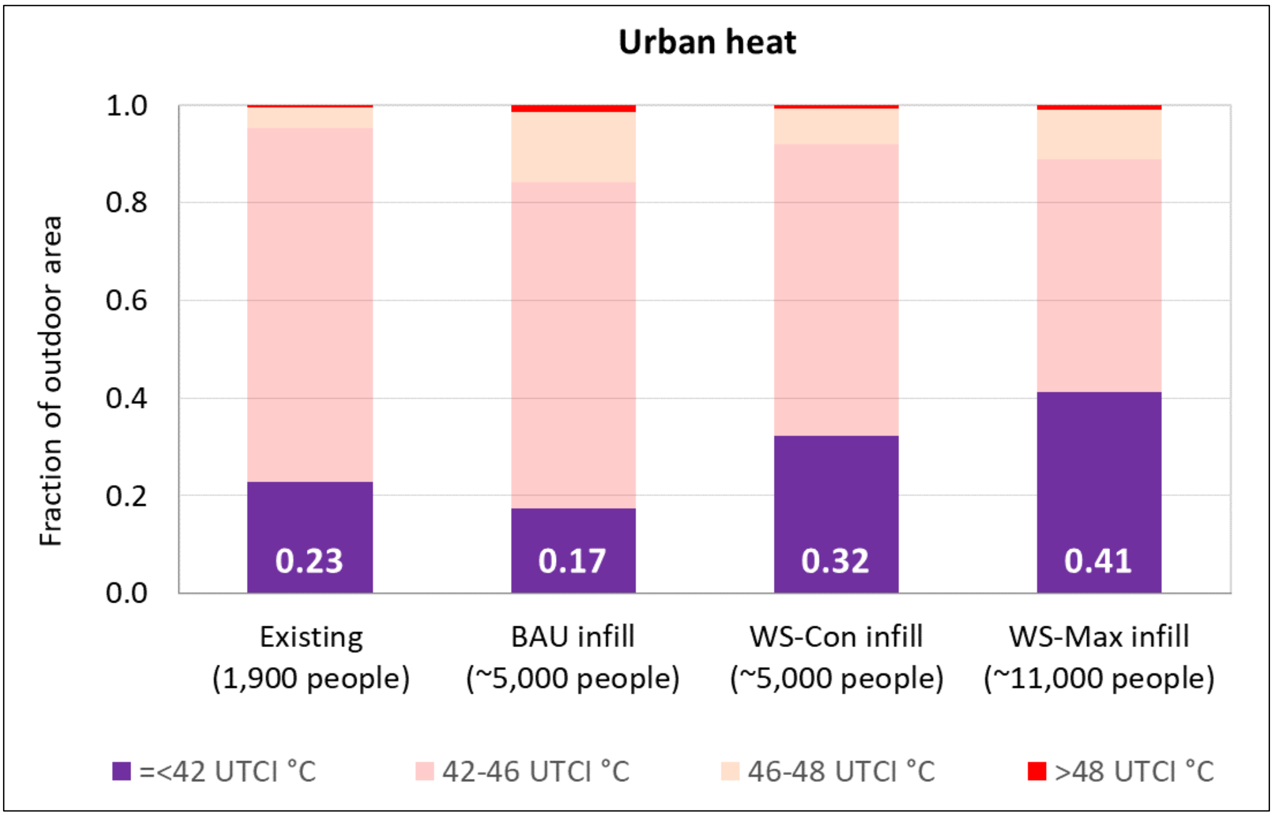


Figure 17: Summary of the precinct-scale outdoor ‘feels like’ (UTCI equivalent) temperature distribution over the study area on a very hot day, for each development scenario

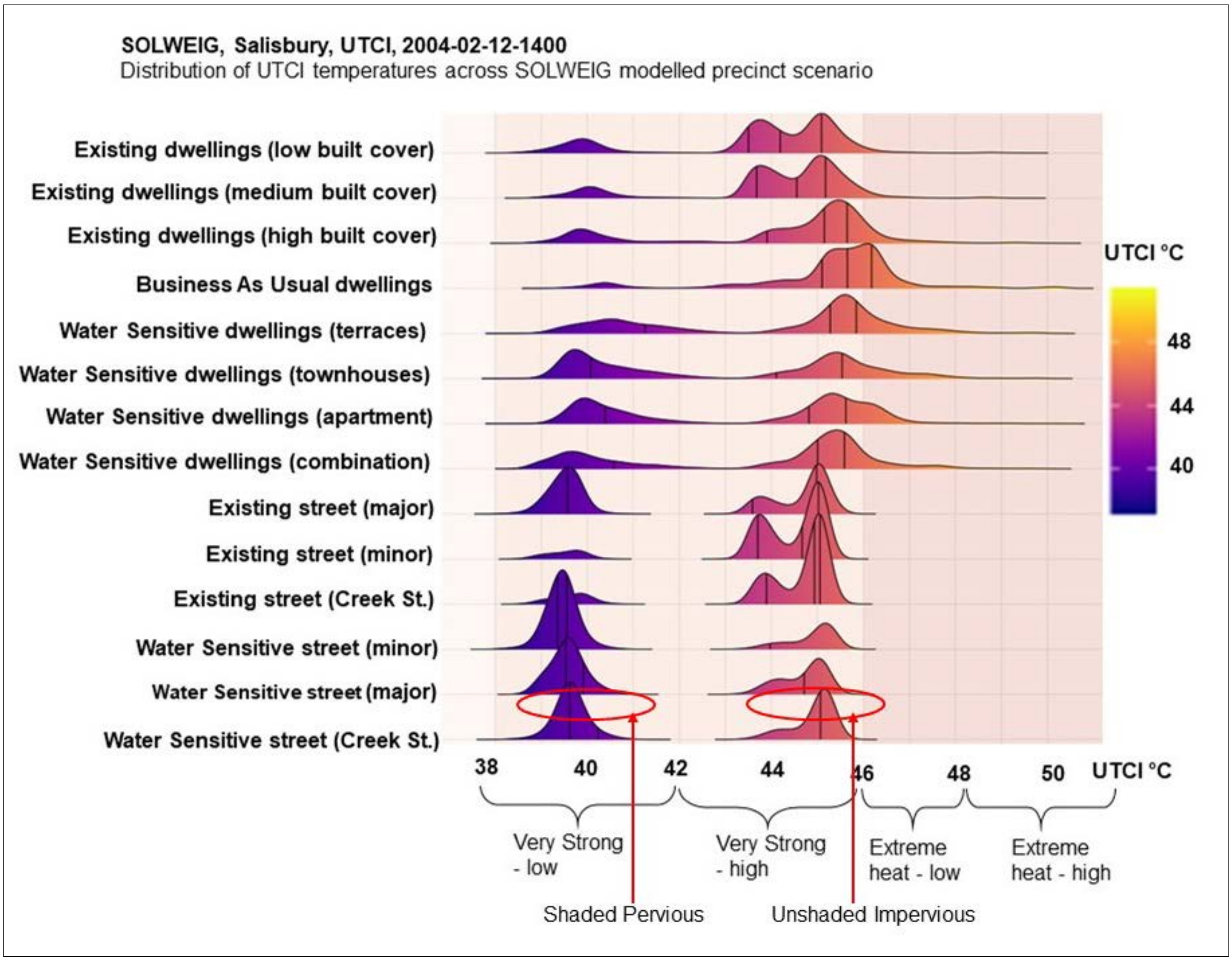


Figure 18: Distribution of outdoor 'feels like' (UTCI equivalent) temperatures for each of the individual dwelling and street typology site plans. Heat stress categories are based on Figure 9. Refer Figure A 15 for site scale distribution

3.6 Architectural and urban space qualities

The architectural qualities of the indoor and outdoor space are scored for the four different site plans across four different performance criteria as shown below. For detailed information refer to the Framework.

The indoor and outdoor spatial aspects are categorised into (i) dwelling interiors (Table 7), (ii) outdoor private space (Table 8), and (iii) outdoor communal space (Table 9) and (iv) outdoor public space (Table 10).

Table 7: Architectural and urban space qualities scoring for dwelling interiors

Rating	**NA**	**0**	**1**	**2**	**3**
Scoring	**Not applicable**	**Absent**	**Low**	**Medium**	**High**
Performance criteria	**Performance indicator**	**EX**	**BAU**	**WS-Con**	**WS-Max**
		Rating	**Rating**	**Rating**	**Rating**
A. Availability and diversity	Dwelling diversity on site, a range of dwelling sizes (number of bedrooms and bathrooms) and types (e.g. townhouse, apartment and other)	'Dwelling interiors' is not applicable in precinct scale. But at site scale, this is a key factor contributing to the overall score of architectural and urban space qualities.			
B. Size and proportion	Adequate internal spatial arrangement (size, proportion, and position appropriate for the use)				
C. Access and connectivity	Appropriate accessibility (e.g. multiple access points separating residential from office, or pedestrian from car access); and appropriate internal connection between spaces				
D. Privacy and noise – balanced transition	Privacy and noise proofing through appropriate positioning of windows, screens, fence (e.g. bedrooms not directly facing private open space used by all occupants or communal/public space)				
E. Multifunctionality, adaptability, flexibility	Dwelling that accommodates a range of occupancies (e.g. flexible space on ground floor could be adapted as office space, granny flat)				
F. Solar access, cross-ventilation	Adequate solar access including positioning of surrounding buildings and deep root zone for trees, avoids excessive westerly exposure, adequate cross-ventilation to all living areas				
G. Outlook to gardens, vegetation, trees	High quality outlooks to open space, gardens, canopy trees				
Overall scoring for dwelling interiors					

Table 8: Architectural and urban space qualities scoring for outdoor private space

Rating	NA	0	1	2	3
Scoring	**Not applicable**	**Absent**	**Low**	**Medium**	**High**
Performance criteria	**Performance indicator**	**EX**	**BAU**	**WS-Con**	**WS-Max**
		Rating	**Rating**	**Rating**	**Rating**
A. Availability and diversity	Adequate number and types of private outdoor space, (e.g. garden, courtyard, balcony, rooftop terrace). Spaces of different orientation and levels of exposure/protection	2	1	3	3
B. Size and proportion	Appropriately sized and proportioned in length, width and height for usability	3	1	2	2
C. Access and connectivity	Accessible to all occupants (e.g. direct accessibility from living areas vs accessibility from a master bedroom only)	3	2	3	3
D. Privacy and noise-balanced transition	Balanced connection between private and communal/public spaces, considering privacy and noise (e.g. shades, screens, fences, etc.)	2	2	2	2
E. Multifunctionality, adaptability, flexibility	Supports a number of uses and users (e.g. balcony accessed from master bedroom will have less users/uses compared to a terrace accessed from living area)	2	1	2	2
F. Solar access, cross-ventilation	Adequate solar access including positioning of surrounding buildings and deep root zone for trees, adequate cross-ventilation, avoids ‘wind tunnels’	2	1	3	3
G. Outlook to gardens, vegetation, trees	Deep root zone providing sufficient space for and adequate positioning of large canopy trees/vegetation	3	0	3	3
Overall scoring of outdoor private space		**17**	**8**	**18**	**18**

Table 9: Architectural and urban space qualities scoring for outdoor communal space

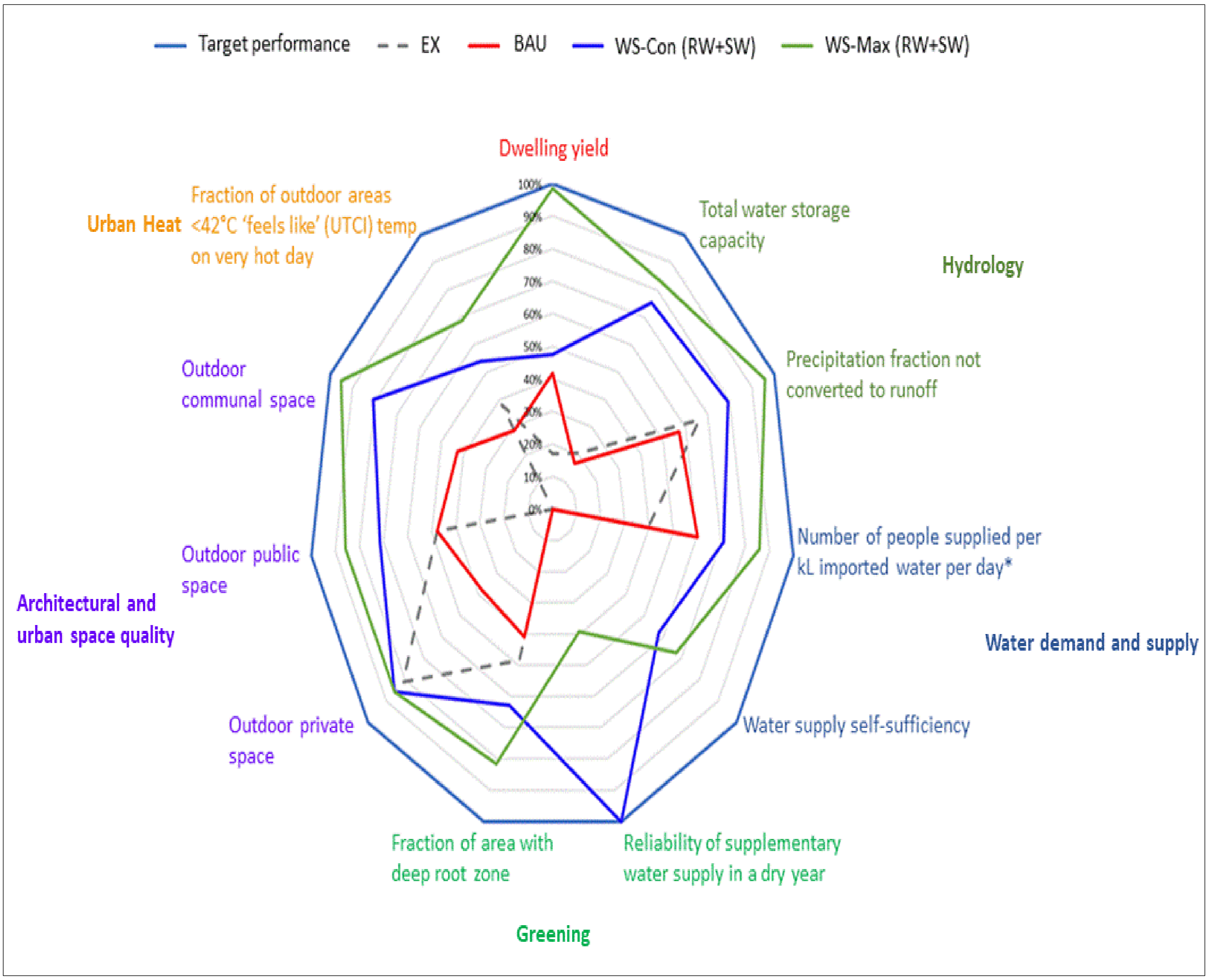
Rating	NA	0	1	2	3
Scoring	**Not applicable**	**Absent**	**Low**	**Medium**	**High**
Performance criteria	**Performance indicator**	**EX**	**BAU**	**WS-Con**	**WS-Max**
		Rating	**Rating**	**Rating**	**Rating**
A. Availability and diversity	Adequate number and type of shared facilities (e.g. vegetable garden, play area, BBQ area)	0	1	2	3
B. Size and proportion	Appropriately sized and proportioned in length, width and height for usability	0	1	3	3
C. Access and connectivity	Accessible to all residents, with physical connections between private and communal spaces	0	2	3	3
D. Privacy and noise – balanced transition	Transition between communal and public open spaces considering privacy and noise (shades, screens, fences, etc.)	0	1	2	2
E. Multifunctionality, adaptability, flexibility	Supports a number of uses and users	0	1	2	3
F. Solar access, cross-ventilation	Adequate solar access including positioning of surrounding buildings and deep root zone for trees, adequate cross-ventilation, avoids 'wind tunnels'	0	2	3	3
G. Outlook to gardens, vegetation, trees	Deep root zone providing sufficient space for and adequate positioning of large canopy trees/vegetation	0	1	2	3
Overall scoring for outdoor communal space		**0**	**9**	**17**	**20**

Table 10: Architectural and urban space qualities scoring for outdoor public space

Rating	NA	0	1	2	3
Scoring	**Not applicable**	**Absent**	**Low**	**Medium**	**High**
Performance criteria	**Performance indicator**	**EX**	**BAU**	**WS-Con**	**WS-Max**
		Rating	**Rating**	**Rating**	**Rating**
A. Availability and diversity	Adequate number and variety of open public spaces (e.g. linear park, pocket park, sports fields, nature reserve)	1	1	2	3
B. Size and proportion	Appropriately sized and proportioned in length, width and height for usability	1	1	2	3
C. Access and connectivity	Adequate bicycle and pedestrian accessibility and connectivity (i.e., walking distance; pedestrian and cycling infrastructure; multiple access points); public transport provision	1	1	2	3
D. Privacy and noise – balanced transition	Balanced transition between public and residential spaces, considering privacy and noise (i.e., commercial/office space facing streets; setbacks; access points)	2	2	2	2
E. Multifunctionality, adaptability, flexibility	Supports a number of uses and users, being suitable for a wide demographic and social mix (appropriate to dwelling diversity of the surrounding area)	1	1	2	2
F. Solar access, cross-ventilation	Adequate solar access including positioning of surrounding buildings and deep root zone for trees, adequate cross-ventilation, avoids 'wind tunnels'	2	2	2	2
G. Outlook to gardens, vegetation, trees	Deep root zone providing sufficient space for and adequate positioning of large canopy trees/vegetation	2	2	3	3
Overall scoring of outdoor public space		**10**	**10**	**15**	**18**

3.7 Multi-criteria performance assessment

An overall comparison of performance across all the performance criteria is shown in Figure 19, with the associated performance ranges and performance ratings summarised in Table 11. The larger the envelope the better the performance. The criteria of 'dwelling yield' has also been added to recognise that achieving a particular dwelling/population yield for the site is also a desired outcome for infill development.



*Note to clarify: This indicator is the inverse of the more familiar water use efficiency indicator of L/p/day. It is represented this way on the graph such that the higher the number the better the performance.

Figure 19: Overall performance comparison across multiple performance criteria

Table 11: Performance ranges and ratings*

	Performance range		Performance rating			
	Bad	**Good**	**EX**	**BAU**	**WS-Con**	**WS-Max**
Precipitation fraction not converted to runoff	0	0.87	0.58	0.50	0.69	0.84
Total water storage capacity	0	150	31	25	113	124
Number of people supplied per kL of imported water per day*	0	10	4	6	5.9	6.8
Water supply self-sufficiency	0	0.50	0	0	0.29	0.34
Reliability of supplementary water supply in a dry year	0	1.00	0	0	1.00	0.39
Fraction of area with deep root zone	0	0.50	0.24	0.20	0.31	0.41
Quality of outdoor private space	0	21	17	8	18	18
Quality of outdoor communal space	0	21	0	9	17	20
Quality of outdoor public space	0	21	10	10	15	18
Fraction of outdoor areas <42°C 'feels like' (UTCI) temp on very hot day	0	0.6	0.23	0.17	0.32	0.41

*This indicator is the inverse of the more familiar water use efficiency indicator of l/p/day. It is represented this way so that the higher the number the better the performance. For further details, refer to Appendix, Table A 4.

Figure 19 shows that the WS infill scenarios (with rainwater harvesting and use of ASR stormwater), shown by the green and blue envelopes, can deliver higher dwelling yields while also providing water sensitive and amenity benefits. The standout benefit, relative to the EX case, is the extent of water storage capacity (including making better use of the very large water storage available from the existing ASR scheme), which leads to significantly higher water self-sufficiency and reliability of water for greening. There are also considerable improvements in the access to quality of outdoor communal and public space, and the amount of deep root zones available for large canopy trees. The additional shade provided by an increased canopy is expected to reduce the urban heat stress. In terms of outdoor private space, the WS typologies are considered to offer similar performance to EX typologies. In terms of hydrology, the WS designs can reduce the amount of stormwater generated, mainly due to the role of rainwater tanks holding back runoff.

In comparison, the BAU infill scenario, shown by the red envelope, can deliver increased dwellings compared with the EX case, but there is an erosion of some performance aspects. Access to quality outdoor private space is expected to be significantly reduced; however, there will be some expected improvement in access to outdoor communal space compared with the EX case. In terms of hydrology, there is expected to be slightly more runoff due to the increase in impreviousness, without any increase in the stormwater holding capacity. The per person use of imported water is reduced compared with the EX case, which means an increased 'water use efficiency', but this is due to no or little water to be used for irrigation since there is little green space to irrigate.

4. Conclusions

Based on the integrated assessment of a 130 ha greyfield urban precinct in the City of Salisbury on the verge of large scale infill development, we can conclude the water-related impacts of infill development are substantial. This case study demonstrated that with alternative designs based on water sensitive principles (WS-Con and WS-Max) it is possible to provide housing for additional (beyond target) population growth, and simultaneously mitigate the negative impacts of urban planning without intervention (BAU). BAU and WS-Con both aim to increase the population of 1,900 (EX) to 5,000 (target) but BAU requires 40 ha of existing greyfield to be redeveloped while WS-Con only requires 26 ha of the residential lots to be redeveloped to support the same population. WS-Max can support double the target population (11,000) by redeveloping 57% of the total study area.

A three-phase procedure was used to evaluate the performance of the proposed infill developments. This involved developing baseline (PRE and EX) and future infill development scenarios (BAU, WS-Con and WS-Max). Guided by the Framework, quantitiative indicators of performance were developed and applied for what we believe to be the first time. Once baseline (PRE and EX) performance was assessed, site plans were developed for residential lots and streets using water sensitive typologies as a template. The third phase involved developing a precinct plan and then assessing urban flows, urban heat and architectural and urban space quality using the Framework. Each phase was an iterative process which involved integration and collaboration between various stakeholders.

The case study confirms that, with water sensitive urban design and alternative services, there are considerable opportunities not only mitigate the impacts of urban densification but to improve performance better than the EX case. Some of the typical improvements of both WS scenarios are better hydrological performance, increased water self-sufficiency, improved availability of water and space for greening, better quality of architectural and urban space, and improved management of urban heat.

Hydrology: For hydrological performance, both WS scenarios perform better than BAU and EX. For example, in WS-Con and WS-Max scenarios, only 31% and 16% of precipitation is converted to runoff. In contrast, 50% of precipitation is converted to runoff in BAU and 42% in EX. Importantly, both the WS scenarios have four times more water storage capacity than EX. Of the total water storage capacity, soil moisture contributes approximately to 25% and SW storage (MAR) contributes nearly 65%.

Water demand and supply: Despite the increased need for more water for irrigation due to increased vegetation, WS scenarios use only 116–141 L/p/day of imported water. While EX uses 251 L/p/day and BAU uses 166 L/p/day, the reduction in per capita use of water in BAU compared with EX is due to a considerable reduction in vegetation cover. Meanwhile, EX and BAU do not have any self-sufficiency since they lack any alternative sources; WS-Con and WS- Max have 29% and 34% self-sufficiency of water because of the combined reuse of RW and SW.

Greening: 41% and 31% of the total area is a deep root zone in WS-Max and WS-Con respectively, whereas only 24% is for EX and 20% for BAU. Meanwhile, in WS-Con reliability of supplementary water is 100%, but is only 39% in WS-Max. This drop results from the increase in irrigation demand due to increased green space. Because of the absence of supplementary water, this performance indicator does not apply to EX and BAU.

Architectural and urban space quality: WS-Con and WS-Max perform nearly twice as well as BAU in all three indicators—outdoor private, public and communal space. Importantly, irrespective of the increase in population, WS scenarios show better performance than EX in terms of outdoor private space.

Urban heat: In EX scenario only 23% of the total area is below the 42°C UTCI threshold on a very hot day, while in BAU it is only 17%. About 32% for WS-Con and 41% for WS-Max is below the threshold as mentioned above.

This increase is due to the conscious design effort to include more vegetated area, in particular large shade trees, and also to increase the availability of water for irrigation through supplementary water sources.

Overall the WS scenarios can support the target population while considerably reducing the volumes of SW discharge compared with the EX state. The enhanced performance of WS scenarios can be attributed to two key factors: (i) application of water sensitive typologies developed for this case study, and (ii) integration of alternative water servicing options. The water sensitive typology design consciously incorporates more permeable and vegetated surfaces to enhance evapotranspiration and infiltration. The second attribute is the integration of rainwater and stormwater harvesting and reuses in water sensitive scenarios. This not only complements the imported water but also retains and detains the runoff (increases the lag time of peak discharge).

This is a significant set of findings and insights only made possible by the development of the Framework and quantitative examination of development options including cumulative and whole of water cycle impacts. This is very important information for helping to solve the often incremental and hidden impacts of urban development on water. It quantitatively and systematically demonstrates how water sensitive approaches can help create precints (and sites and cities) that are not only more sustainable and resilient, but also accommodate more than targetted anticipated growth and demand for dwellings.

The work also provides a significant foundation for developing a more quantified business case for water sensitive designs. For example, the impact on water supply, wastewater flow, flooding, building costs and air conditioning could be quantified from the designs presented in this report; so too could the community reaction to the potential style of development and affordability.

There are multiple options for the performance evaluation presented in this report to influence governance and planning mechanisms that will lead to water sensitive outcomes on the ground. Principal among these is the South Australian Planning and Design Code, and the Salisbury City Council planning mechanisms. A strong business case for WSUD could be firmly embedded in these processes.

Collaboration across design and performance analysis was critical in developing both the performance analysis approach and the resultant designs, particularly for water servicing options. While this case study did not evaluate a wide range of water servicing options, we suggest it as a priority in future because higher levels of development (potentially enabled by WSUD) would potentially lead to greater demand for imported water and discharge of wastewater. We note that in the implementation of the case study, even the language of performance and analysis and design had to develop and evolve so that consistent understanding could be achieved across the different disciplines involved (e.g. engineering, architecture and hydrologist). Refer to the Framework document for details. By comparing across multiple case study sites, we will continue to elicit principles that are emerging for the effective design, water servicing and performance of infill.

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Appendix A

Figures

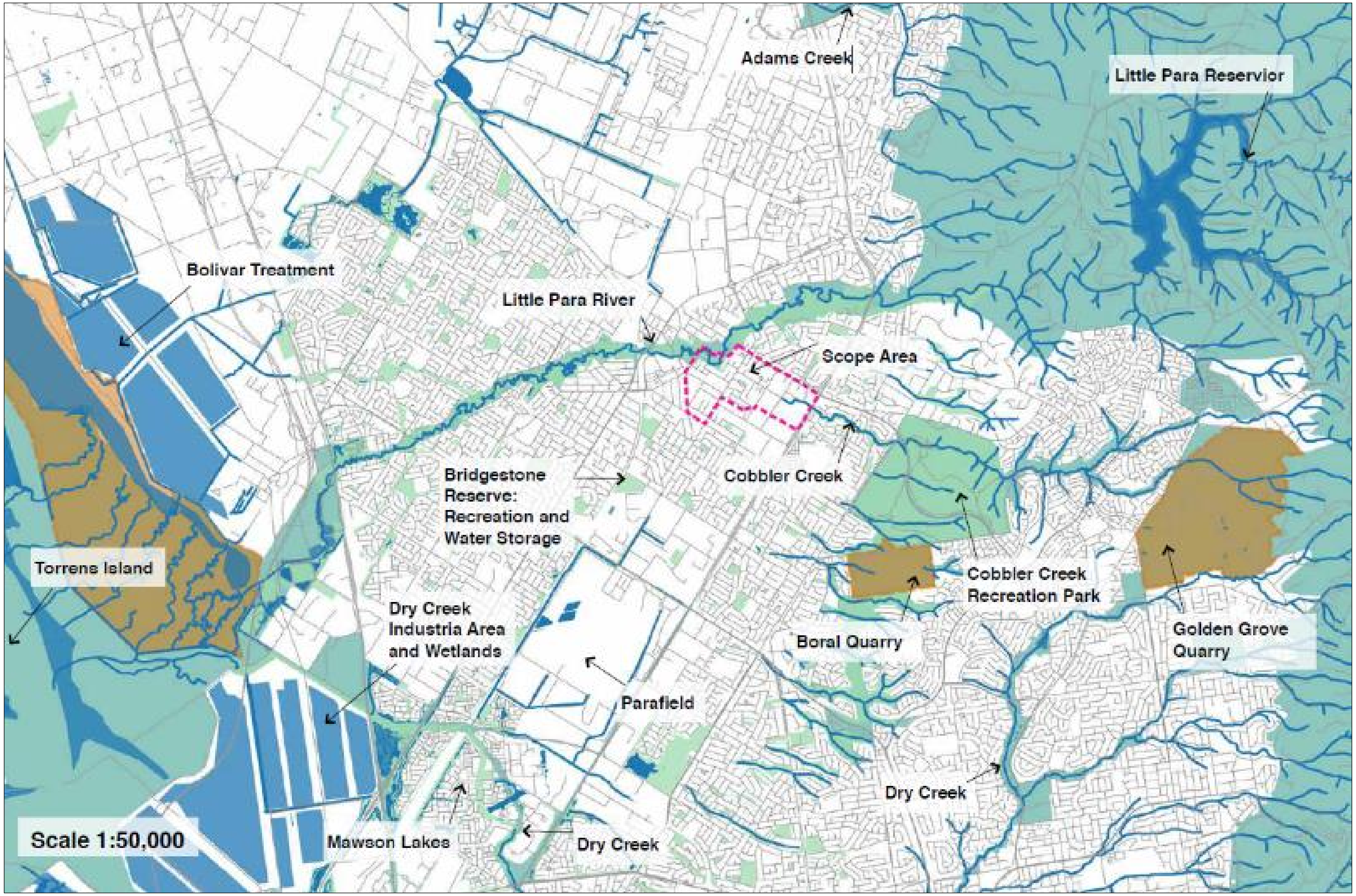

Figure A 1: Context map of study area

Figure A 2: Aerial image of study area

Figure A 3: Site plans of EX and BAU (REL, REM, REH and RBAU)

RWS1 (Water sensitive site 1 – combination of apartments, Salisbury terraces and townhouses)

RWS2 (Water sensitive Site 2 – combination of apartments, Salisbury terraces and townhouses)

RWS3 (Water sensitive site 3 – apartments)

RWS4 (Water sensitive site 4 – terraces)

Figure A 4: Site plans of four WS sites (RWS1, RWS2, RWS3, RWS4)

Road – EX (major) | Road – EX (minor) | Road – EX (Creek St) (Boolcunda Ave to Kirby Ave)

Figure A 5: Site plans of street designs of EX scenario

Road – WS (major) | Road – WS (minor) | Road – WS (Creek St)

Figure A 6: Site plans for the street designs of WS scenario

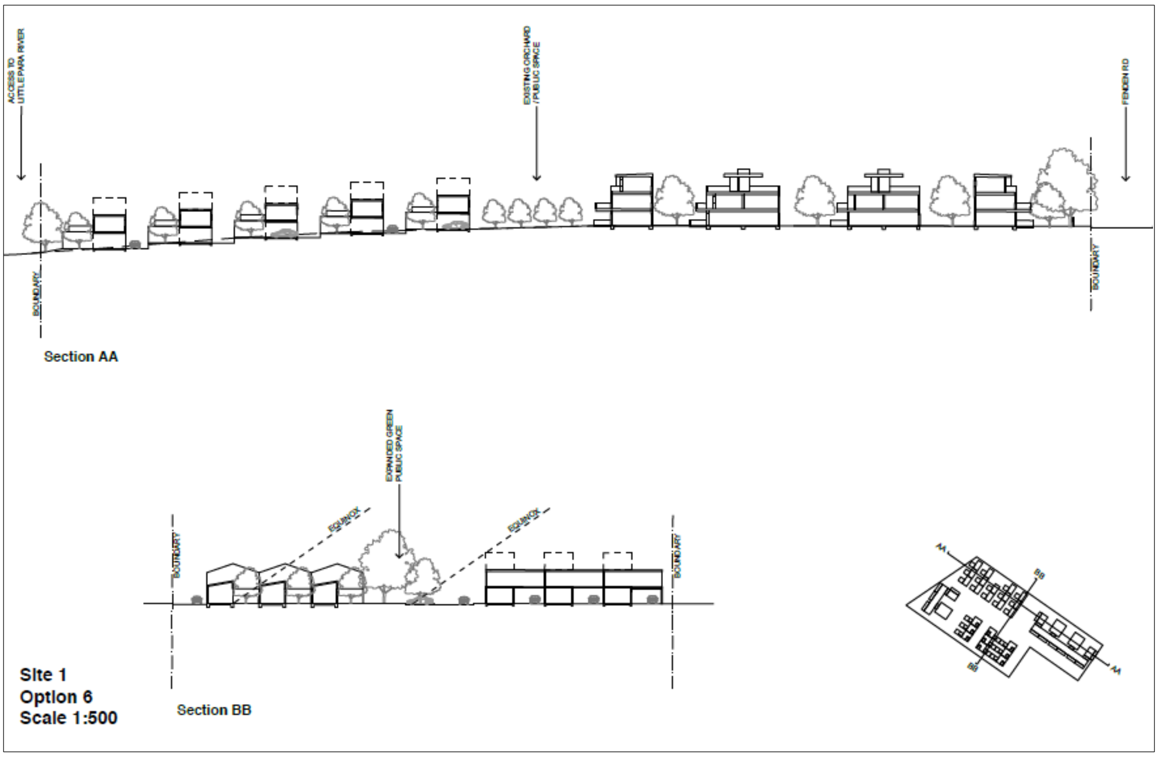

Figure A 7: Cross-section of Site 1 in WS infill (RWS1)

Figure A 8: 3D view of Site 1 in WS infill (RWS1)

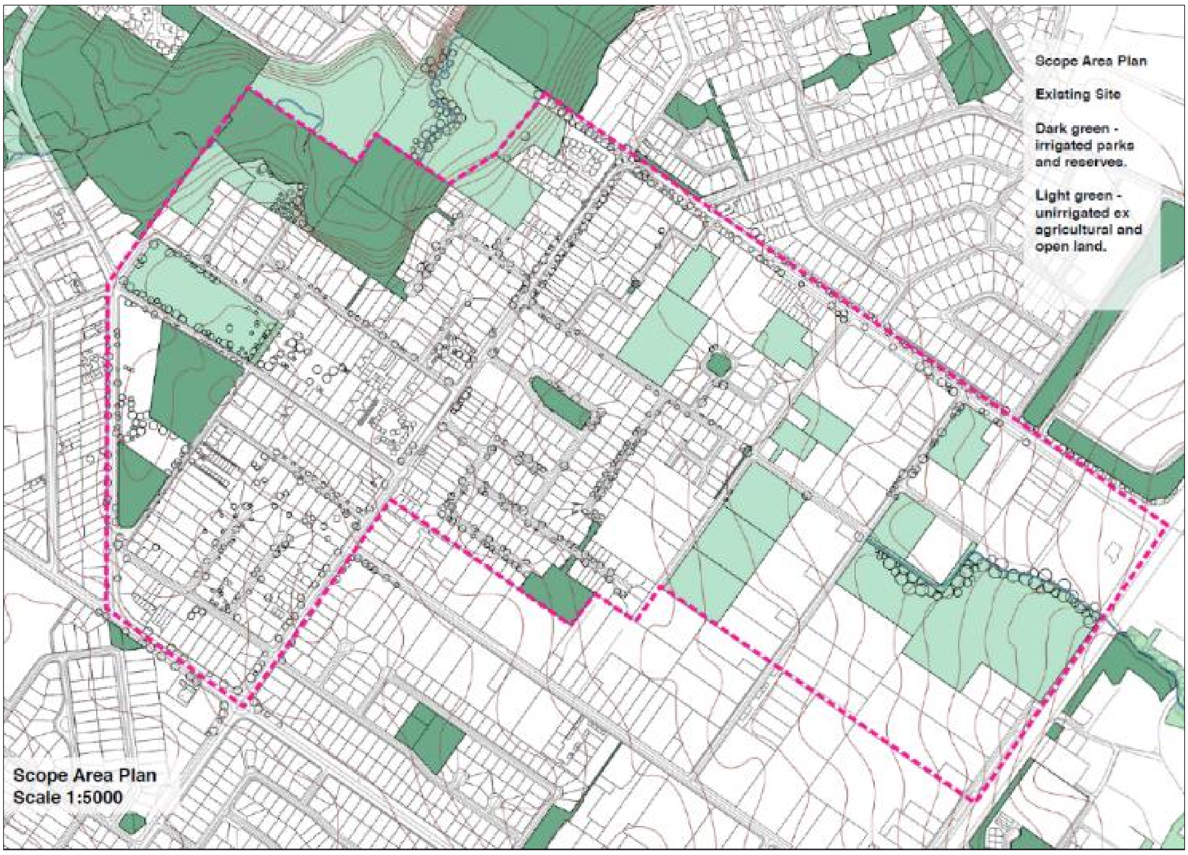

Figure A 9: Precinct-scale plan for the existing (EX) scenario

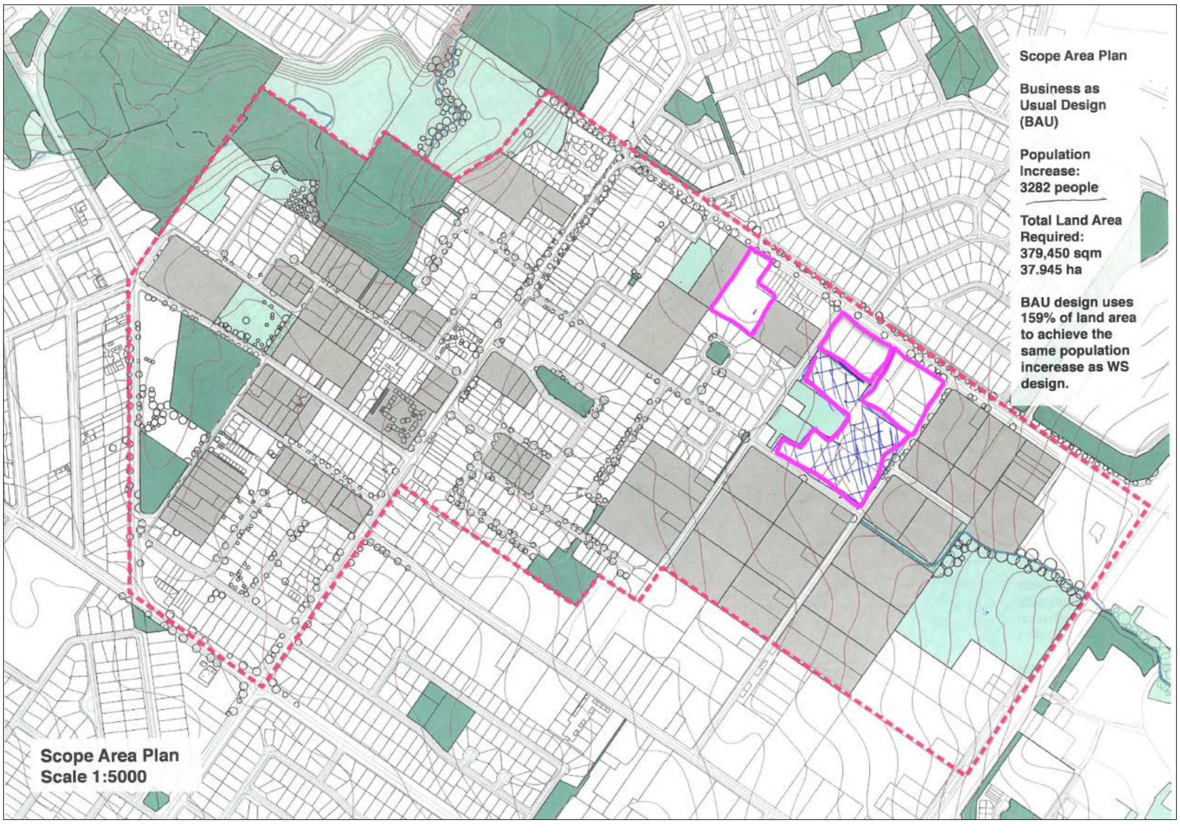

Figure A 10: Precinct-scale plan for the business as usual (BAU) infill scenario

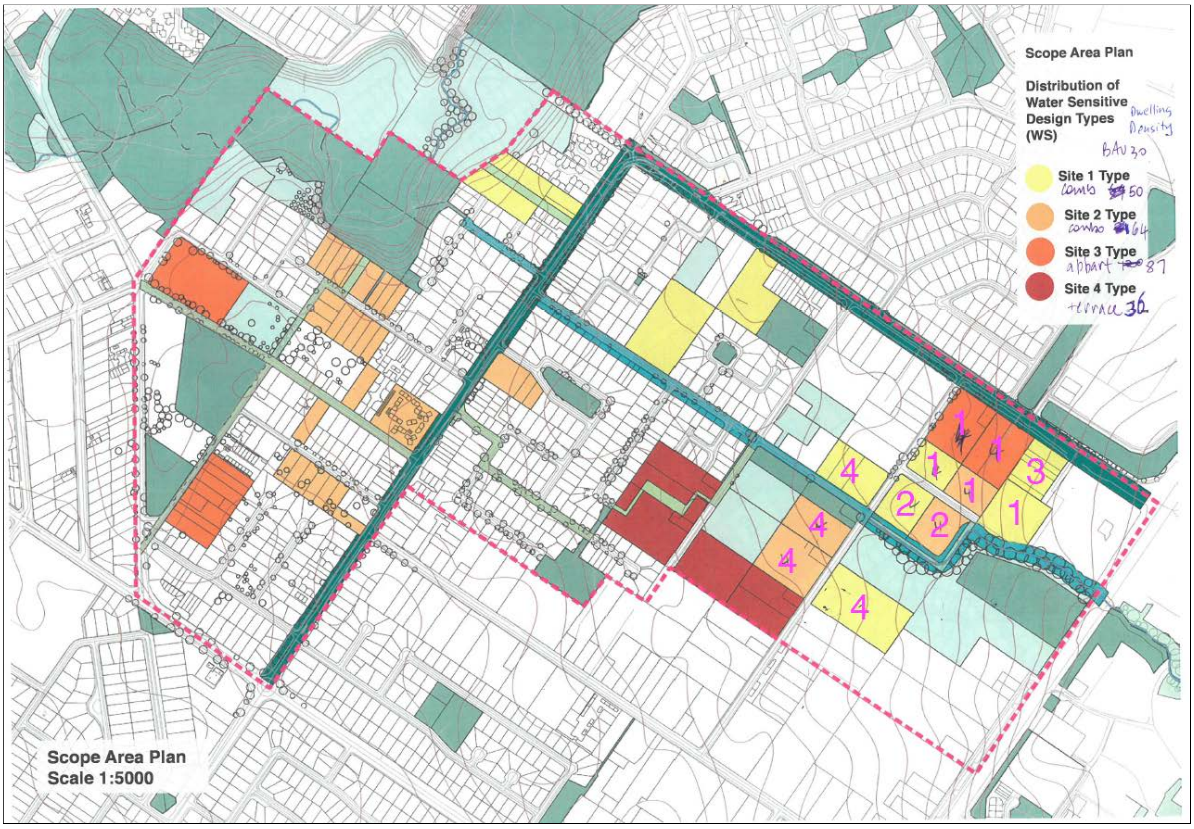

Figure A 11: Precinct-scale plan for the water sensitive conservative (WS-Con) infill scenario

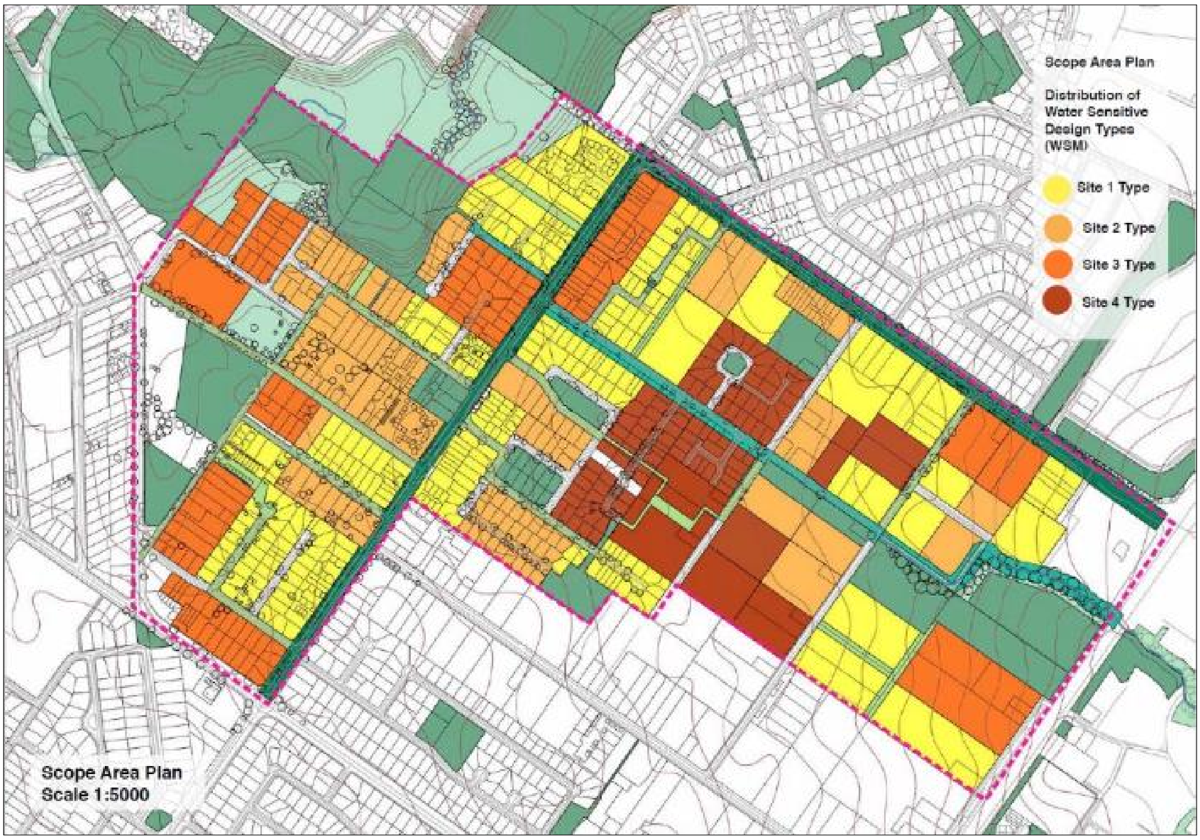

Figure A 12: Precinct-scale plan for the water sensitive maximised (WS-Max) infill scenario

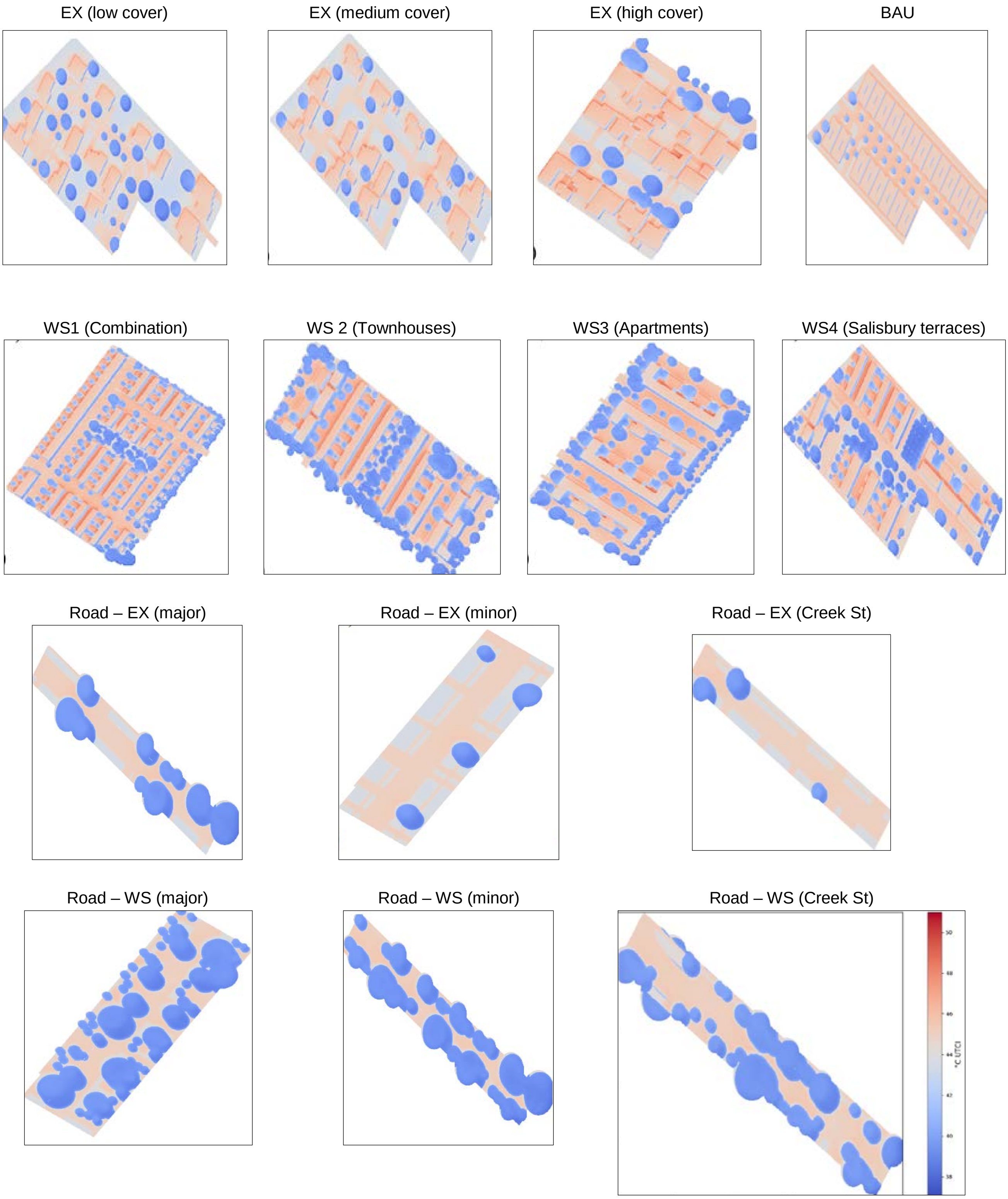

Figure A 13: Site-scale urban heat maps of the individual dwelling and street typologies

Table A 1: Assumed areas (ha) and characteristics of land use clusters within the study area

Cluster		**Area of clusters (m^2)**				**Surface breakdown**		
ID	Description	EX	BAU	WS-Con	WS-Max	Garden fraction	Roof/road fraction	Pavement fraction
GS	Parks and green space	101,113	101,113	143,724	186,864	1	0	0
OS	Vacant land	145,827	70,600	57,045	13,952	1	0	0
OS-shed	Vacant land with shed(s)	76,304	9,518	27,164	-	0.95	0.05	0.00
COM	Commercial uses	258,452	108,160	161,461	62,762	0.17	0.32	0.52
REL	Residential, existing, low built fraction (20–40%)	56,516	-	2,626	-	0.6	0.18	0.22
REM	Residential, existing, medium built fraction (41–60% cover)	200,112	188,953	195,725	-	0.52	0.24	0.24
REH	Residential, existing, high built fraction (61–90% cover)	230,350	184,008	222,194	-	0.43	0.31	0.26
RBAU	Residential, business as usual infill	-	406,322	-	-	0.15	0.39	0.46
RWS1	Residential, water sensitive infill (Site 1 typology)	-	-	83,674	308,859	0.39	0.29	0.32
RWS2	Residential, water sensitive infill (Site 2 typology)	-	-	65,285	162,085	0.35	0.35	0.30
RWS3	Residential, water sensitive infill (Site 3 typology)	-	-	37,580	143,458	0.36	0.27	0.37
RWS4	Residential, water sensitive infill (Site 4 typology)	-	-	72,197	163,840	0.36	0.35	0.29
StEOther	Street, existing, other st	120,835	120,835	120,835	101,958	0.29	0.56	0.15
StEMajor	Street, existing, major	75,157	75,157	-	-	0.43	0.34	0.23
StEMinor	Street, existing, minor	19,762	19,762	-	-	0.29	0.56	0.15
StECreek	Street, existing, Creek St	19,984	19,984	-	-	0.31	0.52	0.17
StWSMajor	Street, water sensitive, major	-	-	75,157	75,157	0.30	0.31	0.39
StWSMinor	Street, water sensitive, minor	-	-	19,762	65,768	0.31	0.40	0.29
StWSCreek	Street, water sensitive, Creek St	-	-	19,984	19,984	0.30	0.41	0.29
TOTAL		**1,304,413**	**1,304,413**	**1,304,413**	**1,304,688**			

Table A 2: Assumed populations in residential areas

Residential clusters		**Dwelling density per ha**	**Number of dwellings in the cluster**				**Occupants per dwelling**	**Population**			
ID	Description		EX	BAU	WS-Con	WS-Max		EX	BAU	WS-Con	WS-Max
REL	Residential, existing, low built fraction (20–40%)	6.9	39	0	3	0	2.0	78		6	
REM	Residential, existing, medium built fraction (41–60% cover)	16.0	320	297	309	0	2.5	803	745	776	
REH	Residential, existing, high built fraction (61–90% cover)	17.6	406	347	397	0	2.5	1,019	871	996	
RBAU	Residential, business as usual infill	30.3		1,141	0	0	3.0		3,422	0	
RWS1	Residential, water sensitive infill (Site 1)	49.9			392	1,515	2.5			979	3,788
RWS2	Residential, water sensitive infill (Site 2)	64.4			327	950	2.6			850	2,471
RWS3	Residential, water sensitive infill (Site 3)	87.1			251	1,173	2.2			552	2,581
RWS4	Residential, water sensitive infill (Site 4)	36.4			366	700	3.0			1,099	2,100
	Total		**765**	**1,785**	**2,045**	**4,339**		**1,900**	**5,039**	**5,259**	**10,940**

Table A 3: Urban water balances generated using Aquacycle for each scenario

Flow descriptor used in Framework		Flow descriptor used in Aquacycle	PRE	EX	BAU	WS-Con			WS-Max		
						RW	SW	RW+SW	RW	SW	RW+SW
INFLOWS			**773**	**947**	**1095**	**1166**	**1166**	**1166**	**1497**	**1497**	**1484**
Precipitation	P	*Precipitation*	773	773	773	773	773	773	773	773	773
Mains water supply – from outside urban system	W	*Imported water volume*		174	322	336	290	279	589	571	472
Recycled greywater from site	*W-ReGW*	*Subsurface greywater use*									
Recycled wastewater from site	*W-ReWW*	*Onsite wastewater treatment unit use*									
Recycled wastewater from cluster	*W-ReWW*	*Cluster wastewater treatment unit use*									
Recycled wastewater from catchment	*W-ReWW*	*Catchment wastewater store use*									
Rainwater from site	*W-Rain*	*Rain tank use*				30	0	30	99	0	112
Stormwater from cluster	*W-SW*	*Cluster stormwater store use*				27	103	84	36	153	128
Stormwater from catchment	*W-SW*	*Catchment stormwater store use*									
Recovered water from aquifer recharge	*W-ReRC*										
OUTFLOWS			**805**	**934**	**1081**	**1108**	**1055**	**1047**	**1361**	**1339**	**1244**
Evapotranspiration	*ET*	*Actual evaporation*	637	479	416	508	508	508	547	546	533
Stormwater runoff discharged	*SW*	*Surface runoff*	101	327	389	302	248	240	230	210	127
Stormwater runoff recharged	*SW-RC*										
Infiltration through soil (1 m below surface)	*I*	*Groundwater recharge*	34	27	25	30	30	30	36	36	36
Wastewater discharged	*WW*	*Wastewater output*		101	251	268	268	268	548	548	548
Greywater sent to recycling	*GW-Re*										
Wastewater sent to recycling	*WW-Re*										
Wastewater recharges aquifer	*WW-RC*										
CHANGE IN STORAGE	ΔS	*Change in storage*	**35**	**28**	**26**	**28**	**31**	**28**	**37**	**40**	**36**

* Refer to the Infill Performance Evaluation Framework (Renouf et al., 2020) for details of the water balance method.

Table A 4: Performance indicators derived from mass balance (Table A 3) and other indicators

Aspect	Indicator	Unit	Estimated values				Performance threshold		Scaled value			
			EX	BAU	WS-Con	WS-Max	Bad	Good	EX	BAU	WS-Con	WS-Max
Population and housing	Dwelling yield	No. of dwellings	765	1875	2,137	4,431	0	4,500	17%	42%	47%	98%
Hydrology	Total water storage capacity	ML	31	25	113	124	0	150	20%	17%	75%	83%
	Precipitation fraction not converted to runoff	%	58	50	69	84	0	90	66%	57%	79%	96%
Water demand and supply	Number of people supplied per kl of imported water per day*	People/kl/day	4	6	7.1	8.6	0	10	40%	60%	71%	86%
	Water supply self-sufficiency	%	0	0	29	34	0	50	0	0	58%	67%
Greening	Reliability of supplementary water supply in a dry year	%	0	0	100	39	0	100	0	0	100%	39%
	Fraction of area with deep root zone	%	24	20	31	41	0	50	48%	41%	63%	81%
Architectural and urban space quality	Outdoor private space	–	17	8	17	20	0	21	81%	38%	86%	86%
	Outdoor public space	–	10	10	15	18	0	21	48%	48%	71%	86%
	Outdoor communal space	–	0	9	17	20	0	21		43%	81%	95%
Urban heat	Fraction of outdoor area < 42° C ‘feels like’ (UTCI) temperature	%	23	17	32	41	0	60	38%	29%	54%	69%

*This indicator is the inverse of the more familiar water use efficiency indicator of litres/person/day. It is represented this way so that the higher the number the better the performance.

Table A 5: Distributions of UTCI heat stress categories (in percentages) for site scenarios. Heat stress categories based on Figure 9

Category	Extreme high	Extreme low	Very strong high	Very strong low	Strong high
Existing dwellings (low built cover)	0.38	2.55	78.63	18.42	0.0
Existing dwellings (medium built cover)	0.54	2.99	82.64	13.81	0.0
Existing dwellings (high built cover)	0.94	10.17	69.67	19.2	0.0
Business as usual dwellings	2.62	32.72	58.54	6.1	0.0
Water sensitive dwellings (terraces)	1.76	19.1	48.05	31.06	0.0
Water sensitive dwellings (townhouses)	1.06	13.71	38.96	46.24	0.0
Water sensitive dwellings (apartments)	0.76	15.53	43.87	39.83	0.0
Water sensitive dwellings (combination)	0.97	10.74	56.2	32.08	0.0
Existing street (minor)	0.0	0.0	52.68	47.31	0.0
Existing street (major)	0.0	0.0	89.76	10.23	0.0
Existing street (Creek St.)	0.0	0.0	87.83	12.16	0.0
Water sensitive street (minor)	0.0	0.0	26.98	73.01	0.0
Water sensitive street (major)	0.0	0.0	41.58	58.41	0.0
Water sensitive street (Creek St)	0.0	0.0	47.14	52.85	0.0

Table A 6: Distributions of UTCI heat stress categories (in percentages) for precinct scenarios. Heat stress categories based on Figure 9

Category (UTCI C)	Existing	Business as usual infill	Water sensitive (conservative) infill	Water sensitive (maximum) infill
Extreme heat high (> 48°C)	0.48	1.24	0.68	0.82
Extreme heat low (46–48°C)	4.27	14.48	7.31	10.28
Very Strong heat high (42–46°C)	72.31	66.92	59.63	47.64
Very Strong heat low (38–42°C)	22.92	17.33	32.35	41.24
Strong heat high (35–38°C)	0.0	0.0	0.0	0.0

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