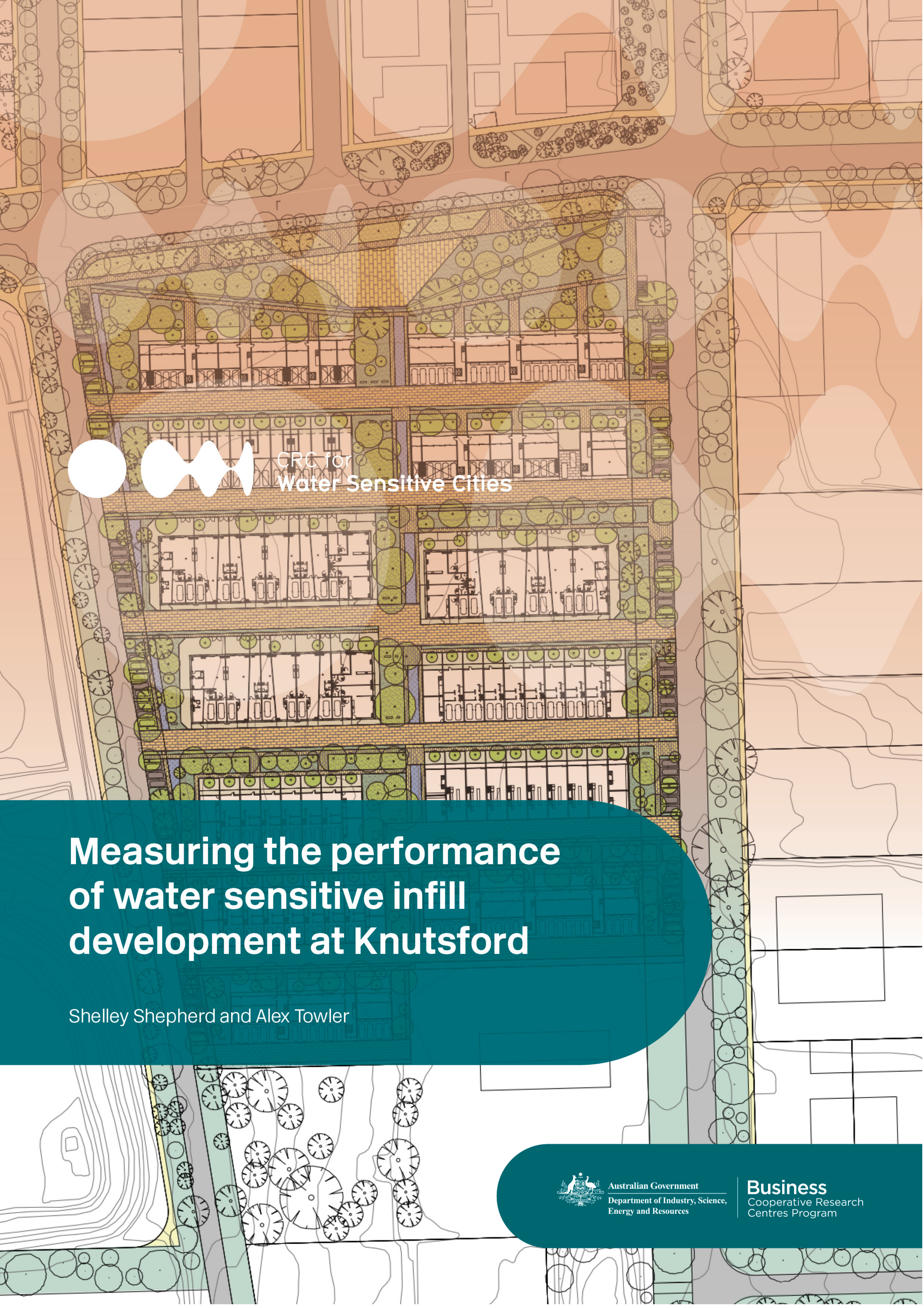

CRC for
Water Sensitive Cities

Measuring the performance of water sensitive infill development at Knutsford

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Australian Government
Department of Industry, Science, Energy and Resources

Business
Cooperative Research
Centres Program

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1. Executive summary

Introduction

To combat urban sprawl, many cities are promoting infill development as a means to revitalise areas and optimise investment in infrastructure and services. Recent research shows, however, that without significant intervention, 'business-as-usual' redevelopment will have a considerable negative influence on urban hydrology, resource efficiency, urban heat, liveability and amenity (London et al. 2020a). Research for the Department of Planning, Lands and Heritage indicated every new dwelling imposes an additional $1,460 per year of costs to the wider community for medium density infill developments with sub-optimal outcomes (SGS Economics and Planning 2020).

Water sensitive development improves the way in which the water cycle is managed as part of the design, construction and use of buildings, transport systems and city landscapes (Box 1). Water sensitive interventions can include maintaining natural water environments (water flows and water quality), using vegetation to manage stormwater, improving water use efficiency, and diversifying water supplies (harvesting rainwater and stormwater runoff, recycling wastewater). These interventions should be applied in an integrated manner to create multifunctional, resilient and productive places that enhance community amenity and liveability.

Box 1. Principles of water sensitive infill design

1. Infill design does not adversely alter the natural hydrology (infiltration, evapotranspiration and stormwater discharge) of the development area, and aims to mimic the hydrological water balance of a desired state. This will help to maintain or improve water quality and help protect the ecological condition of waterways and wetlands.
2. Infill designs facilitate soil moisture storage (where beneficial) through permeable surfaces that promote infiltration consistent with principle 1.
3. Infill designs incorporate water storages to facilitate the availability of supplementary water supply and slow/retain/detain runoff to reduce flooding.
4. Infill designs enable reduced reliance on imported water by facilitating the use of supplementary water supplies (harvested rainwater and stormwater, recycled greywaters and wastewaters), by making space for water storage and/or connections to supplementary supplies.
5. Infill designs include space and deep root zones for vegetation and large trees, to provide greening for cooling, biodiversity and amenity.
6. Infill designs enable irrigation of vegetated areas with supplementary water supplies, to support greening for cooling and amenity.
7. Infill designs enable passive mitigation of outdoor urban heat through building orientation and tree canopy shading.
8. Dwellings and urban spaces are efficiently designed and equipped to enable improved amenity, usability and flexibility.

While the energy performance of homes is being increasingly measured and reported, less information is available about the quantified benefits of water sensitive development. To address this gap, the Cooperative Research Centre for Water Sensitive Cities (CRCWSC) has developed a number of tools that can assist in quantifying some of these benefits. These tools include:

- an Infill Performance Evaluation Framework that quantifies the performance of water sensitive infill development, and

- a BCA Tool as part of the Investment Framework For the Economics of Water Sensitive Cities (INFFEWS) that assesses investments for water sensitive cities.

This case study summarises how the CRCWSC's tools have been applied to a proposed medium density infill development in Perth, as documented in *Knutsford case study final report: water sensitive outcomes for infill development* (London et al. 2020a).

Proposed water sensitive development

The case study site, known as Knutsford, is approximately 4 ha in area and located 1.5 km from Fremantle city centre. It is one of eight potential redevelopment sites (including some existing Industrial land uses) near Knutsford St in Fremantle, Western Australia.

Fremantle has a hot–summer Mediterranean climate, with largely winter-based rainfall ranging from 467 to 861 mm/year. The area has shallow soils on a limestone ridge which poses challenges for traditional drainage via infiltration. The area also has a history of groundwater contamination, which is a legacy of past industrial activity.

The vision for Knutsford is that 'an aged industrial area becomes a high amenity, diverse and adaptable precinct while protecting and incubating Knutsford's unique creative culture and sense of place'. Further, 'Knutsford will be a community asset and an exemplar for design and sustainability across Perth' (Knutsford Master Plan, Landcorp, 2016). A key desired outcome for the project was to improve water security through innovative water servicing that also explores new governance arrangements. This will help create and maintain a green and highly liveable community for a growing population in the context of declining natural water sources. The development is also proposed to achieve net zero energy use through on-site energy generation.

To optimise water sensitive outcomes, several measures were proposed to reduce the demand on mains water supply. Underground rainwater tanks will be plumbed into dwellings, to supply water for non-potable use. Sewer mining will treat wastewater and supply fit-for-purpose water for public open space (POS) and streetscape irrigation. The water sensitive development scenario also aimed to increase access to open space and canopy trees by creating a linear open space corridor along the northern boundary, as well as increased deep soil zones within individual lots (Table 1).

Table 1. Case study site characteristics

Land use / development type	Scale
Residential – medium density infill	Precinct
Water source/supply	**Scale**
Rainwater tanks	Public open space irrigation/non-potable
Sewer mining	Public open space irrigation/non-potable
Site conditions	
Soils	Shallow soil on a limestone ridge
Groundwater level	High
Groundwater availability	Contaminated/unavailable

Measuring performance

The CRCWSC developed a number of scenarios to assess the performance of water sensitive infill development.

An ‘existing development’(EX) scenario provided a baseline that reflected the usual pre-development state of low density residential development (Figure 1).

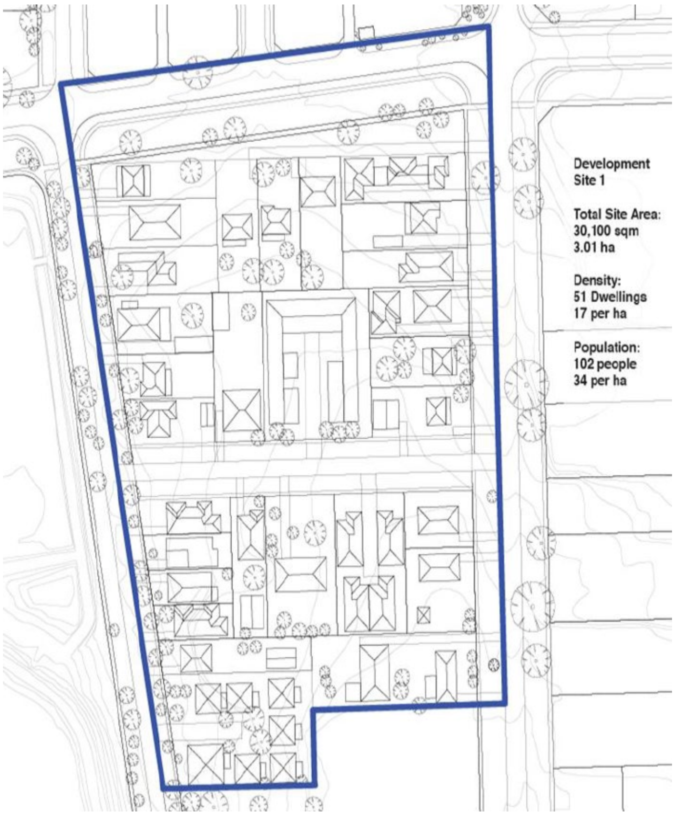

Figure 1. Site plan of existing development scenario

A ‘business-as-usual’ (BAU) scenario reflected the common infill building practices occurring in Perth in 2019 (Figure 2). This scenario comprises single-storey, affordable dwellings, with a large development footprint (58% roof and 34% pavement). BAU assumes 107 dwellings on site with two new internal roads, resulting in a net dwelling density of 45 dwellings/ha. The total landscaped area (including POS and verges) is estimated at 0.65 ha with total tree cover of 8%. Water for the development will be supplied entirely from mains (Water Corporation Scheme) and has been estimated at 13.23 ML/year (London et al. 2020a).

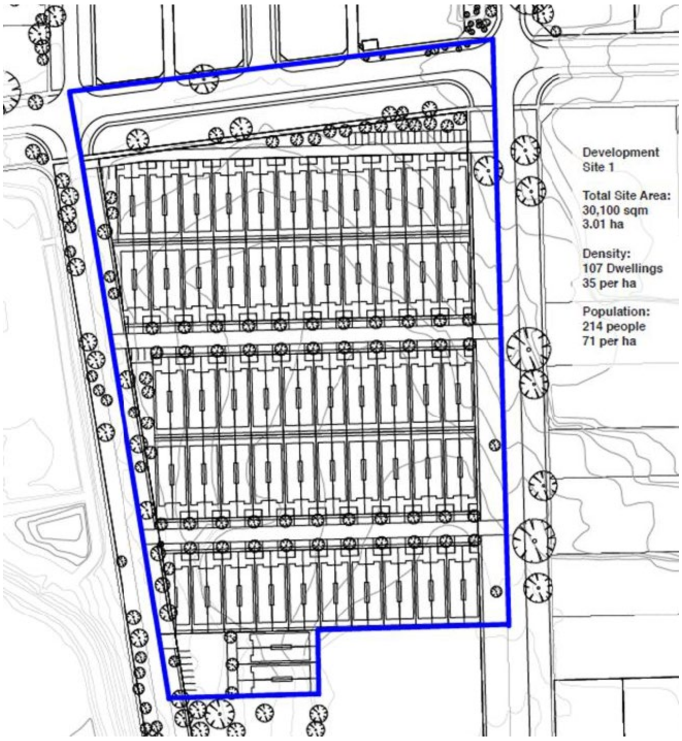

Figure 2. Site plan of business-as-usual development scenario

Two variants of the water sensitive development scenario were created. The conservative water sensitive scenario (WS-Con) involves constructing154 dwellings on the site (Figure 3). These include three distinct typologies: apartments, townhouses and warehouse apartments. The resulting dwelling density is 81 dwellings/ha (not including communal spaces). The average occupancy per dwelling was assumed to be 2.1, giving a site population of 323 people. The total landscaped area (including public open space and verges) is estimated at 1.05 ha with a total tree coverage of 22%.

The maximised water sensitive case (WS-Max) has the same built footprint and water sensitive interventions, but has a greater number of storeys and provides 200 dwellings, giving a site population of 420 people.

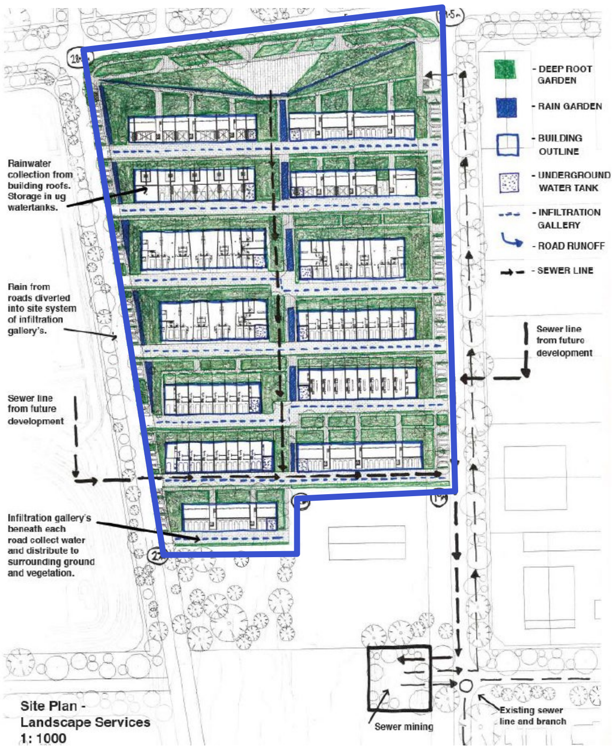

Figure 3. Site plan of water sensitive development scenario

CRCWSC tools

Infill Performance Evaluation Framework

The Infill Performance Evaluation Framework (Renouf et al. 2020) provides a methodology to quantity the benefits of different infill development designs. It proposes three groups of performance criteria: (i) water performance (includes hydrology, water demand and supply, greening); (ii) urban heat; and (iii) architectural and urban spaces quality. It also provides guidance for measuring indicators.

The framework also enables the benchmarking of water sensitive infill development types, compiled in the Infill Typologies Catalogue (London et al. 2020b) as a resource for planners, architects and developers to improve the performance of infill development.

Benefit–cost analysis (BCA)

The CRCWSC's BCA Tool was applied to the Knutsford site and development scenarios to assess the costs and benefits associated with water sensitive infill design and construction for both the developer and the resident/community.

BCA evidence can be used in business cases to support balanced and systematic decision making. It incorporates project benefits, costs and associated risks to a range of stakeholders to determine a net present value (NPV) and benefit–cost ratio (BCR) for the project. It also allows for sensitivity analysis, and considers how risks, costs and benefits are allocated to different stakeholders – information that can also be important in a business case.

Results

The results of applying the CRCWSC tools are summarised below. (Detailed results are presented in the following chapters.)

Water performance

Assessment of the water balance and water supply strategy reveals significant benefits and improved water performance of water sensitive infill. The decreased site coverage compared with BAU significantly benefits the local hydrology. In particular, increased infiltration reduces stormwater runoff and recharges the local groundwater.

The proposed alternative water sources (rainwater tanks and recycled water scheme) reduce the reliance on scheme water and provide a sustainable water source for irrigating private and public open space, which reduces pressure on groundwater aquifers. This supports the proposed level of greening.

Urban heat

The urban heat assessment (Zhu et al. 2020) calculated the cooling felt by residents in high temperature conditions. The results showed the additional open space, canopy trees and shading from buildings provided by the water sensitive scenario could improve the thermal comfort of outdoor areas by several degrees when compared with a BAU development. This magnitude of cooling could sufficiently reduce the level of heat stress of residents in heatwave conditions.

Architectural and urban spaces quality

The need for high quality building design and amenity is increasingly being recognised by the community and in state and local government policy. Key elements of amenity include greening and trees to provide cooling benefits, access to a variety of open space, and diversity and functionality of built form. Applying the Infill Performance Evaluation Framework to three water sensitive infill development types resulted in 80% of the indicators scoring a high level.

Significant improvements in amenity were also observed when the water sensitive building types were compared with BAU. These improvements were largely associated with the smaller building footprint that provided room for private open space and canopy trees. The diversity of development types and increased access to public open space also improved the rating scores.

Combined results

The combined assessment of water performance, urban heat, and architectural and urban space quality is depicted in Figure 4 and Table 2. The water sensitive development performs significantly better than BAU infill development. Water sensitive development achieves scores between 50% and 95% for all indicators, whereas BAU development rates much lower, from 0% to 50%.

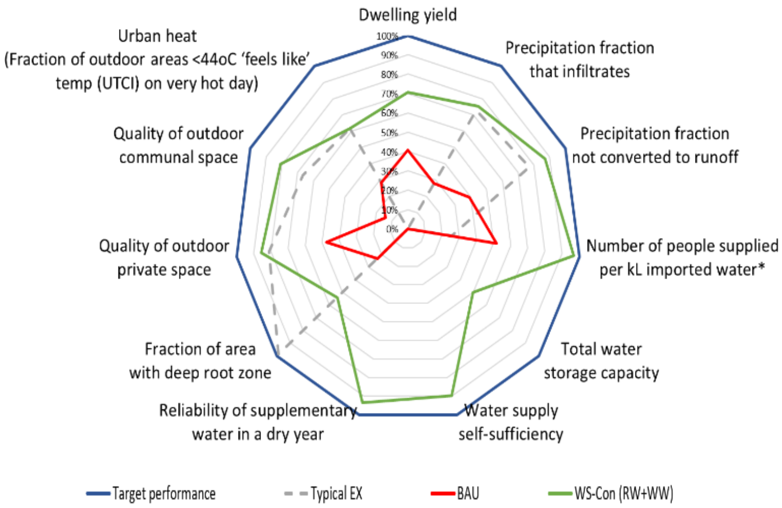

Figure 4. Measuring the water performance of different types of infill development – graphic results

Table 3. Measuring the water performance of different infill development types – indicator scores

Indicator	Performance range		Performance rating		
	Bad	Good (Target)	EX	BAU	WS-Con
Precipitation fraction that infiltrates	0.0	0.4	0.3	0.1	0.3
Precipitation fraction not converted to runoff	0.0	0.97	0.7	0.4	0.8
Total water storage capacity	0.0	3.0	0.0	0.0	1.5
Number of people supplied per kL imported water	0.0	12.0	3.1	6.2	11.6
Water supply self-sufficiency	0.0	0.7	0.0	0.0	0.6
Reliability of supplementary water in a dry year	0.0	1.0	0.0	0.0	0.9
Fraction of area with deep root zone	0.0	0.5	0.5	0.1	0.3
Quality of outdoor private space	0.0	21.0	17.0	10.0	18.0
Quality of outdoor communal space	0.0	21.0	14.0	3.0	17.0
Urban heat – Fraction of outdoor areas <44°C 'feels like' temp (UTCI) on very hot day	0.0	0.6	0.4	0.2	0.4

Benefit–cost analysis

While the greatest benefit of water sensitive infill development is felt by the residents, the BCA Tool results suggest there is still a positive benefit to the developer. Building the conservative water sensitive scenario rather than BAU development represents a net present value of $5.2 million and a benefit–cost ratio of 1.49 for the developer.

Table 3 shows the results for the resident and community and for the developer. The benefit for the developer is captured largely in the increased number of dwellings, with a small premium in house prices for sustainable dwellings and lifestyle. The other main benefits of the water sensitive scenario are decreased demand for mains water supply and decreased power costs to residents from the net zero energy development.

Table 3. Benefit–cost analysis results

Stakeholder	Net present value	Benefit–cost ratio
Overall	$11,260,461	2.06
Project organisation	$5,229,820	1.49

Outcomes

The comparative analysis enabled by the CRCWSC's BCA Tool, Infill Performance Evaluation Framework and Infill Typologies Catalogue demonstrates the significant benefits that can be delivered by water sensitive infill development compared with BAU infill. Key contributors to the additional benefit include smaller building footprints, deep root zones and space for stormwater infiltration, alternative sources of water and increased vegetation and trees.

This case study also enforces the need to look at energy, water and built form in an integrated manner rather than as separate systems. This approach is more representative of the range of outcomes that are delivered. While recognising that housing developments are substantially driven by construction, economic and market factors, the quantification of performance and economic justification in this case study can support better business cases from developers.

The work also demonstrates that with appropriate site-specific consideration, water sensitive designs and servicing options can increase the dwelling yield on the development site, while mitigating and even reversing the potential adverse impacts of densification.

Key considerations to help in applying the CRCWSC tools

- Clarity of project design – Refer to the Infill Typologies Catalogue early in the design process to identify development types that might inform the project. A clear understanding of the development and layout helps define and quantify built form elements and the interventions proposed.
- Options to be assessed – It is important to define the base condition for comparison. This is usually the current state or BAU development.
- Application via a multidisciplinary team approach for both the design and performance analysis – This approach optimises perspectives and opportunities as well as access to information to enable measurement.

2. Estimating the water performance of medium density development

Changing 'business-as-usual practices' is often challenging, but it can be assisted by tools that can quantify and compare the impact of new practices.

The CRCWSC developed an Infill Performance Evaluation Framework that quantifies the performance of water sensitive infill development using three groups of performance criteria: (i) water performance (including hydrology, water storage, water demand and supply, greening); (ii) urban heat; and (iii) architectural and urban spaces quality. This case study outlines the results of the assessment of the water performance (criteria 1) and architectural and urban space quality (criteria 3). The results of the urban heat assessment (criteria 2) are outlined in a supplementary case study.

What does water sensitive infill look like?

While large building footprints and low-rise developments are the most common form of suburban infill, this form of development often results in unusable open spaces, with inadequate tree canopy and poor cross-ventilation and solar access. Water sensitive infill development can yield more outdoor space, reduce overall water and energy demand per dwelling and per person, and provide valuable stormwater infiltration and deep root zones that support tree canopy.

Key principles of water sensitive infill development are: improved water performance (hydrological flows, stormwater management and water use efficiency); access to quality outdoor public, private and communal space; and quality design amenity and function.

The CRCWSC's Infill Typologies Catalogue (London, 2020a) provides ideas for architects to help design water sensitive infill development. It contains a range of housing typologies, at densities and configurations relevant to Australian cities and applicable to different contemporary infill development scenarios. The scenarios have also been evaluated for their water sensitive performance and compared against business-as-usual approaches to provide an evidence base for better design.

How do we measure performance?

The CRCWS's Infill Performance Evaluation Framework helps to assess the performance of a range of outcomes, defined via performance principles, criteria and indicators.

The performance criteria of water sensitive infill are outlined in Table 4.

Table 4. Performance criteria of water sensitive infill development

Aspect	Performance criteria
Hydrology	Restored natural water flows: Infiltration (groundwater recharge) is restored towards a desired state, by the presence of pervious surfaces. Evapotranspiration volume is restored towards a desired state, by the presence of vegetated surfaces, vegetation selection, and irrigation of vegetation. Stormwater runoff volume is restored towards a desired state, by the harvesting, storage and use of rainwater and stormwater.
	Waterway and wetland ecology and water quality: Peak daily stormwater discharges are restored towards a desired state.
	Flood resilience (overland flow): Peak daily stormwater discharges are restored towards a desired state.
Water storage capacity	Storage: Water storage capacity (tanks, basins, etc) within the development is optimised; and soil moisture storage is maximised through permeability.
Water demand and supply	Water demand is minimised by water-efficient appliances, water-efficient behaviours and higher dwelling occupancy (where possible). Water supply self-sufficiency is maximised by harvesting, storing and using supplementary water sourced from the urban system.
Greening	Water and space for vegetation: Reliability of supplementary water supply is sufficient to enable irrigation, even in dry periods, to maintain soil moisture and dense tree canopies. The amount of space for vegetation is optimised.
Urban heat	Outdoor thermal comfort can be maintained within a tolerable range (relevant to the climate).
Architectural and urban space quality	Amenity and useability (private and public): The following qualitative performance criteria are met for dwelling interiors, and outdoor private, communal and public spaces: Availability and diversity Size and proportion Accessibility and connectivity Privacy and noise management though balanced transition between spaces Multifunctionality, adaptability, flexibility Solar access, cross-ventilation Outlook to gardens, vegetation, canopy trees.

The framework also outlines the performance indicators that can be used to measure achievement of the performance criteria, and recommends a range of models and methods of assessment for each group of criteria.

To guide better designs for water sensitive infill, it is also necessary to understand which elements of the urban form (design variables) were directly related to the performance criteria. These linkages are critical to inform improvements in performance through changes in design and also allows users to choose indicators and variables that are most applicable to the climate and landscape qualities of the site. This 'cause and effect' framework is presented in Figure 5.

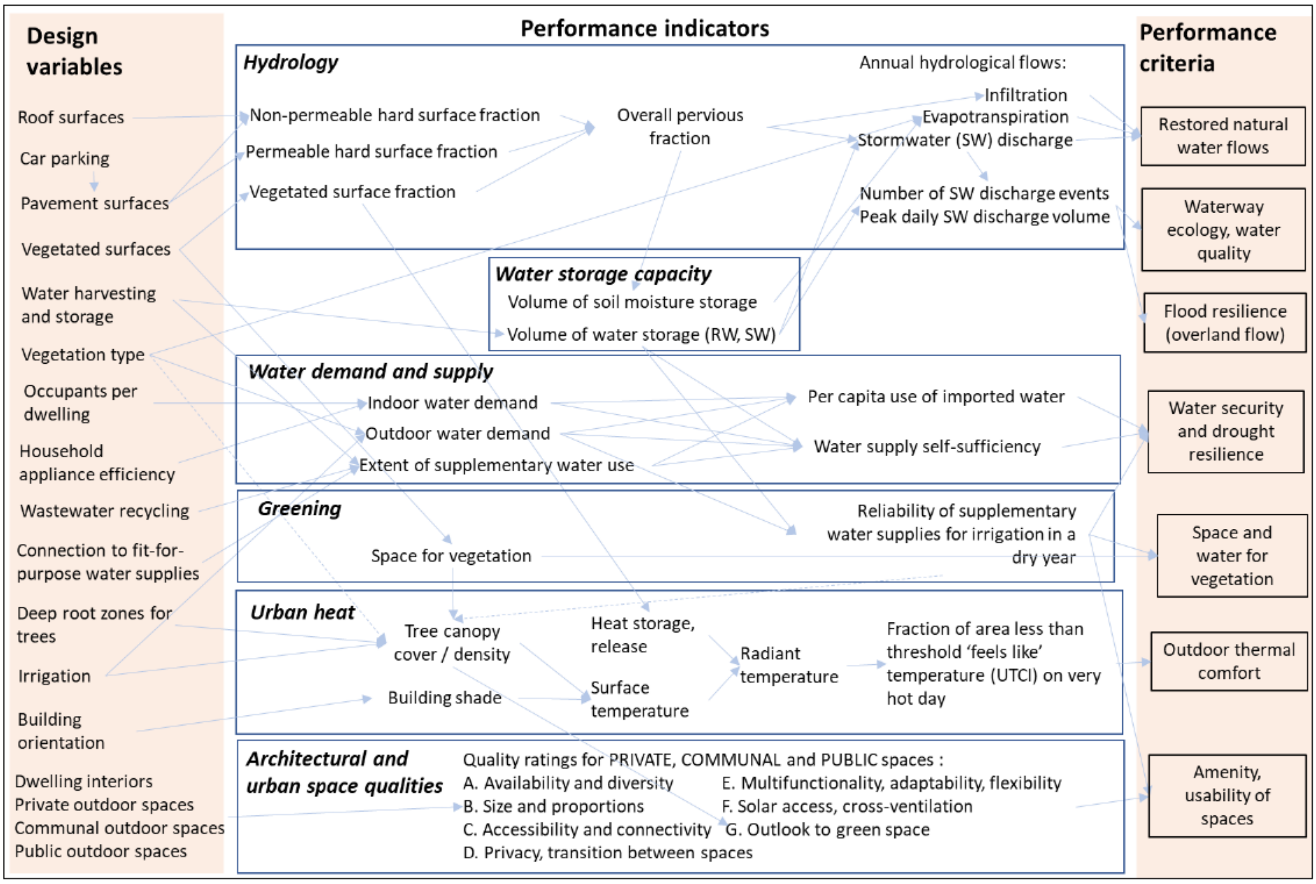

Figure 5. Cause and effect framework linking urban design parameters to water sensitive performance criteria

Comparing development types

To compare the performance of different forms of development, the CRCWSC defined three development scenarios: (i) existing low density development; (ii) business as usual; and (iii) water sensitive (London et al. 2020b).

The existing development scenario (EX) provides a baseline for measurement and reflects the typical pre-development state, providing 43 single-storey detached houses on large (approximately 600 m^2) lots with a net density of 16 dwellings/ha.

The business-as-usual scenario (BAU) comprises single-storey, affordable dwellings and reflects the type of infill likely to be constructed in the 2019 housing market. This scenario assumes 107 dwellings on the site, with a net dwelling density of 45 dwellings/ha.

The water sensitive development scenario (WS) includes three dwelling typologies from the Infill Typologies Catalogue – apartment units, townhouses, and warehouse units. It also incorporates more green space and communal and public space areas, as well as rainwater tanks (RW)and/or a sewer mining scheme (WW) to supply water for irrigation.

The WS scenario provides two design variants: WS-Con and WS-Max. The conservative case provides 154 dwellings on the site (Figure 6), whereas the maximised case has a greater number of stories and provides 200 dwellings. The respective net dwelling densities (not including communal spaces) are 81 and 105 dwellings/ha. There is no difference in the water sensitive strategies included.

Figure 6. Site plan of water sensitive development scenario

Key inputs

Assessing performance of the three scenarios using the framework requires a number of key inputs:

- defining the water servicing arrangements for each scenario including demands and source availability
- defining relevant indicators for each of the performance criteria and context-specific targets to measure against. This step is often influenced by the choice of variables that can be measured and modelled by the framework
- applying the Aquacyle tool to develop a precinct-scale water balance that addresses the performance criteria and provides values for the indicators (and assessment) relating to water performance (hydrology, water storage capacity, water demand and supply, and greening)
- evaluating the architectural and urban space qualities of each development against the agreed criteria and targets.

Applying the framework also includes assessing urban heat. This is provided in the next chapter.

Results

Results from the water balance assessment as documented in *Knutsford case study final report: water sensitive outcomes for infill development* (London et al. 2020b) show that the WS scenarios should all maintain current levels of infiltration (29–30% of rainfall), whereas infiltration will decrease to 11% of rainfall in the BAU scenario due to the significant decrease in pervious surfaces (Figure 7). The WS scenarios also perform better for stormwater runoff, which increases significantly from 25% in the existing scenario to 62% in the BAU scenario. With harvesting, storage, and use of rainwater, stormwater runoff can be reduced to around 4%.

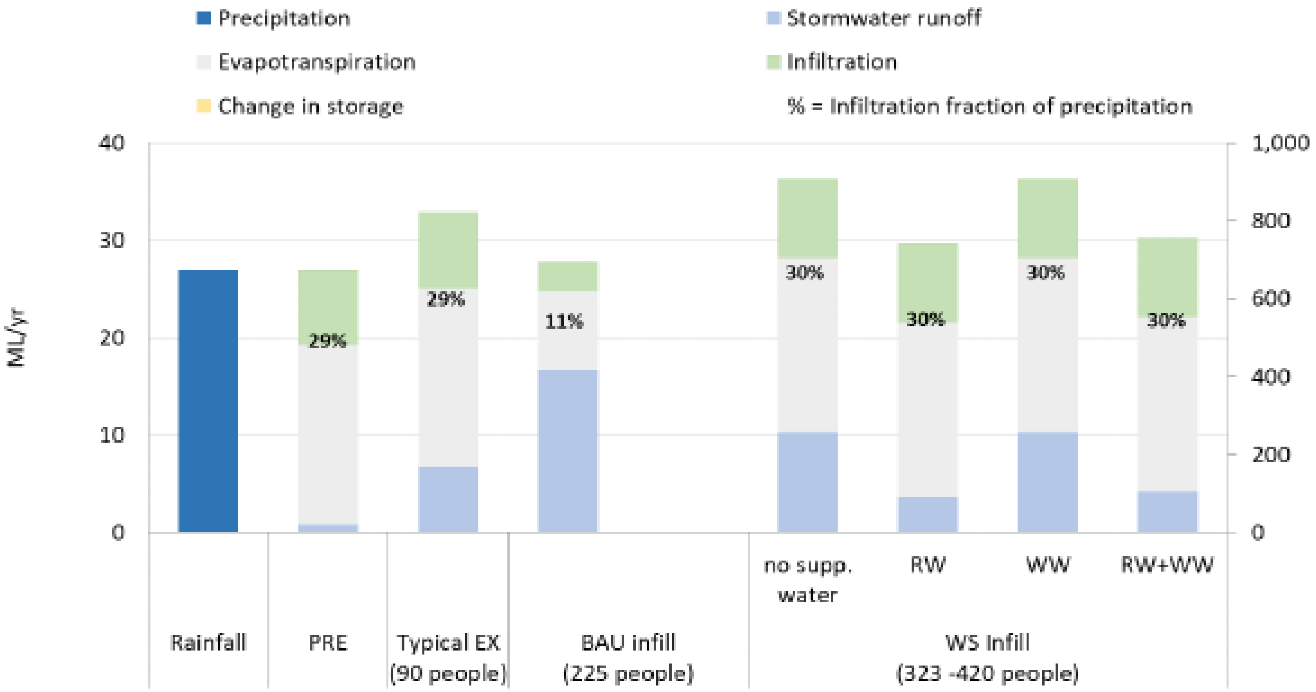

Figure 7. Water balance results for hydrology

The increased population for both the BAU and WS scenarios will increase water demands. However, supplementary supplies of rainwater and/or recycled wastewater reduces the use of imported water by various degrees. The harvesting and indoor use of rainwater (RW) alone provides 25% water self-sufficiency. This concurs with other estimates that suggest ‘an appropriately sized rainwater tank could supply up to 20% of a household’s total water needs’ in Perth (WA Government 2020). The outdoor use of recycled wastewater alone provides an overall 40% water self-sufficiency, meeting all of the outdoor water demand. The combined use of both provides 63% self-sufficiency. This result means the demand for imported water is less than the BAU case, with the added benefits of a higher population yield and greening supported by irrigation (London et al. 2020b).

The WS scenarios are also expected to perform better than the BAU scenario for architectural and urban space qualities. This result reflects the increased access to all forms of open space (private, public and communal) including canopy trees, and increased amenity and functionality through diversity.

Outcome

The results of the Knutsford assessment suggest water sensitive options incorporating alternative water sources such as rainwater harvesting can more closely mimic natural flows. This has additional benefits of significantly reducing reliance on imported mains water supplies, improving reliability of water supply for greening and consequently positively influencing water security and liveability, which is also enhanced through greater access to open space.

Key strategies to ensure optimal performance include:

- designing the built form to include as many permeable and vegetated surfaces as possible to promote infiltration and evapotranspiration
- incorporate retention devices (raingardens and infiltration cells) that capture and hold surface runoff from impervious surfaces to make water available in the soil profile for trees and facilitate infiltration
- harvest and use rainwater, which provides supplementary water supply and reduces runoff.

3. Estimating urban heat of infill development

This chapter study addresses one of the benefits of water sensitive development – creating cooler places by better managing the water cycle and applying green infrastructure.

What is urban heat and thermal comfort?

Urban areas can be several degrees warmer than their rural surrounds, especially at night, because many urban materials absorb and store energy during the day, releasing it slowly at night. This is compounded by waste energy from vehicles and buildings, as well as the larger proportion of impervious area in cities that reduces the amount of water in soils and vegetation, and corresponding levels of evapotranspiration.

Human thermal comfort describes a person's level of heat stress. It is influenced by environmental parameters such as wind speed, humidity, the radiation loading on the body, the amount of clothing, the level of activity, and physiological parameters (age, gender, weight, height, etc.).

The Universal Thermal Climate Index (UTCI) provides a measure of human thermal comfort. UTCI represents the subjective experience and thermal stress of heat on persons in outdoor areas, calculated from the radiant heat (Tmrt) values for each point at ground level (1.5 m). More simply, UTCI values represent the equivalent temperatures of heat stress, which we refer to as the 'feels like' temperature.

Comparing development types

The existing development scenario (EX) contains dwellings that would typically be present in the study area before infill development and provides a baseline to compare the other scenarios. It comprises single-storey detached houses on lot sizes of around 600 m^2, with an average 33% built cover. This scenario assumes 43 dwellings on the site, with a net dwelling density of 16 dwellings/ha.

The business-as-usual development scenario (BAU) contains the type of infill likely be constructed on the case study site in the 2019 housing market. It comprises single-storey, affordable dwellings, with a built cover of 58% roof and 34% pavement. The site plan incorporates two new internal roads of a typology typically associated with standard infill development. This scenario assumes 107 dwellings on the site, with a net dwelling density of 45 dwellings/ha.

The water sensitive development scenario (WS) includes alternative dwelling types that can achieve a higher dwelling density and population, but with more green space and communal and public space areas. It comprises multiple storeys instead of single-storey structures to reduce the amount of built site cover, multifunctional internal roads, and communal green space. Three different dwelling typologies developed for the site (London et al. 2020a) provide diversity – apartment units, townhouses and warehouse units.

The WS scenario provides two design variants (WS-Con) and (WS-Max). The conservative case (WS-Con) provides 154 dwellings on the site, whereas the maximised case (WS-Max) has a greater number of stories and provides 200 dwellings. The respective net dwelling densities (not including communal spaces) are 81 and 105 dwellings/ha. There is no difference in the water sensitive strategies included.

How was it measured?

The Solar Long Wave Environmental Irradiance Geometry model (SOLWEIG) module from the Urban Multi-scale Environmental Predictor model (Lindberg et al. 2009) was used to calculate the mean radiant temperature experienced by a human body (Tmrt), for each point in the modelling domains. Using these values, a human thermal comfort index was calculated for each point in the domains (at ground level: 1.5m) using the UTCI.

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, e.g. 42ºC UTCI.

The modelling was performed for a typical hot summer day in Perth (37.4ºC at 2 pm on 15 February 2004). A base assumption for modelling all scenarios was that the green spaces (grass and trees) were irrigated sufficiently for good health.

Results

The calculated UTCI temperatures for each scenario are presented below: Figures 8, 9, 10 and 11. The difference in UTCI temperatures between the two water sensitive scenarios (WS-Max) and (WS-Con) is shown below (Figure 12).

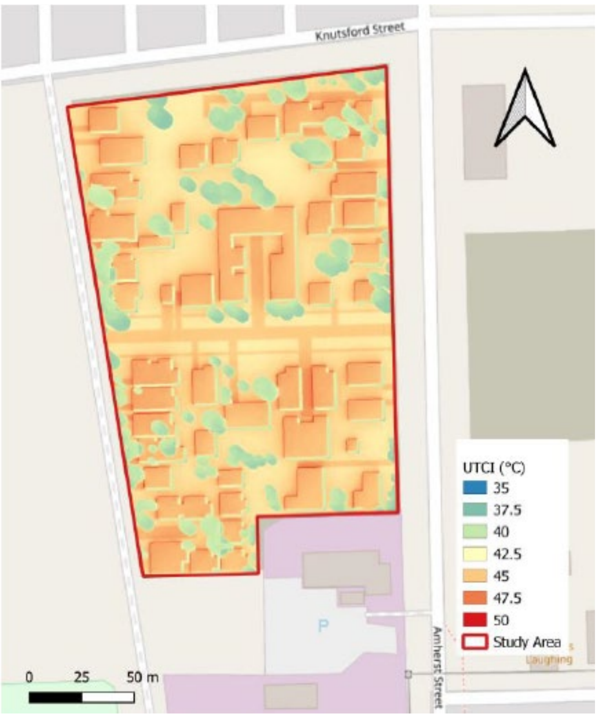

Figure 8. Modelled UTCI for existing scenario

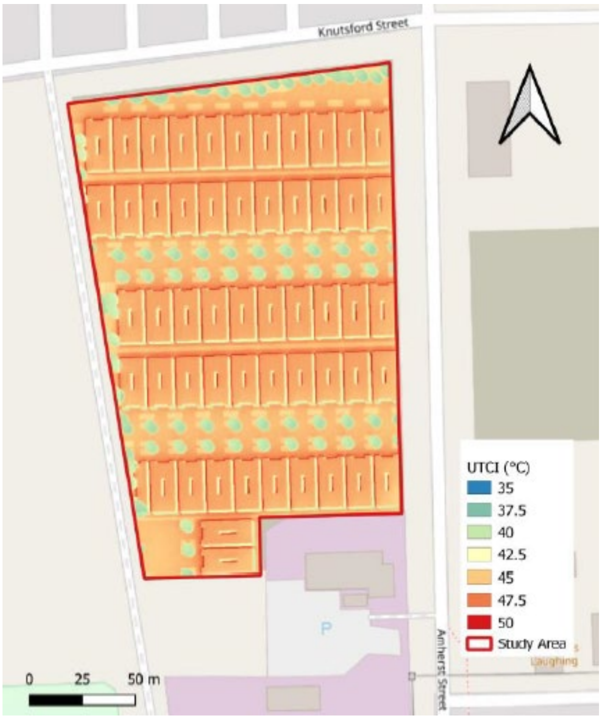

Figure 9. Modelled UTCI for business-as-usual scenario

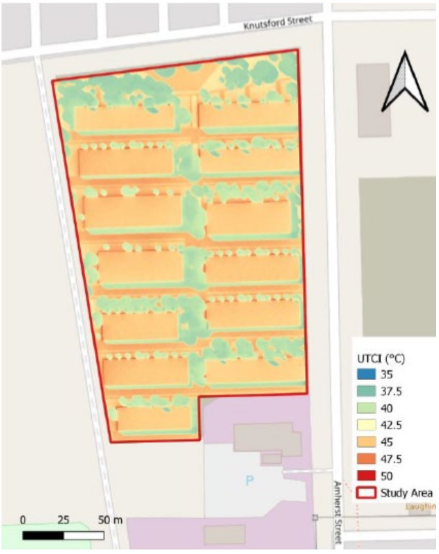

Figure10. Modelled UTCI for WS-Con scenario

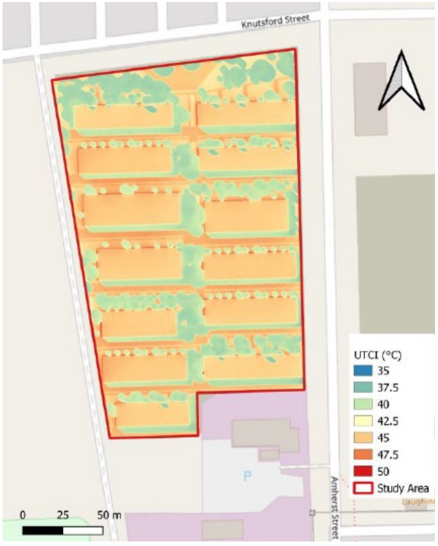

Figure 11. Modelled UTCI for WS-Max scenario

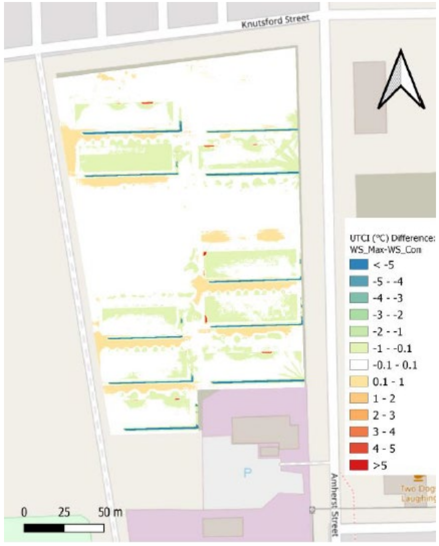

Figure 12. UTCI difference plot: WS-Max and WS-Con

Outcome

The modelling results (Zhu et al. 2020) show human thermal comfort, as measured by UTCI, is within the strong to extreme heat stress categories for all scenarios, reflecting the high human heat stress induced by Perth’s hot summer day temperatures.

Increasing site cover (imperviousness) strongly shifts the distribution of heat stress towards the ‘extreme heat–low’ heat stress category, as shown by the comparison between BAU and existing scenarios. This shift is likely to result from the significant reduction in irrigated garden space in the BAU scenario compared with the existing scenario, compounded by the increase in hard unshaded surfaces (roofs and pavements) in the BAU scenario.

Adopting the water sensitive infill development typologies (London et al. 2020b) reduces the area of hard surface compared with BAU and increases the amount of vegetation. This results in much cooler streets and communal public open space areas, as well as cooler buildings. This approach will provide benefits to the community particularly during heatwave conditions.

Importantly, the performance of the two WS scenarios is comparable to the existing, low density development scenario. This result is likely to reflect the increased shading of ground surfaces from the higher buildings which offsets, in part, the reduction in irrigated garden area compared with the existing scenario.

There is marginal difference between the two water sensitive scenarios since they have the same built footprint. However, there are minor thermal comfort benefits at the base of buildings for the maximised scenario due to the shade produced from increased building heights.

4. Measuring the benefit–cost of water sensitive infill development

Benefit–cost analysis (BCA) is widely used to support decision making about investments in projects or policies, and to underpin business cases for investment. The Cooperative Research Centre for Water Sensitive Cities (CRCWSC) has developed a BCA Tool as part of the Investment Framework For the Economics of Water Sensitive Cities (INFFEWS) that assesses investments for water sensitive cities. It provides evidence for use in business cases to support balanced decision making.

The BCA Tool incorporates project benefits, costs and associated risks to a range of stakeholders to determine a net present value (NPV) and benefit–cost ratio (BCR) for the project and allows for sensitivity analysis. It provides a systematic and user-friendly approach to project evaluation.

A business case for water-sensitive infill development

The CRCWSC's *Water sensitive outcomes for infill development: Knutsford case study final report* (London et al. 2020a) applied the Infill Performance Evaluation Framework (Renouf et al. 2020) to a site within the Knutsford Master Plan area. The report provided evidence about how water sensitive designs can increase the dwelling yield on a development site while mitigating and even reversing the potential adverse impacts of densification.

This case study applies the CRCWSC's INFFEWS BCA Tool to the Knutsford case study to assess the benefits and costs associated with water sensitive infill development, considering design, construction and use.

The CRCWSC's Knutsford case study created dwelling and public space typologies for four development scenarios; existing (EX), business-as-usual (BAU), water sensitive conservative (WS-Con) and water sensitive maximised (WS-Max). The INFFEWS BCA Tool was applied to explore the financial implications to the developer, residents and surrounding community of taking a water sensitive approach to the development. For simplicity in this case study, the 'with project' and 'without project' scenarios were the BAU and WS-Con scenarios, respectively.

'Without project' (BAU) scenario

To focus specifically on the costs and benefits associated with the style of development, the 'without project' scenario in this case study is the business-as-usual (BAU) development scenario.

This scenario includes single-storey, affordable dwellings that are considered to reflect the default infill development occurring nationally, with a built cover of 58% roof and 34% pavement. BAU assumes 107 dwellings on site with two new internal roads, resulting in a net dwelling density of 45 dwellings/ha.

The total landscaped area (including public open space and verges) is estimated at 0.65 ha with a total tree cover of 8%. Water for the development will be supplied entirely from mains (Water Corporation Scheme) and has been estimated at 13.23 ML/year (CRCWSC, 2020).

'With project' (WS-Con) scenario

The conservative water sensitive scenario (WS-Con) involves constructing 154 dwellings on the site. These include three distinct typologies: apartments, townhouses, and warehouse apartments. The resulting dwelling density is 81 dwellings/ha (not including communal spaces). The average occupancy per dwelling was assumed to be 2.1, giving a site population of 323 people.

The WS-Con scenario includes measures to reduce the demand on mains water supply through underground rainwater tanks that will be plumbed into dwellings for non-potable use, and a sewer mining station that will treat wastewater and supply fit-for-purpose water, mainly for public open space irrigation. The resulting mains water supply demand is 10.39 ML/year.

The total landscaped area (including public open space and verges) is estimated at 1.05 ha with a total tree coverage of 22%.

The WS-Con scenario aims to be a net zero energy development. The development will use solar energy and battery systems to supply 100% of the power requirements. Gas connections will not be installed since self-sufficient gas supply is not considered feasible.

Applying the INFFEWS BCA Tool

Applying the BCA Tool requires estimating the building costs associated with each scenario and determining the differences. The differences are therefore the costs and savings for the WS-Con and BAU scenarios.

A majority of the development cost estimates were provided by DevelopmentWA from its nearby East Village development and adjusted to account for the larger Knutsford development area.

A summary of the construction costs for each scenario is included in Table 5.

Table 5. Construction costs by type of development

BAU	WS-Con	Difference
Dwelling construction		
$27,820,000	$34,515,000	$6,695,000
Water-related infrastructure (infiltration galleries, underground rainwater tanks, stormwater pits, pipework for raingardens and verge plantings, soakwells, raingardens)		
$272,998	$1,139,309	$866,311
Landscaping		
$925,000	$1,508,631	$803,869
Sewer mining (installation)		
$0	$1,000,000	$1,000,000
Solar energy		
$535,000	$1,750,000	$1,215,000

The benefit for the developer is entirely captured in the increased number of dwellings sold, as well as a slight premium in house prices for net zero energy dwellings and lifestyle.

A number of the benefits to the residents and wider community were drawn from a report prepared for the Department of Planning, Lands and Heritage (DPLH) by SGS Economics and Planning (2020). The report indicated that every new dwelling imposes an additional $1,460 per year of costs to the wider community for medium density infill developments with sub-optimal outcomes. The most substantial costs include the urban heat island effect and the reduction in amenity from the loss of trees and private open space.

The other main benefits for the WS-Con scenario are decreased demand for mains water supply and decreased power costs to residents from the net zero energy development.

Results

Table 6 shows the results from the BCA for the overall project and for the project organisation. The analysis presents two measures:

- **Net present value (NPV)** measures the present value of net benefits. It is calculated as the present value of all benefits minus the present value of all costs.
- **Benefit–cost ratio (BCR)** is a monetary measure of the overall benefit divided by the overall project costs. It is usually calculated as the present value of all benefits divided by the present value of all costs.

The NPV and the BCR are much higher for the overall project than for the project organisation. This result is not surprising given several benefits of the WS-Con scenario are captured by the residents, surrounding community, and the City of Fremantle, rather than the project organisation.

Table 6. Benefit–cost analysis results

Stakeholder	Net present value	Benefit–cost ratio
Overall	$11,260,461	2.06
Project organisation	$5,229,820	1.49

Outcome

The results from the BCA indicate there are tangible benefits for the residents, community, and local government when infill development applies water sensitive building typologies and water sources. However, while positive, the business case is not as strong for the developer.

For the hypothetical Knutsford infill development, choosing to develop using the WS-Con scenario over the BAU scenario represents a NPV of $5.2 million and a BCR of 1.49 for the developer. These numbers alone are not likely to convince independent developers to ‘break the norm’ and create water sensitive developments, but they do show that sustainability does not need to cost extra.

A potential solution could be found in incentives for communal batteries, rainwater tanks and sewer mining facilities from local or state governments.

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