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QUANTIFYING THE HYDROLOGICAL PERFORMANCE OF INFILL DEVELOPMENT

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KEYWORDS

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ABSTRACT

Water performance will be an important design criterion for urban development in Australia's cities, to mitigate the adverse impacts of urban densification and expansion on hydrology, water quality, and water use efficiency. We demonstrate how one aspect, hydrological performance, can be quantified to inform more water-sensitive urban designs at the site scale. It is one of a set of indicators included in the Infill Development Evaluation Framework, which is being developed by the CRC for Water Sensitive Cities' IRP4 research project. We compared the stormwater runoff, infiltration and evapotranspiration associated with two residential infill typologies (business-as-usual and water sensitive) on a hypothetical site in a couple of Australian climates (Adelaide and Brisbane), against a typical existing typology. Our findings suggest that water-sensitive design can support denser occupancy without further altering hydrological flows.

INTRODUCTION

Significant population growth is expected in Australian capital cities, and infill is being targeted over sprawl to absorb the growth (Commonwealth of Australia 2017). Infill development is densification within established urban areas, typically using previously undeveloped or underutilised parcels of land (greyfield), or redeploying previously developed land (brownfield). Infill should aim to increase dwelling density in Australian capital city suburbs from around 15 dwellings/ha to around 30-55 dwellings/ha (Chandler, 2016).

Urbanisation adversely alters the local hydrology with knock on effects for the environment, liveability and drainage infrastructure. Increased imperviousness leads to more stormwater runoff (and flood risks), urban heat and decreased groundwater infiltration (Walsh et al 2004). Without intervention, business-as-usual infill is expected to further exacerbate these problems and degrade amenity.

It is believed that good infill design that embraces water sensitive principles can mitigate these adverse effects, but there has been no testing of this to date. Here we demonstrate a method for predicting the hydrological performance of different urban designs at the site scale. In this work, hydrological performance refers to the degree to which flows of stormwater runoff, infiltration and evapotranspiration are altered by the urbanised form. It is one of a set of water performance indicators generated by the Infill Evaluation Framework, being developed by the Cooperative Research Centre for Water Sensitive Cities' IRP4 project (CRC WSC 2018).

The aim of this paper was to to see the how dwelling design influences local hydrology, by comparing the hydrological performance of two typologies for residential infill (business-as-usual and water sensitive) on a hypothetical site, against the performance of a typical existing typology.

METHOD

Designs for the following three dwelling typologies were prepared for a hypothetical site (see Figure 1). The development area is the same for all typologies, i.e. a 2-lot site of 1,420m^2. The key design parameters are summarised in Table 1.

- Existing residential dwellings (EX), representing a typical case before infill development (8 occupants).
- Business-as-usual infill development (BAU), representing the type of higher-density dwellings that might be built in suburbs in the current Australian development market (16 occupants).
- Water sensitive infill development (WS), representing an alternative typology to achieve higher density dwellings (18 occupants). The buildings are two-storey instead of single storey to reduce the amount of impervious surfaces.

The annually-aggregated flows of stormwater runoff, evapotranspiration and infiltration (ML/yr) from a hypothetical site for each design were estimated. These were estimated based on assumed design parameters (Table 1), and using the algorithms and factors from the commonly-used MUSIC hydrological model (eWater 2017).

Flows were estimated under both Adelaide and Brisbane conditions (rainfall and soil type), and for an average rainfall year, a wet year and a dry year, to also consider how the designs perform in different environmental contexts (Table 2).

Hydrological performance was represent by how much the flows are altered compared to a pre-development reference state. The pre-development reference case was assumed to be an undeveloped site with an impervious fraction of zero. The inferred intent is that development aims to restore the hydrological flows towards those of the natural reference state.

RESULTS AND DISCUSSION

The annually-aggregated flows (ML/yr) of runoff, evapotranspiration and infiltration estimated for each of the three design typologies are shown in Figure 2 (for Adelaide) and Figure 3 (for Brisbane). Results are for the average rainfall year (dot), but also show the possible range between a dry and wet year (black bar). Also shown for comparison, is the annual rainfall (on the far left of the runoff graph) and the flows for the pre-developed reference state.

In the case of the existing typology (EX), evapotranspiration and groundwater infiltration are both reduced to 60% - 70% of pre-developed flows in both climate cases. Accordingly, runoff volumes increase considerably. For Brisbane, 50% of annual rainfall could be expected to run off from the site be compared to 20% in an undeveloped state. For Adelaide, 35% of annual rainfall could be expected to run off, compared to almost no runoff in the undeveloped state.

In the case of the business-as-usual typology (BAU), these changes are expected to be further exacerbated. Groundwater infiltration and evapotranspiration are expected to reduce to around 30-40% and 20% of a pre-developed state, respectively. Accordingly, annual runoff from the site could be expected to increase to be 70-75% of the annual rainfall in both climate cases.

In the case of the water sensitive typology (WS) the hydrological flows are maintained similar those of the existing typology, in both climate cases. The water sensitive design was assumed to increase dwellings per hectare from 14 of 42 (increasing the number of occupants on the site from 8 to 18, based on an assumed average occupancy of 4 people per dwelling). In comparison, the business-as-usual design increases dwelling density per hectare from 14 to 28 (increasing occupants from 8 to 16, based on an assumed average occupancy of 3 people per dwelling). This means the WS typology can increase the number of occupants on the site to a similar degree as the BAU case without worsening the hydrological flows.

The main factor influencing the hydrological performance is the extent of pervious and vegetated area for infiltration and evapotranspiration. The water-sensitive designs are two-storey, instead of single storey, which reduces the overall building footprint. The structures are arranged more efficiently on the site to maximise the amount of green space for evapotranspiration and infiltration.

The use of permeable paving for driveways and paths was also found to have a significant influence on the outcome. However, the assumed impervious fraction of permeable paving (40%) was an element of uncertainty. To test the sensitivity of the outcomes to this, we also modelled the flows assuming the permeable paving to have 20% and 60% imperviousness (shown as green bars on the results for the WS scenario). It has a noticeably influence but does not change the conclusions.

Future work will the expand the set of water performance indicators evaluated (water efficiency, water-related energy) and also consider water performance alongside the quality and amenity of the spaces provided by the designs (access to quality outdoor private, communal and green spaces, and thermal comfort).

CONCLUSION

We were able to quantify the extent to which residential dwelling designs change the annual flows of stormwater runoff, groundwater infiltration and evapotranspiration for a hypothetical infill development site. These are referred to as hydrological performance indicators, which are part of an evolving set of water performance indicators being develop by the CRC for Water Sensitive Cities' Project IPR4. We found that a more water sensitive dwelling design, which constrains the building footprint to reduce the amount of impervious surfaces and incorporates permeable hard surfaces, can enable increased numbers of occupants on a site whilst maintaining hydrological flows at similar to that of the existing dwelling styles.

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Existing (EX) - 2 single-storey detached houses on a 2-lot site

Business as usual (BAU) - 4 single-storey detached houses on a 2-lot site

Water sensitive (WS) - 6 two-storey integrated dwellings on a 2-lot site

Table 1 Parameters of the infill dwelling designs

Scenario	**Existing (EX)**	**Business as usual (BAU)**	**Water sensitive (WS)**
Site area (m^2)	1,422	1,422	1,422
Number of dwellings	2	4	6
Dwelling density	14	28	42
Assumed occupants per dwelling	4	4	3
Total occupants on the site	8	16	18
Roof / terrace (% of site)	21%	54%	35%
Non-permeable hard surface (% of site)	20%	25%	-
Permeable hard surface (% of site)	-	-	26%
Impervious fraction for permeable paving (for sensitivity analysis)	NA	NA	40% (20%, 60%)
Garden (% of site)	59%	21%	38%

Table 2 Environmental contexts assessed

Scenario	**Average rainfall year**	**Wet year**	**Dry year**
Adelaide	2010	2014	2015
Brisbane	2013	2015	2014

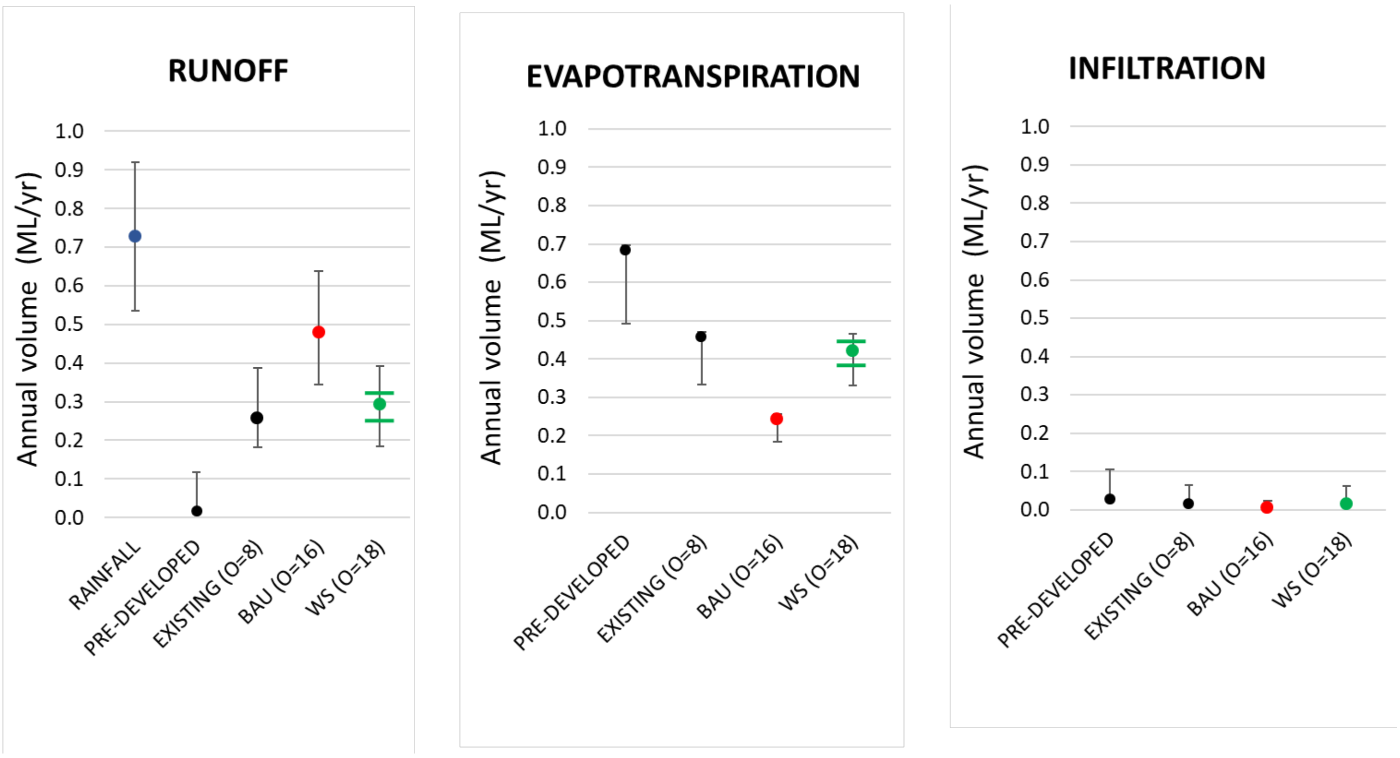

*Figure 2: Hydrological flows for the infill dwelling designs in the **Adelaide** context.*
O=total number of occupants on the site.
The WS case contains permeable paving where impervious fraction is assumed to be 40%. The sensitivity of the results to varying the impervious fraction (20% and 60%) is shown by the green bars .

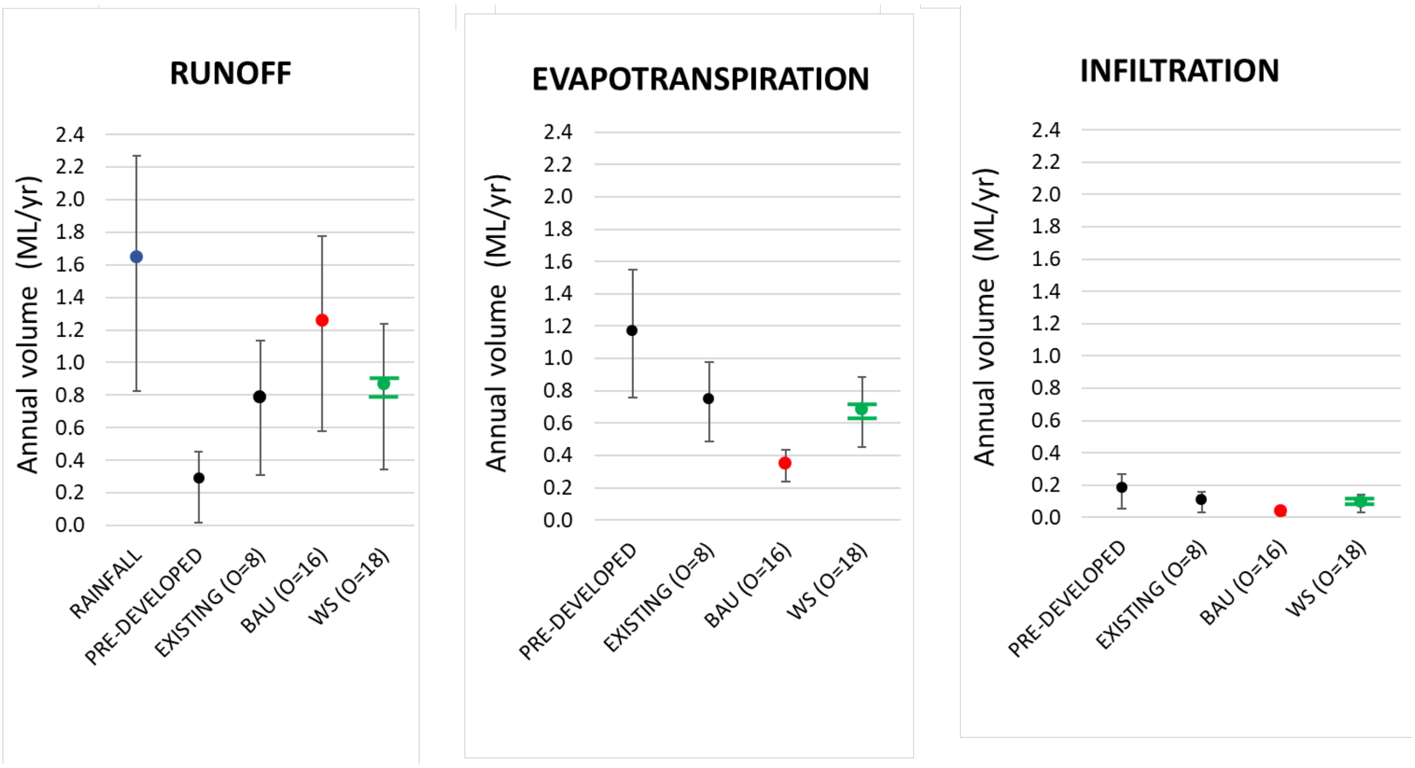

*Figure 3: Hydrological flows for infill dwelling designs in a **Brisbane** context*
O=total number of occupants on the site.
The WS case contains permeable paving where impervious fraction is assumed to be 40%. The sensitivity of the results to varying the impervious fraction (20% and 60%) is shown by the green bars .