CRC for
Water Sensitive Cities

Mind the gap–what we don't know about urban areas with high groundwater

Industry Note
Project B2.4

Urban development in high groundwater areas can create specific challenges, but it's an issue the global water industry doesn't completely understand. We've uncovered the knowledge gaps and made recommendations for how to address them.

For the past quarter century, the water industry has increasingly focused on the impact of urbanisation and changing land use on groundwater, with productive outcomes. Water sensitive urban design (WSUD) technologies, such as source control systems (SCSs), are now globally recommended to help offset the impact of urbanisation on surface hydrology, nutrients, and pollutant export, for example. But, significant questions about these systems remain:

- How do these systems affect shallow groundwater tables?
- How does artificially enhanced infiltrated water travel via the complex urban subsurface hydrology (known as urban karst)?
- How does the altered subsurface hydrology affect nutrient discharge to water bodies?

We know that the dynamics of the urban subsurface hydrology are complex. They're an interplay of the intricate conveyance system (which alters the pre-development soil properties), a variety of artificial recharge sources, and poorly characterised localised sources that were traditionally believed to be impervious (such as pavements, via cracks and joints). This complexity is acute in catchments with significant groundwater–surface water interactions and has implications for nutrient fate and transport. But, while recent literature reviews recognise these issues as knowledge gaps and challenges, they've received little attention in areas with high groundwater. The CRCWSC is working to clarify and help close these knowledge gaps. A clear understanding of the impact of urbanisation and stormwater management on water balances and nutrient pathways in areas of high groundwater is fundamental to the design of more effective control measurements and strategies for mitigating the potential negative impacts of new urban developments.

Identifying the gaps—field assessment and literature review

Our B2.4 research project: 'Hydrology and nutrient transport processes in groundwater/surface water systems' began in 2014, to assess the performance of selected SCSs (for example, infiltration basins, living streams and raingardens) in areas impacted by high groundwater. We undertook an intensive field assessment of SCS performance across the Perth coastal plain in areas where the depth to groundwater seasonally ranged from 0 to 3 metres. We also looked at other regions of the world where urban development in high groundwater areas created specific challenges. At the same time, we reviewed the published literature on the effects of urbanisation and stormwater practices on the water balance and hydrological processes of the urban subsurface, and the implication of these processes for the fate and transport of nutrients along subsurface pathways in areas with high groundwater.

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The literature points to the problems

The published literature confirmed four key knowledge gaps:

1. How do water balances operate in the unsaturated zone beneath urban areas?
2. How do water table dynamics determine the characteristics of infiltrating/exfiltrating water into soil water storage? Further, how do they affect recharge to and discharge from groundwater via underground stormwater infrastructure (urban karst)?
3. What are the relative contributions of different infiltration sources and groundwater to interflow? What is the contribution of interflow to runoff in the urban karst?
4. How does all of this affect environmental conditions and exposure times along different subsurface pathways? Further, how do they ultimately impact on nutrient transformations?

Importantly, our literature review uncovered an important fact: Australia's knowledge gaps are common across the world—the lack of understanding is global.

So, where are these knowledge gaps coming from? Our conclusions from the literature shed light on the missing pieces and the lingering issues:

Infiltration in the urban mosaic

- In the coupled groundwater–surface water models that urban water balances frequently use, the representation of infiltration neglects important aspects of the process.
- Infiltration does occur from hard impervious areas (roads, parking lots etc.) via cracks and joints.
- Large uncertainties remain about 'losses modelling' in urban environments, particularly about the proper quantification of water volumes entering the subsurface environment.

Recharge of groundwater from rainfall events

- Studies report recharge rates of up to 40 per cent more than previously estimated for SCSs.
- Improved estimates of recharge in the urban mosaic and landscape are needed, and mass balances of the unsaturated zone provide a valid approach. Analytical tools for recharge estimates are freely available, but they lack comprehensive datasets to adequately encompass local conditions.

Interflow processes and delivery mechanisms

- We need to better understand the fate of infiltrated water and its pathways in urban areas. Research into this is underway in the United States, Europe and Melbourne.

Nutrient cycling along subsurface flow pathways inurban areas

- No published study has documented how water pathways along the subsurface media (both unsaturated and saturated zones) in urban areas affect nutrient transport and transformations.

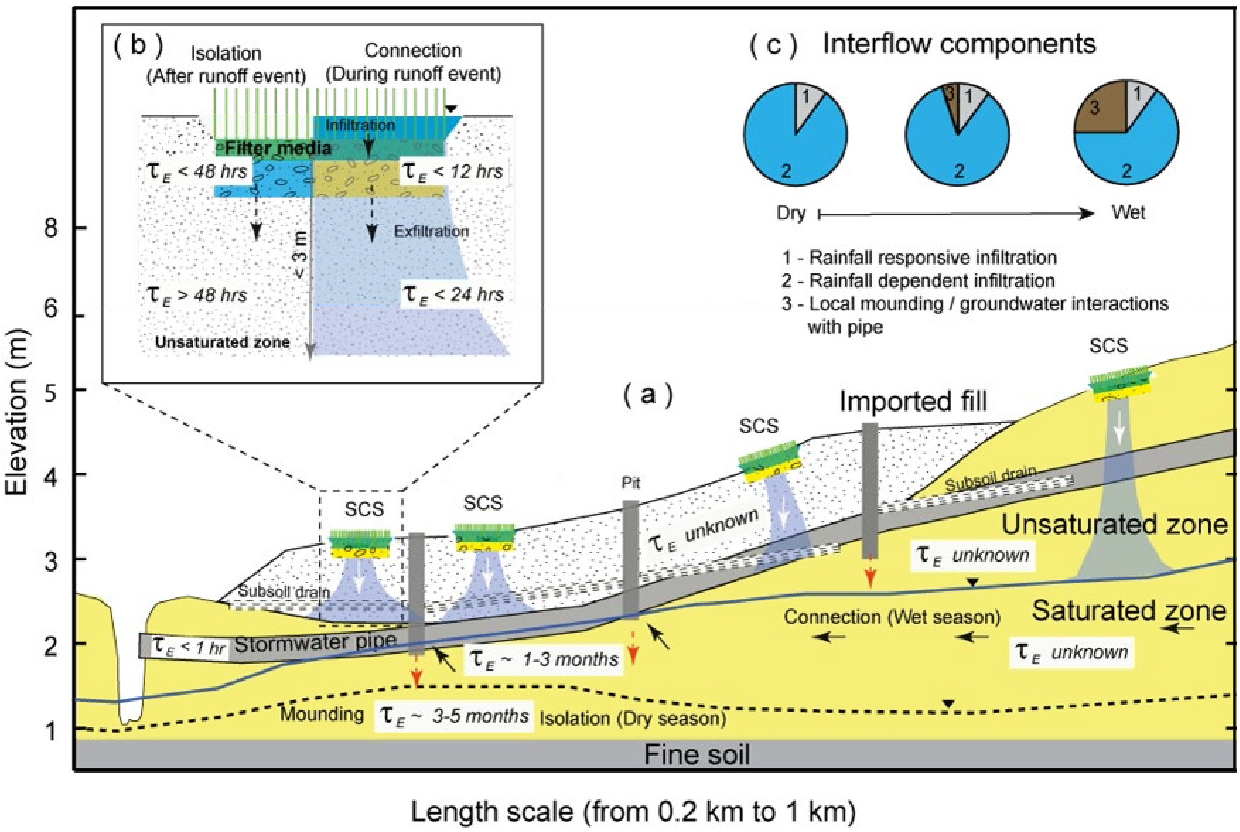
Closing the gaps—conceptual modelling and recommendations

These gaps mean modelling is difficult—there's not an obvious coupling between the more developed areas of stormwater modelling (surface hydrology) and groundwater modelling (hydrogeology). Therefore, accurately predicting changing water balances and nutrient export under urbanisation is extremely challenging. To rectify this, and to guide future work on nutrient fate and transport along subsurface pathways in urban areas of high groundwater, we developed a conceptual model synthesising our literature findings. The model will help improve design aspects of SCSs, the spatial allocation of SCSs in catchments in relation to groundwater dynamics, and the overall effectiveness of SCSs for nutrient attenuation.

The model reflects current built forms and stormwater management practices in Perth (our B2.4 study area), and incorporates different states of hydrological isolation and connection for:

- individual SCS elements (at rainfall event scale)
- local groundwater mounding (at event and seasonal scales)
- shallow water table dynamics (at seasonal scale).

It uses the exposure time scale approach, τ_E, which measures the time available for processing nutrients during transient water storage, and under environmental conditions that promote that processing. This approach, which provides the expected τ_E for nutrient processing, may be more suitable for small SCS where rapid shifts in filter media dissolved oxygen (DO) conditions have been reported, with anoxic conditions present for up to two days after inflow events, then returning to oxic conditions as the water contents decreases.



Conceptual model of hydrological processes and relevant τ_E values for nutrient processing in the urban karst, in areas with high groundwater: (a) landscape representation of current built forms and stormwater management practices; (b) individual SCSs; (c) variation of interflow components over seasonal scales

Recommendations to address knowledge gaps in urban areas with high groundwater

It is essential to quantify infiltration rates, recharge rates, and the relative magnitude of water sources contributing to interflow, within the urban mosaic and for individual SCSs. Yet, neither the design process nor post construction assessment of SCS performance account for any of these factors. Using our conceptual model for any urban area with high groundwater conditions would guide the spatial scale at which the following monitoring activities should be implemented:

1. Estimate infiltration/exfiltration rates from SCSs using hydrograph recession analysis. Hydrograph recession analysis examines the relationship between water storage and outflow rate of a system, or for this case SCSs stormwater captured and its transfer rate to the subsurface. This data will improve our estimates of water mass transfer to the subsurface, and facilitate numerical model testing
2. Compute and report recharge rates and amounts at a standard 2 metres below ground level (including for SCSs) using two soil moisture sensors.
3. Use the above data and suggested analytical techniques (Carleton, 2010) to quantify mounding characteristics (height and extension) and time of relaxation.
4. Undertake interflow monitoring using a combination of hydrometric and environmental tracers, to quantify the relative contributions of infiltration and groundwater discharge.
5. Apply a mass balance approach in the high groundwater, following the control planes and integrative mass flux concept reported in the literature.

Further reading

To find out more about our B2.4 research project: 'Hydrology and nutrient transport processes in groundwater/surface water systems', including the literature review, visit the CRCWSC website (https://watersensitivecities.org.au/content/project-b2-4-3/).

Ocampo, J. (2018). The impact of urbanisation and stormwater management practices on water balances and nutrient pathways in areas of high groundwater: a review of recent literature. Melbourne, Australia: Cooperative Research Centre for Water Sensitive Cities. (https://watersensitivecities.org.au/content/urbanisation-and-stormwater-management-practices-on-water-balances-and-nutrient-pathways-in-areas-of-high-groundwater/).

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