Understanding the interactions between groundwater, surface water and Groundwater Depended Ecosystems

Healthy Waterways Strategy 2018-2028
Port Phillip & Westernport, Victoria

Melbourne Water

Strategic alignment

Regional Performance Objectives

- RPO11: Understanding of groundwater dependent ecosystems is improved and opportunities to maintain or improve these continue to be investigated.

Key Research Areas

- Stormwater Management and Flooding: Improving stormwater treatment performance and determining the optimal maintenance of WSUD systems
- Hydrology and environmental flows: Investigating opportunities for managing stream flows in urban catchments to protect and improve aquatic biodiversity, amenity, recreation and reduce flooding

Summary

Melbourne Water makes substantial investments in groundwater depended ecosystems (GDEs), but there is low confidence on the risk of contamination or changes to their hydrologic regime. The Healthy Waterways Strategy sets infiltration targets across the Melbourne region, ranging from 3% to 21%. MW therefore promotes stormwater infiltration as an important strategy in the restoration of baseflows which are typically depleted in urban streams (which are thus a type of GDE). However, there is substantial uncertainty on the fate of infiltrated stormwater. Questions remain such as how much infiltrated stormwater becomes stream baseflow? and how much is used by downslope vegetation? Another important gap is the potential for infiltrated stormwater to mobilise legacy pollutants to the stream. Our experimental work found that in the warmer months, downslope vegetation can use significant volumes of infiltrated stormwater. In addition, use of stormwater infiltration can mobilise legacy contaminants such as nitrate. Our work highlights the importance of site selection in the placement of infiltration-based systems.

Recommendations:

- Given the Healthy Waterways Strategy infiltration targets, stormwater infiltration is a critical tool for the protection and restoration of waterways. However, a range of techniques will need to be considered, including infiltration and bio-infiltration basins, as well as controlled-release systems such as rainwater tanks or specifically-designed detention/retention systems capable of releasing flows into streams at a rate compatible with baseflows of the receiving water.
- Infiltration water balance models, including the use of industry-standard tools such as MUSIC, should account for evapotranspiration fluxes not only in the infiltration basin, but downstream, with implications also for models which may then look at contributions to groundwater recharge, and for models that consider impacts of evapotranspiration on the local microclimate.
- The objectives of a given stormwater infiltration system should be considered before its construction. If the aim is to restore baseflows to streams, then location of systems near the stream (and using a more centralised approach), and without a significant treed landscape between the system and the stream, should be preferred. On the other hand, where an objective is to provide soil moisture to enhance the health and growth of urban trees, location of infiltration systems upstream of trees can be very effective. In this case, more distributed at-source infiltration systems will be preferred. Such arrangements will also have other important community benefits, such as provision of well-watered greenspace, supporting attempts to mitigate the urban heat island and increase urban biodiversity.
- Designers of infiltration systems should ideally first undertake an analysis of geology and existing subsurface infrastructure in the surrounding area, in order to predict the likely pathway and fate of infiltrated water. In particular, designers should consider the likely impact of the 'urban karst' (the network of porous sub-surface trenches, such as surround water pipes, sewer pipes, electrical and telecommunications conduits, which are ubiquitous in the urban environment) on flow paths and behaviour.
- Stormwater infiltration should not be considered as the sole means to return more natural flow regimes in urban streams; meeting these objectives requires a suite of technologies, including systems that reduce overall flow volume by means such as harvesting and use of the water for human purposes (Walsh et al., 2015). Ideally this would leave only the "natural" proportion of rainfall to be infiltrated, rather than attempting to infiltrate the large additional runoff volume caused by impervious areas.
- Construction downslope of an infiltration basin should consider high levels of groundwater and could require specific structural engineering to avoid movement effects on foundations.
- Innovative approaches may be needed to restore more natural baseflows. This might include controlled-release systems, such as multi-stage outlets in stormwater control measures which aim to mimic natural recession and baseflow behaviour or 'smart' real-time monitoring and control systems e.g. Monbulk Creek Smart Water Network/ Troups Creek West Smart stormwater wetland.

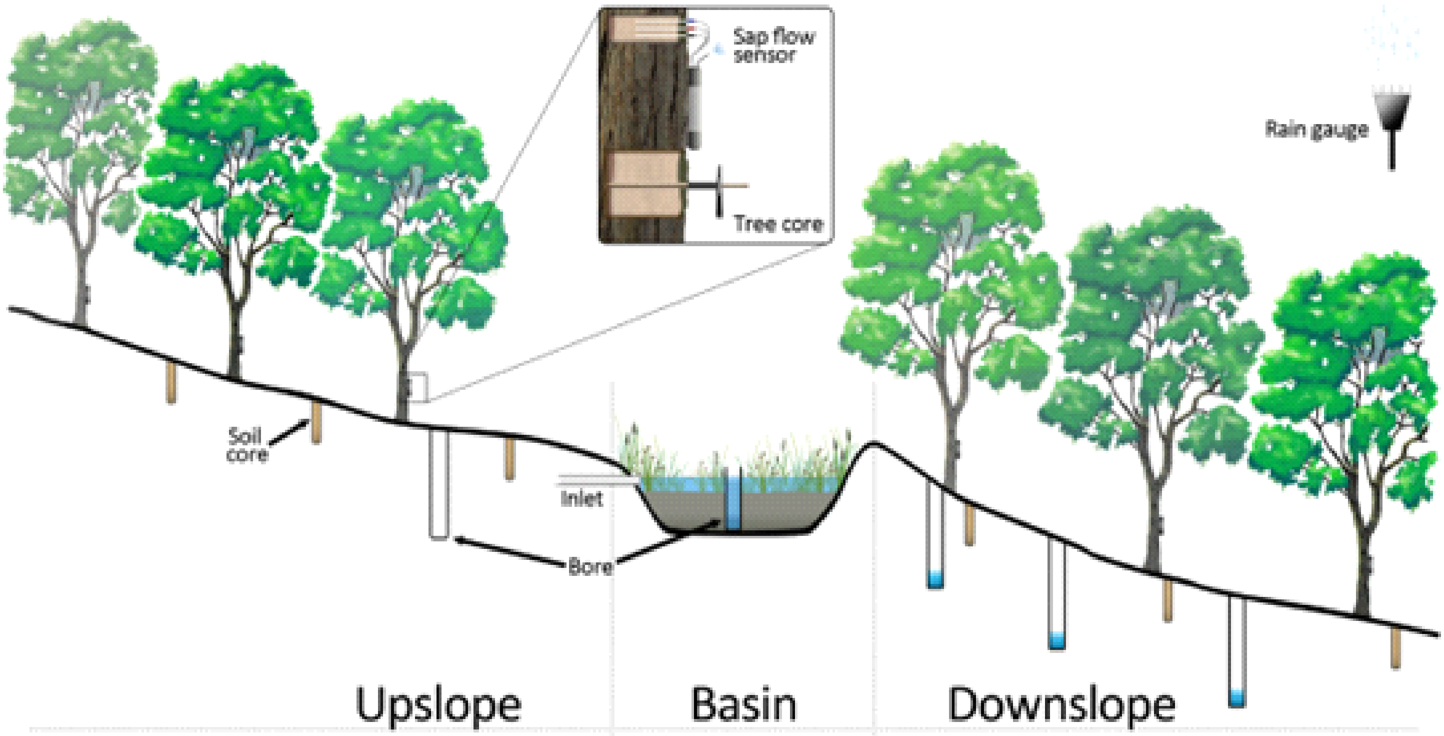

Figure 1: *Conceptual representation of experimental design, showing Upslope (reference), 'Basin' and Downslope (treatment) zones. Depth to water table was monitored continuously in five shallow bores (<3 m), located upslope (1), within (1) and downslope of the infiltration basin (3). Isotopic composition is measured during three separate campaigns (spring, summer, autumn) in all bores (except upslope, which remained dry throughout), basin water, tree cores (6 upslope, 6 downslope), soil cores (3 upslope, 3 downslope) and rainfall. Sap flow was measured within 6 trees in the Upslope (3) and Downslope (3) zones.*

- Protecting groundwater and stream baseflow quality might require very high treatment standards for stormwater control measures, in particular for highly soluble and thus mobilizable pollutants such as micropollutants (herbicides, pesticides, etc.). In other words, groundwater is also a receiving water in need of protection, just as surface waters (streams) are.

What did we do?

Impact of stormwater infiltration on groundwater quality and flow paths

We examined the fate of infiltrated stormwater in the urban context, including examining its impacts on water quality and the potential for flushing groundwater pollutants into surface water, and the interactions between infiltrated water and the downstream landscape (including trees). This research was a combined field and laboratory-based study, using the Wicks Reserve bio-infiltration basin (in the eastern suburbs of Melbourne) as a case-study site. We measured the migration of infiltrated water and associated pollutants between the basin and the receiving water, quantifying the influence of the basin on groundwater levels, along with evapotranspiration by nearby trees. Laboratory-based columns were used to better understand the mechanisms at play, so that the field results can be extrapolated more broadly.

Transit time of infiltrated water

Using the urban catchment of Little Stringybark and the reference catchment of Lyrebird Creek, stream and ground water samples were analysed for the stable isotopes of water (deuterium and oxygen [O-18]). Using transient time modelling, these data told us about where infiltrated water moved and how fast it travelled and the results are detailed in Bonneau et al. (2018). We found that baseflow in the reference catchment was likely from a well-mixed reservoir of older water. In contrast, baseflow in the urban catchment came from rapid pathways, particularly following summer rain events. This allowed us to identify the critical role of the 'urban karst' and preferential flow paths in urban and peri-urban catchments.

What did we find?

- The infiltration basin at Wicks Reserve was very effective in infiltrating water into surrounding soils. In this case, with a heavily treed downslope landscape, much of that water served to support the growth of trees. Although infiltrated stormwater did produce a large plume of groundwater downslope, infiltrated stormwater did not make it to the stream as baseflow for almost half the monitoring period (the water table was below the streambed, i.e. stream was losing). During these periods the plume of infiltrated stormwater was consumed by downslope vegetation.
- In winter, however, when plant water use was lower, the water table rose and then flowed towards the stream. Groundwater levels were then above the streambed next to the stream, consistent with local baseflow being contributed by the infiltration basin.
- While the magnitude of 'natural' baseflow contributions along the receiving stream (Dobsons Creek) were unknown, the observed conditions (e.g. lateral bores to the infiltration basin being dry and riparian bores being below the streambed level during summer) suggest that this reach of stream would get little to no baseflow at any time of the year without the contribution of the plume of infiltrated stormwater. The groundwater plume contributing to increased groundwater levels in the riparian zone is

evidence that along this reach, the infiltration basin increased baseflow per unit of stream length.

- Baseflow in a nearby forested catchment (natural 'reference' stream not impacted by urban stormwater) was found to be composed of mostly winter recharge, with long transit times (typically months, years or even decades) and a high mixing of past rainfall events within the catchment. The nearby urban catchment, however, was found to have a much more variable and seasonal isotopic signature, reflecting contribution from recent rainfall, and baseflow recession constants indicating shorter residence times (ranging from hours to days), especially in the drier months of the year. These data suggest an acceleration of transport of groundwater (yielding much younger baseflow) in the urban catchment and that the urban catchment has a more variable and complex set of stores and pathways delivering water to the stream. Whether these differences are entirely due to urbanization rather than to inherent catchment characteristics cannot be validated by the presented data. However, given the magnitude of the differences observed, it is conceivable that urban features (i.e. the urban karst, and a lower storage capacity) are drivers of hydrological alteration.
- The results of this study highlight the need to replenish groundwater recharge if the aim to restore baseflow is to be achieved. However, alteration of groundwater transport processes by the urban karst means that restoring volumes of infiltration to pre-urban levels may not result in the delivery of pre-urban stream baseflow, at least in terms of timing and seasonality.
- Attention needs to be paid to the location, scale and distribution of measures which promote stormwater infiltration systems, and how they interact with subsurface pathways. This work points to the existence of changes in subsurface flow pathways (through soil disturbance and the presence of high-permeability trenches) meaning that innovative approaches may be needed to restore more natural baseflows. This might include controlled-release systems, such as multi-stage outlets in stormwater control measures which aim to mimic natural recession and baseflow behaviour, or and real-time control management systems, such as those being trialled in the catchments of Monbulk Creek and Troups Creek West.
- Groundwater transport via fast pathways and contribution of recent water might also influence baseflow water quality. Any acceleration of groundwater transport could reduce the filtering properties of transport through the soil matrix. As such, protecting groundwater and stream baseflow quality might require very high treatment standards for stormwater control measures, in particular, for highly soluble and thus mobilizable pollutants such as micropollutants (herbicides, pesticides, etc.).

Future direction and Knowledge gaps

- Our work has demonstrated the importance of designing infiltration systems according to the objectives – be it baseflow restoration or augmentation of soil water available to enhance tree growth. Our most recent modelling work confirms this finding and reinforces the different performance of distributed vs downstream-centralised application of infiltration. Ideally, empirical validation of these models would be desirable, although such work would be resource intensive.
- In addition, the advent of small-scape application of real-time control opens up possibilities to deliver baseflows in a highly precise way, using controlled releases from distributed storages (be they rainwater tanks, rain-gardens or wetlands, for example) throughout the catchment.

How are we sharing findings?

Publications

- Western, A. W., Arora, M., Burns, M. J., Bonneau, J., Thom, J. K., Yong, C. F., . . . Fletcher, T. D. (2021). Impacts of stormwater infiltration on downslope soil moisture and tree water use. Environmental Research Letters, 16(10), 104014.
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- Behroozi, A., Arora, M., Fletcher, T. D., & Western, A. W. (2020). Sorption and transport behavior of zinc in the soil; Implications for stormwater management. Geoderma, 367, 114243.
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- Bonneau, J., Fletcher, T. D., Costelloe, J. F., Poelsma, P. J., James, R. B., & Burns, M. J. (2020). The hydrologic, water quality and flow regime performance of a bioretention basin in Melbourne, Australia. Urban Water Journal, 1-12.
- Bonneau, J., Burns, M. J., Fletcher, T. D., Witt, R., Drysdale, R. N., & Costelloe, J. F. (2018). The impact of urbanization on subsurface flow paths–a paired-catchment isotopic study. Journal of Hydrology.
- Bonneau, J., Fletcher, T. D., Costelloe, J. F., Poelsma, P. J., James, R. B., & Burns, M. J. (2018). Where does infiltrated stormwater go? Interactions with vegetation and subsurface anthropogenic features. Journal of Hydrology.
- A Poozan, AW Western, MJ Burns, M Arora (2022). Modelling the interaction between vegetation and infiltrated stormwater. Journal of Hydrology 607, 127527

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