Re-designing streetscapes for managing stormwater and increasing tree canopy cover

Strategic alignment

Regional Performance Objective (RPOs):

- RPO 14: Standards, tools and guidelines are in place and implemented to enable re-use and infiltration of excess stormwater, and protect and/or restore urban waterways.

Key Research Areas:

- Stormwater Management and Flooding: Improving stormwater treatment performance and determining the optimal maintenance of WSUD systems
- Stormwater Management and Flooding: Understanding the costs and benefits of various stormwater management interventions for biodiversity, amenity and recreational outcomes
- Stormwater Management and Flooding: Developing improved technologies and systems to support stormwater harvesting and re-use

Summary

This project targets a primary cause of the urban stream syndrome: excessive surface runoff volumes. At the same time, it applies a core principle of integrated water management (IWM) and water sensitive urban design (WSUD): using stormwater runoff as a resource to irrigate street trees and restore pre-development hydrological processes, particularly infiltration and evapotranspiration.

Urban streams are severely degraded by the large volumes of runoff created by road networks and other hard surfaces, and conveyed by stormwater drains. Competition for space in streetscapes is fierce, therefore, stormwater control measures are typically small and lack design features required to meaningfully reduce runoff volumes (Burns et al., 2012). Streetscapes also represent one of the limited opportunities to integrate vegetation into public landscapes, providing liveability benefits such as urban cooling and greening (Livesley et al., 2016). Trees take time to grow, especially in harsh roadside environments, and can therefore benefit from additional water resources during establishment (Grey et al., 2018a; Thom et al., 2022a). Established trees may not grow faster when passively irrigated with runoff (Szota et al., 2019), but they can transpire significant volumes of water and can therefore boost the hydrological performance of roadside measures (Thom et al., 2020). Streetscapes therefore provide the opportunity to make use of runoff to rapidly increase tree canopy cover, as well as benefit urban streams by substantially reducing runoff volumes and associated pollutants.

The simplest, low maintenance intervention for roadside runoff is to remove the kerb and facilitate overland flow to a vegetated swale (Melbourne Water, 2005). On wide roads, there is space in the streetscape to create bioretention swales between lanes of traffic. Biofiltration swales can achieve significant water quality treatment and runoff detention (Deletic and Fletcher, 2006; Lucke et al., 2014), where they are designed with a high system/catchment area ratio, native soil is replaced with high-conductivity biofiltration media, and have control structures such as check-dams (Monrabal-Martinez et al., 2018). However, biofiltration swales typically lack design elements which can substantially improve volumetric retention, such as large subsurface storage (Nichols and Lucke, 2015; Tu et al., 2020), perforated pipes and outlet control structures (Li et al., 2015; Scharenbroch et al., 2016). We can only speculate that integration of these design elements is limited by perceived risks of nuisance flooding, damage to road and building infrastructure and the perception of increased costs associated with installation and maintenance; all of which are driven by a lack of empirical evidence and effective knowledge transfer.

Creating “big storage” for runoff near street trees requires a significant change in current practice which needs to be supported by rigorous empirical evidence and demonstration. However, there is likely no new radical technology which will transform our streetscapes. More likely, solutions can be found by combining design elements proven to work in stormwater control measures; e.g. simple inlets and large storage (Grey et al., 2018a; Szota et al., 2019), coupled with technologies used to support vegetation, e.g. porous asphalt and structural soils (Bartens et al., 2009; Mullaney and Lucke, 2014). This project is employing these design elements to identify alternative streetscapes which specifically target volumetric reduction in stormwater runoff and support rapid canopy development.

Recommendations:

We have established a solid understanding of how alternative designs impact runoff capture, tree growth and water use from experiments completed to date:

- Lintel and pit inlets should be avoided as they accumulate sediment and debris which limits volumetric capture and increases maintenance cost (Szota et al., 2019).
- Simple inlets such as kerb cuts are more efficient at runoff capture and require less maintenance (Grey et al., 2018a, 2018b).
- Small tree pits with large catchment/area ratios must have an underdrain to avoid waterlogging in heavy clay soils (Grey et al., 2018a) and will likely not meaningfully

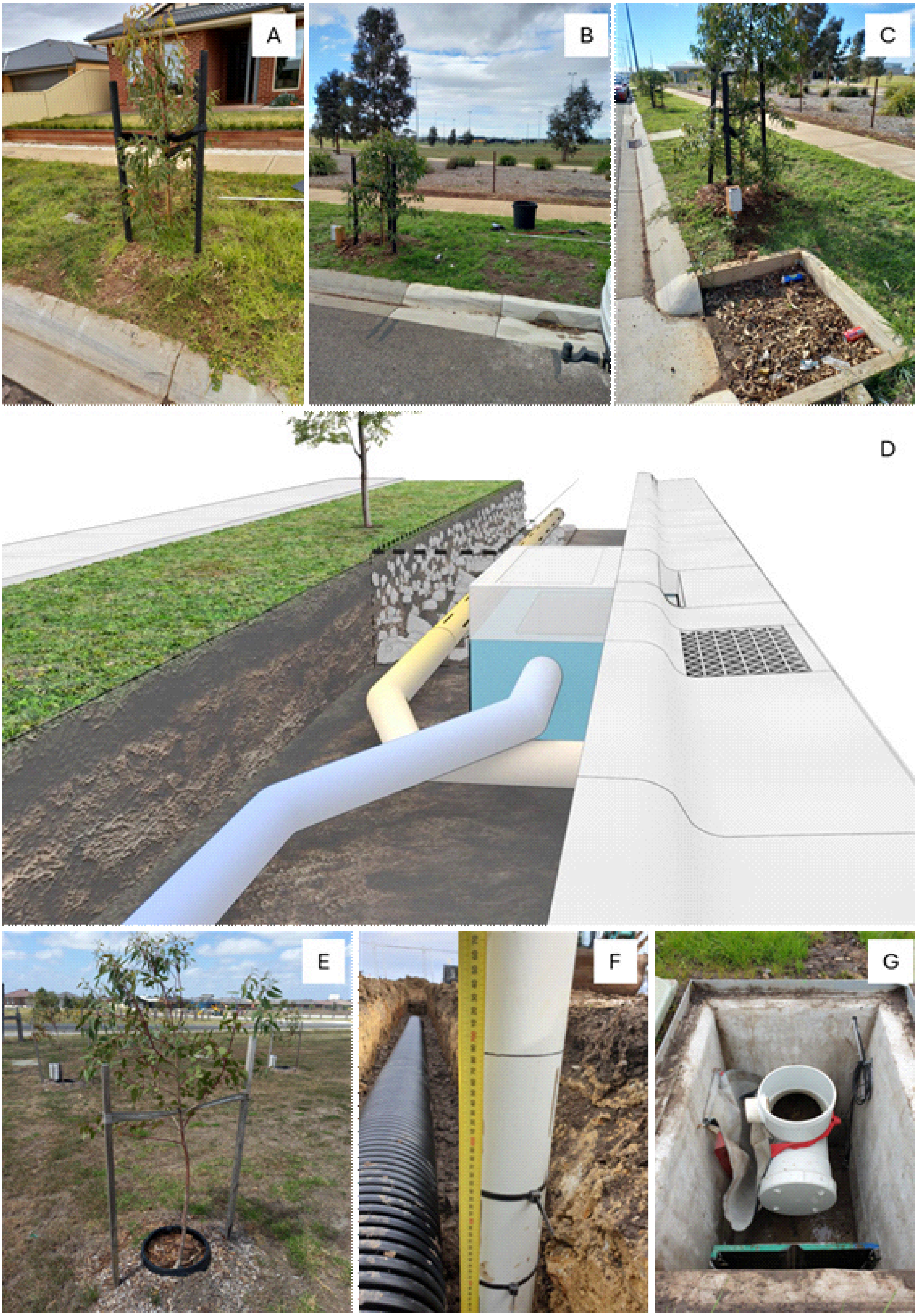

Figure 1: Melton field experiment where infiltration trenches receive stormwater from A) private roofs, B) lintel inlets and C) kerb cuts. D) shows a "big storage" concept designed for a typical suburban nature strip and E-G) show this design as tested in Cardinia Shire where E) trees are planted alongside F) an infiltration trench filled with structural soil with G) an internal water storage created by a downstream pit riser.

contribute to volumetric runoff reduction (Grey et al., 2018b; Thom et al., 2022a).

- With regard to tree species selection for passive irrigation systems, species should have a high transpiration rate, high stomatal sensitivity to declining soil moisture and rapid recovery after drought stress to effectively reduce runoff volumes (Szota et al., 2018; Thom et al., 2022b).

What did we do?

This project can only be addressed in the field, although we have undertaken glasshouse experiments to inform species selection. Given the time lag involved from beginning the design process to capturing performance data from systems in situ, we are delivering this project in two phases. In the first phase, we have been working with local government partners to design and install pilot-scale installations (Figure 1). The project has established partnerships with six LGAs so far, where we have:

- Designed, installed and commenced monitoring an experiment in City of Melton to compare alternative tree pit designs
- Designed and installed and commenced monitoring an experiment with Cardinia Shire to test out our 'big storage' design concepts
- Designed an experiment creating large storage for stormwater in median strips in the City of Port Phillip (yet to be constructed)
- Designed an experiment using a permeable kerb and channel in the City of Moreland
- Designed experiments testing 'big storage' concepts with Blacktown and Penrith city councils (Sydney; yet to be constructed)

Each of our experiments manipulate two aspects: the inlet and subsurface storage. Inlets are low-maintenance and deliver inflows via no kerb/large kerb cuts or modified side entry pits. Subsurface storage is created by replacing native soil with either structural soil or high conductivity media, in combination with control structures to promote detention and retention of flows.

What did we find?

- Established trees are likely accessing adequate soil moisture and we should not assume that additional irrigation will increase tree growth rates or decrease incidence of water stress (Szota et al., 2019).
- Established trees can transpire approximately 70% of the runoff generated by residential streets and should be considered a viable means of volumetric stormwater reduction (Thom et al., 2020).
- Establishing trees irrigated with stormwater and fitted with an underdrain will grow at twice the rate of standard plantings for at least two years (Grey et al., 2018a; Thom et al., 2022a).

Future direction and Knowledge gaps

In the second phase of this project, we will use the network of sites and project partners as the basis for a research grant application. In this grant application, we will propose to co-design and install large-scale ambitious designs to demonstrate the stormwater capture and infiltration potential of a fully functional 'leaky' streetscape.

The project will focus on quantifying system performance and address key knowledge gaps:

- The long-term potential of streetscapes to reduce runoff volume
- Maintenance requirements and impact on road infrastructure
- Contribution to deep infiltration and the fate of infiltrated stormwater
- Magnitude and duration of tree growth benefits

The potential outcomes of this project are significant as street tree SCMs are expected to be an important contribution to achieving our HWS stormwater targets. Based on what we have observed so far, we expect to be able to infiltrate the majority of water generated by roads which will dramatically shift our current approach to stormwater management. Reducing runoff volumes will have additional benefits to downstream headwater streams or stormwater control measures such as undersized constructed wetlands that may be overwhelmed by excessive stormwater.

How are we sharing findings?

We have developed bluegreenstreets.org as a major conduit for sharing our research with stormwater professionals and it includes:

- Current research project installations, including detailed design drawings
- Slides from our workshops detailing the state of the art
- New standard drawings for comment, modification and use

We are developing live data platforms for our field experiments where both researchers and project partners can check in on system operation. At present, these are (slow) simple and tailored to assessing data quality (e.g. battery status), but we aim to develop additional outputs which will be of greater interest to partners (e.g., reporting on runoff capture from the last rainfall event).

For more details on the research outcomes of this project, or other projects of the MWRPP, please contact:

Rhys Coleman
Waterways & Wetlands Research Manager (Applied Research)
rhys.coleman@melbournewater.com.au

Slobodanka Stojkovic
Knowledge Broker, Waterways & Wetlands Research
slobodanka.stojkovic@melbournewater.com.au

Publications:

- Grey, V., Livesley, S.J., Fletcher, T.D., Szota, C., 2018a. Establishing street trees in stormwater control measures can double tree growth when extended waterlogging is avoided. Landscape and Urban Planning 178: 122–129.
- Grey, V., Livesley, S.J., Fletcher, T.D., Szota, C., 2018b. Tree pits to help mitigate runoff in dense urban areas. Journal of Hydrology 565: 400–410.

- Szota, C., Coutts, A. M., Thom, J. K., Virahsawmy, H. K., Fletcher, T. D., Livesley, S. J., 2019, Street tree stormwater control measures can reduce runoff but may not benefit established trees, Landscape and Urban Planning 182:144-155.
- Thom, J. K., Fletcher, T. D., Livesley, S. J., Grey, V., Szota, C., 2022a, Supporting growth and transpiration of newly planted street trees with passive irrigation systems, Water Resources Research 58(1):e2020WR029526.
- Thom, J. K., Livesley, S. J., Fletcher, T. D., Farrell, C., Arndt, S. K., Konarska, J., Szota, C., 2022b, Selecting tree species with high transpiration and drought avoidance to optimise runoff reduction in passive irrigation systems, Science of The Total Environment 812:151466.
- Thom, J. K., Szota, C., Coutts, A. M., Fletcher, T. D., Livesley, S. J., 2020, Transpiration by established trees could increase the efficiency of stormwater control measures, Water Research:115597.

References

- Bartens, J., Day, S.D., Harris, J.R., Wynn, T.M., Dove, J.E., 2009. Transpiration and root development of urban trees in structural soil stormwater reservoirs. Environmental Management 44, 646–657.
- Burns, M.J., Fletcher, T.D., Walsh, C.J., Ladson, A.R., Hatt, B.E., 2012. Hydrologic shortcomings of conventional urban stormwater management and opportunities for reform. Landscape and Urban Planning 105, 230–240.
- Deletic, A., Fletcher, T.D., 2006. Performance of grass filters used for stormwater treatment—a field and modelling study. Journal of Hydrology 317, 261–275.
- Grey, V., Livesley, S.J., Fletcher, T.D., Szota, C., 2018a. Establishing street trees in stormwater control measures can double tree growth when extended waterlogging is avoided. Landscape and Urban Planning 178, 122–129. https://doi.org/10.1016/j.landurbplan.2018.06.002
- Grey, V., Livesley, S.J., Fletcher, T.D., Szota, C., 2018b. Tree pits to help mitigate runoff in dense urban areas. Journal of Hydrology 565, 400–410. https://doi.org/10.1016/j.jhydrol.2018.08.038
- Li, J., Joksimovic, D., Tran, J., 2015. A right-of-way stormwater low impact development practice. Journal of Water Management Modeling C390, 1–7.
- Livesley, S.J., McPherson, E.G., Calfapietra, C., 2016. The urban forest and ecosystem services: Impacts on urban water, heat, and pollution cycles at the tree, street, and city scale. Journal of Environmental Quality 45, 119–124.
- Lucke, T., Mohamed, M.A.K., Tindale, N., 2014. Pollutant removal and hydraulic reduction performance of field grassed swales during runoff simulation experiments. Water 6, 1887–1904.
- Melbourne Water, 2005. WSUD Engineering Proceedures: Stormwater. CSIRO Publishing, Melbourne.
- Monrabal-Martinez, C., Aberle, J., Muthanna, T.M., Orts-Zamorano, M., 2018. Hydrological benefits of filtering swales for metal removal. Water Research 145, 509–517.
- Mullaney, J., Lucke, T., 2014. Practical review of pervious pavement designs. CLEAN – Soil, Air, Water 42, 111–124.
- Nichols, P.W.B., Lucke, T., 2015. Local level stormwater harvesting and reuse: a practical solution to the water security challenges faced by urban trees. Sustainability 7, 8635–8648.
- Scharenbroch, B.C., Morgenroth, J., Maule, B., 2016. Tree species suitability to bioswales and impact on the urban water budget. Journal of Environmental Quality 45, 199–206.
- Szota, C., Coutts, A.M., Thom, J.K., Virahsawmy, H.K., Fletcher, T.D., Livesley, S.J., 2019. Street tree stormwater control measures can reduce runoff but may not benefit established trees. Landscape and Urban Planning 182, 144–155. https://doi.org/10.1016/j.landurbplan.2018.10.021
- Szota, C., McCarthy, M.J., Sanders, G.J., Farrell, C., Fletcher, T.D., Arndt, S.K., Livesley, S.J., 2018. Tree water-use strategies to improve stormwater retention performance of biofiltration systems. Water Research 144, 285–295. https://doi.org/10.1016/j.watres.2018.07.044
- Thom, J.K., Fletcher, T.D., Livesley, S.J., Grey, V., Szota, C., 2022a. Supporting growth and transpiration of newly planted street trees with passive irrigation systems. Water Resources Research 58, e2020WR029526. https://doi.org/10.1029/2020WR029526
- Thom, J.K., Livesley, S.J., Fletcher, T.D., Farrell, C., Arndt, S.K., Konarska, J., Szota, C., 2022b. Selecting tree species with high transpiration and drought avoidance to optimise runoff reduction in passive irrigation systems. Science of The Total Environment 812, 151466. https://doi.org/10.1016/j.scitotenv.2021.151466
- Thom, J.K., Szota, C., Coutts, A.M., Fletcher, T.D., Livesley, S.J., 2020. Transpiration by established trees could increase the efficiency of stormwater control measures. Water Research 115597.
- Tu, M., Caplan, J.S., Eisenman, S.W., Wadzuk, B.M., 2020. When green infrastructure turns grey: plant water stress as a consequence of overdesign in a tree trench system. Water 12, 573.