

A permeable kerb for passively irrigating street trees

Une bordure perméable pour l'irrigation passive des arbres de rue

Christopher Szota¹, Mahdi M. Disfani¹, Peter Poelsma¹, Robert James¹, Abbas Rezamand¹, Tim D. Fletcher¹, Amir Mehdizadeh², Vaughn Grey³ and Micah Pendergast³

1. The University of Melbourne (cszota@unimelb.edu.au, mahdi.miri@unimelb.edu.au, peter.poelsma@unimelb.edu.au, james.robert@unimelb.edu.au, a.rezamand@unimelb.edu.au, timf@unimelb.edu.au)
2. Porous Lane (amir@porouslane.com.au)
3. Melbourne Water (vaughn.grey@melbournewater.com.au, micah.pendergast@melbournewater.com.au)

RÉSUMÉ

De nombreux systèmes ont été développés pour traiter et retenir les eaux de ruissellement pluviales. Cependant, peu sont capables de réduire significativement les volumes de ruissellement, c'est-à-dire de retenir les eaux de ruissellement. Dans cette étude, nous avons développé une bordure et un caniveau perméables, conçus pour infiltrer de grands volumes d'eaux de ruissellement de la route dans les accotements, afin d'irriguer les arbres de rue. À Melbourne, en Australie, nous avons construit une section de 20 m de bordure et de caniveau perméables desservant une tranchée d'infiltration de sol structurel plantée d'arbres et avons surveillé les performances hydrologiques pendant un an. Malgré les faibles taux d'exfiltration du sol argileux sablonneux in situ ($<1,5 \text{ mm h}^{-1}$), la rétention du ruissellement était de 81 % et la réduction du débit de pointe était de 79 % pour les événements qui ont généré un écoulement. L'humidité du sol a augmenté autour de la tranchée d'infiltration, indiquant que l'exfiltration était la principale perte de ruissellement. La bordure a maintenu des taux d'infiltration $>30\,000 \text{ mm h}^{-1}$, qui ont augmenté à $54\,000 \text{ mm h}^{-1}$ après un lavage sous pression, indiquant qu'un colmatage s'était produit. Les taux d'infiltration devraient diminuer de 99 % avant que la bordure et le caniveau ne puissent plus infiltrer l'intensité de pluie la plus élevée observée pour l'emplacement. La bordure et le caniveau perméables ont maintenu leur stabilité et leur rigidité, indiquant qu'il n'y a pas eu de tassement ou de mouvement significatif dû à l'infiltration des eaux de ruissellement. Nous prévoyons de continuer à surveiller l'expérience pour déterminer les besoins d'entretien. Dans l'ensemble, la bordure et le caniveau perméables représentent une solution prometteuse pour l'infiltration de grands volumes d'eaux de ruissellement dans les zones urbaines.

ABSTRACT

Many systems have been developed to treat and detain stormwater runoff. However, few are capable of significantly reducing runoff volumes, i.e. retaining runoff. In this study, we developed a permeable kerb and channel, designed to infiltrate large volumes of road runoff into road verges, to irrigate street trees. In Melbourne, Australia, we constructed a 20-m section of permeable kerb and channel servicing a structural soil infiltration trench planted with trees and monitored hydrological performance over one year. Despite slow exfiltration rates of the in-situ sandy clay soil ($<1.5 \text{ mm hr}^{-1}$), runoff retention was 81% and peak flow rate reduction was 79% for events which generated outflow. Soil moisture increased around the infiltration trench, indicating exfiltration as the major loss of runoff. The kerb maintained infiltration rates $>30,000 \text{ mm h}^{-1}$, which increased to $54,000 \text{ mm h}^{-1}$ after pressure washing, indicating clogging occurred. Infiltration rates would need to decrease by 99% before the kerb and channel could no longer infiltrate the highest observed rainfall intensity for the location. The permeable kerb and channel maintained stability and stiffness, indicating no significant settling or movement due to infiltration of runoff. We plan to continue to monitor the experiment to determine maintenance requirements. Overall, the permeable kerb and channel represents a promising solution for infiltrating large volumes of runoff in urban areas.

KEYWORDS

Green stormwater infrastructure, passive irrigation, permeable kerb, runoff retention, street tree

1 INTRODUCTION

The large volume of runoff generated in cities is highly damaging where impervious surfaces are directly connected to waterways. Although many nature-based systems exist to treat and detain runoff, space constrains typically limit system size and therefore the ability to retain runoff. Restoring hydrological process such as infiltration and evapotranspiration is key to reducing runoff volumes. Urban forests, including street trees, are increasingly being valued for their shade and cooling benefits. Trees are also highly efficient at transpiring large volumes of water and therefore represent a means of reducing runoff volumes (Thom et al., 2020). However, systems designed to passively irrigate street trees with runoff have typically only achieved 20% runoff retention, largely due to system inlets clogging and requiring excessive levels of maintenance (Szota et al., 2019). Previous attempts at passive irrigation have also focussed on individual systems, i.e., one system servicing a single tree, again, increasing the maintenance burden and limiting the ability to deploy systems throughout a city.

In this study, we developed a permeable kerb and channel, designed to be installed on typical suburban streets. In effect, the permeable kerb and channel acts as a distributed inlet, much like a 'no kerb' system often observed on high-speed roads. Although we expect this system to be impacted by clogging over time, as for other permeable materials, sediment and debris should be distributed across the permeable kerb and channel, rather than being concentrated at an inlet, e.g. a kerb cut (Grey et al., 2018). As such, maintenance requirements should be lower and runoff should be able to infiltrate through the kerb into road verges or an infiltration trench. In the design tested here, the permeable kerb and channel was connected to a structural soil infiltration trench in which trees were planted, mimicking a streetscape in a highly urbanised area.

2 METHODS

In October 2024, A 20-m section of permeable kerb and channel was installed in Melbourne, Australia. We manipulated the connected impervious surface area to replicate the design intent, i.e., such that the kerb and channel received runoff from a catchment area equivalent to half a standard road width (3.5 m). A rain gauge installed at the site combined with the catchment area (97 m²) were used to estimate runoff generated. Rainfall events were defined with a 3-hour minimum window (only events with total depth >0.2 mm were used) and we conservatively assumed a runoff coefficient of 1. The permeable kerb and channel was made of crushed rock, recycled tire rubber, and a polyurethane binder and had a porosity of 40% (Raeesi et al., 2020). Below the kerb was a geocell filled with aggregate (Figure 1). An impermeable liner was used to minimise runoff movement under the road. A structural soil infiltration trench (20 m long, 0.6 m wide and 0.9 m deep with porosity 0.22) was installed behind the kerb with a drainage pipe at the base. A monitoring pit was installed downstream of the infiltration trench and fitted with a weir and pressure transducer to gauge outflow. The weir created a 350 mm deep reservoir in the infiltration trench with total storage volume of 1,312 L, equivalent to a rainfall depth of 13.5 mm. An additional pressure transducer was installed in the infiltration trench to monitor exfiltration rates. Soil moisture sensors were installed in in-situ soil 0.5 and 1-m from the edge of the infiltration trench to monitor the fate of runoff. Double-ring infiltrometer measurements were taken four times during the study on small sections of the permeable channel. Each time, infiltration was measured first, a small section of the channel was washed with a pressure washer and the measurement repeated.

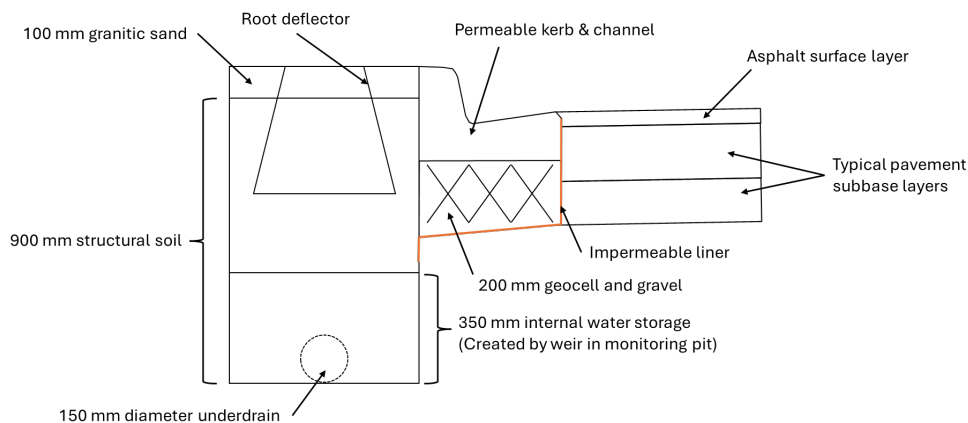


Figure 1. Cross-section of the permeable kerb and channel and infiltration trench.

3 RESULTS AND DISCUSSION

The permeable kerb and channel system retained 81% of runoff (Figure 2). Previous passive irrigation systems designed to achieve ~80% retention have only retained ~20% of runoff due to inlets clogging with sediment and debris (Szota et al., 2019). The median peak flow reduction 79% for events generating outflow; the permeable kerb and channel therefore represents a viable option for significantly decreasing runoff volumes and potentially mitigating flooding if installed at scale.

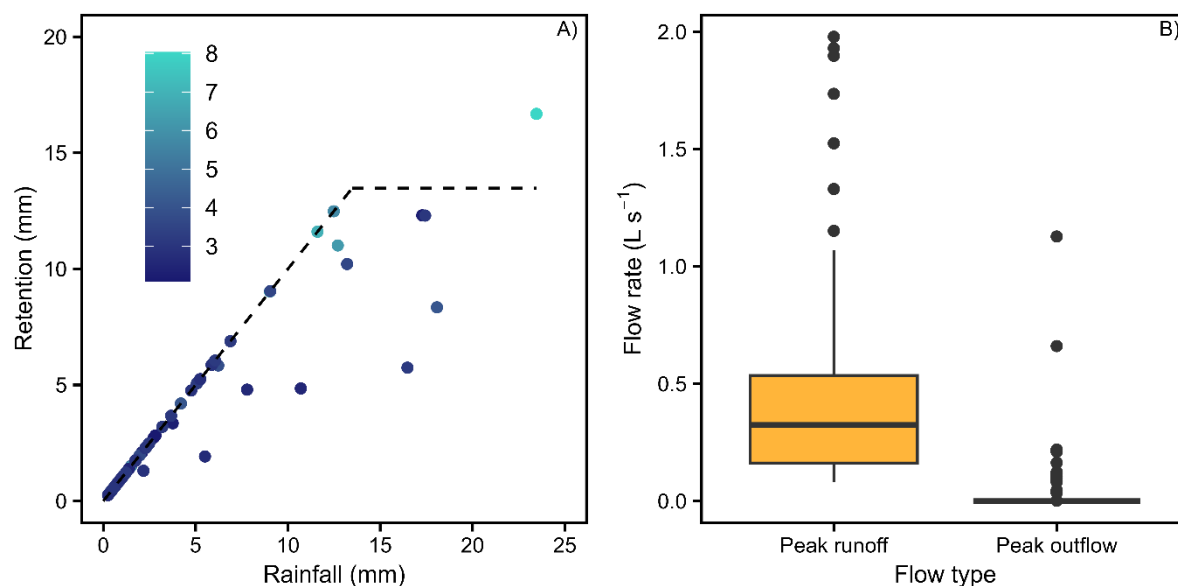


Figure 2. Cross-section of the permeable kerb and channel and infiltration trench.

A number of complementary factors likely contributed to high retention and peak flow performance:

1. **High permeability of the kerb and channel:** The permeable kerb and channel maintained infiltration rates exceeding 30,000 mm hr⁻¹; higher than reported for typical permeable surfaces (Zhang et al., 2018). However, most permeable materials show high infiltration rates initially (Winston et al., 2016) and further monitoring over time is required to estimate clogging rates, maintenance needs and effectiveness.
2. **Large inlet-to-catchment area ratio:** The inlet (permeable kerb and channel) occupied 12% of the impervious catchment area, significantly higher than typical designs (Davis et al., 2009). The distributed nature of the inlet as compared with systems with a kerb cut or grated inlet likely contributed to efficient runoff capture and conveyance to the infiltration trench.
3. **Substantial storage volume:** The combined structural soil infiltration trench and permeable kerb system occupied 25% of the catchment area. The large storage capacity of the infiltration trench was critical for facilitating exfiltration, however removal and replacement of large volumes of soil will likely not be possible at scale (Hanley et al., 2024). A more cost-effective design would use the gravel/geocell layer as the reservoir facilitating exfiltration into in-situ soil behind the kerb. Such a system may be less efficient but would have only slightly less storage on account of higher porosity of the gravel compared with the structural soil. We would need to determine impacts on stability and stiffness under traffic loads if water was allowed to pond in the gravel/geocell and permeable channel.
4. **Effective exfiltration:** Despite relatively slow rates (up to 1.5 mm hr⁻¹), exfiltration was sufficient to facilitate high runoff retention and peak flow reduction.
5. **Atypical rainfall distribution:** The study period experienced lower than average rainfall (306 mm), which was low compared with the previous 10 years (365-705 mm). Therefore, we expect retention to be lower than 81% under more typical rainfall conditions. We plan to calibrate a model from data collected to date in order to simulate performance under different rainfall depths, duration and peak intensities.

Soil moisture increased at depth around the infiltration trench, indicating that exfiltration was likely the key process driving high retention and peak flow reduction. However, we cannot rule out the possibility that captured runoff leaked back into the stormwater drainage network (Bonneau et al., 2017). Higher soil moisture at depth will likely not impact establishing street trees, however waterlogged conditions may negatively impact established trees.

Stability and structural integrity of the permeable kerb were maintained throughout the study, with only minor settlement observed (1 mm more than the concrete kerb). The material's stiffness remained consistent, indicating no significant degradation over time. However, more studies will be required to provide the evidence base required by road and other infrastructure engineers to accept infiltration of runoff in and around the built environment.

4 CONCLUSION

The permeable kerb and channel system shows promise for runoff retention at scale throughout urban areas. Its ability to retain runoff, reduce peak flows, and potentially support tree growth while maintaining structural integrity makes it a compelling option for future urban design. However, longer-term studies and modelling across various conditions are necessary to fully understand its potential and limitations. Substantial work will be required to change the current approach to constructing traditionally grey infrastructure, especially road infrastructure given the safety implications.

LIST OF REFERENCES

- Bonneau, J., Fletcher, T.D., Costelloe, J.F., Burns, M.J., 2017. Stormwater infiltration and the 'urban karst' - a review. *Journal of Hydrology* 552, 141–150.
- Davis, A.P., Hunt, W.F., Traver, R.G., Clar, M., 2009. Bioretention technology: Overview of current practice and future needs. *Journal of Environmental Engineering* 135, 109–117.
- Grey, V., Livesley, S.J., Fletcher, T.D., Szota, C., 2018. 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>
- Hanley, P.A., Livesley, S.J., Fletcher, T.D., Grey, V., Szota, C., 2024. Stormwater retention performance of tree integrated infiltration trenches designed for suburban streetscapes. *Science of The Total Environment* 954, 176634. <https://doi.org/10.1016/j.scitotenv.2024.176634>
- Raeesi, R., Soltani, A., King, R., Disfani, M.M., 2020. Field performance monitoring of waste tire-based permeable pavements. *Transportation Geotechnics* 24, 100384. <https://doi.org/10.1016/j.trgeo.2020.100384>
- 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>
- 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.
- Winston, R.J., Al-Rubaei, A.M., Blecken, G.T., Viklander, M., Hunt, W.F., 2016. Maintenance measures for preservation and recovery of permeable pavement surface infiltration rate – The effects of street sweeping, vacuum cleaning, high pressure washing, and milling. *Journal of Environmental Management* 169, 132–144. <https://doi.org/10.1016/j.jenvman.2015.12.026>
- Zhang, J., Ma, G., Dai, Z., Ming, R., Cui, X., She, R., 2018. Numerical study on pore clogging mechanism in pervious pavements. *Journal of Hydrology* 565, 589–598. <https://doi.org/10.1016/j.jhydrol.2018.08.072>