Eco-hydrological model of water dynamics in a small-scale urban reserve

V.Marchionni, Department of Civil Engineering, Monash University, Melbourne, Australia,
M. Camporese, Department of Civil, Environmental and Architectural Engineering, University of Padua, Padua, Italy,
E. Daly, Department of Civil Engineering, Monash University, Melbourne, Australia

Key words: Urban reserve, water dynamics, hydrological model

Abstract

Urbanization and the associated land transformations generate a fragmented and heterogeneous landscape where patches of vegetation, often remnants of native trees, are surrounded by built structures. These areas create important corridors to maintain high levels of urban biodiversity and provide environmental and social services essential to the quality of life of urban dwellers [1]. Urban expansion on natural ecosystems, in addition to reducing the extent of the vegetation cover, changes the ecosystem hydrologic regime. The increase of impervious surfaces and the introduction of drainage infrastructure reduce the volume of water infiltrating soils, and hence soil moisture and groundwater recharge, decreasing the water available to sustain vegetation growth and health [2]. Moreover, urbanization creates unique biotic communities where pockets of remaining native vegetation and introduced non-native species may coexist, having occasionally higher water demand, different patterns of evapotranspiration (ET), interception, and infiltration [3].

In the Greater Melbourne area in southeastern Australia, for instance, projections show that less than 4% cover of native vegetation will remain within the 2030 growth boundary, mainly as pockets of urban reserves managed by government authorities and private land [4]. Reduced water availability associated with urbanization in combination with periods of drought and extreme heat has increased the water stress of these areas and the resulting decline in their health conditions. Therefore, assessing their water dynamics is important to guide reserve management to maintain a hydrological regime able to preserve these ecosystems.

Efforts to understand interactions and feedback between ecological and hydrological processes are commonly directed to large bio-diverse ecosystems, often in natural environments or mildly affected by human activities. Other recent studies in southern California, whose climate is similar to that of southeastern Australia, estimated ET from vegetated urban landscapes [5, 6] and showed that water use of native urban trees may differ from that of non-native ones [7]. However, considerable less research has investigated the water dynamics within small-scale urban reserves.

This study aims to fill this gap, focusing on a small urban reserve (4.1 ha), Napier Park, embedded in a northwestern suburb of Melbourne (Victoria, Australia). The reserve is home to valuable remnant vegetation, mainly *Eucalyptus Camaldulensis*, and is highly managed, with about 85% of its area being passively irrigated. Across the park, low permeability clay soils are present at shallow depths, restricting most surface infiltration into the topsoil profile. Topography is characterized by a moderate slope towards the south-east with a high point in the north-west of the site. Average monthly temperatures range from 27.5 °C in January to 6.3 °C in July and precipitation averages 534 mm annually; reference evapotranspiration is about 1290 mm, exceeding rainfall for the majority of the year (Bureau of Meteorology (BoM), Essendon Airport location, station number 86038, 2009-2017). The reserve has 6 fully encapsulated probes measuring volumetric water content up to 1.2 m every 15 minutes (Drill & Drop, Sentek) since August 2014. Sap flow has been measured every 30 minutes with 4 sapflow meters SFM1 (ICT International, Australia) starting from February 2017. Sap flow measurements are then used to assess actual evapotranspiration (ET_a).

To simulate the reserve water dynamics we use the physically-based spatially-distributed hydrological model CATchment HYdrology (CATHY). The model couples the three-dimensional Richards equation for subsurface flow in variably saturated porous media and a path-based one-dimensional diffusion wave approximation of the de Saint-Venant equation for surface water dynamics [8]. ET_a is computed using a sink term in the Richards equation to account for root water uptake, as in [9]. Starting from a 5 m x 5 m resolution DEM, a three-dimensional subsurface grid is constructed (Figure 1). Using rainfall and potential evapotranspiration (ET_p) as atmospheric boundary conditions, the model is calibrated and validated against observed volumetric soil moisture, and assessed by comparing modeled with observed ET_a. The initial conditions for the calibration simulations are generated by running a warm-up period of 1 year to obtain a state that is physically realistic and essentially independent of the conditions assigned at the beginning of the warm-up.

Applying such a modeling approach to small spatial scales allows a more detailed description of the variations of land-surface properties, such as topography, vertical and horizontal soil heterogeneity, and vegetation. Other contributions are the selection of proper boundary conditions to represent a small catchment embedded in urban environment and the appropriate description of irrigation as a source of water in different locations of the reserve. The study showcases the use of a distributed model to potentially support management practices of urban bushland reserves, such as the prediction of land management impacts.

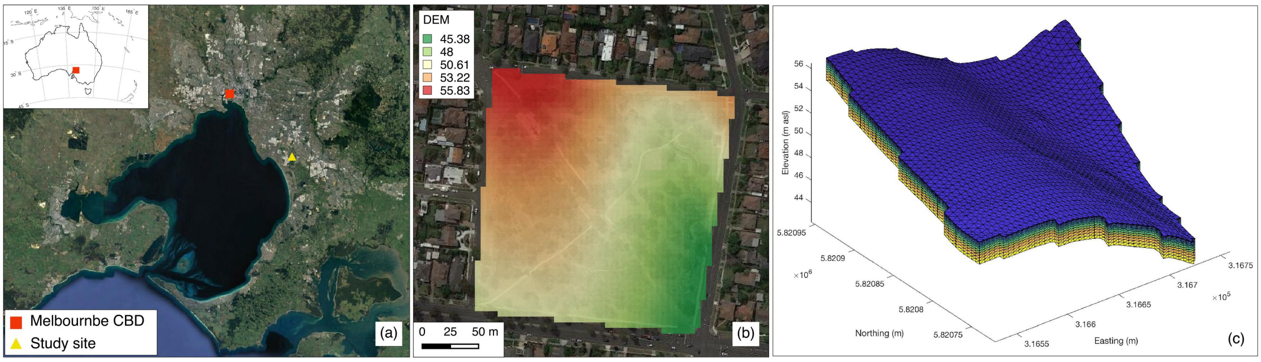

Figure 1: (a) Location of the study site in the Greater Melbourne area in Victoria, Australia. (b) Digital elevation model (5 m x 5 m) of the study area. (c) CATHY 3D grid resulting from the simulation.

References

[1] Livesley, SJ and McPherson, EG and Calfapietra, C. 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(1)**, 119–124, (2016).

[2] Xiao, Q and McPherson, EG and Simpson, JR and Ustin, SL. Hydrologic processes at the urban residential scale. *Hydrological processes*, **21(16)**, 2174–2188, (2007).

[3] Pataki, DE and Boone, CG and Hogue, TS and Jenerette, GD and McFadden, JP and Pincetl, S. Socio-ecohydrology and the urban water challenge. *Ecohydrology*, **4(2)**, 341–347, (2011).

[4] Hahs, Amy K and McDonnell, Mark J. Extinction debt of cities and ways to minimise their realisation: a focus on Melbourne. *Ecological management & restoration*, **15(2)**, 102–110, (2014).

[5] Litvak, Elizaveta and Pataki, Diane E. Evapotranspiration of urban lawns in a semi-arid environment: An in situ evaluation of microclimatic conditions and watering recommendations. *Journal of Arid Environments*, **134**, 87–96, (2016)

[6] Litvak, E and Manago, KF and Hogue, TS and Pataki, DE. Evapotranspiration of urban landscapes in Los Angeles, California at the municipal scale. *Water Resources Research*, **53**, (2017).

[7] McCarthy, Heather R and Pataki, Diane E. Drivers of variability in water use of native and non-native urban trees in the greater Los Angeles area. *Urban Ecosystems*, **13(4)**, 393–414, (2010).

[8] Camporese, M and Paniconi, C and Putti, M and Orlandini, S. Surface-subsurface flow modeling with path-based runoff routing, boundary condition-based coupling, and assimilation of multisource observation data. *Water Resources Research*, **46(2)**, (2010).

[9] Camporese, M. and Daly, E. and Paniconi, C. Catchment-scale Richards equation-based modeling of evapotranspiration via boundary condition switching and root water uptake schemes. *Water Resources Research*, **51(7)**, 5756–5771, (2015).