UrbanBEATS: A strategic planning tool for exploring water sensitive futures

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Abstract.

Computational models have the potential to enhance interdisciplinary collaboration and participatory planning of future urban water infrastructure. However, we currently lack suitable tools to explore and assess adaptation measures of our water infrastructure to cope with future challenges of climate change, population and urban growth. A tool was developed which, simulates interactions between urban planning, water management and Water Sensitive Urban Design (WSUD): The Urban Biophysical Environments and Technologies Simulator (UrbanBEATS)—a spatial model for testing scenarios of planning, design and placement of WSUD in urban catchments under regulatory/policy constraints. The model reconstructs urban form with planning rules and assesses many possible WSUD interventions to meet various targets (e.g. pollution, recycling). It provides recommended locations for suitable WSUD and a possible 'blueprint' on how to implement suitable strategies over time. Such a tool has the potential to bring stakeholders together to engage in effective participatory planning.

Introduction

Changes in urban water management over the last decade have called for greater diversity of solutions, both structurally/non-structurally and consideration of more holistic and integrated approaches (Brown et al, 2009). The use of numerical models to support these approaches is becoming more widespread. Water Sensitive Urban Design (WSUD) has received more attention in the last decade and its design and performance has been captured in several well-known software tools e.g. MUSIC (eWater, 2011). Yet, planning and implementation of WSUD infrastructure in new and existing areas also requires an understanding of its interaction with urban form and the constraints that define these. Although existing models e.g. SUSTAIN (Lee et al, 2012), UWOT (Makropoulos et al., 2008, Makropoulos and Butler, 2010) and SUDSLOC (Viavattene and Ellis, 2013) investigate the design and placement of WSUD, they are limited in how interactions with urban planning and water management policies are considered and their ability to undertake rigorous scenario testing.

The UrbanBEATS (Urban Biophysical Environments And Technologies Simulator) model is a strategic planning tool that explores the planning, design and implementation of WSUD in urban catchments under different urban form and policy scenarios (Bach, 2012). It enables planners and water managers to rigorously explore a large number of feasible interventions for stormwater quantity, quality management and water recycling at a range of scales. UrbanBEATS can be applied to new greenfield developments as well as retrofit in existing urban areas and can be used to better understand how future changes may affect current and potential future infrastructure. This paper aims to give an overview of model features and showcase it in a greenfield suburban development case study located west of Melbourne, Australia.

Model Overview

UrbanBEATS is an integrated spatial model that uses geographic (GIS maps) and climate input to determine catchment characteristics and urban form of a user-defined region (e.g. small urban catchments to large-scale developments or entire cities). Representation of the urban environment is conceptualised as a grid of square city blocks (of user-defined size), each containing information about the land use mix, demographics, urban form and other characteristics that will allow the model to design and implement WSUD infrastructure. The modelling process can be broken down into five key steps (see Figure 1).

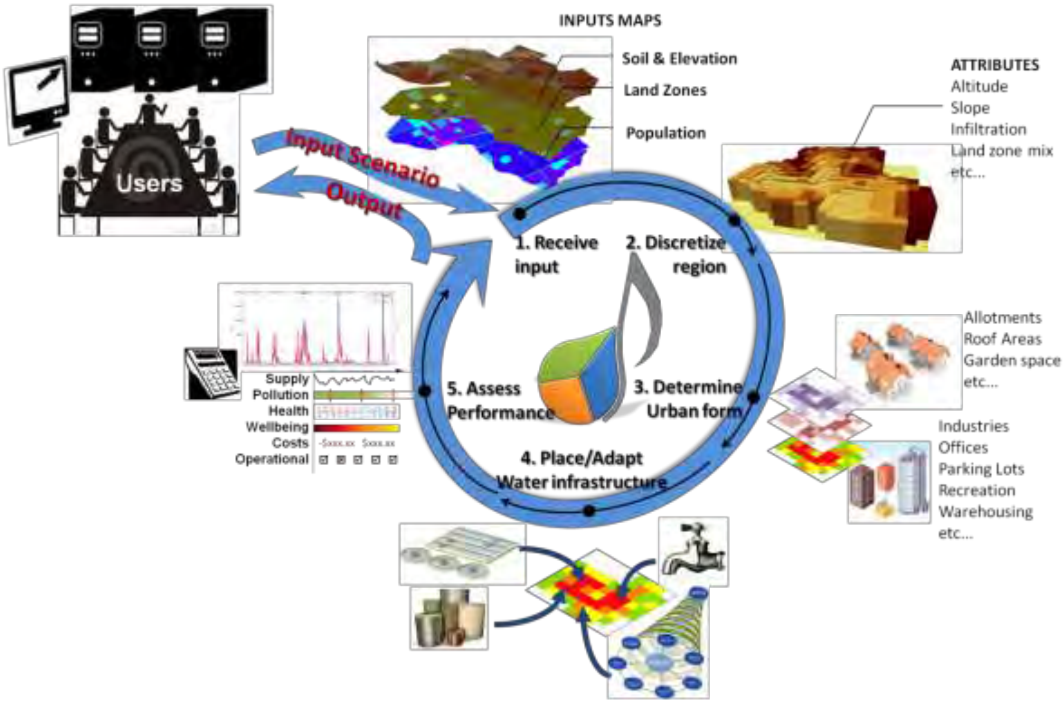

Figure 11. UrbanBEATS Overview (Source: Bach, 2012)

User-defined input raster maps of land use, population, elevation and soil information is fed into the model. Whilst UrbanBEATS can also process additional inputs (e.g. rivers, existing WSUD systems), these four maps are minimal spatial input requirements. Spatial data is then disaggregated into individual city blocks. Topographical information is used to determine drainage paths across blocks and group these into sub-catchments or basins. The model then uses a large set of urban planning information obtained from planning schemes and building codes to calculate urban form characteristics (e.g. allotment sizes, roof areas, parking areas). Different land uses have different urban typologies. More information on this algorithm can be found in a previous study (Bach et al., 2013). Once this urban form information has been determined, the model can adapt existing WSUD infrastructure or design and place new systems to meet current legislation.

The planning algorithm for WSUD technologies in UrbanBEATS is described in detail by Bach et al., (in press), comprising two parts: (i) assessment of all possible locations and scales (lot, street, neighbourhood and sub-basin) at which different WSUD technologies can be implemented to meet water management targets for a given proportion of upstream impervious area and/or population and

(ii) randomly generating technological combinations to meet water management targets for each sub-catchment or basin within the simulation region. This process is additionally influenced by multi-criteria assessment, which scores and ranks each of the different technological configurations based on technical, environmental, economic and social aspects. Top-scoring strategies that best match simulation constraints are selected from the array of options for further analysis. The final step converts these strategies using their design and urban information into input files for the MUSIC software (eWater, 2011), which can be used to simulate system performance.

UrbanBEATS currently supports six WSUD technologies (biofilters, infiltration, surface wetlands, ponds, swales and raintanks). The model uses design curves (created with MUSIC—system size expressed as a % of catchment imperviousness), equations and storage behaviour analysis to size these systems based on current user-defined targets for runoff reduction, total suspended solids (TSS), total nitrogen (TN) and total phosphorus (TP) load reduction and reliability of recycled water supply. Additional space requirements are computed based on the urban characteristics derived in the previous steps of the model for the current block. WSUD interventions can also be designed to service all or only a fraction of impervious area and/or population within the simulation region.

Case Study

To showcase the features of UrbanBEATS, a newly planned greenfield suburban development was simulated. Toolern Precinct is an approximately 24 km^2 future suburban mixed use development within Melbourne's Urban Growth Boundary and is envisioned with a population of 55,000 and 22,000 jobs (GAA, 2011). According to its precinct structure plan (PSP), the development should strive to achieve an environmentally sustainable community and harness WSUD to provide flow retardation, water quality control and recycling.

Data for the Toolern Precinct was obtained from authorities and the published PSP (GAA, 2011), comprising basic model inputs (see Figure 2) and contextual urban planning information required to determine input parameters (e.g. street types and dimensions). Land use and population data were derived from the PSP's proposed land use budget, soil type obtained from the Australian Soil Atlas (McKenzie et al, 2000) and elevation data from contours of one metre vertical resolution.

Figure 12. The Toolern Precinct Modelling Case Study—Location and Data

A block size of 500 m was chosen for the simulation as this was regarded as reasonable (for computational efficiency and planning accuracy) from previous research (Bach et al., in press). However, to ensure that the model provides accurate results on drainage paths and basins, a test run on 200 m blocks was conducted as a comparison. To ensure that the outputs reflect reality, key components throughout the simulation were calibrated using contextual information:

- Urban planning parameters were adjusted for outputs to reflect the PSP requirements of population and jobs provided

- The amount of proposed WSUD infrastructure to service the development was determined from the acquired data and input into the model as a ‘level of service’. Planning of interventions was limited to cover one third of the catchment.

The discussion of results will only be about interventions for stormwater quality management. These results are part of the first stage of this study, which aims to generate initial outputs to facilitate discussion and participatory modelling among stakeholders.

Results & Discussion

Results for the first part of the modelling process (Steps 1–2, Figure 1) are shown for 200 m and 500 m block sizes in Figure 3 below. It can be seen that a finer block size is able to capture more detailed drainage information including local depressions in the area. For planning purposes drainage paths and the grouping of blocks into sub-catchments appears to be consistent across the development.

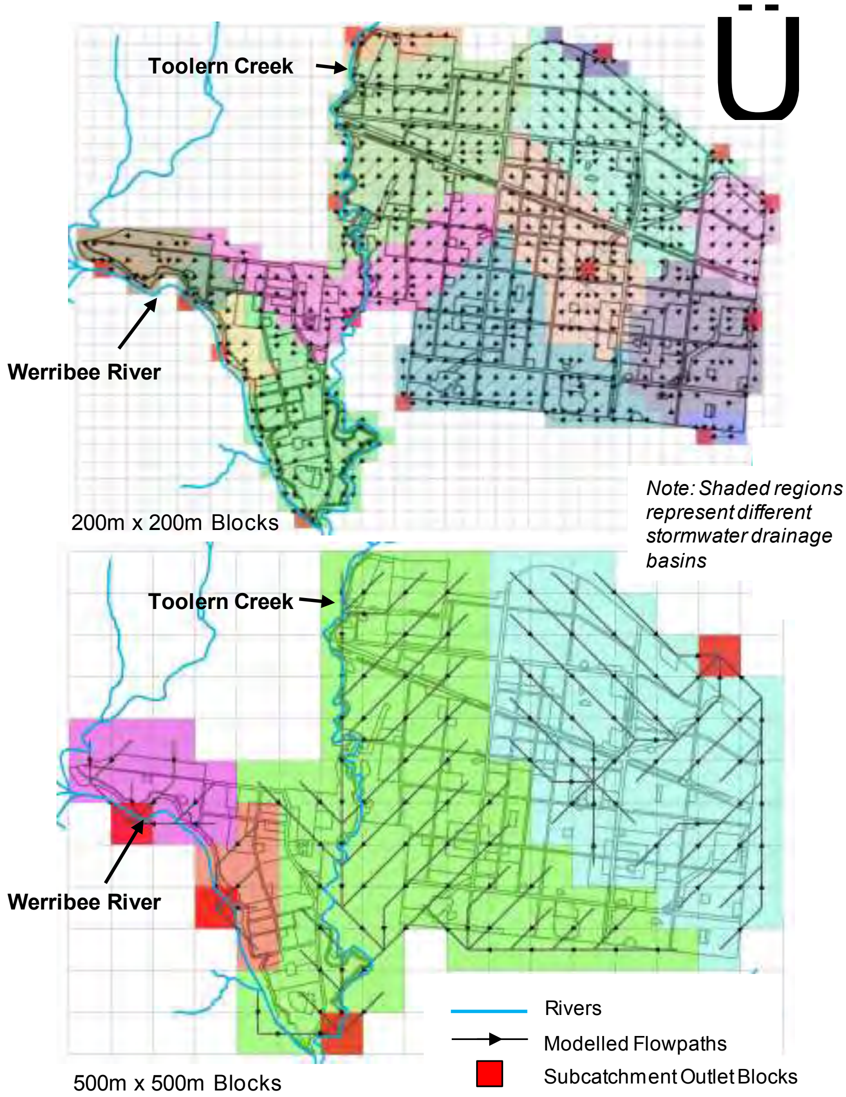

Figure 13. Resulting Building Blocks, Stormwater Flow Paths and Basins for Toolern Precinct

Results show that there are three key drainage areas: the central catchment that drains into Toolern Creek, the eastern parts of the development that flow into Kororoit creek north of the development and smaller catchments along the west draining into the Werribee river. This is consistent with what the PSP reports, thereby ensuring that model algorithms are valid and not heavily influenced by block size.

Modelled impervious area and the distribution of residential dwellings (see Figure 4) are two examples of outputs from the model's urban planning algorithms (Step 3, Figure 1). Users can also obtain information on typical roof and garden sizes in residential districts or available space for WSUD implementation based on different planning restrictions on open spaces in the model.

Figure 14. Modelled Imperviousness and Residential Dwellings within Toolern Precinct

Total impervious area ranges from very low to as high as 90% in highly dense districts such as the activity centre in the north or high density residential areas in the central development area. The lower imperviousness of the employment district in the north-east can be attributed to the low intensity of land developed for industrial and commercial purposes (the model was calibrated to provide 22,000 jobs in these areas). In terms of stormwater management, it can be seen that WSUD interventions would be of particular importance in the central catchment area (of Toolern creek) due to high imperviousness compared to the other sub-catchments.

UrbanBEATS provides spatially explicit maps and summaries of WSUD options that meet management targets under user-defined constraints. For Toolern Precinct, model outputs are shown in Figure 5. Of the different systems available, biofilters, wetlands and ponds were deemed most feasible for stormwater quality management (TSS-TP-TN load reduction targets of 85%-40%-40% were specified). 'Utilisation', a metric that characterises the prevalence of a particular technology in relation to others (see Bach et al., in press for more information), was calculated for the top 10 options and shows that conditions in Toolern favour the use of basin-type systems (ponds and wetlands). This is also consistent with the proposed systems for the development: several large wetlands and basins distributed throughout the area.

Whilst biofilters are not as widely present in the different suggested options, their use has nevertheless been suggested by the model. Figure 5's example shows that these systems can be implemented both as at-source controls within the residential and employment areas of the development as well as larger end-of-pipe solutions. These first stage results indicate several important features about the WSUD opportunities within the Toolern development and future work will involve a more participatory modelling approach to refine these findings and understand the effectiveness of UrbanBEATS in informing the strategic planning process.

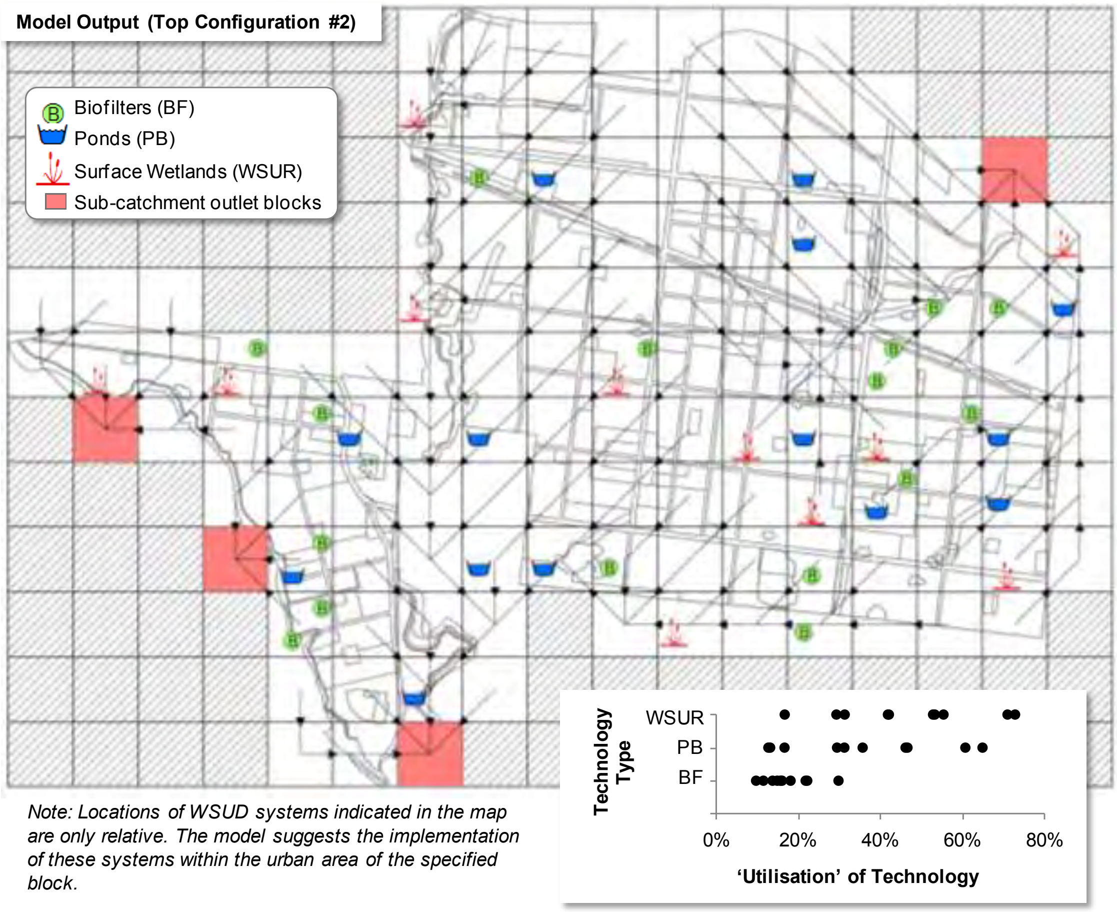

Figure 15. WSUD Planning Outputs: (a) Example Output Map for Top-ranked Configuration, (b) Relative Utilisation of different technologies across top ten configurations.

Conclusion

UrbanBEATS is an exploratory model that can support the participatory and adaptive planning of WSUD in urban catchments. This paper sought to present an overview of its features and showcase its application on the Toolern Precinct development. The first stage of this modelling case study produced realistic representations of the urban environment and an insight into possible WSUD opportunities for stormwater quality management. Model outputs can be used to facilitate further discussion among stakeholders involved in the development about new insights that can be gained from using such exploratory software tools.

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