Assessing the combined benefits of water recycling technologies by modelling the total urban water cycle

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1. Introduction
Typical pressures on the environment due to urbanisation are changes in the hydro-system's water flow pattern and the water abstractions. Water-aware technologies, like Sustainable Urban Drainage Systems (SUDS) and water recycling schemes, can be implemented to reduce these pressures. These technologies introduce interactions between the components of the urban water cycle. Rainwater harvesting, for example, apart from the positive water demand reduction, has significant influence on the generated runoff. In this study, two hypothetical developments, termed as development H and development L (corresponding to high and low urban density), which implement water recycling schemes and SUDS are simulated using the integrated model Urban Water Optimising Tool (UWOT).

2. UWOT
UWOT (Rozos et al., in press, Makropoulos et al., 2006) is a decision support tool that simulates the urban water cycle by modelling individual water uses and technologies, and assessing their combined effects at development scale. The water system components of the development are represented inside UWOT using three level hierarchical structure. The tree levels are:
- Lower level: the individual household water appliances
- Middle level: the households as well as "central" technologies
- Higher level: urban development as a whole.
UWOT implements for optimisations the genetic algorithm NSGA-II (Deb et al., 2005).

3. Representation of a development by UWOT
The hypothetical developments employ Central Treatment (CT) and Sustainable Urban Drainage Systems (SUDS). These technologies help to reduce the potable water demand and abate both the peak and the volume of the generated runoff.

4. UWOT Interface

5. UWOT rainfall-runoff module
UWOT distinguishes the development areas into pervious and impervious. The rainfall that falls on impervious areas is either evaporating or infiltrating. The rainfall that falls on impervious areas generates any spill from tanks and basins (3). To simulate the routing of the rainfall that falls on impervious areas into the development output (H), UWOT implements a simple water storage based module with only two parameters, the capacity K and the recession coefficient ε of the entire at the bottom of the reservoir.

6. Hypothetical developments H and L
To assess the role of the urban-density of a new development on its environmental impact, two hypothetical developments, one with high (H) and one with low (L) urban density, were assumed and examined separately. The households inside each development were considered identical. The total area of both developments was assumed to be 120 hectares (88 hectares occupied by the households and 32 hectares of public areas).

7. Water cycle of the hypothetical developments
The hypothetical developments employ: Central Treatment (CT) and Sustainable Urban Drainage Systems (SUDS). These technologies help to reduce the potable water demand and abate both the peak and the volume of the generated runoff.

8. Water cycle of the hypothetical households
Each household includes a tank (the green water tank) that stores both the harvested rainwater and the water from the central treatment. The water of this tank is used only by the washing appliances and for toilet flushing. The supply from central treatment is activated whenever the tank water level drops below a minimum threshold. The central treatment treats the water coming from the handbasins, showers and baths of the households (these appliances are supplied with potable water from a tank). A typical demand water demand fluctuation pattern [SA, 2008] is assumed throughout the whole simulation, repeated as many times as the number of the days of the simulation period. The household occupancy is 4.

9. Water cycle of the hypothetical households

10. Runoff from the hypothetical household
The runoff from each household equals the sum of the water that spills from the green water tank (Dw) plus the runoff (Rl) from the impervious area (AI). The pervious area (AP) does not give any runoff.

11. Rainfall data, runoff synthetic 'observations'
Rainfall data (10 minutes time step) were obtained from a meteorological station on the NTUA campus in Athens, Greece (NTUA, 2007). The time series length is 61 days starting from 1st of January 2003 and ending at 29th of March 2003. Three sets of observed time series of runoff were produced with the model ZWOG (Zygouras, 2006) using each set a different set of parameters at this model. The first set corresponds to the undisturbed landscape whereas the other two to the developments H and L.

12. Calibration of the runoff module
UWOT is simulating the runoff generated in the development at each time step (caused by rainfall at both public and household impervious area plus any spill from the household tanks). The simulation of the routing of the generated runoff to the development output is accomplished with the UWOT runoff module. The parameters of this module (capacity and recession coefficient of the reservoir) were calibrated to fit the simulated runoff to the observed runoff (produced with ZWOG using parameter sets 2 and 3) at the output of the developments. The calibration resulted in two different sets of UWOT module parameters, one for the development H and one for the development L. The simulations presented in the following panels correspond to a rainfall event that started at 25/3/2003 0:40:00 pm and ended at 26/3/2003 4:20:00 am.

13. Runoff module calibration - development H

14. Runoff module calibration - development L

15. Water-cycle optimisation
The capacity of the household’s green water tanks, the capacity of the SUDS and the central treatment were optimised to achieve simultaneously: a) rainfall-runoff response similar to the one before the urbanisation and b) minimisation of the potable water demand. The objective function was the weighted summation of the potable water demand plus the deviation of the simulated runoff at the development output from the observed runoff of the undisturbed landscape. The deviation was defined as the weighted sum of the difference of the maximum values plus the difference of the standard deviations. The optimisations were performed with the NSGA-II algorithm.

16. Optimisation results – development H

17. Optimisation results – development L

18. Sensitivity analysis
An alternative type of toilet is assessed ( ‘ dual flush tanks’ instead of ‘conventional tanks’) to investigate the influence of the specifications of the appliances that use green water on the runoff generation. Also the sensitivity of the development runoff on the SUDS and on the CSOs tanks’ capacity is investigated using the one-at-time method (Sahbali et al., 2005).

19. Conclusions
- The environmental impact of a new developments (water demand, maximum runoff) increases with the urban density.
- In the water recycling schemes that implement tanks of dual purpose (to store treated grey water and harvested rainwater), the efficiency of the appliances that use grey water inflow considerably the generated runoff.
- The sensitivity of the maximum runoff to the capacity of the local rainwater tanks and on the central CSOs increases with the urban density.
- The previous indicate the need for integrating modelling both for the design of new developments (along with optimisation algorithms) and for the investigation of the impacts of any planned modification to the urban-water cycle.