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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 of the hydrosystem'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 potable water demand reduction, has significant influence on the generated runoff. In this study, two hypothetical developments, referred hereafter as development H and development L (correspond to high and low urban density), which implement water recycling scheme and SUDS are simulated using the integrated model Urban Water Optioneering Tool (UWOT).

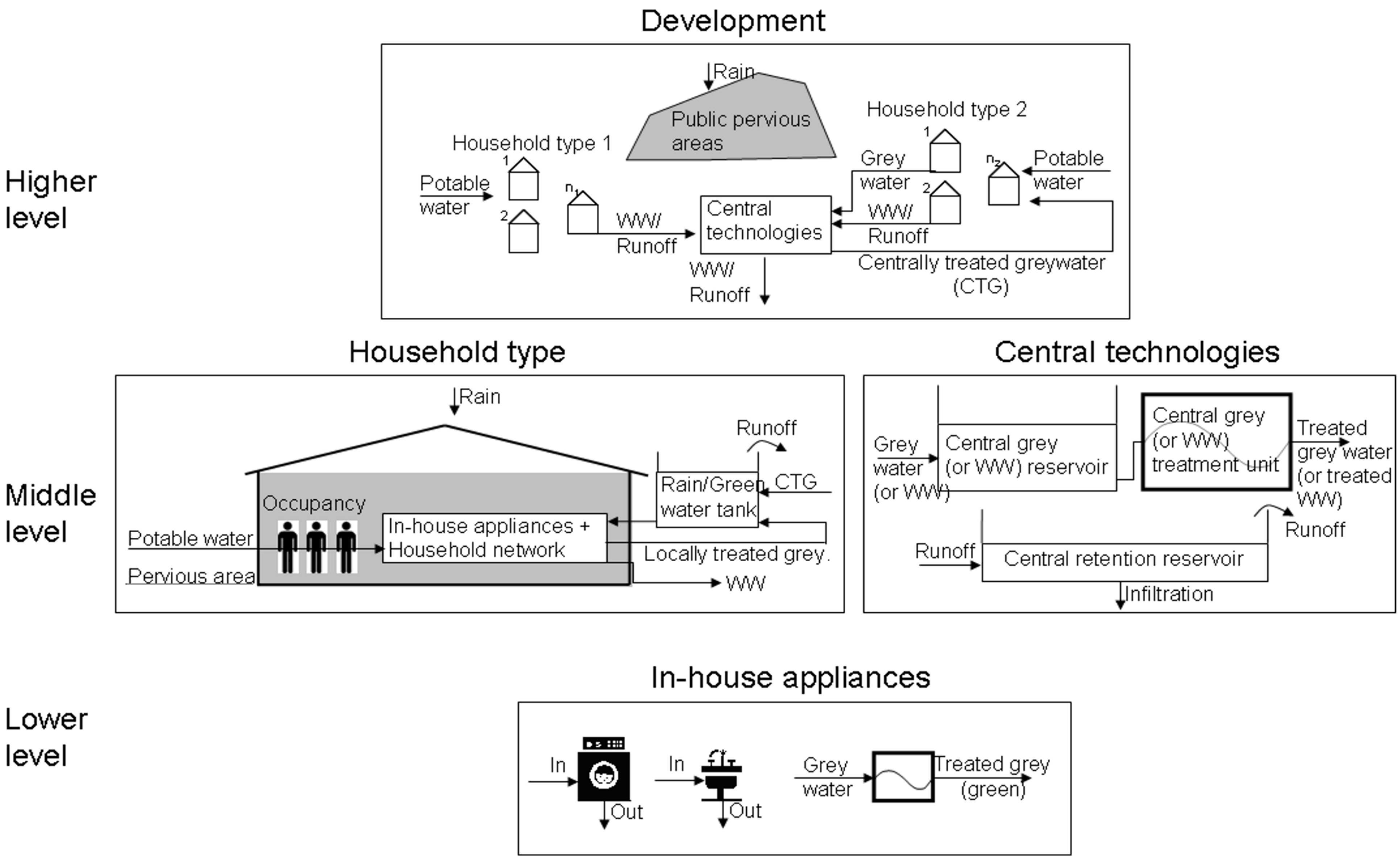
2. UWOT

UWOT (Rozos et al., in press; Makropoulos et al., 2008) 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 a 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: the urban development as a whole.

UWOT implements for optimisations the genetic algorithm NSGA-II (Deb et al., 2000).

3. Representation of a development by UWOT



4. UWOT Interface

File Edit View Insert Format Tools Data Window Help

Full Screen

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SUPPLY GREY / PRIORITY TABLE

	Washing Machine	Toilet	Treatment	Shower	Bath	HandBasin	KitchenSink	Dish Washer	Garden	OutsideUse
Supply grey	0	0	0	1	1	1	0	0	0	0
Potable Water priority	2	2	99	1	1	1	1	1	2	1
Treated Grey water priority	1	1	99	99	99	99	99	99	1	99
Grey Water priority	99	99	1	99	99	99	99	99	99	99

INSTALLED HOUSEHOLD APPLIANCES PER HOUSEHOLD TYPE

	Type 1	Type 2	Type 3	Type 4	Type 5	Type 6
Washing Machine	5	5	5	0	0	0
Toilet	2	2	2	0	0	0
Treatment	1	1	1	0	0	0
Shower	3	3	3	0	0	0
Bath	2	2	2	0	0	0
Handbasin	1	1	1	0	0	0
Kitchen Sink	2	2	0	0	0	0
Dish Washer	0	0	1	0	0	0
Garden	2	2	2	0	0	0
Outside use	1	1	1	0	0	0
SUDSlocal	0	0	0	0	0	0

HOUSEHOLD PROPERTIES

Occupancy	2.3	3.5	4.1	0	0	0
Number of Houses	407	771	162	0	0	0
Impervious Area (m2)	70	100	130	0	0	0
Pervious Area (m2)	280	400	520	0	0	0
Rain Harvesting Area (m2)	70	100	130	0	0	0

RECYCLE SCHEME FLAGS

Greywater Recycling	0	1	2	0	0	0
Rainwater Recycling	0	1	2	0	0	0

HOUSEHOLD TANK CAPACITIES

Grey Tank Capacity (L)	300	1000	515	0	0	0
Green Tank Cap. (L)	0	1203	1000	0	0	0
Green floater (L)	200	1000	200	0	0	0
Grey Tank ini condition (L)	200	200	200	0	0	0
Green Tank ini condition (L	300	300	300	0	0	0
Grey Tank Quality	4	4	4	0	0	0
Green Tank Quality	3	3	2	0	0	0

Abs err (m3) 0.0

PUBLIC AREAS

Rain Harvesting Area (m2)	420000
Total Impervious Area (m2)	420000
Total Pervious Area (m2)	200000

RESERVOIR CAPACITIES

		Initial condition	Ini Quality
Harvested Rainwater (L)	0		
Green (L)	100000	15000	2
SUDS (L)	0		

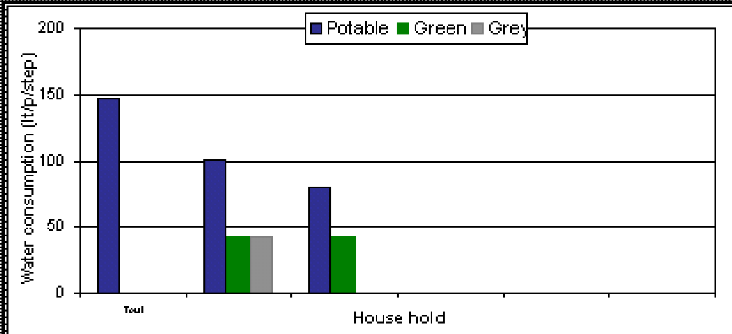
CENTRAL TECHNOLOGIES

SUDS Central	6
Rain Treatment	1
Grey Treatment	1
WW Treatment	2

Number of setps	366
Evaporation	0.2
Spill-yield sequen	0

RAINFALL RUNOFF MODULE

kappa (L)	0
mi	0.9



METRICS

Max runoff (m3/st	18745.64
Mean waste (m3/s	287.12
Water dmnd (hm3	0.22
Op. Cost (M£)	0.21
Energy (MWh)	5637.98
Cap. Cost (M£)	7.57

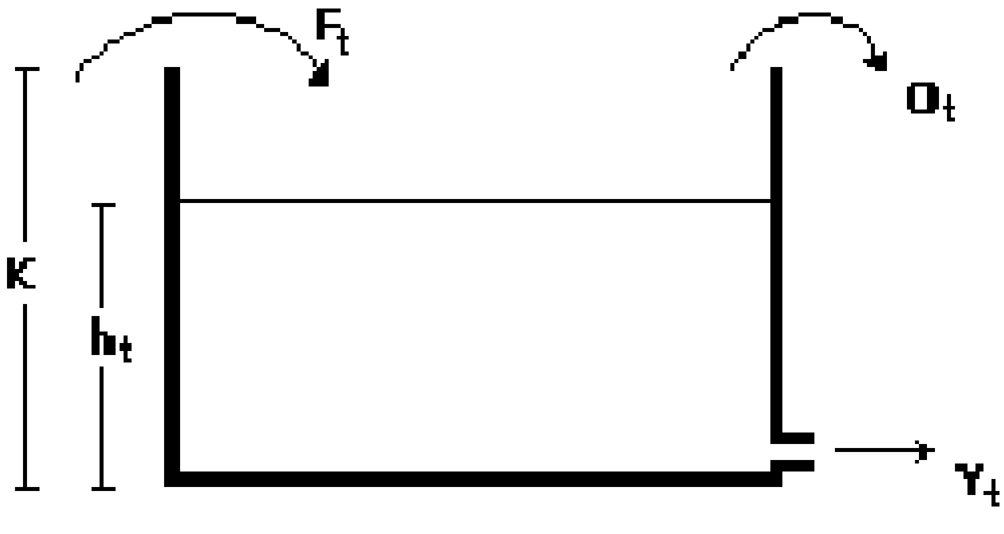
BUDGET

Rain input (hm3)	1.22
Potable input (hm	0.17
Dev. Output (hm3)	0.62
Infiltration (hm3)	0.55
Losses (hm3)	0.08
Evaporation (hm3)	0.14

Model parameters / Frequencies_Leakages / Rain / Future / Results / Problem

5. UWOT rainfall-runoff module

UWOT distinguishes the development areas into pervious and impervious. The rainfall that falls onto pervious areas is either evaporating or infiltrating. The rainfall that falls on impervious areas (plus any spill from tanks) runs off (F_t). To simulate the routing of F_t to the development output (O_t+Y_t), UWOT implements a simple reservoir based module with only two parameters, the capacity K and the recession coefficient μ of the orifice at the bottom of the reservoir.



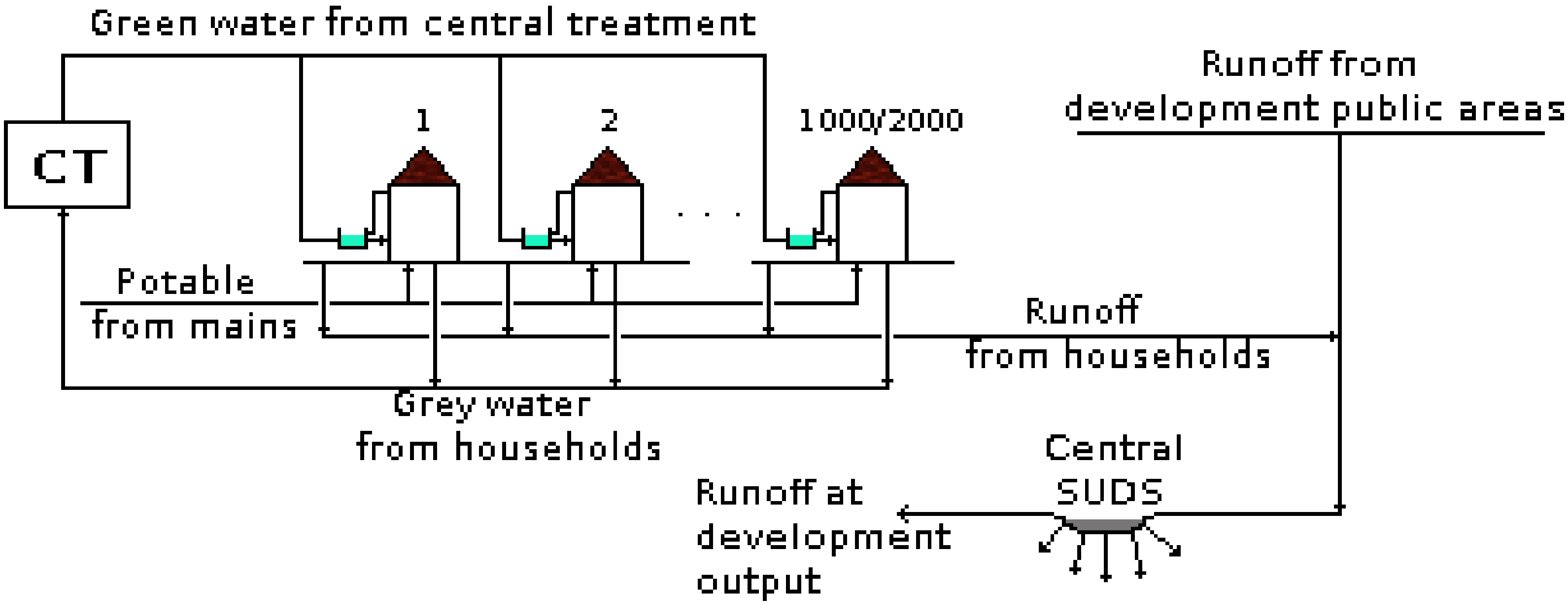
6. Hypothetical developments H and L

To assess the role of the urban density of a new development on its environmental impact, two hypothetic 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 126 hectares (68 hectares occupied by the households and 58 hectares of public areas).

	Development H	**Development L**
Household floor-area ratio	0.47	0.24
Number of households	2000	1000
Public pervious areas	16 hectares	32 hectares
Public impervious areas	42 hectares	26 hectares

7. Water cycle of the hypothetical developments

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

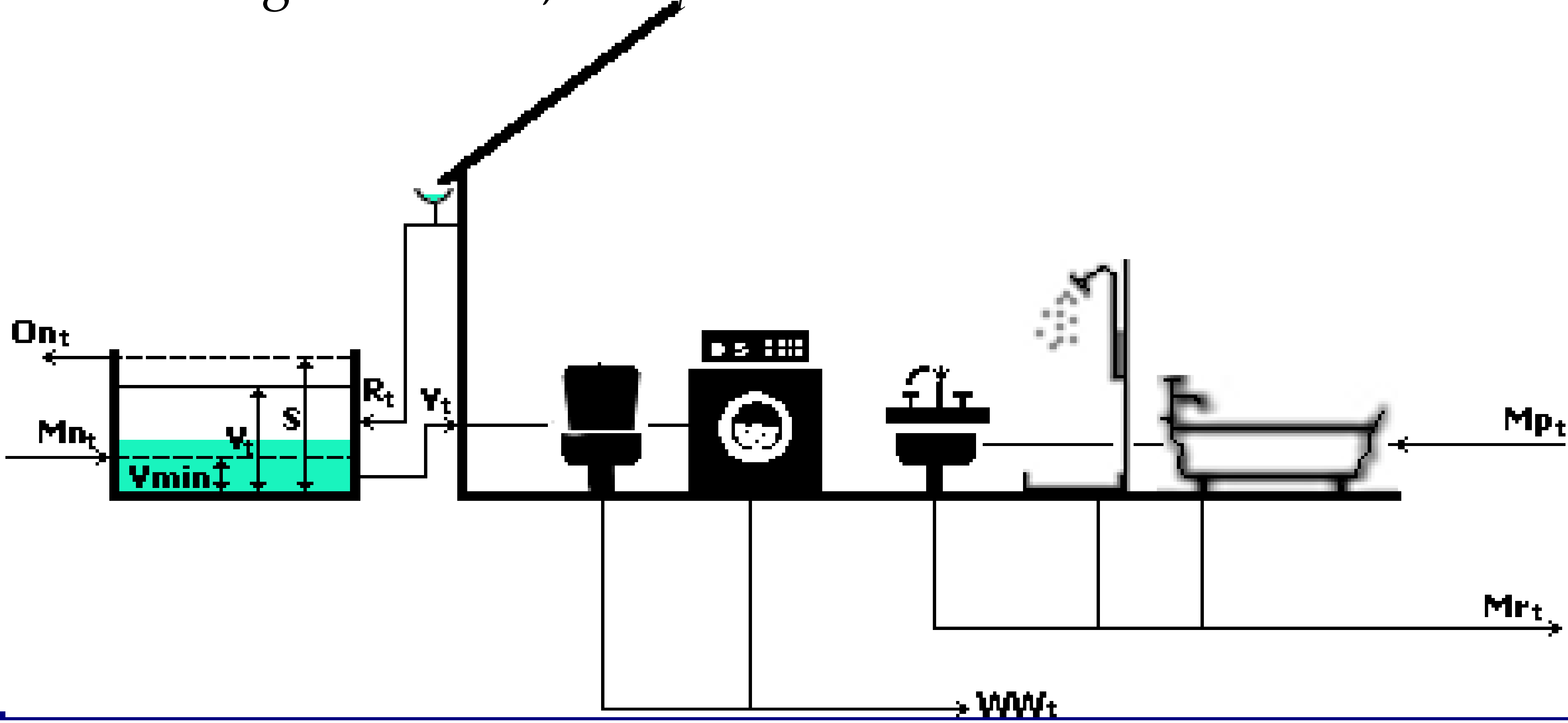


8. Water cycle of the hypothetical households

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 machines 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 hand-basins, showers and baths of the households (these appliances are supplied with potable water from mains). A typical diurnal water demand fluctuation pattern (EA, 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.

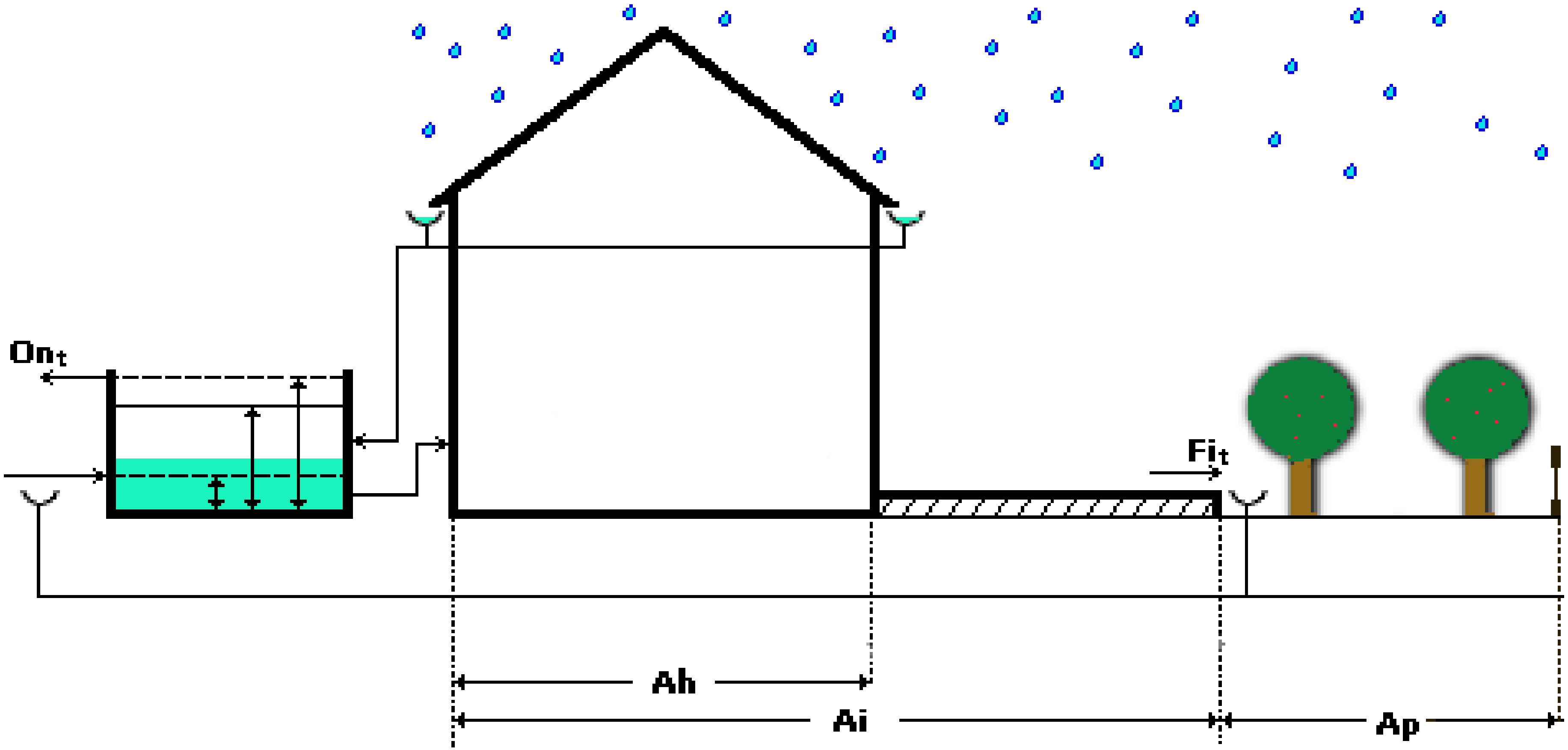
9. Water cycle of the hypothetical households

On_t: spill from green water tank; R_t: harvested rainwater, Mn_t: water from the central treatment;Vmin threshold that activates Mn_t; S: tank capacity; V_t: volume of stored water; Mr_t: grey water from household appliances towards central treatment; Mp_t: potable water supply; Y_t: demand of green water; WW_t: waster water.



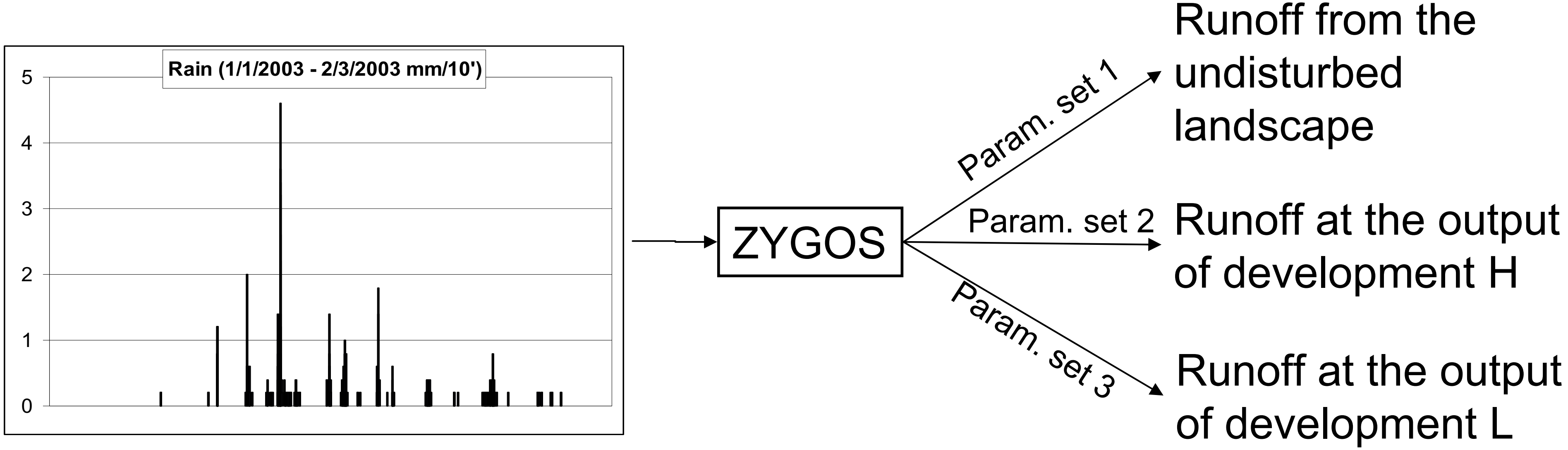
10. Runoff from the hypothetical household

The runoff from each household equals the sum of the water that spills from the greenwater tank (On_t) plus the runoff (Fi_t) from the impervious area (Ai-Ah). The pervious area (Ap) does not give any runoff.



11. Rainfall data, runoff synthetic ‘observations’

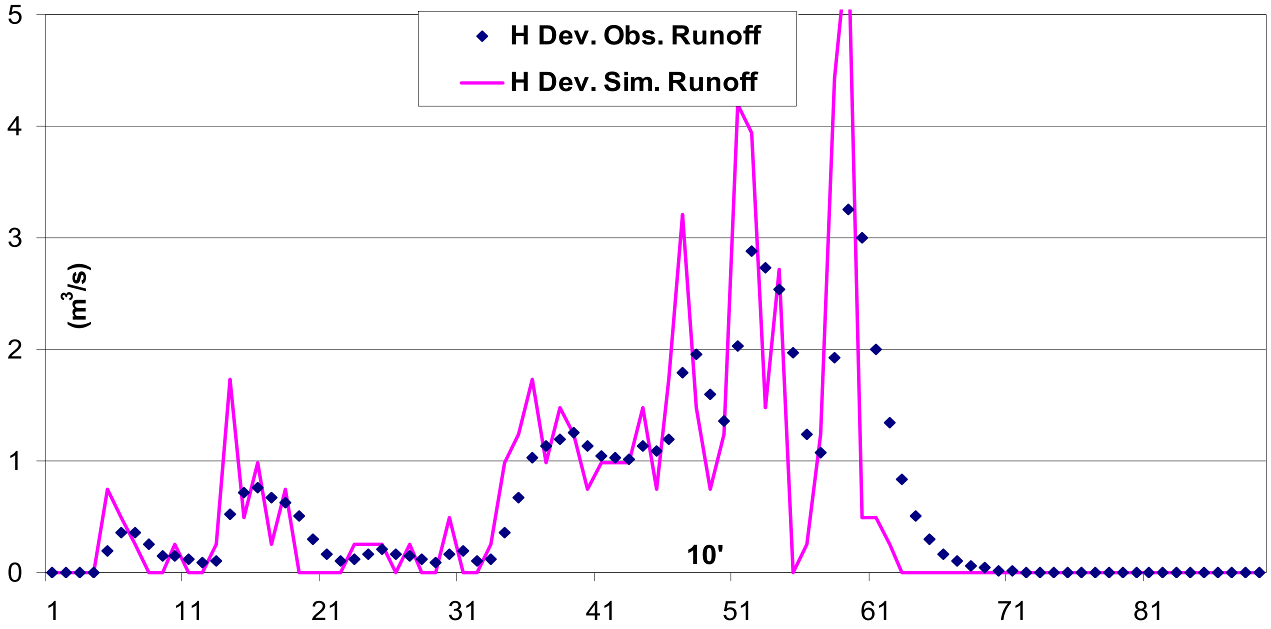
Rainfall data (10 minutes time step) were obtained from a meteorological station on the NTUA campus in Athens, Greece (NTUA, 2008). The time series length is 61 days starting from 1st of January 2003 and ending at 2nd of March 2003. Three sets of ‘observed’ time series of runoff were produced with the model ZYGOS (Zygos, 2008) using each time 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.



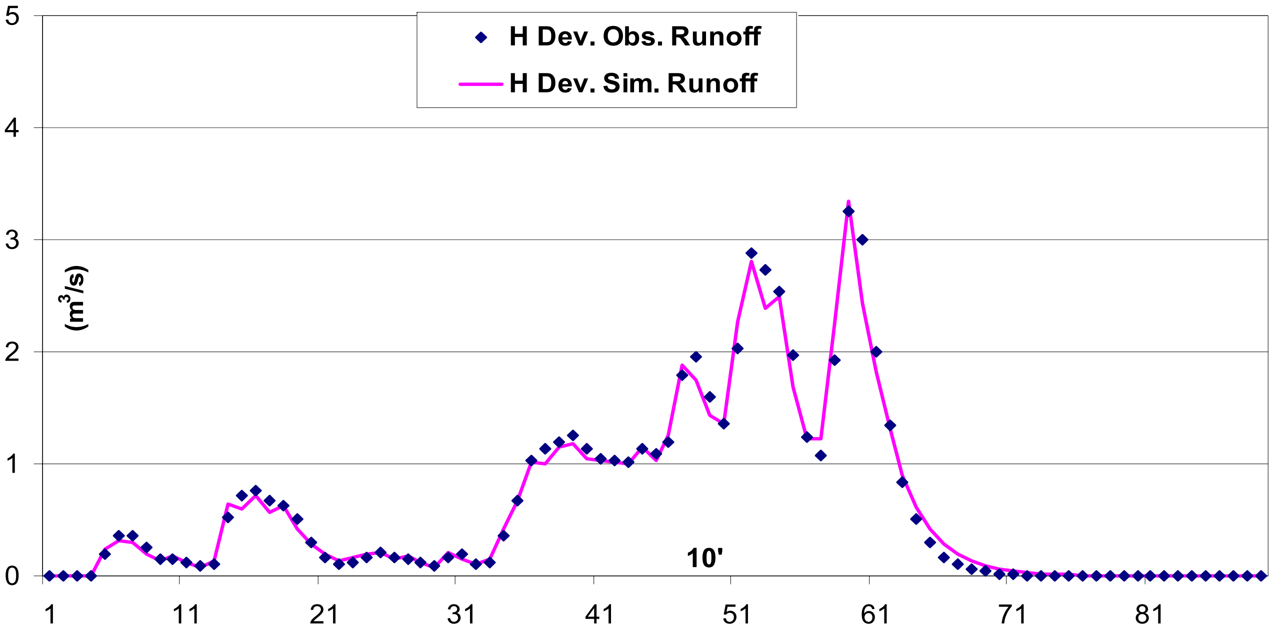
12. Calibration of the runoff module

UWOT is simulating the runoff generated in the development at each time step (caused by rainfall at both public and household impervious areas 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 of the virtual tank and recession coefficient of the orifice) were calibrated to fit the simulated runoff to the 'observed' runoff (produced with ZYGOS 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 25/1/2003 3:40:00 pm and ended at 26/1/2003 6:20:00 am.

13. Runoff module calibration - development H

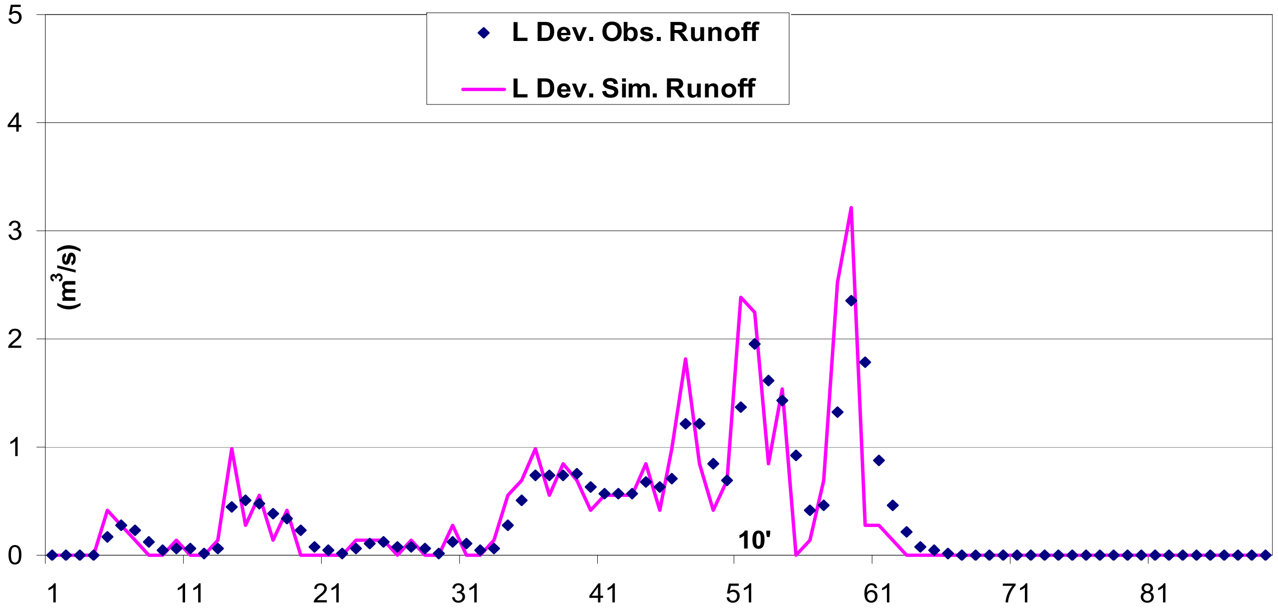


The simulated generation of runoff at the development H versus the 'observed' runoff at the output of the development H.

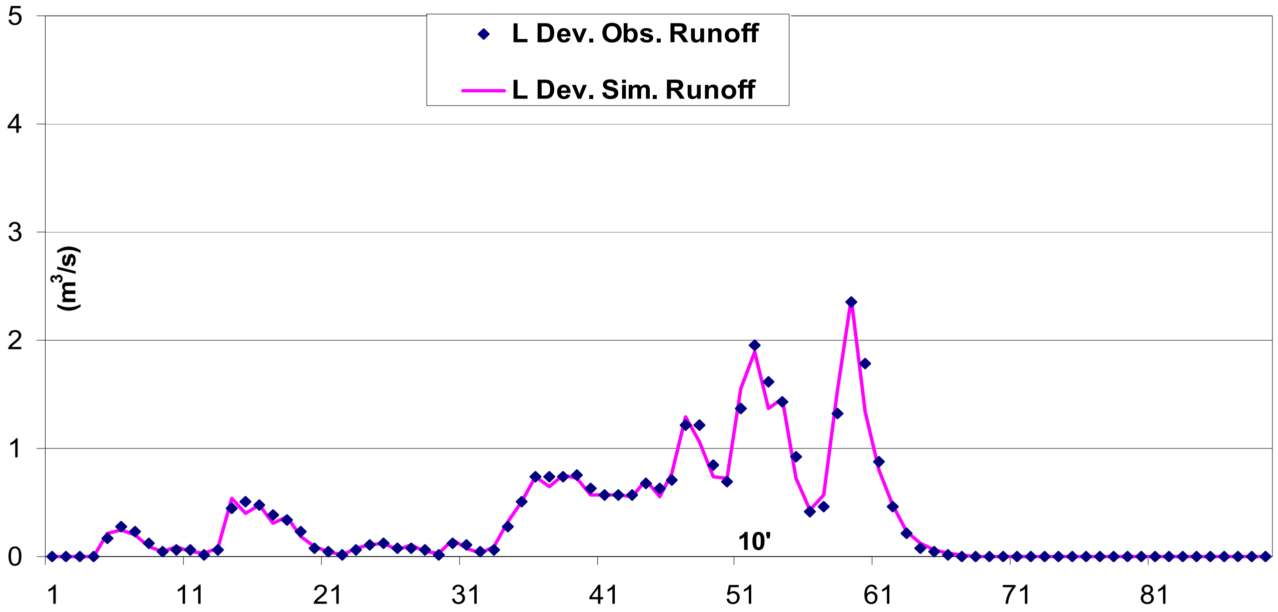


The simulated runoff at the output of the development H after the calibration of the runoff module (parameters *K*=7000 m^3 and μ =0.3) versus the 'observed' runoff at the output of the development H.

14. Runoff module calibration - development L



The simulated generation of runoff at the development L versus the 'observed' runoff at the output of the development L.



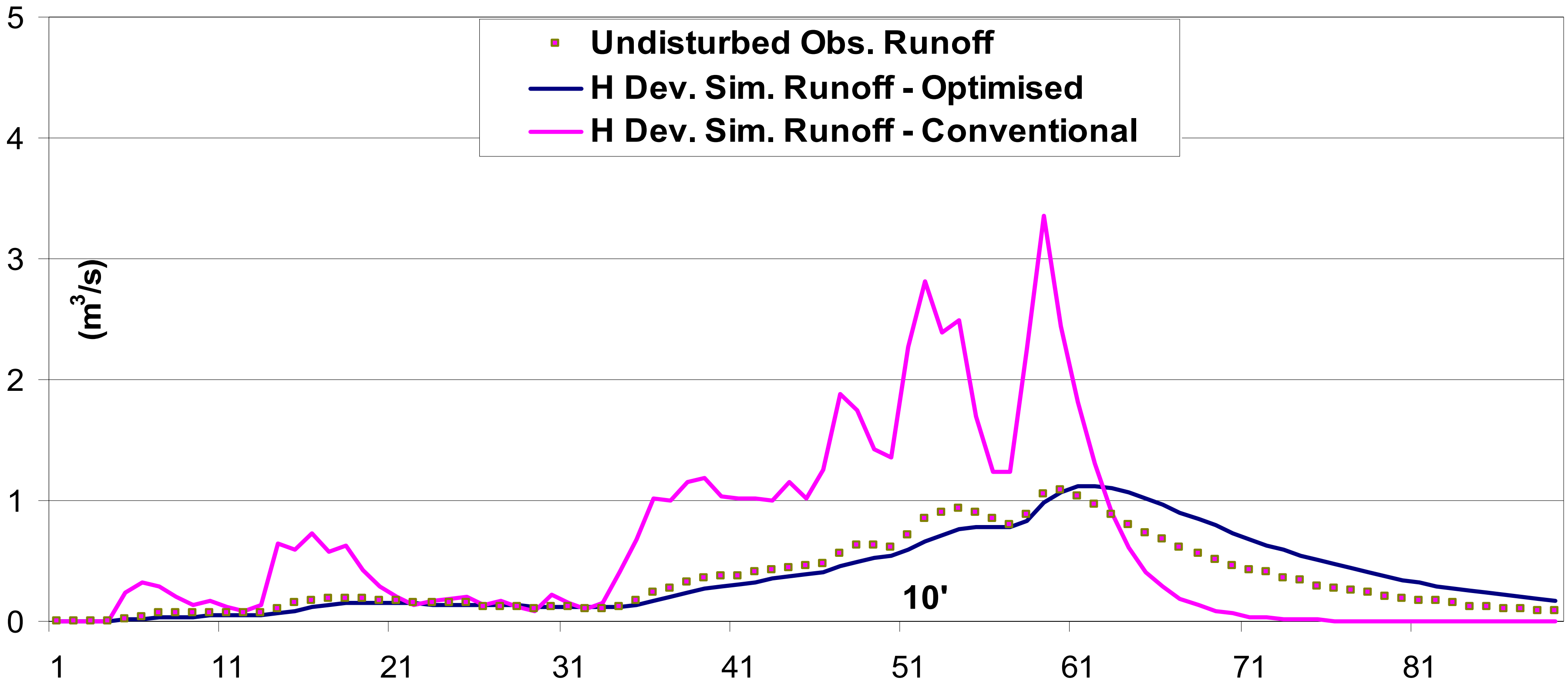
The simulated runoff at the output of the development L after the calibration of the runoff module (parameters K=3000 m^3 and μ =0.50) versus the 'observed' runoff at the output of the development L.

15. Water-cycle optimisation

The capacity of the households' green water tanks, the capacity of the SUDS and the central treatment were optimised to achieve simultaneously: a) rainfall-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.

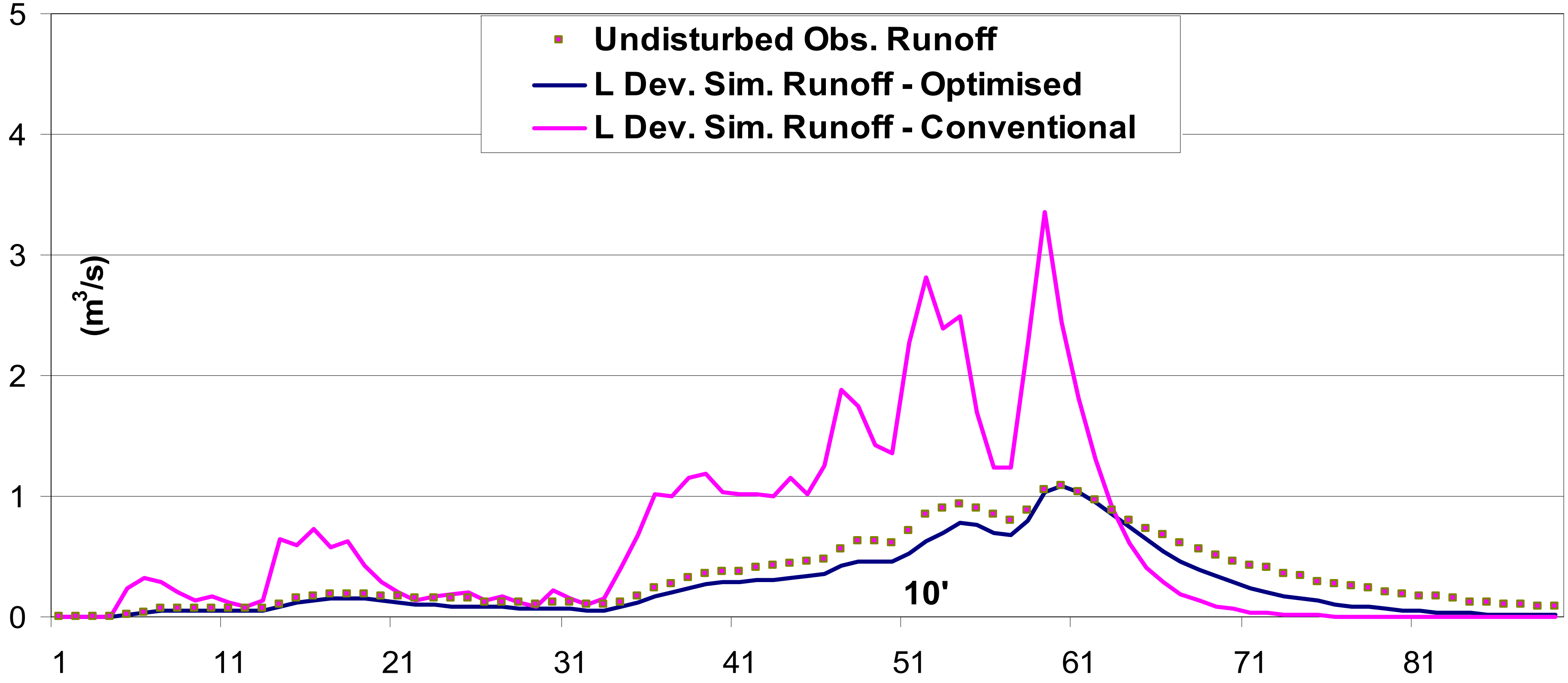
16. Optimisation results – development H

	Conventional development	Optimised development
Maximum runoff (m^3/s)	3.26	1.12
Potable water demand (m^3/d)	1116	834



17. Optimisation results – development L

	Conventional development	Optimised development
Maximum runoff (m^3/s)	2.38	1.09
Potable water demand (m^3/d)	563	413



18. Sensitivity analysis

An alternative type of toilet is assessed (‘dual valve flush’ instead of ‘conventional siphon’) 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 green water tanks’ capacity is investigated using the one-at-a-time method (Saltelli et al., 2000).

	Percentage increase of runoff (H)	**Percentage increase of runoff (L)**
Dual valve flush	58	31
Decrease 10% of local tank capacity	86	33
Decrease 10% of SUDS capacity	57	33

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 green water influences considerably the generated runoff.
- The sensitivity of the maximum runoff on the capacity of the local rainwater tanks and on the central SUDS increases with the urban density.
- The previous indicate the need for integrated modelling both for the design of new developments (along with optimisation algorithms) and for the investigation of the impacts of any planed modification to the urban-water cycle.

20. References

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