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A Generic Hydrological Model for a Green Roof Drainage Layer

Gianni Vesuviano & Virginia Stovin
The University of Sheffield

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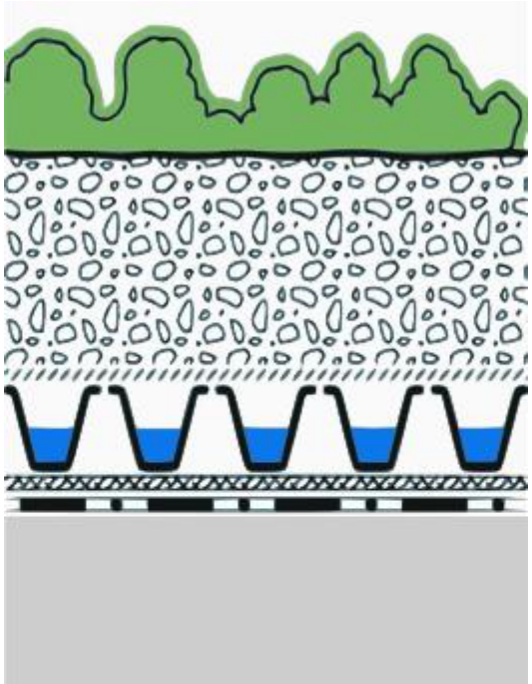
Background

Green roof system

- Vegetation cover, low-density substrate, particle filter, drainage layer, protection layer, all above roof's waterproofing
- Drainage layer may consist of large particles (e.g. gravel) but is more commonly synthetic (e.g. HDPE, expanded polystyrene)

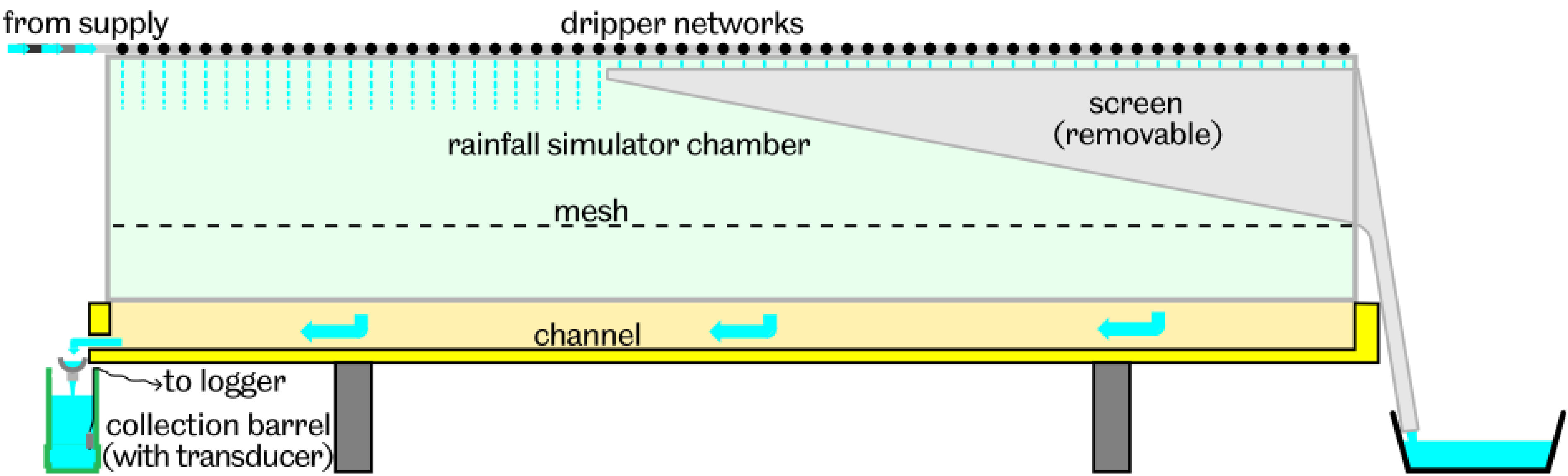


Green roofs

- Multiple benefits, including sustainable urban drainage – water quantity, water quality, amenity value
- Retention and detention of runoff, attenuation of peak flow
- Substrate and whole-system hydrological models already tested
- No hydrological model for non-granular green roof drainage layer

Experimental Setup

The rainfall simulator

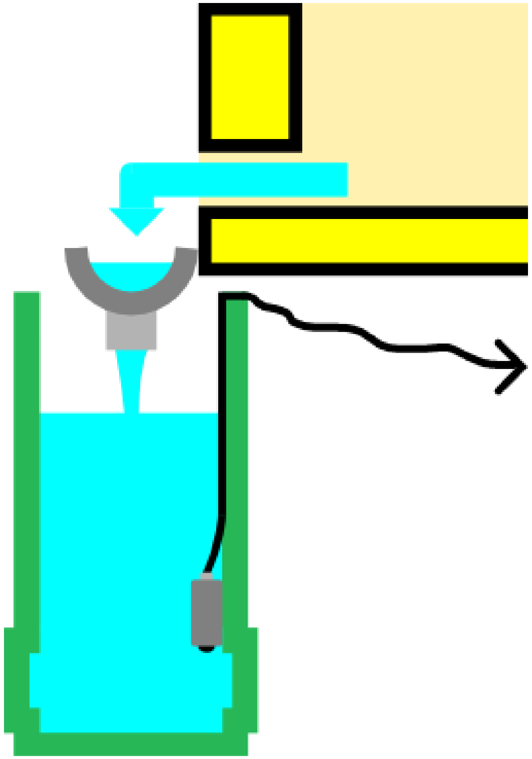


The rainfall simulator

- 5 metre length, 1 metre width, adjustable slope
- Pressure-compensating drippers in three networks
- Removable screen can “block” drippers effectively shortening length
- Controlled electromagnetic valves gate each dripper network

Monitoring equipment

- Runoff collected in cylinder with 50 litre maximum capacity
- Pressure transducer secured to side of cylinder
- Linear relationship between collected volume and recorded pressure
- Time resolution: 1 second
- Depth resolution: 0.0028 mm
- Campbell CR800 data logger



Test programme

- 5 component configurations – ZinCo Floradrain FD 25, Floradrain FD 40, Floraset FS 50, Floradrain FD 25 with Protection Mat SSM 45, bare channel (waterproofing material)
- 5 rainfall rates: approximately 0.1, 0.3, 0.6, 1.2 and 2.0 mm/minute
- 2 roof slopes: 1.15 and 10°
- 2 drainage lengths: 2 and 5 metres

Test programme

- $5 \times 5 \times 2 \times 2 = 100$ configurations
- Minimum 3 repeats per configuration
- All components filled at beginning of test – detention effects only

Modelling methods

- Average runoff response generated for each configuration, by taking mean value of runoff across repeat tests, at each time step
- Smoothed over centred 19-second moving average
- Non-linear storage routing:

$Q_{t+1} = kS_t^n$ $\quad\quad$ $S_t = S_{t-1} - Q_t + I_t$

Modelling methods

- A third parameter, *delay,* offsets rainfall record relative to runoff record, to account for time delays introduced by the monitoring setup
- *k* and *n* parameters optimized using *lsqcurvefit* routine in Matlab, for all *delay* values from 0 to 100 seconds
- Combination of *k*, *n* and *delay* with highest R^2 value stored

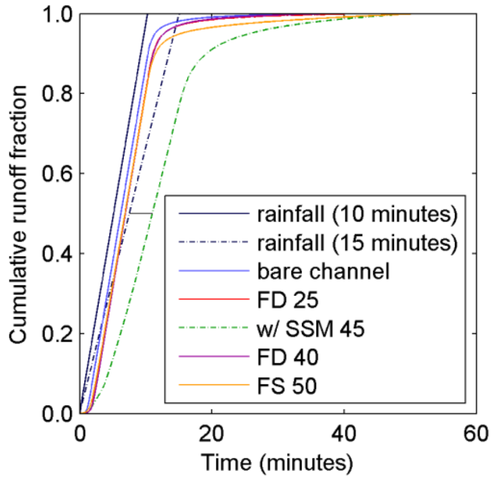
Statistical methods

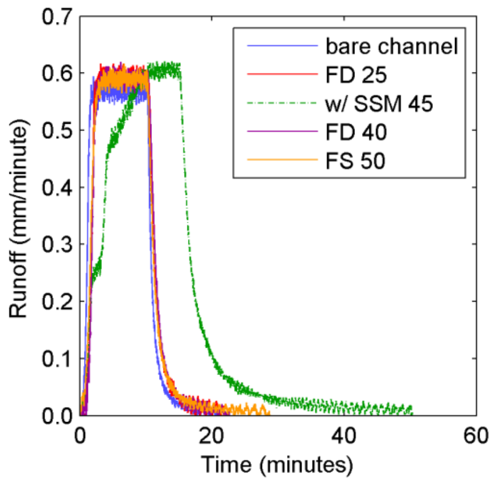
- *k*, *n* and *delay* grouped according to divisions within one test variable
- Welch's *t*-test/ANOVA used to assess whether the group means are different, at 0.05 significance level

Results and discussion

Data overview

- All test configurations found to be highly repeatable
- Mean t_{50} found to be 111 seconds, inversely related to inflow rate, lowest for bare channel, highest for FD 25/SSM 45 combination
- Runoff profiles for configurations with components (except SSM 45) not very different to runoff profiles for bare channel





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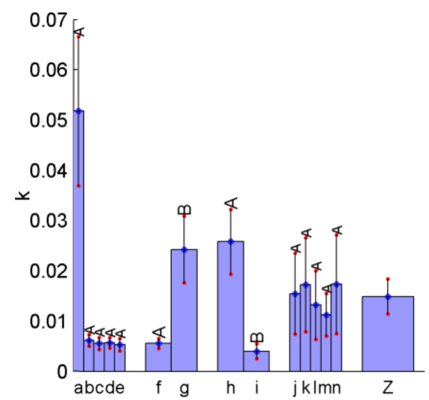
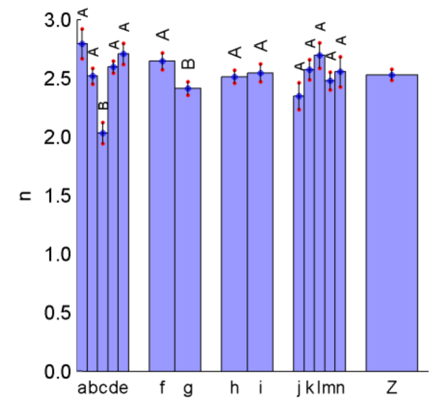
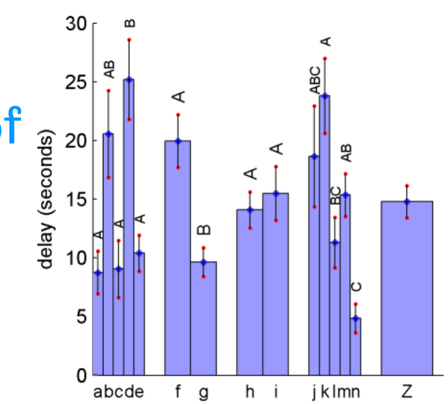
Modelling

- R_t^2 Mean: 0.9889

  Min: 0.8851 Max: 0.9991
- R_t^2 over 0.99 for 73 configurations
- *n* and *delay* independent of drainage length
- All parameters dependent on roof slope
- *k* and *n* independent of inflow intensity
- FD 25 and FD 40 always closely matched/in same statistical group







Key: symbol on x-axis represents all tested configurations using:

a	bare channel	(total 20)
b	FD 25	(total 20)
c	FD 25 with SSM 45	(total 20)
d	FD 40	(total 20)
e	FS 50	(total 20)
f	roof slope 1.15 degrees	(total 50)
g	roof slope 10 degrees	(total 50)
h	drainage length 2 m	(total 50)
i	drainage length 5 m	(total 50)
j	intensity 0.1 mm/minute	(total 20)
k	intensity 0.3 mm/minute	(total 20)
l	intensity 0.6 mm/minute	(total 20)
m	intensity 1.2 mm/minute	(total 20)
n	intensity 2.0 mm/minute	(total 20)
Z	all tested configurations	(total 100)

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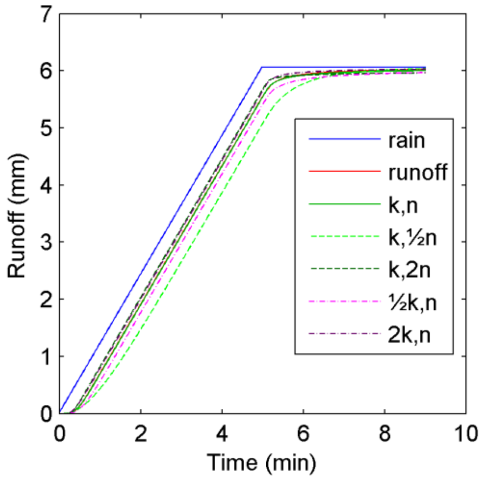
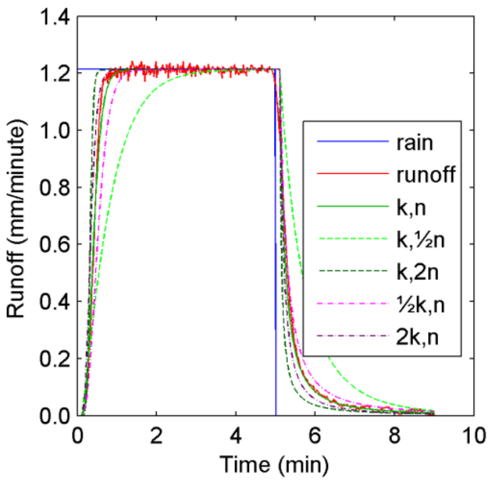
Parameter sensitivity analysis

- Bare channel, 10° slope, 5 m length, 1.2 mm/minute inflow
- $k = 1.59\times10^{-2}$, $n = 2.48$, $delay = 6$, $R_t^2 = 0.9989$
- Model run with values for *k*, *n* and *delay* given above, and with *k* and *n* individually doubled or halved (5 combinations of values for *k* and *n*)





Parameter sensitivity analysis

- Increasing value of either *k* or *n* increases gradient of rising and falling limbs
- Multiple optima a possibility
- May be feasible to fix *n* to one value and let *k* compensate

Conclusions

Conclusions

- Small time delay introduced by drainage layer
- Nonlinear storage routing successfully models time-series runoff response
- *k* and *n* parameter values independent of drainage length and potentially inflow rate
- Varying either *k* or *n* parameter has similar effect – potential to simplify model by holding one parameter constant