Experimental Analysis of Green Roof Substrate Detention Characteristics

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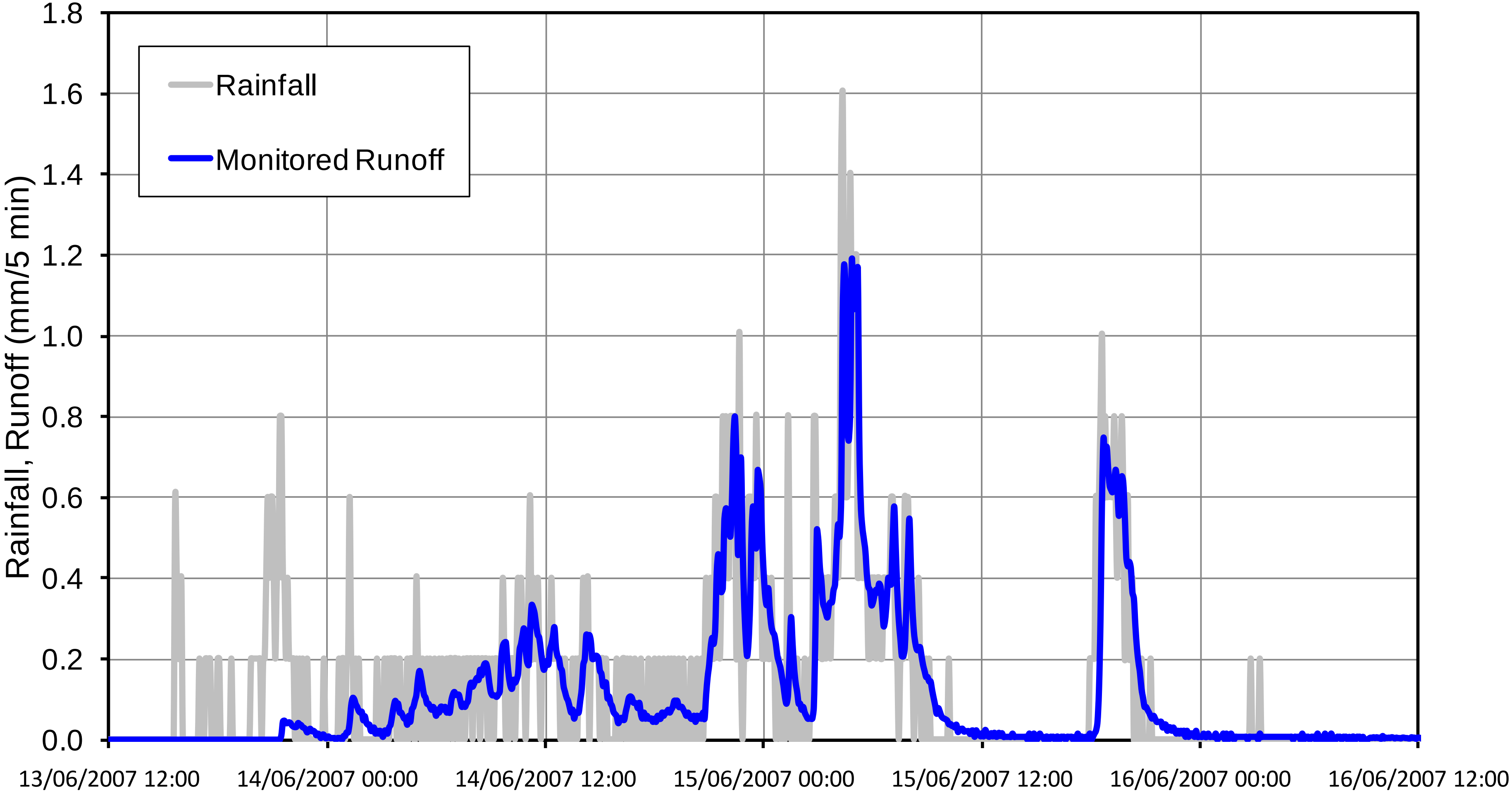
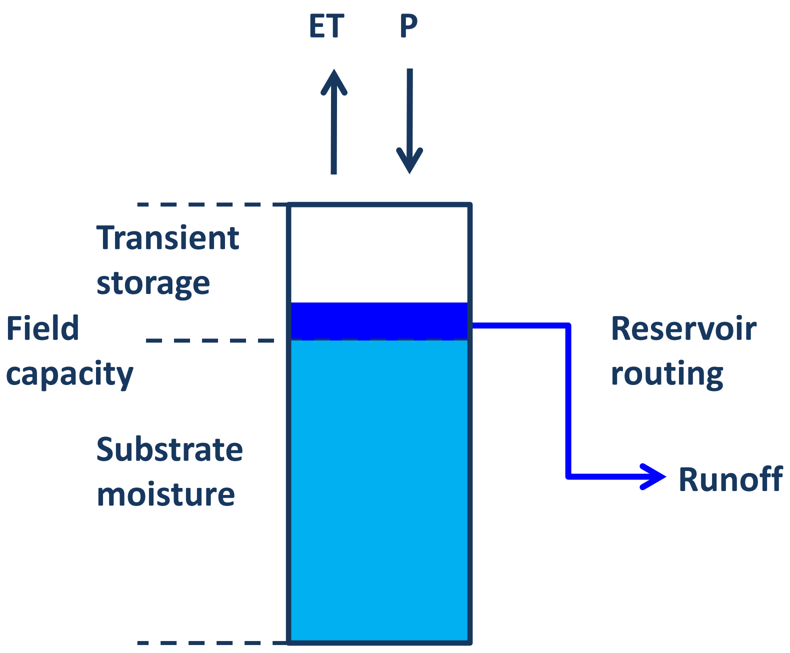
Rainfall-Runoff Performance Monitoring

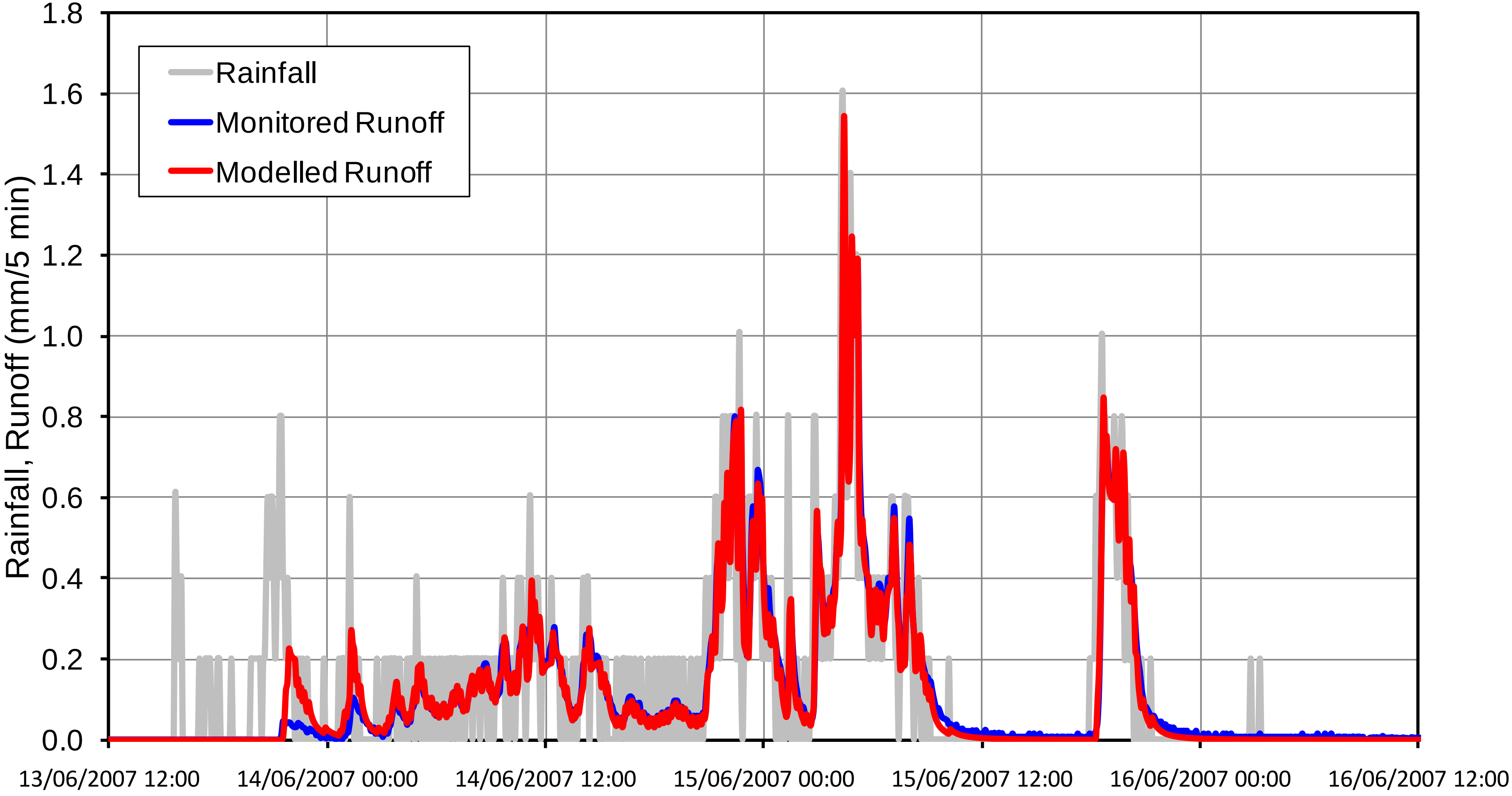


Conceptual Hydrological Model

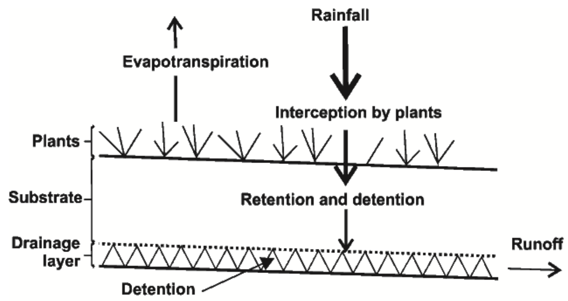


- Following a storm event, the substrate will drain under gravity to field capacity
- Evapotranspiration will remove moisture from the substrate
- Rainfall will be retained by the substrate up to field capacity
- Subsequent rainfall will be temporarily detained in the roof before becoming runoff

Model Calibration/Validation

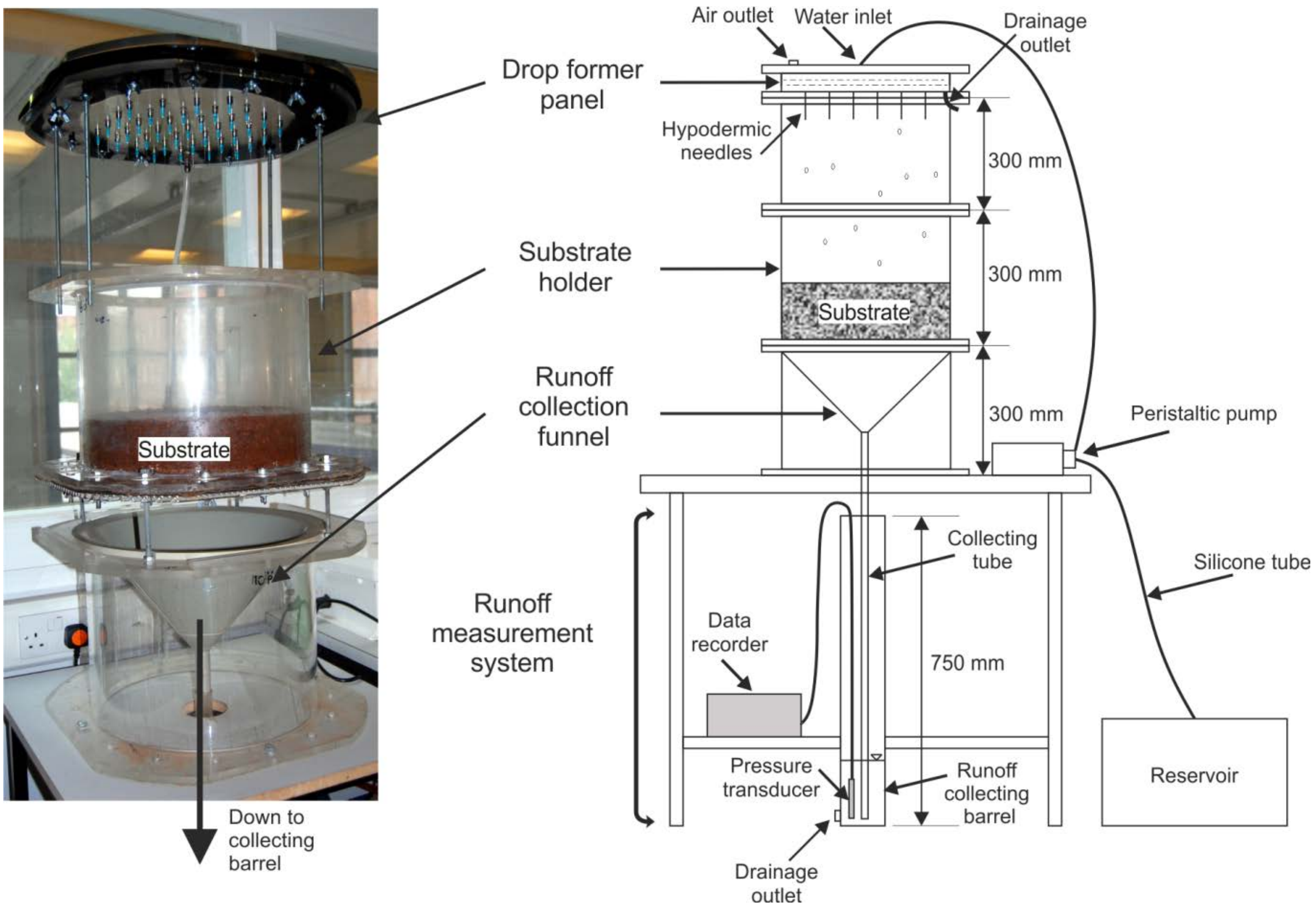


Green roof components



- For general applicability, need to
  - Separate out detention effects due to plants, substrate and drainage layer
  - Identify model parameters for different substrates and drainage layer components
  - Relate model parameters to measurable physical characteristics
  - Detention depends on:
    - Substrate permeabilty and depth
    - Drainage layer configuration, roof size and slope
- EU Marie-Curie Industry-Academia Partnerships and Pathways (IAPP) 'Green Roof Systems' collaboration between the University of Sheffield and ZinCo (Germany).

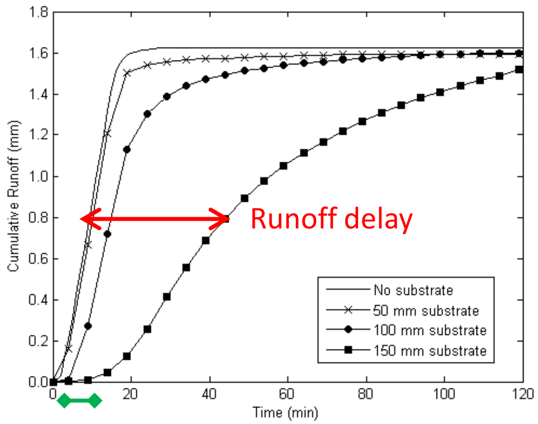
Laboratory apparatus



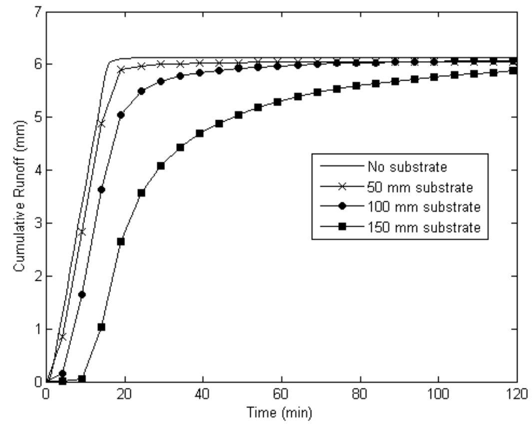
Test Configurations

- Effect of substrate depth on detention:
  - 50, 100 & 150 mm
  - Marie Curie Substrate (MCS): 55% crushed brick; 30% pumice; 10% coir & 5% compost (by volume)
- Effect of organic matter on detention:
  - Mineral substrate (crushed brick & pumice) + Coir [0, 5, 15%]
  - Mineral substrate + composted bark [0, 5, 15%]
- Two rainfall intensities (based on 60-minute events for Sheffield):
  - 1 yr return period – 5.92 mm [0.10 mm/min]
  - 10 yr return period – 21.94 mm [0.37 mm/min]
- 15-minute constant intensity rainfall events

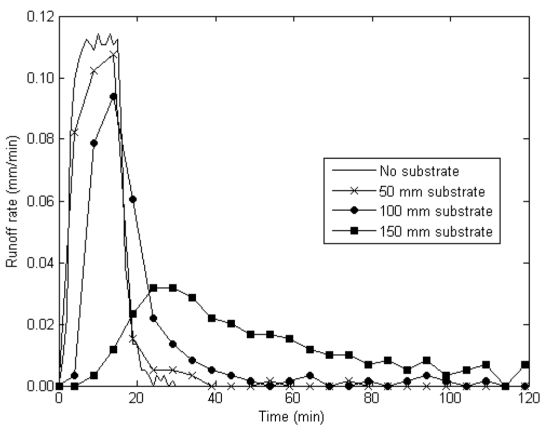
Results



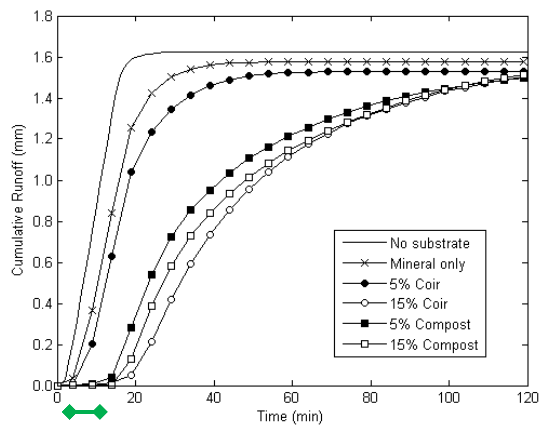
a) Effect of substrate depth,
i = 0.10 mm/min



b) Effect of substrate depth,
i = 0.37 mm/min



c) Effect of substrate depth,
i = 0.10 mm/min



d) Effect of organic matter content,
i = 0.10 mm/min

- Recorded runoff compared to runoff from system without substrate
- Detention times increase with substrate depth, though this is not linear
- Detention times decrease at higher rainfall intensity
- Highest Runoff delay of 33 minutes
- Deeper substrates appear to provide significant attenuation (peak reduction), but only because tests did not reach equilibrium
- Delays to start of runoff of up to 10 mins for deepest substrate and highest organic content

Model Structure

- $h_t = h_{t-1} + Qin_t \Delta t – Qout_t \Delta t$

  Qin = flow rate into substrate layer (mm/min)

  Qout = flow rate out of the substrate layer (mm/min)

  h = depth of water stored within the substrate (mm)

  Δt = discretisation time step (which in this case was one minute)

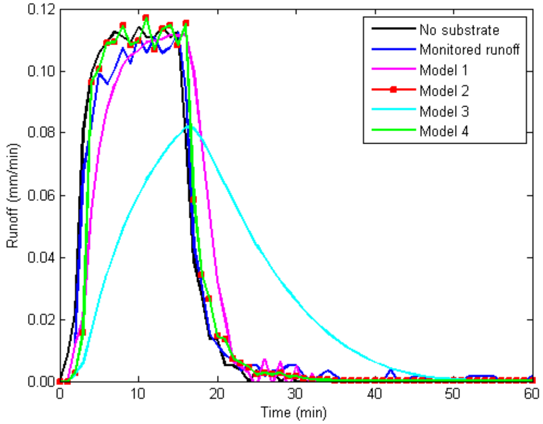
- $Qout_t$ is given by: $Qout_t = kh_{t-1}^{n}$

- The *lsqcurvefit* function in MATLAB (2007) was utilised to identify the best-fit parameter values (k & n), based on the monitored runoff data

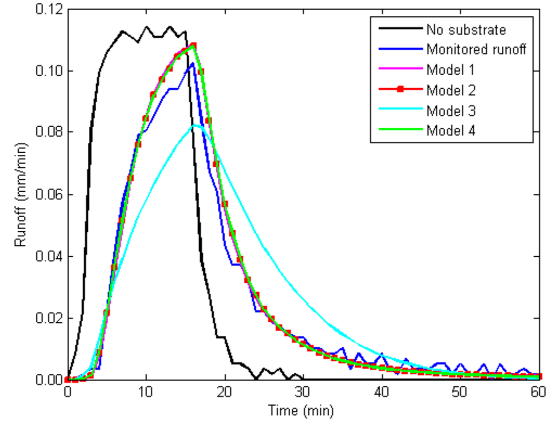
Parameter Identification

- Model 1 – k and n both determined by optimisation for each specific configuration
- Models 2 and 3 – n and k respectively were fixed at a typical value in an attempt to evaluate whether it might be feasible to reduce the required number of model parameters to one
- The reservoir routing model inherently generates runoff immediately rainfall commences. However, significant time delays were observed in the laboratory for some of the tested configurations
- Model 4 – n was fixed at 1.5; k and Delay (in minutes) were estimated via optimisation

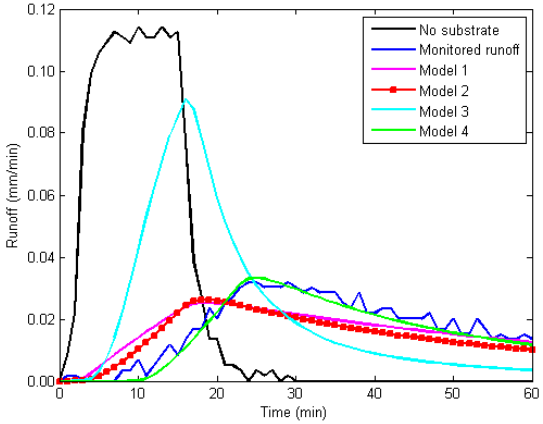
Model Evaluation



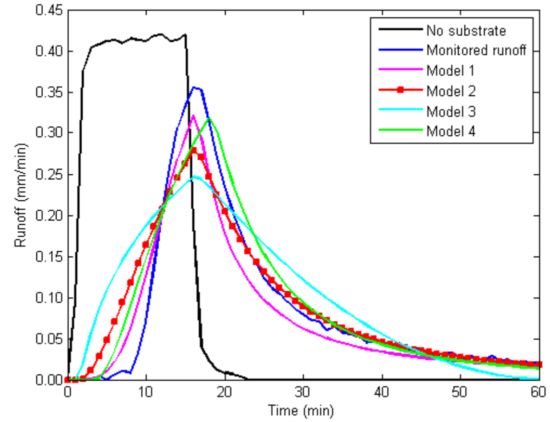
a) *i* = 0.10 mm/min, 50 mm substrate



b) *i* = 0.10 mm/min, 100 mm substrate



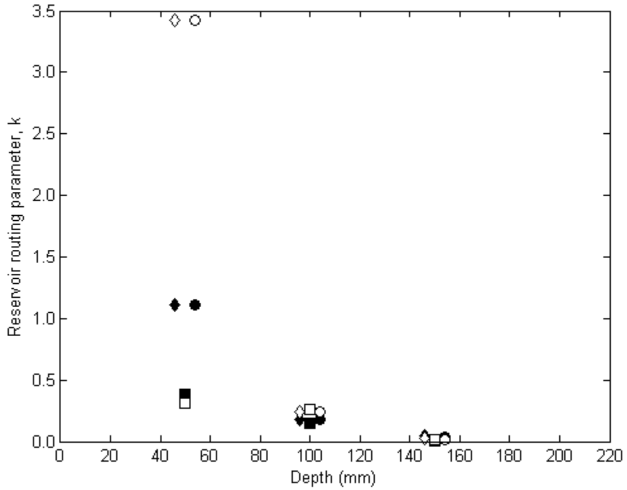
c) *i* = 0.10 mm/min, 150 mm substrate



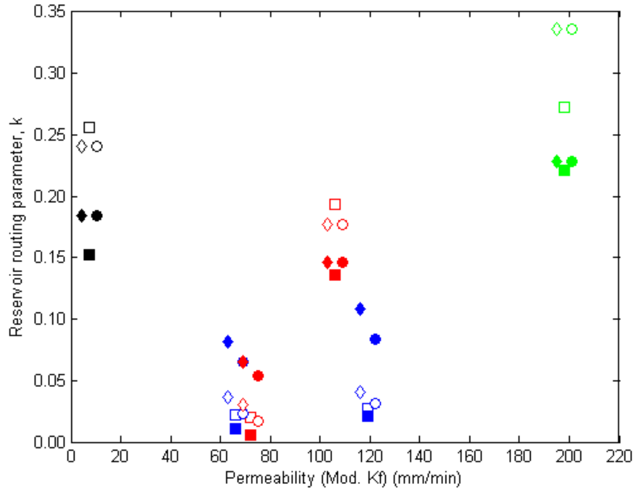
d) *i* = 0.37 mm/min, 150 mm substrate

- Model 3 (fixed *k*) performs consistently badly
- Model 2 (fixed n) genrally reasonable
- Model 4 (fixed n, optimised k and Delay) generally performs best, and especially when there is a delay to start of runoff
- Model 4 – mean R_t^2 of 0.97

Parameter identification



a) Depth variation tests



b) Organic content variation tests

- Substrate mix is indicated by colour: black – MCS; green – MS; red – MS+coir; blue – MS+composted bark.
- Rainfall intensity is indicated by fill: solid filled symbols – 0.37 mm/min; open symbols 0.10 mm/min.
- Model number is indicated by symbol: square – Model 1; circle – Model 2; diamond – Model 4.
- k values appear to be related to depth and permeability, but also affected by composition
- Routing coefficient relatively insensitive to rainfall intensity
- Potential to identify detention parameters from measurable physical properties, independent of storm event characteristics

Conclusions

- New laboratory rainfall simulator & data on substrate detention
- Detention in green roof substrates increases as a function of depth and organic matter content.
- The most suitable model structure to represent the substrate layer appears to comprise an initial delay plus a one-parameter reservoir routing model.
- Reservoir routing parameters are largely independent of rainfall intensity, and it appears feasible to predict them from known physical characteristics of the substrate, specifically its depth and permeability.