Quantifying the Magnitude and Quality of Green Roof Runoff

Patricia Culligan
Professor of Civil Engineering & Engineering Mechanics

Columbia University, New York
Contributors

Dr. Wade Mcgillis (LDEO)
Dr. Stuart Gaffin (CCSR)
  Tyler Carson
  Andrea Conte
  Robert Elliot
  Nadine Els
  Marco Finazzi
  Rebecca Gibson
  Raha Hakimdavar
  Diana Hsueh
  Daniel Marasco
Green Roof Site Locations

CU 118 Residence
Xeroflor 1- 2” Matt System
3,200 sf

CU 115 Environmental Stewardship
Xeroflor 1 - 2” Matt System
650 sf

ConEdison Learning Center
Modular 4” Tray System
10,000 sf

Bronx Design & Construction Academy
Modular 4” Tray System
1,200 sf

USPS Morgan General Mail Facility
Complete 4 - 6” System
108,900 sf

Regis High School
Complete 4-6” System
20,000 sf

Ethical Cultural Fieldston School
Complete 4 - 6” System
5,100 sf
Current Investigations

Basic Atmospheric Parameters
• Autonomous Monitoring
• Wind Speed & Direction, Relative Humidity, Temperature, Pressure, Rainfall, Incoming Solar Radiation

Rainfall-Runoff Comparisons
• Quantity - Stormwater Retention & Detention
  • Autonomous Monitoring
    – Tipping Buckets
    – Custom-Built In-Drain Weirs
• Quality
  • Spot Sampling During Rain Events
  • Developing Autonomous Monitoring
    – pH, Conductivity, True & Apparent Color, Chemical Composition
Typical Rooftop Setup

Rain Gauge
Runoff Weir
Soil Moisture Gauges

Optional:
- Evapotranspiration
- Automatic water sampler

(Most data accessible through internet)
Roof Runoff Weirs: External Drainage Pipe
Roof Runoff Weirs: Internal Drainage Pipe
Example Calibration Curve

\[ y = 1358.5x^3 - 13133x^2 - 43892x + 50681 \]

\[ R^2 = 0.9901 \]
Magnitude of Runoff
Precipitation vs Runoff (mm/min): 118

10-Aug-09

Flow Rate, mm/min

Rain, mm/min
GR, mm/min
CR, mm/min

0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45

8/11/13 0:00
8/11/13 1:12
8/11/13 2:24
8/11/13 3:36
8/11/13 4:48
8/11/13 6:00
Cumulative Runoff (mm): 118
Example Summary Plot: 118
Result Summary: 118 Peak Runoff
Initial Analysis of Three Roof Systems

- **Pre-Vegetated Mat**
  - Owner: Columbia University
  - Roof Type: Pre-Vegetated Mat
  - Plant Type: Sedum Mix
  - Media Depth: 65 mm
  - Monitored Area: 300 m²
  - Percent Vegetated: 82%
  - Cost: $150/m²

- **Modular Tray**
  - Owner: ConEdison
  - Roof Type: Modular Tray
  - Plant Type: Sedum Mix
  - Media Depth: 100 mm
  - Monitored Area: 900 m²
  - Percent Vegetated: 80%
  - Cost: $175/m²

- **Naturally Landscaped**
  - Owner: U.S. Postal Service
  - Roof Type: Naturally Landscaped
  - Plant Type: Natives & Sedum Mix
  - Media Depth: 140 mm
  - Monitored Area: 500 m²
  - Percent Vegetated: 75%
  - Cost: $320/m²
Runoff vs Precipitation
Estimated average attenuation over 25 years.
Results Summary

• Empirical model of green roof performance based on observations of runoff retention rates

• Model indicates 40 – 70% runoff retention per unit area per annum for different extensive roof systems in New York City, based on 25 years of historic rainfall data

• Need to refine the analyses based on antecedent moisture conditions

• Significant reduction in peak runoff – needs further study
Quality of Runoff
Control and Green Roof Runoff higher than Rain pH
Conductivity (µS/cm)

Green Roof Runoff Has higher conductivity than Control Roof and rain
Some indication of higher turbidity in green roof runoff
True color of green roof runoff higher than control roof runoff and rain.
Nitrate lower than control roof runoff and rain for the older systems
Ammonium in runoff from green roofs lower than control roof runoff and rain
Calcium runoff from green roofs higher than control roof runoff and rain
Potassium in runoff from green roofs higher than control roof runoff and rain
Magnesium in runoff from green roofs higher than control roof runoff and rain
Phosphorus (ppm)

Green Roof

Phosphorous in runoff from green roofs higher than control roof runoff and rain
Sodium in runoff from green roofs is higher than in control roof runoff and rain.
Results Summary

• Green roofs mitigate acid rain and decrease ammonium, and in some cases, nitrate effluence in comparison to control roofs

• Green roofs increase calcium, potassium, magnesium, phosphorous and sodium effluence

• No discernable difference between heavy metal concentrations measured in rain or runoff from green roofs and control roofs

• Role of growing medium composition, age and runoff quality needs further investigation
Small-Scale Test Boxes

Role in Measurement and Design?
Comparison of Small- & Full-Scale System: Cumulative

![Graph comparing total runoff per unit area to total precipitation for Full Scale, Small-Scale Prototype, and Precipitation. The x-axis represents total precipitation in mm (0.71, 0.81, 1.22, 1.50, 3.73, 3.76, 5.52, 7.20, 7.90), and the y-axis represents total runoff per unit area in mm (0-8). The graph shows the comparison between Full Scale, Small-Scale Prototype, and Precipitation for different levels of precipitation. The Full Scale has the highest runoff for most precipitation levels, followed by Small-Scale Prototype, and Precipitation has the least.]
Comparison of Small- & Full-Scale System: Peak Flow
Comparison of Small- & Full-Scale System: Time of Peak
Results Summary

• Small-scale model under-estimated cumulative volume reduction for storms >5mm
• Small-scale models under-estimated peak intensity reduction
• Time of Concentration similar between small- and full-scale green roof