METER
ENVIRONMENT

GREEN ROOFS—DO THEY WORK?

Green roofs are being built in large cities to provide stormwater management, reduce the urban heat island effect, and improve air quality—but are they effective? John Buck, an innovative soil scientist based in Pittsburgh, Pennsylvania, has been trying to quantitatively answer this question in many different cities using soil monitoring equipment in order to determine the efficacy and best types of green infrastructure for managing stormwater.

WHY GREEN ROOFS?

In older cities, stormwater runoff is typically combined with sewage flows, and these combined waters are treated at a sewage treatment plant during dry weather and light rain events. Unfortunately, during more substantial storms (sometimes just a few mm of rain) the combined flows exceed the ability of the sewage treatment plant, and are discharged without treatment to surface waters as "combined sewage overflows" (CSOs). One of the ways to mitigate CSOs is to capture and store stormwater to keep it out of the combined sewer.

A green roof is essentially a garden on a roof, but rather than growing plants in soil, installers use a synthetic substrate made of expanded shale, expanded clay, crushed brick, or other highly porous, lightweight material with high infiltration rates. During a storm event, water will soak into the air-filled pore space in the substrate, which acts like a sponge to soak up the rain. Excess water will flow into a subsurface drainage layer and will leave the roof garden via existing roof drains. Because a substantial fraction of the stormwater is stored in the substrate, it can later dissipate through evapotranspiration instead of contributing to stormwater volume and CSOs.

FINDING ANSWERS

Designers and regulators want to know how well green roofs work and if they are being over-engineered. They want answers to questions such as: "What sort of substrate should I be using? What type of plants can survive green roof conditions?

Will I need to irrigate the green roof when there are no storms to water the plants?" and, "Will the green roof work as well during a one-inch storm that occurs over a half hour versus a five-inch storm that occurs over five days?"

ZL6 data logger

Buck is using soil lysimeters and modified tipping bucket rain gauges to measure the quantity, intensity, and quality of water coming into and going out of the green roofs. He also tracks weather parameters and calculates daily evapotranspiration of landscapes. Using METER soil sensors, he measures electrical conductivity (dissolved salts), volumetric water content, and temperature. He has installed METER data loggers that send data to the web via GSM cellular connection, allowing stakeholders access to the data in real-time. This data telemetry provides additional data security, immediately updated results, instant feedback of system problems, and an easy way to share data with others.

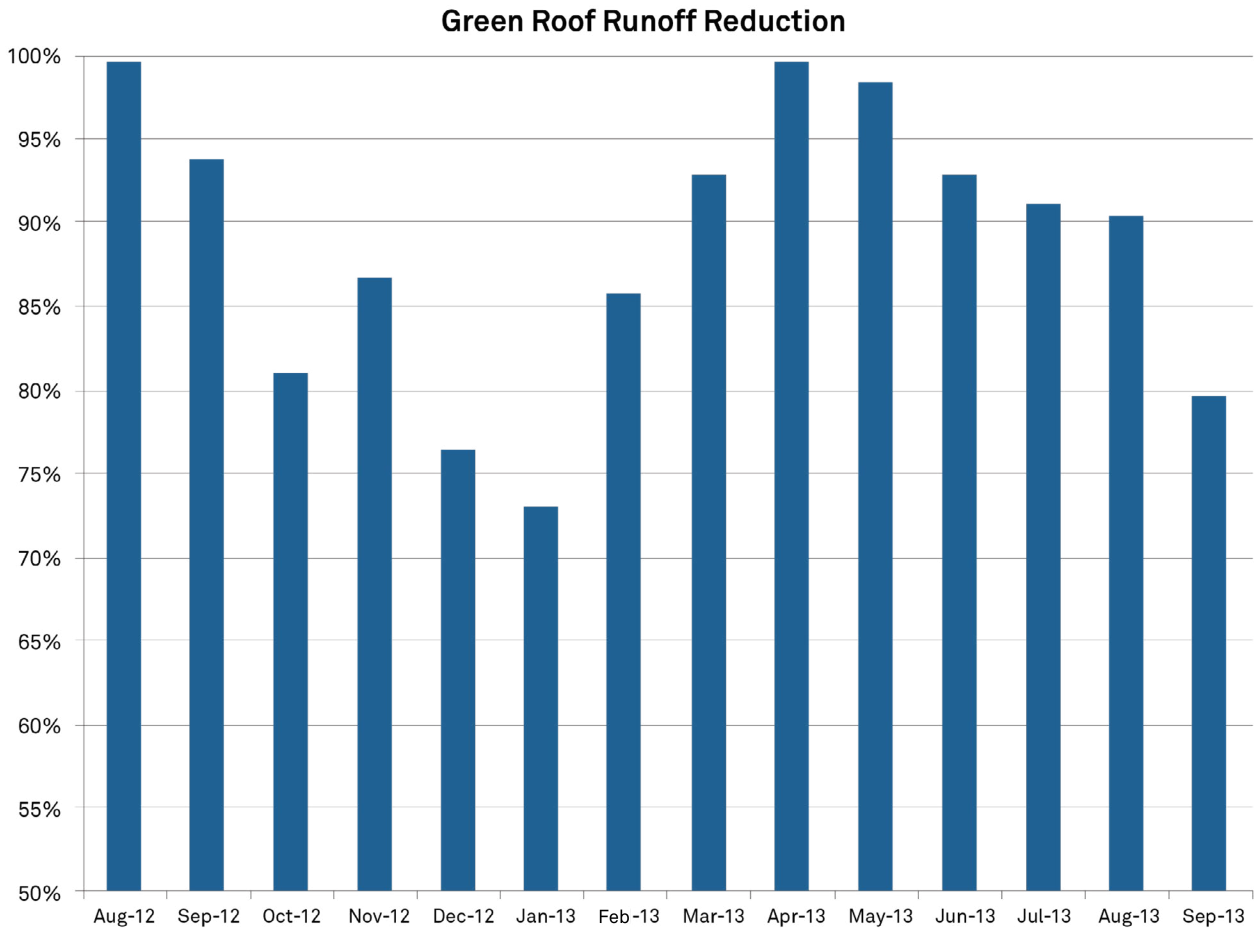

Figure 1. Visualized data of the 87% annualized runoff reduction at Phipps Conservatory green roof site in Pittsburgh, PA

WHAT HAS BEEN LEARNED?

Buck discovered that green roofs have much more capacity than people ever imagined. At The Penfield Apartments in St. Paul, Minnesota, the green roof retained enough water to reduce runoff to about half of a conventional roof, and the peak intensity of the runoff was about one-quarter of what it would have been without the green roof. At Phipps Conservatory in Pittsburgh, there was an 87% annualized runoff reduction and almost no runoff from typical summer rain events. Buck comments, "Interestingly, on the Penfield project, we expected better hydrologic performance where soils were thicker, but there was no difference, or results were slightly the reverse of expectations. That reversal was likely due to the confounding influence of irrigation, which was probably non-uniform and not metered or measured by the rain gauge."

NEW CHALLENGES FOR GREEN ROOFS

Green roof results are promising, but they present a new challenge: making sure the plants have enough water. The crux of the challenge is that the lightweight, expanded shale/clay substrate material, the standard in green roof design, does a good job of soaking up the water, but has some peculiar properties that are unlike typical soils. Specifically, the expanded shale and expanded clay media tend to be dominated by sand and fine gravel-sized particles that provide a high proportion of macropores, but the interior porosity of the large particles is dominated with micropores. That pore size distribution leads researchers to two important questions— How much water will be readily available for plant growth? And, will the unsaturated hydraulic conductivity be adequate to avoid starving the roots under high-evaporative demand by allowing water to flow to roots from the bulk soil? These are critical questions as green roof technologies continue to evolve.

MEASUREMENTS REQUIRED FOR GREEN ROOF VALIDATION

Still, Buck has learned a great deal from his work. Considering the wild spatial distribution of summer storms, quantitative green roof performance studies require that rainfall be measured locally. Monitoring of soil moisture content measurements in concert with rainfall and soil lysimeter measurements of drainage, reveal the degree of total and capillary saturation, drainage rate, and porosity available for storage. METER soil water potential sensors, placed within the capillary fringe of water ponded over subsurface drainage layers, can provide useful insights regarding the dryness of the drainage layer and overlying soil, as well as the available storage of stormwater within the drainage layer.

TEROS 21 water potential sensor

Direct measurement of soil drainage using lysimeters is a key supplemental measurement on green roof performance quantification projects because there is an unmeasured component of water storage where drought-resistant alpine succulents (typically *Sedum* species) are used on green roofs. The *Sedum* plants can absorb up to 10 mm of rainfall equivalent in their plant tissues.

OTHER PROJECTS AND FUTURE PLANS

At ground level, Buck is quantifying the performance of intensive stormwater infiltration areas known as rain gardens, bioretention areas, or more generically, infiltration-based stormwater best management practices (Infiltration-based BMPs). When monitoring infiltration-based stormwater BMPs, Buck has used similar tools to those used on green roofs, but has added water-level sensors and piezometers. Buck has found that ancillary measurements of electrical conductivity, often available on water content sensors, along with surface and pore water sampling, can be used to document transformations taking place in infiltration systems. These measurements now combine to show that green roofs and infiltration-based BMPs are indeed making a difference to urban environments and contributions to CSOs. The challenge now is how to implement this technology more widely. But, with the validation now in hand, that job should be quite a bit easier.

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