Sensor networks for real-time green infrastructure monitoring

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Highlights

- We introduce a wireless sensor network to measure green infrastructure (GI) performance.
- The sensor measures real-time infiltration at 21 GI sites in Detroit, Michigan, US.

Introduction

Green infrastructure (GI), including bioretention cells and rain gardens, has been widely adopted by cities around the world. GI is the use of natural processes to filter, capture, and store stormwater at its source (William et al. 2020). Although we currently operate under the hypothesis that site-scale GI practices will positively affect cumulative system-scale flow regimes and water quality, system-scale impacts remain uncertain (Golden and Hoghooghi, 2018). While some research has modelled the system-level impact of GI (Avellaneda et al. 2017), to our knowledge, large-scale and long-term in-site measurement campaigns are rare.

Using the Open-Storm technology platform (Bartos et al. 2018), this paper introduces a novel, quick-to-install, wireless sensor node to measure real-time stormwater capture in GI. A network of 21 of these sensor nodes has been deployed in Detroit, Michigan, US; part of a pilot study to identify system-level effects of rain gardens in proximity to each other. To our knowledge, this sensor network is one of the largest of its kind to measure stormwater capture data at this spatial and temporal resolution.

Methodology

Sensor design

At the core of our sensor network is a $1500 USD, wireless sensor node which measures real-time water depths in rain gardens (Figure 1a). The form factor of the sensor is similar to a water well. A 1.5 m long, slotted PVC pipe is buried a meter deep into the soil. At the top of the pipe, a solar panel, microcontroller, cellular modem, and battery pack are mounted. At the bottom of the pipe, a pressure transducer (Stevens SDX 93720-110) measures the water depth by sensing pressure. Installation of the sensor node requires digging a meter deep hole, placing the sensor in the hole, and backfilling soil around the sensor. Altogether, this process takes less than 30 minutes (Figure 1b-d). The sensor takes readings once every ten minutes and reports data back to a cloud hosted web server once every hour.

The sensor measures water depth using a pressure transducer, which converts a barometric reading to a 4-20 milliampere (mA) output. When it rains, the water level above the pressure transducer rises, and after the storm has passed, the water level recedes. The rate at which water enters (i.e., infiltration) and exits (i.e., exfiltration and evapotranspiration) the GI can be estimated by measuring the change in water depth (dh/dt). Infiltration corresponds to a positive derivative, whereas exfiltration and evapotranspiration correspond to a negative derivative. Another useful metric is stormwater runoff captured by GI. The depth measurement can be converted into an estimation of water runoff (Q) captured by the garden by multiplying the rate of change of depth by the area of the garden (A): $Q = \frac{dh}{dt}A$.

(a) (b) (c) (d)


Figure 1. The sensor node before installation (a). Installation requires digging a 7.6 cm wide by 1 m deep hole (b), placing the sensor node in the hole (c), and backfilling the soil around the sensor node (d).

Sensor network

A network of 21 sensors was installed in June 2021 and spans 420 km^2 of the city (Figure 2). The GI sites range from 9.30 m^2 to 261 m^2 in surface area, 24.5 m^2 to 3110 m^2 in drainage area, and 0.95 m^3 to 23.3 m^3 in storage volume. Sites were selected such that the network includes rain gardens of varying size (i.e., surface area, drainage area, and storage volume), installation year, soil type, position in the watershed (both upstream and downstream), and surrounding land use type (i.e., residential, commercial, and recreational). Sites were also selected to include several spatial clusters of rain gardens to maximize the potential of observing inter-network effects.

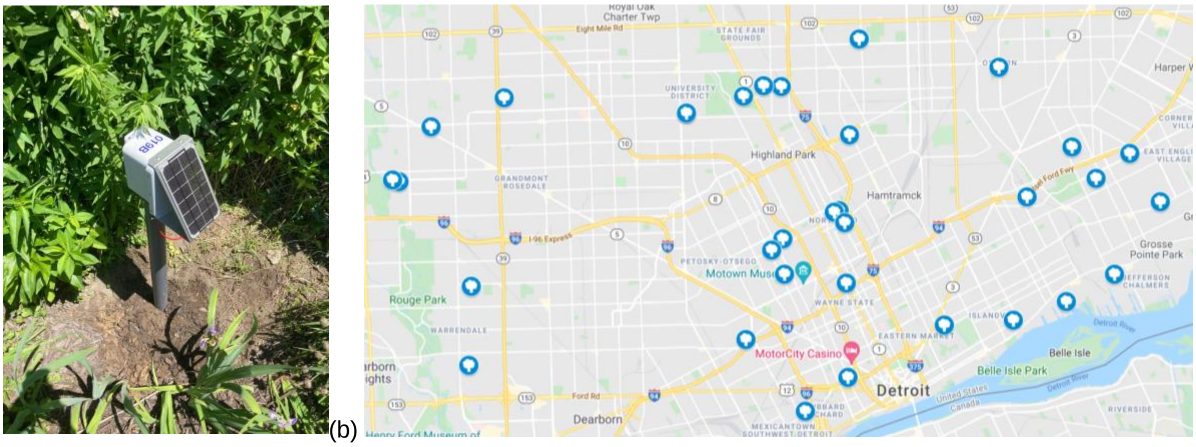
(a) (b)


Figure 2. A sensor node installed in a rain garden (a) and a map of sensor placement (blue tree icons) in Detroit, Michigan, US (b).

Results and discussion

Figure 3 shows depth measurements from 4 of the 21 deployed sensors. Depth measurements taken by the pressure transducer (dark blue) have been plotted alongside change in height (magenta). These sensors are buried at a depth of 1 m in the rain gardens; a measurement of 0 m indicates an empty garden, while a measurement near 1 m indicates the garden has reached its storage capacity. Measurements above 1 m indicate ponding. Figure 3 also indicates that these sites are observing the same storm events, but the individual response of each rain garden varies greatly. The dh/ht plots show the rain gardens are infiltrating water as designed, with peak rates ranging from 6 to 16 cm/hr. To our knowledge, this dataset is one of the largest of its kind to measure green infrastructure performance across this scale in real-time.

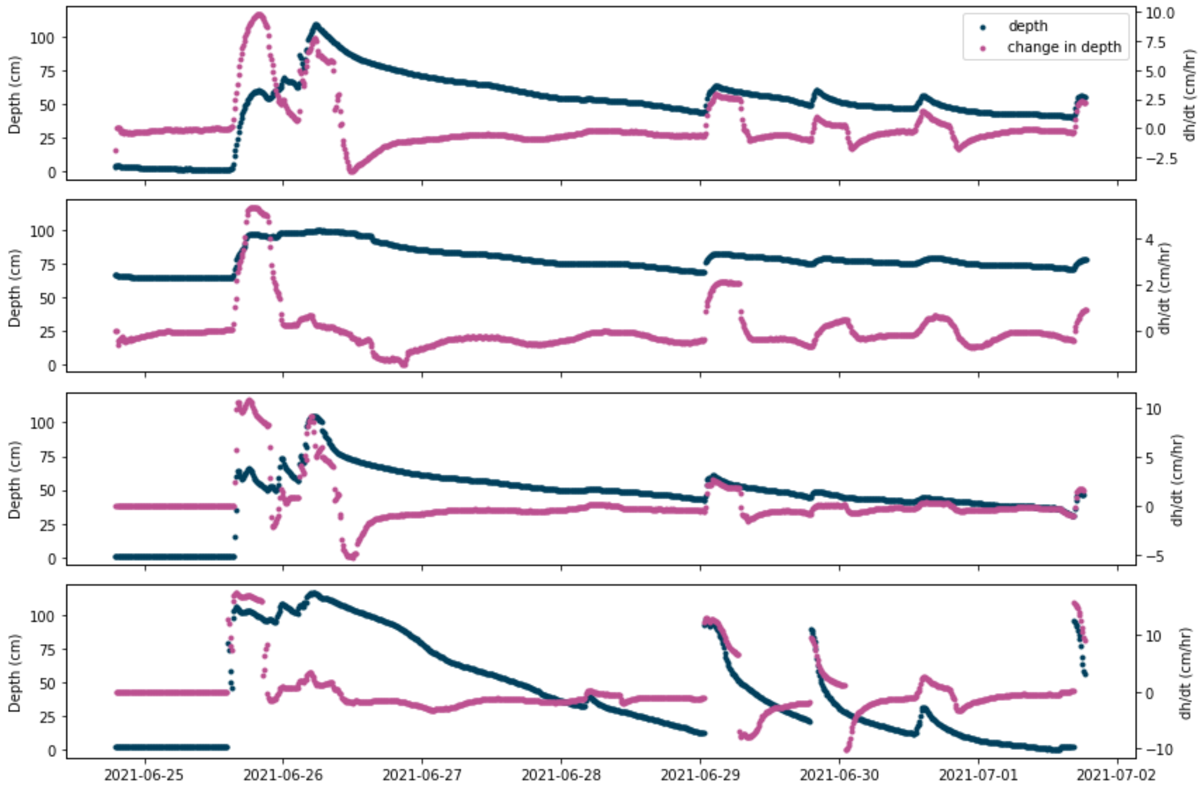


Figure 3. Sensor data, including depth (cm) and change in depth (cm/hr), from four of the GI sensor nodes during a record storm in Detroit. Detroit received 6 cm of rain over two days; the equivalent of a 2-day, 25-year design storm.

For a sensor network to be sustainable over the long-term, it must provide reliable data and require little to no maintenance. The network will be monitored for data quality concerns such as sensor calibration drift and data gaps. Thus far, no data quality issues have been observed. Since deployment, the battery levels have remained charged by the solar panel, fluctuating only by ±0.03 V (3.7 V nominal). It is expected these sensor nodes will not need a battery replacement for years, even during long Midwestern US winters.

Conclusions and future work

The goal of this paper was to introduce a novel green infrastructure sensor node and monitoring network in Detroit, Michigan, US. We presented stormwater performance data at an unprecedented spatial and temporal scale from four of the monitored sites. These sensor nodes provide a quick-to-install, wireless method for monitoring green infrastructure performance across the scale of entire cities. The dataset produced by this network could be used in the optimization of city-scale real-time control strategies. Future work will calculate stormwater volume captured by the gardens and look for system-level impacts on flow regimes and water quality.

References

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