Radar Level Data Reveals Impact of Urban Expansion

water simplified.

Case Study

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Abstract

Rapid urban development can significantly alter watershed hydrology, affecting both the timing and magnitude of runoff events. This study documents baseline hydrologic conditions downstream of a newly completed 95-unit housing development and prior to construction of a large department store. Using a non-contact radar water level sensor and remote telemetry, high-frequency water level and flow data were collected in a flood-prone culvert to quantify the system's response to rainfall events. The results revealed substantially faster and higher runoff responses than predicted by federal impervious surface models, underscoring the need for upstream retention infrastructure.

Introduction

Urban expansion and associated land use changes modify watershed hydrology, altering the frequency, magnitude and spatial distribution of runoff, erosion and pooling. Construction activities, in particular, exacerbate the impact of runoff on water quality as stormwater carries high concentrations of nutrients and sediment from development sites to downstream locations. Without sustainable management strategies, this can overload receiving waters and threaten water quality. Establishing a hydrologic baseline prior to additional development is essential for identifying impacts and informing mitigation strategies.

In this study, Chris Davis, founder of Lower 48 Instruments based in Dayton, Ohio, collected water quantity data downstream of a recently completed residential development and ahead of planned commercial construction. The study aimed to evaluate potential impacts to downstream water quality by monitoring hydrologic responses to rainfall events and comparing observed responses to predictive models.

Methodology

1 Site Characteristics

The monitoring site was selected based on its location ~1000 meters downstream of a recently completed 95-unit housing development (Figure 1). High-frequency level and flow data would provide a baseline understanding of downstream impacts of urban development in advance of planned department store construction and support implementation of stormwater management strategies like retention ponds, cascading waterways and vegetation buffers to intercept and treat runoff before it hits the stream.

Figure 1: Overview map showing the monitoring site location with respect to surface water flow patterns and development locations

Like most stormwater culverts and conduits, this site regularly receives flows that carry large objects downstream with considerable force. Debris poses a significant risk to submerged sensors and limits the feasibility of traditional monitoring installations. Davis needed durable, compact monitoring equipment that could operate in flood-prone terrain with minimal infrastructure.

2 Instrumentation

Davis used an In-Situ Level TROLL NC, a non-contact radar water level sensor. The Level TROLL NC was deployed above and perpendicular to the water surface to ensure accurate distance to surface reflection measurements and water depth calculations. Installing at an angle could result in missing data due to poor reflections, or incorrect data if the radar reports an oblique length rather than a perpendicular length. The Level TROLL NC's mounting system ensured correct installation, with a bubble level included on the device (Figure 2) and additional confirmation of the tilt angle in the VuSitu mobile app.

Figure 2: The Level TROLL NC's bubble level for ensuring correct installation

Figure 3: Site photo showing Level TROLL NC mounted to the top of the stormwater culvert

Figure 3 shows the Level TROLL NC installed at the monitoring site, attached to the top of the stormwater culvert. The device suited the needs and constraints of the project well. Installing the sensor out of range of high flows, logs and sediment eliminated risks of equipment damage and data loss. A non-contact installation also minimized maintenance needs; equipment exposed to heavy flows and high concentrations of sediment would otherwise require frequent cleaning and readjustment.

Dense canopy foreclosed on solar panel installation and the constrained site couldn't accommodate an enclosure. But high-frequency, remote data transmission was essential to the project goals. The In-Situ VuLink served as power supply, data logger and telemetry unit. Davis selected VuLink for its compact and portable size as well as its compatibility with the Level TROLL NC. Davis secured the VuLink to a tree (Figure 4); the unit's small footprint made the installation possible in a spot where larger systems simply wouldn't fit. This enabled continuous remote data transmission without site visits for manual downloads.

Figure 4: Site photo showing the VuLink installation in a nearby tree

3. FMCW Radar Explained

Frequency-Modulated Continuous Wave (FMCW) radar determines water level by continuously transmitting a microwave signal whose frequency varies within a specified wave band. As the signal travels toward the water surface, it is reflected back to the radar sensor. The time delay for return is proportional to the distance between the sensor and the water surface. Because the transmitted frequency is constantly changing, the reflected signal returns with a slightly different frequency than the one currently being transmitted.

The radar mixes the transmitted and received signals to generate a beat frequency, which represents the difference between the two. This frequency offset is directly related to the round-trip travel time of the radar wave and can be expressed as:

$$D = (c * \Delta f)/(2 * S)$$

where *D* is the distance to the water surface, c is the speed of electromagnetic waves, Δf is the beat frequency and S is the frequency sweep rate or slope of the chirp. Once the distance is known, the water level is calculated relative to a fixed reference point.

FMCW radar offers high accuracy, reliability and non-contact operation, under varying temperature, humidity and atmospheric conditions, and is unaffected by surface turbulence, foam or debris.

4 Data Collection
The Level TROLL NC measured tilt, signal-to-noise ratio (SNR) and distance to water surface during the ~3-month deployment from March 29 to July 2, 2025. The VuLink recorded ambient temperature and barometric pressure. Data were uploaded to the cloud and accessed using In-Situ's HydroVu software. Water depth and surface water elevation were obtained from the Level TROLL NC. Discharge flow (Q, m^3/s) was calculated from the radar measurements using the Manning equation:

$$Q = A \times (k/n) \times R^{2/3} \times S^{1/2}$$

where
n = Manning's roughness coefficient
k = conversion factor between SI and English units (k = 1 for SI units)
A = cross-sectional area (m^2)
R = hydraulic radius (m)
S = slope of the energy grade line (m/m)

The information provided in HydroVu also included the data collection settings, read rate, upload rate and flow estimation from the Level TROLL NC.

Results

The system recorded high-resolution water level and flow data alongside supporting parameters (tilt, SNR, barometric pressure and temperature) throughout the ~3-month deployment during spring and summer of 2025 (Figures 5–7). The radar sensor remained operational despite physical disturbances from bird activity. No data loss occurred. Battery life exceeded three months without recharging or replacement.

Hydrographs indicated rapid increases in water level and flow during rainfall events (Figure 7), with spikes occurring within five minutes of rainfall onset. Peak flows were nearly three times higher than estimates generated by federal impervious surface models.

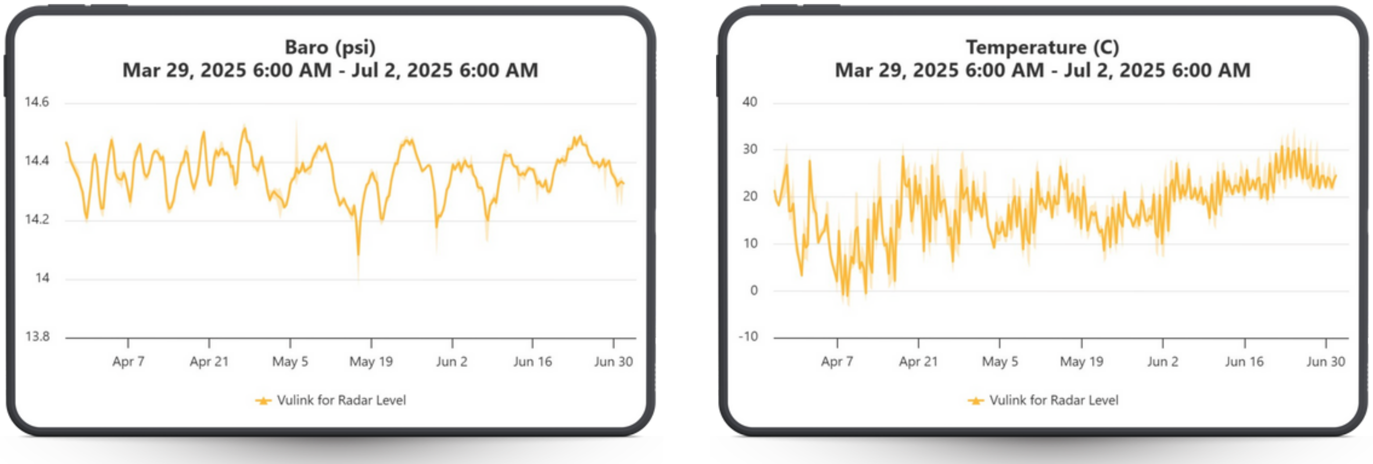

Figure 5: Barometric pressure and ambient temperature during the study

Figure 6: Radar tilt angle and signal level over the deployment period

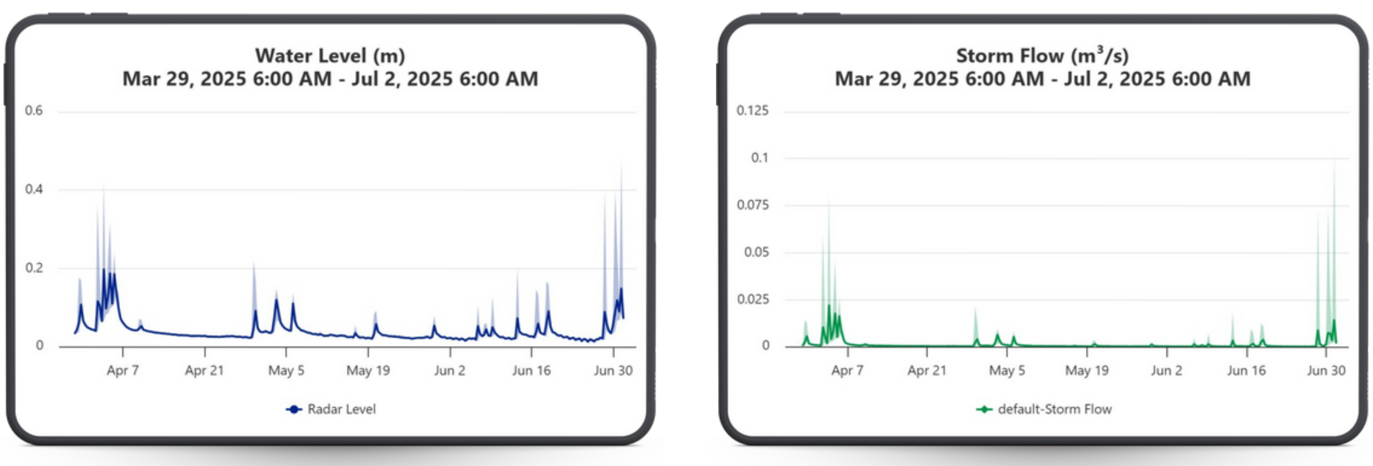

Figure 7: Water level and calculated flow show storm events over the deployment period

Discussion

Field conditions at the site–heavy debris loads, dense canopy cover and limited infrastructure–necessitated use of a non-contact sensor. The Level TROLL NC's above-water design reduced the risk of damage, avoided frequent maintenance and ensured data continuity through major storm events.

The radar's compact footprint and ease of installation enabled deployment in a constrained location. On-site configuration via Bluetooth and the VuSitu mobile app allowed quick alignment checks and real-time verification of the instrument's tilt angle. This streamlined the setup and deployment, and ensured correct installation for the collection of accurate level data.

The hydrologic data revealed a watershed system with minimal buffer, in critical need of retention mechanisms. Rainfall was translated into downstream flow almost immediately, allowing little opportunity for pollutant attenuation. Immediate runoff poses heightened risks for receiving waters, carrying construction-related contaminants, nutrients and debris directly downstream. The disparity between modeled and observed peak flows points to an underestimation of development impacts in predictive tools and underscores the need to integrate stormwater infrastructure and retention mechanisms into development planning.

Conclusion

This baseline hydrologic monitoring project demonstrated that non-contact radar sensing paired with compact telemetry can overcome the physical and logistical challenges of monitoring in flood-prone sites with limited infrastructure capacity. The Level TROLL NC provided reliable, low-maintenance data collection, revealing that runoff responses to rainfall were significantly faster and larger than predicted.

These findings suggest that existing models may underestimate the impacts of recent and planned development on downstream hydrology. The data support the need for upstream retention measures such as retention ponds, cascading waterways and vegetation buffers to mitigate rapid delivery of pollutants, sediment and nutrient loads. Stormwater infrastructure is imperative to slow runoff infiltration, which aids to improve water quality outcomes.

Additionally, continued collection of high-frequency telemetered data will be essential for evaluating the effectiveness of such interventions and for refining predictive modeling approaches.