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Toward health-aware urban flood resilience: A conceptual framework linking drainage conditions to flood forecasting and control

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Urban flood forecasts often treat underground drainage capacity as fixed, overlooking changes caused by blockage, siltation, and structural damage. This commentary proposes a conceptual framework for health-aware urban flood resilience that connects asset-condition observations, hydraulic modelling, and intervention feedback across inspection and storm-event time scales. The framework integrates established sensing, diagnosis, forecasting, and control approaches through explicit defect-to-model mappings, uncertainty propagation, and decisions informed by hydraulic consequences. Two offline InfoWorks ICM sensitivity experiments in the Dajiangou area of Jinan, China, illustrate the condition-to-model link. Under identical rainfall forcing, a blocked downstream connection increased simulated peak surface-water depth from 0.081 to 0.202 m, while a 20 cm sediment layer in an 800 mm pipe increased peak depth from 0.314 to 0.372 m. These results demonstrate flood-hazard sensitivity to drainage condition; they do not validate an operational closed loop or quantify resilience improvement. Future work should connect inspection records, hydraulic observations, and intervention outcomes to evaluate service continuity, recovery, and maintenance benefits. The framework positions drainage condition as an updateable input to urban flood management.

THE UNDERGROUND BLIND SPOT IN URBAN FLOOD RESILIENCE

Urban floods are increasingly sudden and spatially uneven, and delayed information can undermine response. Recent flood-intelligence research pushes toward multimodal observation and minute-level delivery of actionable information,[1] yet it largely treats the underground drainage network as a fixed boundary condition. That simplification is risky where networks have been patched and re-routed: siltation shrinks the effective flow area, fractures and collapses break connectivity, and misconnections redirect flow, so under storm loads the network can carry far less than its design capacity.

Surface and subsurface observation, defect diagnosis, forecast updating, and maintenance decisions run in separate workflows, yet numerical studies show clogging can materially alter flood processes.[2,3] We use health-aware flood resilience for the capacity to anticipate, absorb, and recover from pluvial flooding while explicitly accounting for changes in drainage assets (Figure 1). The analysis extends beyond the rainfall event to the coupled system of rainfall, surface water, and pipes: cities can build capacity but also preserve it through inspection, cleaning, repair, and adaptive operation; network health becomes an observed, updateable state variable.

WHY NETWORK HEALTH CHANGES THE PROBLEM

Conventional assessments describe a pipe by its mapped diameter, slope, roughness, and connectivity—attributes of the design, not necessarily of the capacity available in a storm. Defects change hydraulic resistance or topology and may cause surcharge or ponding beyond the affected segment. A health-aware record should carry defect type, location, severity, uncertainty, and hydraulic context; a flat capacity-loss percentage cannot capture these distinctions. Design capacity and operational condition must therefore be considered together when assessing resilience.

Health-aware flood resilience does not claim that its component fields—condition-based sewer modelling, asset management, digital twins, data assimilation, or real-time control—are new. We propose an explicit workflow connecting them across inspection and storm-event time scales. The contribution is threefold: asset health becomes an observed, updateable input to flood forecasting; explicit mappings translate defect records into hydraulic model changes; and forecasted consequences guide inspection, maintenance, and control actions whose outcomes update the health record.

Digital twins combine sensors, hydraulic solvers, and online assimilation for state estimation and forecasting.[4] The proposed workflow connects these hydraulic states to asset condition and maintenance decisions, while distinguishing observations, inferences, and simulations.

A CLOSED-LOOP HEALTH-AWARE FRAMEWORK

No single sensor covers both surface and underground, so the observation layer combines complementary evidence: satellite and aerial imagery for catchment change and surface inundation; rain gauges, water-level sensors, flow meters, and video for event dynamics; closed-circuit television, robots, sonar, and radar for pipe interiors. Every stream needs timestamps, spatial references, quality flags, and uncertainty; placement should follow hydraulic criticality and information gain. Data from different agencies must be comparable; when readings disagree, the cause may be a defect, a measurement error, or an omitted boundary condition.

The diagnostic and forecasting layer turns observations into actionable states. Computer vision can screen inspection imagery, but defect labels still need review against engineering standards and hydraulic significance; detected blockages or fractures then update model topology, effective area, roughness, or boundary conditions. Physics-guided learning imposes constraints such as mass balance and network connectivity,[5] and calibrated hydrodynamic models remain the reference. Validation in operation should report lead time, depth and extent error, false-alarm and missed-event rates, latency, and performance when sensors fail.

Forecasts earn their keep only when they change decisions. Warnings should report expected depth and timing plus the network-health assumptions behind the risk. Before a storm, the proposed system would prioritize inspection and cleaning; during the event, it would support pump, gate, road-closure, and field-team dispatch; afterward, hydrographs, confirmed defects, and intervention outcomes would update the health archive. Evaluation should go beyond prediction accuracy: avoided exposure, service continuity, restoration time, and maintenance cost would indicate whether impacts actually fell.

OPERATIONAL SPECIFICATION OF THE LOOP

Each state in Figure 1 is observed, inferred, or simulated. Observed states are inspection defect records with confidence levels; inferred conditions, such as effective area between inspections, are estimated from hydraulic signatures or data assimilation; simulated states describe hydraulic variables between observations. Observation and parameter uncertainty can enter ensembles over rainfall and asset-condition scenarios, with forecast spread informing decisions. For example, plausible defects that increase inundation at a critical location can raise inspection priority. Depending on the observed condition, defects may modify connectivity, effective cross-section, roughness, or boundary conditions through explicit mapping rules; the specific rule applied depends on the defect class and the scenario.

EVIDENCE FROM DAJIANGOU

We used two hydraulic sensitivity experiments in the Dajiangou area of Jinan, China, to illustrate the condition-to-model link. The 598.851-ha study area receives converging hillside runoff and contains low-lying intersections, aging drainage assets, and sections affected by rainwater–sewage separation works. We built a coupled one-dimensional pipe and two-dimensional surface model in InfoWorks ICM on a 1 m digital elevation model, calibrated against rainfall, flow, and water-level monitoring with the reported peak-flow error within 15%.

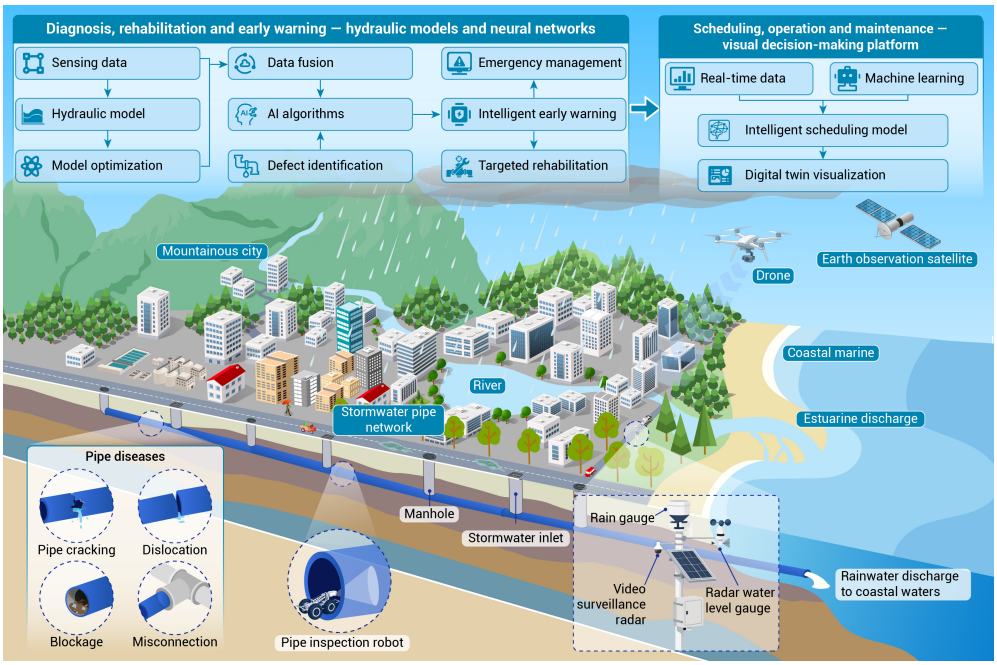


Figure 1. Health-aware urban flood resilience as a closed loop linking multimodal observation, health diagnosis, hydrodynamic forecasting, and control actions; arrows connect components and return intervention outcomes to the health record.

The Qixian site is at the Erhuan South Road–Jiwei Road junction in the northern core of the study area. Converging runoff from Shifangyu Hill and surrounding gullies, a principal waterlogging location, aging assets, and disturbance from the 2024 rainwater–sewage separation works make it an illustrative case of vulnerable drainage, rather than a statistically representative sample of urban networks. Both scenarios use the same 3-year design storm (peak rainfall intensity q = 45.2 L/(s·ha)), lasting 120 min with a Chicago-type temporal distribution; the fracture scenario has an upstream contributing area of 1.334 km^2.

Under this storm, closing the downstream connection of a fractured pipe segment raised the simulated peak surface-water depth at Qixian from 0.081 to 0.202 m, approximately 149.4%; a separate scenario with a 20 cm sediment layer in an 800 mm pipe raised the peak depth near the affected manholes from 0.314 to 0.372 m, approximately 18.5%.

The scenario mappings are specified here. Field-reported construction damage and downstream blockage were represented by closing the downstream link at manhole YSEHNL194 (invert elevation 48.509 m); this assumes complete blockage of that connection, not that every fracture causes disconnection. Field-surveyed sediment depths were 15–20 cm. For a circular pipe of diameter D with sediment depth s, the sediment occupies a circular segment of area $A_{sed} = (D^2/8)(\theta - \sin\theta)$, with $\theta = 2\arccos(1 - 2s/D)$; the effective flow area is $A_{eff} = A_{full} - A_{sed}$. In the sediment scenario, a 20 cm horizontal deposit in the 800 mm pipe YSJWGL387.1 occupied approximately 0.098 m^2 of the circular cross-section, leaving an effective area of 0.404 m^2, about 19.5% below the full area. As a result, the simulated peak flows of the two downstream trunks fell from 1.123 to 0.307 m^3/s and from 1.204 to 0.378 m^3/s, and both manholes surcharged about 52 min after rainfall onset. This impairment was represented as a reduced cross-section; area reduction is not equivalent to the same percentage reduction in conveyance.

These are offline hydraulic sensitivity experiments, not measured project benefits. They illustrate observed defect records translated into model changes and the resulting inundation sensitivity under identical rainfall. Both simulated peaks exceed the 0.15 m threshold of the Chinese standard GB/T 51222-2017 below which pedestrian safety is not significantly affected, implying interruption of pedestrian and light-vehicle service during the event. Service continuity, recovery time, and intervention benefits remain to be evaluated.

LIMITATIONS, SCOPE, AND FUTURE DIRECTIONS

The framework is most relevant where drainage networks materially control pluvial flooding and asset or event data exist. River overtopping and coastal surge require additional coupled processes. Practical limits include sensor drift, incomplete labels, uncertain severity-to-loss mappings, computational demand, and data ownership. Open benchmarks linking inspection records, hydraulic states, rainfall, inundation, and interventions should test generalization and operational benefits. Exact reproduction of the illustrative scenarios also requires the rainfall series, model settings, and inspection records. Decisions must weigh repair cost, disruption, equity, and environmental consequences.

CONCLUSION

Urban flood forecasts lose reliability when they ignore changes in underground drainage capacity. A health-aware approach keeps forecasts and decisions updated with observations of both hydraulic state and asset condition. The Dajiangou simulations provide bounded evidence that fracture and siltation can substantially change local inundation under identical rainfall, instantiating the loop's observation-to-parameter step. Near-term work should focus on a verifiable integration layer, one that distinguishes observations from inferences, carries uncertainty into hydraulic predictions, and records whether interventions improve outcomes. Building a larger standalone AI model will not address these needs by itself. The goal is to make underground drainage condition an operational input to flood management rather than a static map attribute.

REFERENCES

1. Yao J., Ma C., Wang M., et al. (2026). Toward minute-level flood stereoscopic intelligence: Real-time multimodal remote sensing under an on-orbit AI paradigm. *Innov. Inform.* **2**:100022. DOI:10.59717/j.xinn-inform.2026.100022
2. Xue B., Lichtfouse E. and Zhou X. (2025). Methods to monitor the defects of the drainage pipe network: A review. *Environ. Chem. Lett.* **23**:1877–1894. DOI:10.1007/s10311-025-01874-z
3. Wang X., Xia J., Feng J., et al. (2025). Numerical modelling of the impact of drainage system clogging on urban flood processes. *J. Environ. Manage.* **388**:125969. DOI:10.1016/j.jenvman.2025.125969
4. Bartos M. and Kerkez B. (2021). Pipedream: An interactive digital twin model for natural and urban drainage systems. *Environ. Model. Softw.* **144**:105120. DOI:10.1016/j.envsoft.2021.105120
5. Karniadakis G.E., Kevrekidis I.G., Lu L., et al. (2021). Physics-informed machine learning. *Nat. Rev. Phys.* **3**:422–440. DOI:10.1038/s42254-021-00314-5

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AUTHOR CONTRIBUTIONS

Wei Lu: Conceptualization, Methodology, Funding acquisition, Writing-review & editing. Bingchen Liang: Methodology, Supervision. Yilin Wu (Corresponding author): Methodology, Visualization, Writing – original draft, Writing-review & editing. Lingxiao Meng: Investigation, Data curation, Software.Hai Sun: Conceptualization, Formal analysis. Wenlin Jing: Investigation, Data curation, Resources.All authors contributed to the manuscript and approved the final version.

DECLARATION OF INTERESTS

The authors declare no competing interests.