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Two-Dimensional Hydrodynamic Simulations in Urban Water Systems

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In the studies presented here, we demonstrate the latest simulation capabilities of two-dimensional (2D) free-surface flow modeling through specific case studies. In hydrodynamic investigations, it is often necessary to use coupled one-dimensional (1D) and two-dimensional (2D) modeling. For the unsteady 1D–2D tasks at hand, we employed the widely accepted HEC-RAS (Hydrologic Engineering Center's River Analysis System) and HEC-HMS (Hydrologic Modeling System) simulation software. In one case study, a one-kilometer urban reach of a stream flowing through the outskirts of a major city was analyzed in connection with plans to improve water quality in recreationally impounded lakes. The hydrodynamic assessment of the planned lake conditions was carried out using 2D modeling. The spatial resolution of the model enabled the identification of potential sediment deposition zones and the verification of the proper operation of the weir and outlet structures. In another case, we analyzed surface runoff generated by precipitation falling on the site of a planned solar power plant located within a small riverside town. The results helped assess the need for and potential design of a stormwater drainage system. The spatial resolution of the 2D model allowed for an accurate determination of both the quantity and extent of surface runoff accumulation.

Keywords: *HEC-HMS, HEC-RAS, hydrodynamic, runoff, distributed model*

Introduction

In the study of urban stormwater management, one-dimensional (1D) hydraulic models are often sufficient. The assessment of sewer network capacity is fundamentally a 1D task. Surface flooding occurs when the stormwater network cannot accommodate the runoff generated within contributing sub-catchments connected to inlet manholes. Such overflows can also develop at downstream points in the network where the channel capacity is lower than the incoming discharge. Insufficient capacity may result from a combination of factors such as slope, conduit cross-section size, sediment deposition, and pipe roughness. Additionally, due to backwater effects, surface flooding may occur even upstream of the actual capacity restriction.

While 1D models can be used to calculate the volume of inundation, determining the spatial extent of flooding is inherently a two-dimensional (2D) problem. This is because even shallow water depths can result in widespread overland flow across urban surfaces.

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In smaller watercourses, flow dynamics can often be modeled adequately using 1D techniques. However, when cross-sectional complexity or significant lateral flow expansion exists — such as in shallow impoundments or floodplains — a 1D model may no longer be sufficient. In such cases, a 2D model becomes necessary to simulate the flow conditions accurately. These hydrodynamic processes are typically unsteady and temporally variable, with discharges potentially fluctuating by orders of magnitude during flood events.

High-flow events may coincide with peak discharges in both receiving watercourses and urban runoff systems. In such scenarios, the performance of gravity-based stormwater systems or combined sewer overflows (CSOs) becomes critical. Backwater effects can lead to upstream flooding and surface ponding. To simulate these conditions accurately, coupled 1D–2D modeling is required, which integrates detailed channel flow with surface flow dynamics.

In urban settings, the spatial resolution of sub-catchment delineation generally aligns with the location of inlets in the sewer network. For stormwater runoff modeling, more detailed delineation is typically unnecessary, as average hydrologic responses within each sub-catchment provide adequate representation. However, in larger or undeveloped catchments, the spatial resolution of a lumped 1D hydrologic-hydraulic model may be insufficient to yield accurate spatial results. In such cases, 2D modeling enables the identification of runoff and ponding zones, as well as the estimation of water accumulation volume and depth.

In the first case study, we conducted a 2D hydrodynamic analysis along a 1-kilometer urban section of the Hosszúréti Stream, which flows through the southern districts of Budapest. This section includes artificially impounded recreational lakes, such as Kána Lake. As part of plans to improve water quality, we examined flow conditions under low, medium, and high streamflow scenarios. The spatial resolution of the 2D model allowed for the evaluation of sediment transport, deposition zones, and the performance of weir and outlet structures.

The second case study focused on surface runoff generated by rainfall over a proposed solar park site within a riverside town (Tiszaújváros). Due to local topography, fluvial flooding was not a concern. The objective of the analysis was to provide foundational calculations for the design of a stormwater drainage system. The 2D runoff model was constructed with sufficient spatial resolution to accurately determine the volume, depth, and extent of accumulated surface runoff.

Urban hydrology faces increasing challenges due to the intensification of rainfall events, rapid urbanization, and the growing complexity of drainage systems. Traditional one-dimensional (1D) modeling approaches often fall short in representing the spatial variability of urban runoff, especially in complex topographies and densely built environments. The aim of this paper is to explore modern two-dimensional (2D) hydrodynamic modeling techniques and demonstrate their applicability to solving key urban runoff problems. Through case studies, the paper presents practical examples of how state-of-the-art 2D tools can be applied in real-world scenarios, illustrating the current capabilities, methods, and solution approaches available to practitioners and researchers. The scope includes simulations of both urban creek overflow and stormwater runoff on a solar park site, showcasing the versatility and limitations of 2D methods. The central research question addressed is: How effectively can current 2D hydrodynamic models capture and represent urban stormwater processes? This paper is structured as follows: after this introductory section, Section 2 details the case study areas and the modeling setup. Section 3 discusses the simulation results and evaluates model performance. Section 4 offers conclusions drawn from the findings and suggests future research directions.

The modeling of open-channel and surface water flows has long been a central concern in hydraulic and hydrological engineering. Traditional one-dimensional (1D) models have proven effective in simulating flows within confined channels where lateral flow variations are negligible (Chow 1959). However, with the increasing complexity of urban landscapes and the growing need for detailed flood risk assessments (Perera 2024), two-dimensional (2D) modeling has gained prominence due to its ability to capture lateral flow dynamics, especially in floodplains, surface runoff zones, and shallow impoundments (Hunter et al. 2007, Horritt & Bates 2002).

The integration of 1D and 2D modeling approaches has become standard practice in simulating urban water systems. In combined 1D–2D frameworks, 1D models represent in-channel flows, while 2D models are used to simulate out-of-bank flows or surface runoff, providing a more holistic view of hydrodynamic behavior under unsteady, gradually varied flow conditions (Fread 1992, Lin 2006). This hybrid approach is particularly important in urban flood modeling, where infrastructure such as culverts, weirs, and detention basins interacts with terrain-driven surface processes.

HEC-RAS and HEC-HMS, developed by the U.S. Army Corps of Engineers, are widely used in both research and practical applications for hydrodynamic and hydrological modeling, respectively. HEC-RAS has evolved to support 2D unsteady flow modeling using a finite volume solution of the shallow water equations, enabling detailed simulation of floodplain dynamics and urban drainage systems (Brunner 2024). Likewise, HEC-HMS supports the simulation of precipitation-runoff processes and can be integrated with HEC-RAS for comprehensive watershed analysis (USACE 2024). The synergy of these tools allows for detailed spatial and temporal analysis of flow patterns, flood extents, and runoff accumulation, which are essential in modern urban water infrastructure planning.

Several studies have successfully applied these tools in urban settings. For instance, Madhuri et al. (2021) demonstrated the advantages of 2D modeling in assessing flood hazards in highly urbanized areas with complex topographies. Similarly, Thakur et al. (2017) used coupled HEC-HMS/HEC-RAS simulations to evaluate drainage system performance under extreme rainfall events. These case studies underscore the increasing demand for high-resolution hydrodynamic modeling in response to climate change, urbanization, and infrastructure development.

Recent studies have focused on enhancing the accuracy and stability of coupled 1D–2D models. For instance, Xiang et al. (2024) developed a two-dimensional hydrodynamic urban flood model based on equivalent drainage of manholes, providing a more accurate representation of urban flood dynamics. This model accounts for the complex interactions between surface runoff and subsurface drainage systems, which are critical in densely populated urban areas. Ata et al. (2023) utilized HEC-HMS and HEC-RAS for flood hazard mapping at the Junjung River catchment, demonstrating the effectiveness of integrating hydrological and hydraulic models in flood risk assessment. Their approach highlighted the importance of combining different modeling tools to capture the multifaceted nature of urban flooding. Miremad et al. (2025) applied also HEC-RAS and HEC-HMS for Sustainable Urban Drainage Systems such as green roofs and permeable pavement comparing the results with previous situation.

In the context of water quality and sediment transport, 2D models also provide valuable insights into spatial patterns of deposition and scouring, particularly in shallow, slow-moving zones (Wu 2007). Accurate prediction of such dynamics (Mohammad et al. 2016, Raji et al. 2024) is critical in planning recreational water bodies and stormwater retention basins, where sediment management and hydraulic structure performance are closely linked. The sediment yield of a river upstream of a reservoir can be estimated using Geographic Information Systems (GIS) (Sabri et al. 2017).

The integration of hydrodynamic models with GIS has enhanced the spatial analysis capabilities of flood modeling. By incorporating high-resolution topographic data and land use information, models can more accurately predict flood extents and identify vulnerable areas. For example, the integration of HEC-RAS and HEC-HMS with GIS has been utilized to develop flood hazard and risk maps, aiding in urban planning and disaster management (Peker et al. 2024).

Several studies have been published on the application of HEC-HMS and HEC-RAS software for urban flood simulations (El Alfy 2016, Rangari et al. 2019a, Rangari et al. 2019b, Sahu et al. 2023, Alshammari et al. 2024). While numerous works focus on fluvial flood modeling, the application of HEC software to pluvial flood events remains relatively scarce.

Overall, the transition from purely 1D to integrated 1D–2D modeling reflects a broader trend toward spatially distributed, data-driven, and scenario-based analysis in urban hydrology. The present study builds upon this foundation by applying 2D hydrodynamic simulations to evaluate design and operational challenges in contemporary urban water systems, using real-world case studies to highlight the practical utility of high-resolution models.

Methodology/Materials and Methods

Case Study 1

For hydrodynamic modeling, we selected the Hydrologic Engineering Center's River Analysis System (HEC-RAS), due to its widespread acceptance and its capability to simulate gradually varied, unsteady 1D–2D flow conditions. HEC-RAS also includes comprehensive GIS-based visualization tools. HEC-RAS solves the system of partial differential equations governing open-channel flow using the finite difference method for 1D flow and the more numerically stable finite volume method for 2D flow.

The digital terrain model (DTM) of the study area represented the future configuration of the Kána lakes, bounded by embankments (Figure 1). The DTM was imported into HEC-RAS in GeoTIFF format, with a resolution set to 0.25 m, matching the 0.5 m sampling of the original topographic survey. The 2D Flow Area mesh was created using an average cell spacing of 0.25 m, resulting in approximately one million mesh elements, each with an average area of about 0.06 m^2.

Figure 1. *Digital Terrain Model*

In the hydrodynamic model, the upstream and downstream reaches of the stream were linked with the 2D flow area representing the lakes. The upstream and downstream boundaries of the lake matched the cross sections of the respective river reaches. The terrain model included the internal embankments separating the three impounded lakes, but we refined the DTM further by implementing weir structures within HEC-RAS.

The Manning roughness coefficient for the streambed was set to 0.06 $s/m^{1/3}$, corresponding to a partially vegetated channel. For the lakebed, we performed a sensitivity analysis with roughness values ranging around $n = 0.03 \pm 50\%$. The flow velocities within the lakes remained in the same order of magnitude across this range. The observed differences in flow patterns were attributed more to numerical instability—especially with higher n values (e.g., 0.06)—than to changes in hydraulic resistance. Ultimately, we selected a stable and realistic value of $n = 0.03$ $s/m^{1/3}$, representing a coarse sandy or gravel bed.

The upstream boundary condition in the model was defined by a flow hydrograph applied at the top cross section of the upstream river reach. At the downstream end, a normal depth condition was specified at the lower cross section of the river reach. The initial conditions included a predefined water surface elevation across the entire 2D flow area. The computational time step for the unsteady simulations was set to 1 minute, with a total simulation duration of 24 hours. To ensure numerical stability at the beginning of the simulation, a 60-minute steady inflow period was introduced along the 1D reaches, followed by a 60-minute gradual ramp-up of inflow at the interfaces between the 1D and 2D domains.

We performed three separate simulations representing low (100 L/s), average (500 L/s), and high (29.7 m^3/s) flow conditions. A large flood simulation was performed using a synthetic flood wave characterized by a rapid rising limb followed by a slowly receding limb, representing a peak flow scenario.

The HEC-RAS "particle tracking" feature was used to visualize the flow patterns, helping to assess directional flow behavior and relative velocities. For a more quantitative depiction, we applied a color-coded visualization of velocity magnitudes across the 2D domain.

The sediment transport module of HEC-RAS was not utilized in this study due to the significant uncertainties associated with several model parameters, and the lack of sediment transport measurements required for proper calibration. Since the sediment transport formulations in HEC-RAS are primarily based on shear stress at the water-sediment interface and the derived stream power—defined as the product of shear stress and flow velocity—we instead calculated the stream power values for each cell of the lake areas under various streamflow scenarios. This approach provided a spatial representation of potential sediment transport capacity without relying on the full sediment transport model.

Case Study 2

For the approximately 1.5 km² design area, a TIN surface was created based on a LIDAR survey, consisting of over 4 million points and more than 8 million triangles. The design boundaries were determined by the cadastral parcel boundaries.

Soil investigation data were available from 12 borehole sections, which included the composition of sand–silt–clay soil layers, infiltration coefficients, and moisture content.

As precipitation input, we used the 10-minute interval aggregated data from the nearest automatic weather station of the national meteorological service, located approximately 15 km away. Data is available from 2005 onward, providing 20 years of records, which reflect climate change well over this period. For surface flooding assessments, longer-duration rainfall events can be more critical. We selected the ~60 mm, 24-hour rainfall event from April 19–20, 2005 for runoff analysis.

The delineation of subcatchments was carried out using HEC-HMS 4.12 software. To do this, we exported the TIN surface into DTM format, setting a 1 m × 1 m grid size. Using HEC-HMS's GIS functions, we first filled shallow terrain depressions (< 0.25 m) to avoid numerous small internally draining areas. Roads were raised a few meters above the terrain (visible as lighter lines) so that flow paths would adjust accordingly. We clipped terrain areas outside the design boundary to match the cadastral parcel lines. The main flow paths were then identified (Figure 2). The green–yellow–red shading and increasingly thicker lines indicate the direction and concentration of water accumulation. Based on the flow paths, we delineated 17 subcatchments (Figure 3) for further detailed runoff calculations.

Figure 2. *Flow Paths and Digital Terrain Model*

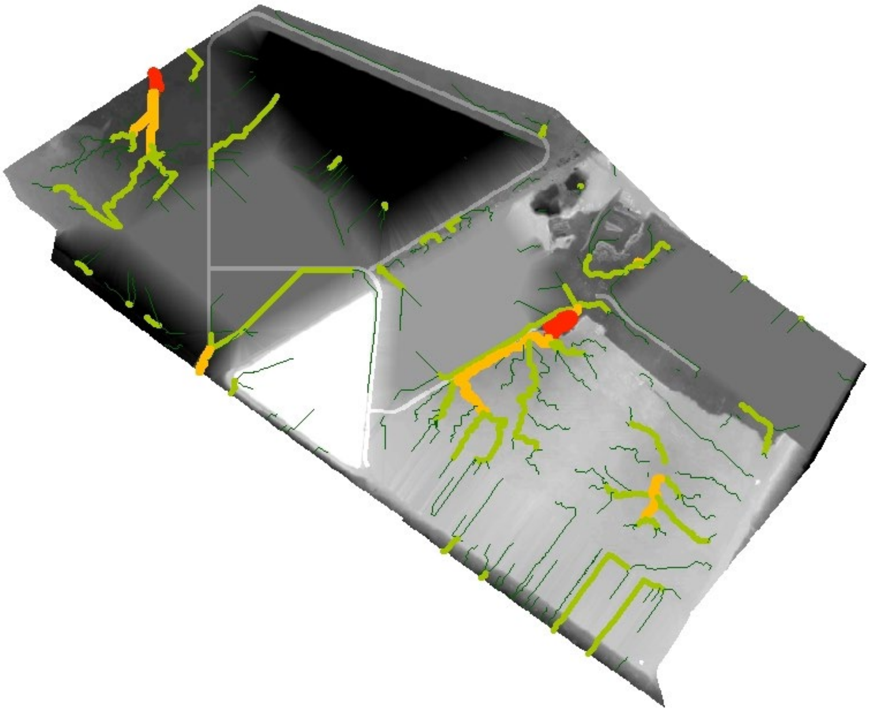
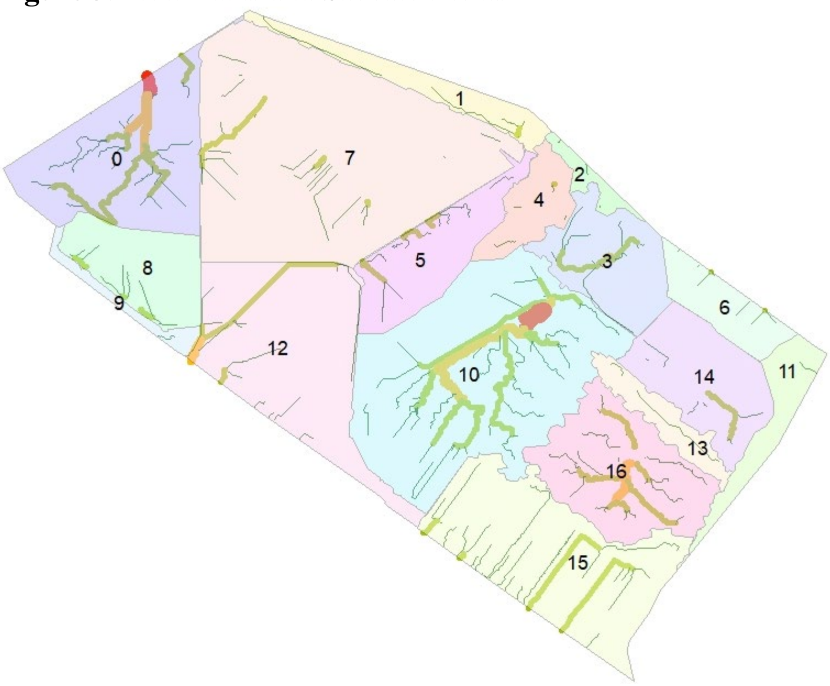


Figure 3. *Flow Paths and Subcatchments*



To calculate surface runoff and infiltration, we used the HEC-RAS 6.6 simulation software. The HEC-RAS 2D runoff model applies the finite volume method to numerically solve the Saint-Venant equations. Given the nature of the task (slowly varying flow), we chose the diffusion wave model to solve the momentum equations.

A computational mesh had to be created for the 2D flow domain. We generated 2D flow areas from the catchment regions, using 1 m × 1 m (in some cases 2 m × 2 m) grids composed of unstructured polygons.

For infiltration modeling, we used the Green-Ampt model, as it fit well with the available soil parameters. This model assumes a downward-moving, horizontally flat-bottomed saturated zone (wetting front), homogeneous soil, constant infiltration rate, and constant suction head. Total infiltration is calculated by solving the corresponding ordinary differential equation. For each subcatchment, we interpolated infiltration parameters (saturated hydraulic conductivity, suction head, initial and saturated moisture content) from the borehole section data. In HEC-RAS, infiltration is calculated by directly subtracting it from the precipitation depth. It does not consider any additional infiltration due to the depth of surface water that accumulates on the terrain.

To perform the runoff simulation in HEC-RAS, we developed an unsteady flow model, specifying the geometric layout, precipitation loading, and other parameters necessary for the simulation.

Results

Case Study 1

Under low-flow conditions, a steady-state flow regime is established within 24 hours (Figure 4). The water surface elevations are primarily determined by the crest levels of the transverse weirs. Flow velocities remain in the order of 1/1000 m/s in all three lakes (Figure 5). Flow directions and relative velocities are shown in more detail for the middle lake (Figure 6).

Figure 4. *Steady-state Water Surface Elevations Under Low-flow Conditions Across the Entire Lake System*

Figure 5. *Steady-state Velocities Under Low-flow Conditions Across the Entire Lake System*

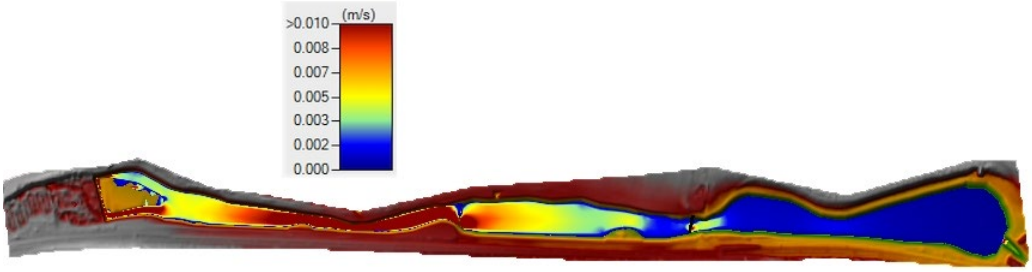
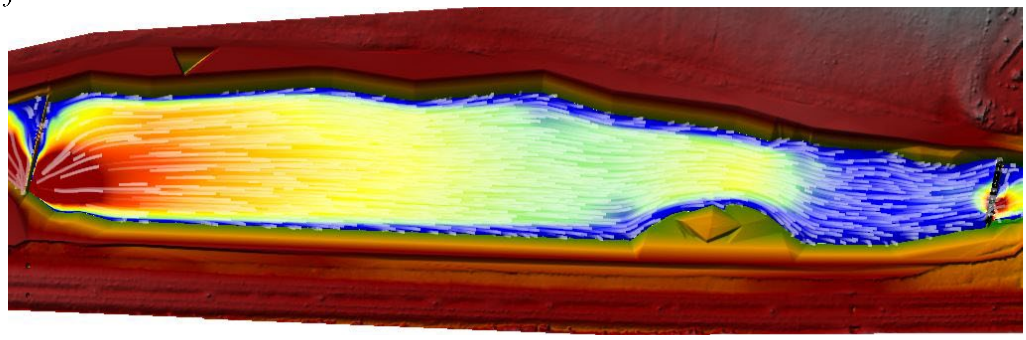


Figure 6. *Flow Directions and Relative Velocities in the Middle Lake Under Low-flow Conditions*



Under medium-flow conditions, water levels similar to those in the low-flow scenario are reached within 24 hours, but with flow velocities an order of magnitude higher.

In the case of a high-flow flood wave, water levels exceed the crest levels of the transverse weirs in all three lakes. The boundary between the lower and middle lakes becomes nearly indistinguishable (Figure 7), while a higher water level develops in the upper lake. Maximum velocities in all three lakes range from 0.1 to 2.0 m/s (Figure 8 and Figure 9).

Figure 7. *Maximum Water Surface Elevations in the Lakes Under High-Flow Flood Conditions*

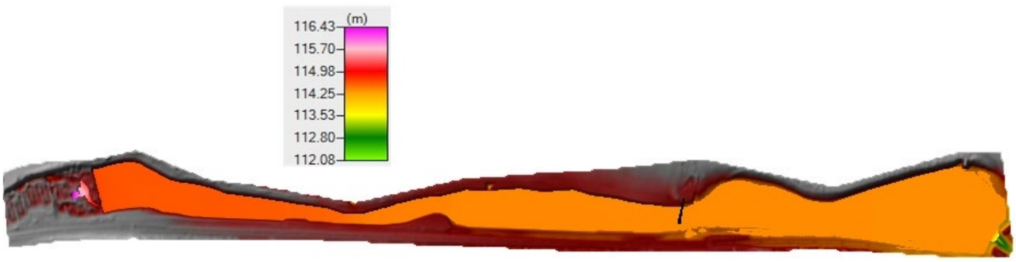


Figure 8. *Maximum Velocities in the Lakes Under High-flow Flood Conditions*

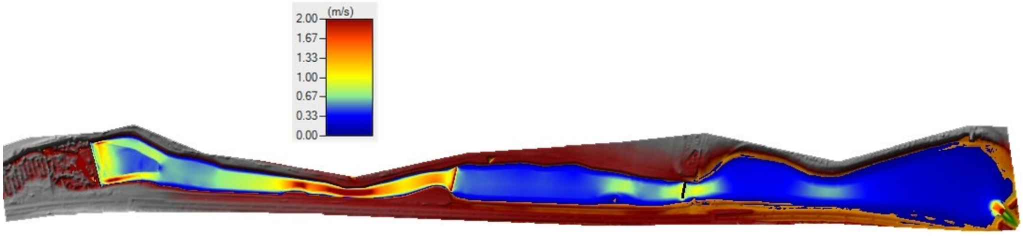
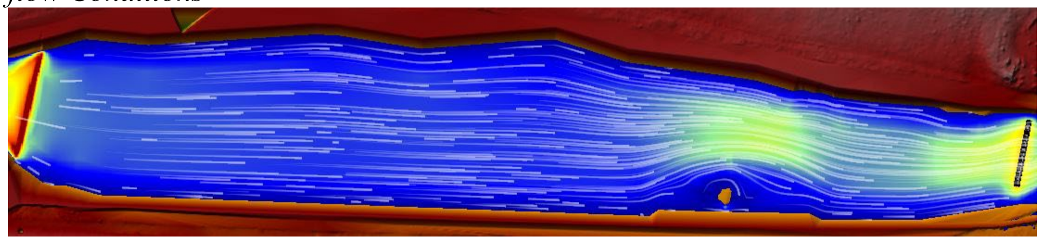


Figure 9. *Flow Directions and Relative Velocities in the Middle Lake Under High-flow Conditions*



Under both medium- and high-flow stream conditions, the sediment transport capacity of the lakes is characterized by calculated "stream power" values for each grid cell (Figure 10 and Figure 11).

Figure 10. *Stream Power Under Medium-flow Conditions*

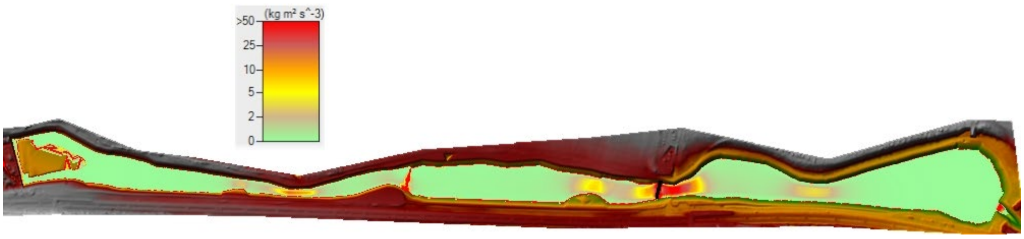
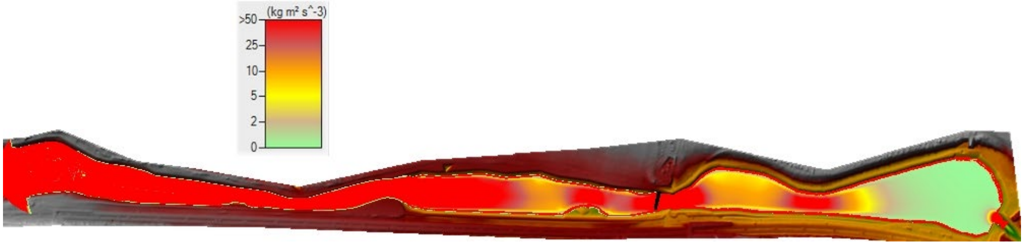


Figure 11. *Stream Power Under High-flow Conditions*



Case Study 2

As a result of the runoff simulation, key hydrodynamic parameters—water depth, flow velocity, and water surface elevation—were calculated and stored for each computational cell at the defined time steps (Figure 12).

Additionally, the maximum and minimum values of these parameters over the entire simulation period can be visualized (Figure 13 and Figure 14).

Figure 12. *Simulated Water Depths After 24 Hours*

Figure 13. *Maximum Water Depths During the Simulation*

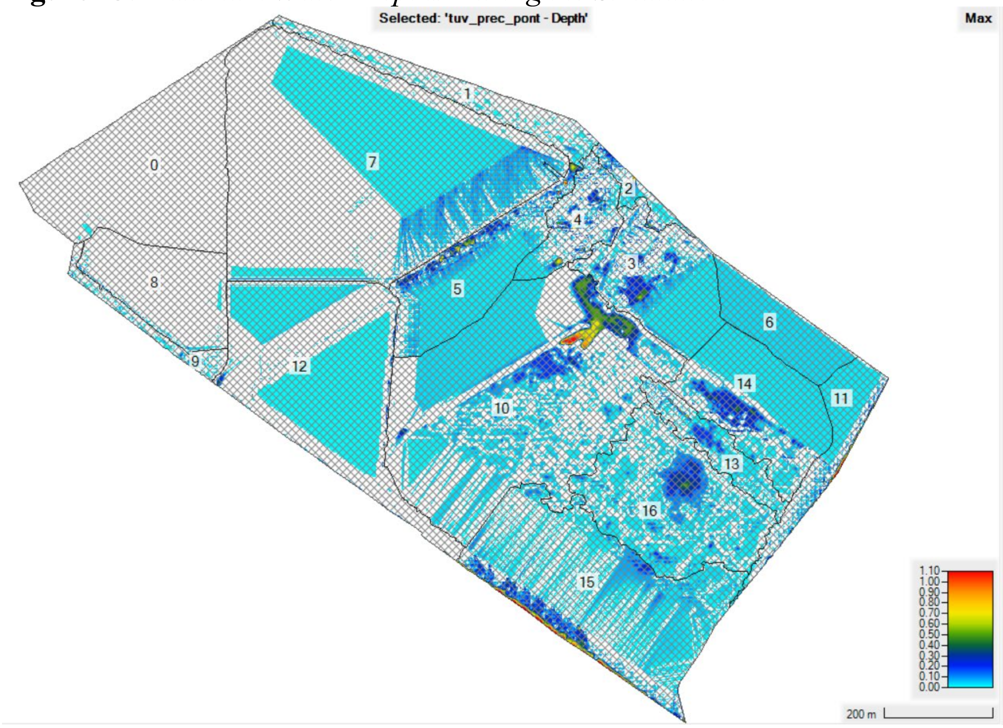
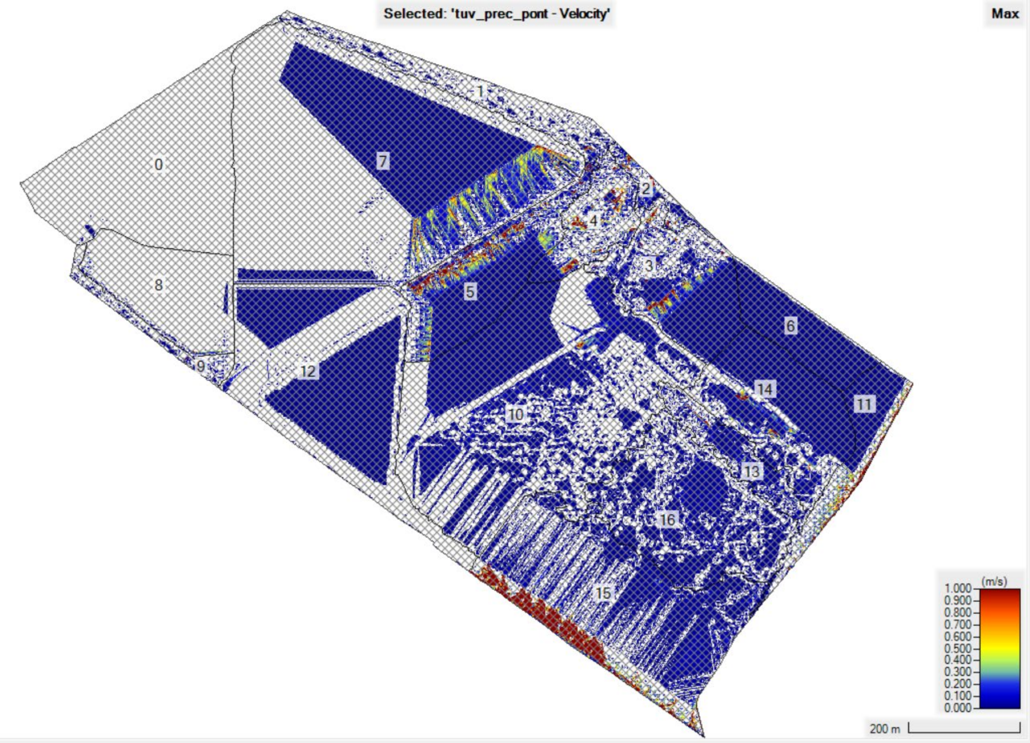
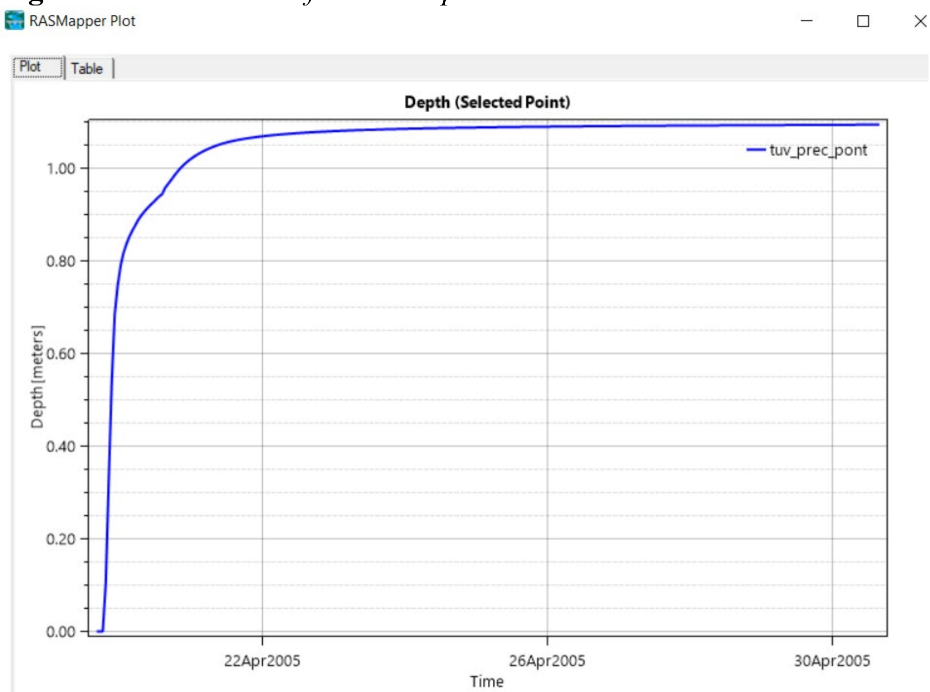


Figure 14. *Maximum Flow Velocities During the Simulation*



After 24 hours of simulation time (by April 20, 2005, at 16:00), the water levels had generally stabilized across the domain. Figure 15 shows the time series of water depth at the lowest elevation point within the terrain.

Figure 15. *Time Series of Water Depth at the Lowest Terrain Elevation Point*



Discussion

Case Study 1

Based on the steady-state velocities, the calculated residence time of water within the lake system is approximately 56 hours under low-flow and 35 hours under medium-flow conditions. The peak of the high-flow flood wave passes through the system from the upstream to the downstream end in about 40 minutes.

According to the flow maps, velocity distributions are uniform. Flow is nearly parallel throughout the lakes in all characteristic flow conditions, without eddies or dead zones. Flow becomes constricted near the transverse weirs, which were represented as DTM surfaces in the model. Due to the resolution of the DTM, the weirs are not perfectly level; however, a few meters downstream from each weir, flow once again becomes uniform.

Simulation results suggest that under low- and medium-flow conditions, sediment movement is not expected within the lakes themselves, but may occur at the weirs. From approximately 2 m^3/s flow rate (corresponding to return periods of 2 to 5 years, i.e., 20%–50%), sediment erosion is likely to begin in the lower lake. However, even under flood conditions, sediment is not expected to be mobilized from the upper lake. Therefore, periodic dredging will likely be necessary in the upper lake.

Case Study 2

Thanks to the high-resolution terrain model and the corresponding mesh grid, the HEC-RAS model was able to accurately simulate surface runoff across the area. Due to the existing terrain conditions, rainfall runoff flows outward from the outer sub-catchments of the planning area. In contrast, within the internal sub-catchments, all rainfall accumulates, as any water that cannot infiltrate at the point of precipitation remains within these enclosed areas.

The majority of the flow velocities (Figure 14) remain below 0.2 m/s across the site, with only very short sections of a few meters experiencing higher velocities. As such, erosion-related issues are not expected.

Infiltration is only partially accounted for in the model — by subtracting it directly from the precipitation depth based on predefined values. However, the simulation does not consider additional infiltration during surface flow or in inundated areas, which may lead to an overestimation of flow depths and inundation extents.

Conclusions

This study demonstrates that two-dimensional (2D) hydrodynamic models, particularly those implemented in HEC-RAS, are highly effective tools for simulating both fluvial and pluvial flood events in urban environments. Through two case studies—one involving stream channel modifications near recreational lakes and the other addressing rainfall runoff in a planned solar park—the paper highlights how 2D simulations provide detailed insights into water depth distributions, flow velocities, and potential sediment transport. Based on our simulation results, rehabilitation work around the lakes has already commenced (Figure 16), focusing on eliminating critical sedimentation zones and reconstructing dam structures.

Figure 16. *Ongoing Excavation and Drying of Sediment from the Lakes as Part of the Rehabilitation Process*

In situations characterized by shallow but widespread surface flow, 2D models prove especially valuable for delineating flood extents, assessing hydraulic structure performance, and informing sediment management strategies. The case studies confirm that while 1D lumped models such as HEC-HMS are useful for subcatchment-level hydrologic processes (e.g., infiltration, depression storage, and evapotranspiration), they lack the spatial resolution required for precise hydraulic analysis. By coupling HEC-HMS and HEC-RAS, it is possible to leverage the strengths of both tools for integrated hydrologic-hydraulic modeling.

A key conclusion is that modern 2D modeling techniques are not only technically feasible but also necessary for capturing the spatial complexity of urban runoff, particularly under changing climate conditions. The findings also underscore the importance of high-resolution terrain data and appropriate mesh design in achieving accurate simulation outcomes.

Future research should focus on improving model calibration methods, enhancing the integration of real-time data, and developing user-friendly tools to make these advanced models more accessible to engineers and decision-makers. In doing so, urban water systems can be designed and managed with greater resilience and precision.

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References

Alshammari E, Rahman AA, Ranis R, Seri NA, Ahmad F (2024) Investigation of Runoff and Flooding in Urban Areas based on Hydrology Models: A Literature Review. *International Journal of Geoinformatics* 20(1): 99–119.

Ata FM, Toriman ME, Desa SM, San LY, Kamarudin MKA (2023) Development of hydrological modelling using HEC-HMS and HEC-RAS for flood hazard mapping at Junjung River Catchment. *Planning Malaysia* 21.

Brunner GW (2024) *HEC-RAS 2D User's Manual* (Version 6.6). Hydrologic Engineering Center, U.S. Army Corps of Engineers.

Chow VT (1959) *Open-channel hydraulics*. McGraw-Hill.

El Alfy M (2016) Assessing the impact of arid area urbanization on flash floods using GIS, remote sensing, and HEC-HMS rainfall–runoff modeling. *Hydrology Research* 47(6): 1142–1160.

Fread DL (1992) Flow Routing. In *Handbook of Hydrology*, Chapter 10, pp. 10.1–10.36. New York: McGraw-Hill.

Horritt MS, Bates PD (2002) Evaluation of 1D and 2D numerical models for predicting river flood inundation. *Journal of Hydrology* 268(1–4): 87–99.

Hunter NM, Bates PD, Horritt MS, Wilson MD (2007) Simple spatially-distributed models for predicting flood inundation: A review. *Geomorphology* 90(3–4): 208–225.

Lin B, Wicks JM, Falconer RA, Adams K (2006) Integrating 1D and 2D hydrodynamic models for flood simulation. In *Proceedings of the institution of civil engineers-water management* (Vol. 159, No. 1, 19–25). Thomas Telford Ltd.

Madhuri R, Raja YS, Raju KS, Punith BS, Manoj K (2021) Urban flood risk analysis of buildings using HEC-RAS 2D in climate change framework. *H2Open Journal* 4(1): 262–275.

Miremad S, Concilio G, Azzellino A (2025) Sustainable Urban Drainage Systems for reducing Flood Risk at the Catchment Scale: The Seveso River Basin Case Study. *Athens Journal of Technology & Engineering* (forthcoming).

Mohammad ME, Al-Ansari N, Issa IE, Knutsson S (2016) Sediment in Mosul Dam reservoir using the HEC-RAS model. *Lakes & Reservoirs: Research & Management* 21(3): 235–244.

Peker İ B, Gülbaz S, Demir V, Orhan O, Beden N (2024) Integration of HEC-RAS and HEC-HMS with GIS in flood modeling and flood hazard mapping. *Sustainability* 16(3): 1226.

Perera KKE (2024) An analysis of stream flow and flood frequency: A case study from downstream of Kelani river basin, Sri Lanka. *Athens Journal of Sciences* 11(1): 55–74.

Raji BM, Turabi H, Nasimi MN (2024) Sedimentation Analysis of Kabul River by Using HEC-RAS. *Journal of the Institution of Engineers (India): Series A* 105(1): 229–238.

Rangari VA, Sridhar V, Umamahesh NV, Patel AK (2019a) Rainfall runoff modelling of urban area using HEC-HMS: a case study of Hyderabad City. In *Advances in Water*

Resources Engineering and Management: Select Proceedings of TRACE 2018, 113–125.

Rangari VA, Sridhar V, Umamahesh NV, Patel, AK (2019b) Floodplain mapping and management of urban catchment using HEC-RAS: a case study of Hyderabad City. *Journal of the Institution of Engineers (India): Series A* 100(1): 49–63.

Sabri E, Boukdir A, El Meslouhi R, Mabrouki M, El Mahboul A, Ekouele Mbaki VR, et al. (2017) Predicting soil erosion and sediment yield in Oued El Abid watershed, Morocco. *Athens Journal of Sciences* 4(3): 225–243.

Sahu MK, Shwetha HR, Dwarakish GS (2023). State-of-the-art hydrological models and application of the HEC-HMS model: a review. *Modeling Earth Systems and Environment* 9(3): 3029–3051.

Thakur B, Parajuli R, Kalra A, Ahmad S, Gupta R (2017) Coupling HEC-RAS and HEC-HMS in precipitation runoff modelling and evaluating flood plain inundation map. In *World Environmental and Water Resources Congress* 2017, 240–251.

U.S. Army Corps of Engineers – USACE (2024) *HEC-HMS Hydrologic Modeling System User's Manual* (Version 4.13.0). Hydrologic Engineering Center.

Wu W (2007) *Computational river dynamics*. Taylor & Francis.

Xiang M, Zhang S, Wu C, Tang C (2024) A two-dimensional hydrodynamic urban flood model based on equivalent drainage of manholes. *Journal of Hydroinformatics* 26(2): 519–533.