



Evaluation of The Performance of The Terboyo Retention Pond in Flood Control Using The Hec-Ras 2d Simulation Approach

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Abstract

This study evaluated the performance of the Terboyo Retention Pond in controlling urban flooding using a HEC-RAS 2D rain-on-grid simulation under a 10-year return-period rainfall scenario. Two comparable scenarios, without and with the retention pond, were assessed using four indicators: peak inundation depth, inundated area, inundation duration, and recession time. The results showed that the pond reduced peak inundation depth from 0.489 m to 0.465 m, equivalent to 4.91% effectiveness. Inundation duration decreased from 32 to 29 hours, while recession time improved from 30 to 27 hours, representing effectiveness values of 9.38% and 10.00%, respectively. However, the inundated area slightly increased from 13.25 ha to 13.31 ha, producing an effectiveness value of -0.44%. These findings indicate that the retention pond provides measurable temporal and depth-related benefits but does not uniformly reduce flood extent. The limited performance is associated with hydraulic bottlenecks in inlet conveyance and pumping capacity. Therefore, improving inlet efficiency, pump performance, and drainage connectivity is essential to enhance flood-control effectiveness in the Terboyo area. This assessment demonstrates the importance of evaluating storage infrastructure as an integrated hydraulic system.

Keywords: flood control, HEC-RAS 2D, inundation, retention pond, urban flooding.



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INTRODUCTION

Urban flooding has become an increasingly complex hydrological problem because rapid urbanization, changes in land cover, extreme rainfall, and inadequate drainage capacity can intensify surface runoff and increase flood exposure. Recent advances in urban flood research indicate that interactions among rainfall, topography, drainage systems, and built environments must be evaluated simultaneously to adequately represent flood processes in densely developed areas (Agonafir et al., 2023; Luo et al., 2022). In Indonesia, flood events remain one of the most frequent hydrometeorological disasters and continue to affect major urban centers, particularly low-lying coastal cities with limited drainage capacity. These conditions demonstrate the need for flood-control infrastructure that is supported by reliable hydrological and hydraulic evaluation rather than by structural construction alone.

Semarang is particularly vulnerable because its coastal areas are exposed to the combined influence of intense rainfall, upstream runoff, tidal processes, declining ground elevation, and constrained urban drainage networks. The eastern part of the city, including the Terboyo area in Genuk District, has repeatedly experienced inundation associated with river flooding, local drainage congestion, and tidal flooding, while land subsidence can further increase the spatial extent and persistence of inundation (Pujiastuti et al., 2016; Taufiq et al., 2022). Previous spatial analysis in Semarang has also demonstrated that increasing discharge can substantially expand flood-prone areas, emphasizing the importance of topography and hydraulic conveyance in determining inundation patterns (Karomah et al., 2014). Consequently, flood management in Terboyo requires an integrated approach capable of addressing not only peak water levels but also the spatial and temporal characteristics of inundation.

Retention ponds are widely implemented as structural measures to temporarily store stormwater, delay runoff concentration, and reduce excessive hydraulic loading on downstream

drainage systems. Their effectiveness, however, depends on storage volume, catchment characteristics, inlet and outlet capacity, pumping performance, and the temporal distribution of inflow during rainfall events (Acheampong et al., 2023; Hosseinzadeh et al., 2023). Studies of detention and retention facilities have shown that their hydraulic performance may vary significantly when evaluated under different rainfall scenarios and operational configurations (Herath et al., 2023; Murphy et al., 2025). Therefore, the performance of a retention pond should be assessed through multiple hydraulic indicators rather than interpreted solely from its nominal storage capacity.

The Terboyo Retention Pond was developed as part of the structural flood-control system serving a low-lying urban and industrial area of Semarang. Its fundamental function is to receive stormwater and drainage inflow, provide temporary storage, and support the controlled evacuation of water through hydraulic structures and pumping facilities. Previous studies in Indonesia have confirmed that retention ponds can contribute to flood reduction, although their actual effectiveness is highly dependent on local drainage configuration and operational conditions (Fitriana et al., 2021; Khoiri et al., 2022). Nevertheless, a large storage area does not automatically guarantee a proportional reduction in urban inundation when the transfer of runoff into and out of the pond is restricted by inlet, outlet, or pumping capacity.

A major limitation in conventional assessments of flood-control facilities is the tendency to evaluate performance using only one hydraulic variable, such as peak discharge or maximum water depth. Such an approach may overlook other important consequences of flooding because flood severity is also determined by the spatial extent of inundation, the duration of waterlogging, and the time required for floodwaters to recede. Contemporary urban flood studies therefore increasingly employ spatially distributed hydrodynamic models that can represent the dynamic interaction between rainfall, overland flow, drainage pathways, and local topographic depressions (Guo et al., 2023; Li et al., 2022). A multi-indicator evaluation is particularly important in densely occupied lowlands because modest changes in flood depth may coexist with substantial changes in inundation duration or spatial distribution.

Two-dimensional hydrodynamic modeling provides a more appropriate framework for evaluating these complex flood processes because it allows water movement to be simulated across both longitudinal and lateral directions. HEC-RAS 2D has increasingly been applied for flood-inundation analysis because it can represent terrain-controlled flow propagation, spatially distributed roughness, hydraulic structures, and rainfall applied directly to computational cells (Ansori et al., 2023; Ennouini et al., 2024). The reliability of two-dimensional flood simulations is nevertheless influenced by terrain resolution, computational-mesh configuration, surface-roughness coefficients, boundary conditions, and hydrological inputs (Alipour et al., 2022; Arash & Yasi, 2023). Accordingly, careful model configuration is essential when HEC-RAS 2D is used to quantify the effects of urban flood-control infrastructure.

The *rain-on-grid* approach is particularly relevant for the Terboyo catchment because rainfall can be applied directly across the two-dimensional computational domain, allowing runoff generation and surface-flow routing to be represented within a unified hydraulic framework. Recent research has demonstrated the usefulness of HEC-RAS 2D *rain-on-grid* simulations for assessing hydraulic hazards under complex terrain and rainfall conditions, including catchments where conventional discharge observations are limited (Ennouini et al., 2024). Coupled and spatially distributed modeling studies further show that detailed simulation can reveal local inundation patterns that may remain obscured when flood performance is assessed only from river discharge or water-level observations (Khatooni et al., 2025; Sim & Kim, 2024). This capability makes HEC-RAS 2D suitable for comparing flood conditions before and after the operation of a retention pond within the same rainfall scenario.

Despite the strategic role of the Terboyo Retention Pond, quantitative evidence regarding its performance across several hydrodynamic indicators remains limited, particularly when the pond is assessed through comparable simulations with and without the infrastructure. This study therefore evaluates its flood-control performance by examining changes in maximum inundation depth, inundated area, inundation duration, and recession time under a 10-year design-rainfall scenario using HEC-RAS 2D. By comparing identical rainfall conditions between the two model scenarios, the analysis is designed to isolate the hydraulic contribution of the retention pond and identify possible operational constraints within the surrounding drainage system. The findings are expected to provide

a more comprehensive basis for evaluating existing flood-control infrastructure and for supporting improvements to inlet capacity, pumping performance, and integrated urban drainage management in the Terboyo area.

RESEARCH METHODS

This study employed a quantitative hydrological–hydrodynamic modeling approach to evaluate the flood-control performance of the Terboyo Retention Pond in Genuk District, Semarang City. The two-dimensional computational domain covered approximately 22.802 km² of the drainage catchment associated with the Sringin and Tenggang systems, with terrain characteristics represented using 8 m resolution DEMNAS data obtained from the Indonesian Geospatial Information Agency. Historical daily rainfall data for 2015–2024 were collected from three nearby observation stations operated by the Indonesian Agency for Meteorology, Climatology, and Geophysics (BMKG), while technical information on the retention pond and pumping facilities was obtained from the Semarang City Public Works Agency. Areal rainfall was estimated using the Thiessen Polygon method, and frequency analysis using the Gumbel distribution produced a 10-year return-period design rainfall of 154.82 mm. The daily rainfall depth was subsequently transformed into an hourly hyetograph using the Alternating Block Method, with the highest hourly rainfall intensity of 53.68 mm occurring between the 11th and 12th simulation hours. This rainfall was applied directly over the computational domain using the HEC-RAS 2D *rain-on-grid* approach to reproduce spatially distributed runoff generation and overland flood propagation.

The hydraulic model was constructed in RAS Mapper by integrating the digital elevation model, land-surface roughness, drainage pathways, retention-pond geometry, and hydraulic structures into a two-dimensional flow area. Twenty-one breaklines were introduced along major roads, embankments, and primary drainage channels to improve the representation of hydraulic controls, while the computational mesh used a general cell size of 15 m × 15 m and was refined to 5 m × 5 m along hydraulically critical features, resulting in approximately 104,600 computational cells. Spatial Manning’s roughness coefficients were assigned according to surface characteristics, including a value of 0.080 for residential areas and 0.025 for asphalt surfaces and river channels, consistent with the need to represent variations in flow resistance across the urban landscape (Arcement & Schneider, 1989). Two simulation scenarios were then executed under identical rainfall conditions: a baseline scenario without the retention pond and an intervention scenario incorporating the 189 ha Terboyo Retention Pond together with the Sringin and Tenggang inlet systems and a modeled pumping capacity of 0.5 m³/s. The performance of the retention pond was evaluated by comparing four hydrodynamic indicators between the two scenarios, namely maximum inundation depth, total inundated area, inundation duration, and recession time. Percentage changes in these indicators were used to quantify the effectiveness of the retention pond and to identify potential hydraulic limitations associated with inlet conveyance and pumping capacity.

RESULTS AND DISCUSSION

Peak Inundation Depth and Hydrodynamic Response

The HEC-RAS 2D simulation demonstrated a measurable difference in peak inundation depth between the baseline condition and the scenario incorporating the Terboyo Retention Pond. Under the scenario without the retention pond, the maximum simulated inundation depth reached 0.489 m during the peak phase of the rainfall event. When the retention pond and its associated hydraulic system were activated, the maximum depth decreased to 0.465 m, indicating that the storage facility modified the hydraulic response of the surrounding drainage system. This result is consistent with the general function of retention facilities in temporarily storing storm runoff and attenuating flood peaks before water is conveyed downstream (Acheampong et al., 2023; Hosseinzadeh et al., 2023).

The absolute decrease in maximum inundation depth was 0.024 m, corresponding to a reduction of approximately 4.91% relative to the baseline scenario. Although this percentage confirms a positive hydraulic contribution from the retention pond, the magnitude of improvement remains relatively limited when considered against the overall flood depth. Similar studies have shown that retention and detention infrastructure does not always produce large reductions in local flood depth because performance depends strongly on the interaction between storage volume, inflow hydrograph, drainage connectivity, and outlet operation (Herath et al., 2023; Murphy et al., 2025). Therefore, the

Terboyo result should be interpreted as evidence of partial hydraulic attenuation rather than complete flood elimination.

The relatively modest reduction in water depth is particularly important in the context of low-lying coastal urban areas such as eastern Semarang. Flooding in this area is controlled not only by local rainfall but also by land subsidence, drainage congestion, river flow, and tidal influence, which collectively reduce the efficiency of gravity-based drainage (Pujiastuti et al., 2016; Taufiq et al., 2022). Spatial studies of Semarang have also demonstrated that flood extent and depth are highly sensitive to topographic conditions and increases in hydraulic loading within the drainage network (Karomah et al., 2014). These interacting processes help explain why the addition of a single storage facility may reduce peak depth without completely removing inundation from the affected area.

The observed depth reduction also reflects the capacity of two-dimensional hydrodynamic modeling to capture distributed flow behavior across a heterogeneous urban surface. Unlike one-dimensional approaches that primarily describe longitudinal channel flow, HEC-RAS 2D represents lateral propagation, local depressions, and spatial variations in terrain-controlled flow paths (Ansori et al., 2023; Vashist & Singh, 2023). This capability is particularly relevant in Terboyo because floodwater can spread across roads, residential zones, industrial land, and drainage corridors rather than remaining confined within a single channel. Recent research has similarly emphasized the importance of two-dimensional modeling for understanding complex urban inundation patterns and evaluating the performance of flood-control interventions (Luo et al., 2022; Guo et al., 2023).

The quantitative comparison between the two modeled conditions is summarized in Table 1. The table indicates that activating the retention pond reduced the modeled peak water depth from 0.489 m to 0.465 m, producing an absolute difference of 0.024 m. Expressed as a percentage, the improvement was 4.91%, confirming that the intervention exerted a measurable but moderate influence on the maximum hydraulic response. Such scenario-based comparisons are commonly applied in hydrodynamic flood studies because they allow the contribution of a specific intervention to be isolated while rainfall and other boundary conditions remain unchanged (Ennouini et al., 2024; Sim & Kim, 2024).

Table 1. Comparison of Peak Inundation Depth Between Simulation Scenarios

Indicator	Without Pond	Retention With Pond	Retention Change	Effectiveness
Peak inundation depth (m)	0.489	0.465	−0.024 m	4.91%
Peak inundation depth (cm)	48.9	46.5	−2.4 cm	4.91%

The difference of 2.4 cm in maximum water depth may appear small in absolute terms, yet it provides important information regarding the hydraulic role of the retention pond. In urban flood systems, even limited reductions in peak depth indicate that a portion of the runoff volume has been temporarily redistributed or stored before contributing to surface inundation. However, the effectiveness of such redistribution depends on whether runoff can reach the storage facility rapidly enough during the critical phase of the storm hydrograph (Hosseinzadeh et al., 2023; Acheampong et al., 2023). Consequently, the limited depth reduction observed in Terboyo may indicate that the principal constraint lies not exclusively in storage availability but also in the efficiency of hydraulic conveyance toward the pond.

The modeling results should also be interpreted in relation to the *rain-on-grid* configuration used in this study. In this approach, rainfall is applied spatially across the two-dimensional computational domain, allowing runoff to develop directly over the modeled terrain rather than entering the system only through predefined upstream discharge boundaries. Studies using HEC-RAS 2D *rain-on-grid* simulations have demonstrated that this technique is useful for representing distributed runoff generation and local hydraulic accumulation in complex catchments (Ennouini et al., 2024; Ansori et al., 2023). For the Terboyo catchment, this means that the simulated 4.91% depth reduction represents the integrated response of rainfall, topography, surface resistance, drainage pathways, and retention infrastructure rather than a simple comparison of channel discharge alone.

Terrain representation and roughness parameterization also influence the calculated maximum inundation depth and its spatial distribution. Hydrodynamic sensitivity studies have shown that digital elevation data, computational mesh configuration, and Manning's roughness coefficients can materially affect simulated flood depths and inundation boundaries (Alipour et al., 2022; Arash & Yasi, 2023). In hydraulic theory, greater surface resistance reduces flow velocity and alters water-surface gradients, making the selection of appropriate Manning coefficients essential for realistic flood simulation (Arcement & Schneider, 1989; Chow, 1959). The spatial assignment of roughness values in the Terboyo model therefore provides an important basis for representing differences between residential areas, roads, and drainage channels during the simulated rainfall event.

The reduction in peak depth nevertheless suggests that the retention pond alone cannot be expected to solve the entire flood problem in the Terboyo drainage system. Urban flood processes are increasingly understood as the result of interactions among rainfall intensity, drainage capacity, terrain morphology, land use, and engineered infrastructure, rather than the performance of a single structural component (Agonafir et al., 2023; Li et al., 2022). High-resolution modeling studies have similarly shown that local land-use configuration and drainage connectivity can cause substantial spatial variation in flood depth even under the same rainfall event (Li et al., 2022; Yan et al., 2024). The 4.91% reduction should therefore be viewed within an integrated system in which the retention pond interacts with inlet channels, pumping capacity, surrounding drainage, and local surface depressions.

From an engineering perspective, the peak-depth results provide initial evidence that the Terboyo Retention Pond performs a flood-attenuation function, but its present configuration does not generate a substantial reduction in maximum surface water level. This finding supports the need to evaluate the facility through additional indicators, because peak depth alone cannot describe whether the pond reduces the spatial extent of flooding or accelerates post-event drainage. Contemporary flood-risk assessment increasingly combines several hydrodynamic variables to avoid drawing conclusions from a single performance measure (Xu et al., 2023; Khatooni et al., 2025). Accordingly, the effectiveness of the Terboyo system must also be examined through changes in inundated area, inundation duration, and recession behavior before its overall flood-control performance can be comprehensively assessed.

Spatial Changes in Inundation Area and Flood Distribution

The spatial extent of inundation exhibited a different response from the reduction observed in peak water depth. In the baseline scenario without the retention pond, the simulated flooded area reached approximately 132,527 m², equivalent to 13.25 ha. After the Terboyo Retention Pond was incorporated into the hydraulic system, the inundated area increased slightly to approximately 133,114 m² or 13.31 ha. This result indicates that structural flood-control measures may reduce water depth while simultaneously redistributing floodwater laterally across surrounding low-lying surfaces (Guo et al., 2023; Li et al., 2022).

The difference between the two scenarios amounted to an increase of 587 m², corresponding to an effectiveness value of approximately -0.44% for the inundation-area indicator. This finding demonstrates that flood-control performance cannot be interpreted solely from reductions in peak water level because spatial expansion may occur even when local depth decreases. Urban flood behavior is governed by complex interactions among microtopography, land cover, drainage pathways, and local storage depressions, which can redirect water toward adjacent areas during high-flow conditions (Luo et al., 2022; Yan et al., 2024). Therefore, the observed increase in flooded area should be interpreted as a redistribution effect rather than direct evidence that the retention pond universally worsened flood conditions.

The spatial redistribution detected in the model is particularly plausible in the low-gradient environment of Terboyo. Coastal sections of Semarang contain extensive flat and subsiding terrain where small differences in elevation can strongly influence the lateral movement of shallow floodwater (Pujiastuti et al., 2016; Nando, 2024). In such settings, a modest reduction in peak water depth may allow water to occupy broader shallow depressions rather than remain concentrated within deeper localized zones. Similar spatial behavior has been reported in high-resolution urban flood simulations where minor topographic variations substantially influence the geometry and connectivity of inundated areas (Li et al., 2022; Zotou et al., 2022).

The role of drainage connectivity is also central to explaining the change in flood extent. Retention ponds can only reduce surrounding inundation effectively when runoff is conveyed into the storage facility at a rate consistent with the timing and magnitude of inflow generated by the storm event. Where inlet structures, secondary drainage channels, or conveyance routes restrict transfer toward the pond, excess water may remain distributed across the urban surface before reaching the storage area (Hosseinzadeh et al., 2023; Khoiri et al., 2022). This mechanism is relevant to Terboyo because the model includes concentrated inflow through the Sringin and Tenggara inlet systems rather than unrestricted hydraulic connectivity across the entire catchment.

The numerical comparison of inundation extent is summarized in Table 2. The results reveal that the absolute increase in modeled flooded area was relatively small compared with the total inundated surface, representing only 0.44% of the baseline condition. Nevertheless, the negative effectiveness value is important because it highlights the non-uniform hydraulic response of the drainage system to the operation of the retention pond. Scenario-based evaluations in flood modeling similarly emphasize the importance of examining spatial flood patterns rather than relying exclusively on changes in discharge or water depth (Arash & Yasi, 2023; Khatooni et al., 2025).

Table 2. Comparison of Simulated Inundation Area Between Scenarios

Indicator	Without Retention Pond	With Retention Pond	Change	Effectiveness
Inundated area (m ²)	132,527	133,114	+587	−0.44%
Inundated area (ha)	13.25	13.31	+0.06	−0.44%

The apparent contrast between reduced flood depth and increased inundation extent reflects the multidimensional nature of two-dimensional hydraulic behavior. When a structural intervention reduces vertical accumulation at one location, remaining flood volume may spread across neighboring cells with lower elevation or lower hydraulic resistance. HEC-RAS 2D is capable of representing this redistribution because momentum and mass exchange occur between adjacent computational cells across the simulated terrain (Ansori et al., 2023; Ennouini et al., 2024). This is one of the principal advantages of two-dimensional modeling over simplified approaches that cannot adequately represent lateral flood propagation.

Surface roughness may further influence the expansion of shallow inundation across the modeled domain. Manning’s roughness affects flow velocity, hydraulic resistance, and the ability of water to move between local depressions, roads, residential areas, and drainage corridors (Arcement & Schneider, 1989). Variations in land cover may therefore cause floodwater to become shallower but more widely distributed when flow encounters spatially heterogeneous resistance. Sensitivity research in flood-inundation modeling confirms that roughness and terrain representation can significantly affect simulated inundation boundaries and depth distributions (Alipour et al., 2022).

The increase in flooded area may also be associated with the limitations of storage access rather than the gross capacity of the retention pond itself. A large retention volume is hydraulically beneficial only when inflow structures can capture and transfer water during the critical stage of the hydrograph. Studies of retention and detention systems have demonstrated that hydraulic efficiency depends on the coordinated performance of storage volume, inlet configuration, outlet operation, and drainage-system connectivity (Acheampong et al., 2023; Herath et al., 2023). In the Terboyo case, the small increase in flooded area suggests that some runoff may have been redistributed over adjacent surfaces before it could be effectively transferred into the pond.

From a flood-risk perspective, an increase in inundated area does not necessarily imply a proportional increase in overall damage because hazard severity is also controlled by water depth, duration, flow velocity, and exposure of critical assets. A broader area of shallower inundation can generate different consequences from a smaller area experiencing greater flood depth, particularly in dense urban and industrial environments. Integrated flood-risk studies therefore increasingly emphasize the simultaneous consideration of several hydraulic indicators instead of using a single measure to characterize system performance (Xu et al., 2023; Yu et al., 2024). The Terboyo results reinforce this principle because the retention pond reduced peak depth while producing a slight spatial expansion of shallow flooding.

The inundation-area analysis indicates that the Terboyo Retention Pond produces a spatially complex hydraulic response rather than a uniform contraction of flooded surfaces. The increase from 13.25 ha to 13.31 ha indicates that the pond did not reduce the total modeled inundation footprint under the simulated 10-year rainfall event, even though it contributed to a reduction in maximum depth. This finding suggests that future optimization should focus not only on retention volume but also on improving hydraulic connectivity, inlet capacity, drainage conveyance, and pumping coordination so that runoff can be directed toward storage more efficiently (Fitriana et al., 2021; Suryadinata et al., 2013). The subsequent analysis of inundation duration and recession time is therefore essential to determine whether the retention pond provides stronger benefits in terms of temporal flood recovery even when its effect on inundation extent remains limited.

Inundation Duration, Recession Time, and Hydraulic Performance

The temporal analysis revealed that the Terboyo Retention Pond produced a more pronounced improvement in inundation duration than in maximum water depth or inundated area. Under the scenario without the retention pond, water levels remained within the defined inundation condition for approximately 32 hours. After the retention pond and pumping system were activated, the simulated inundation duration decreased to 29 hours, representing a reduction of 3 hours or an effectiveness of 9.38%. This finding confirms that retention infrastructure can provide important temporal benefits by storing part of the incoming runoff and reducing the persistence of water on urban surfaces (Acheampong et al., 2023; Fitriana et al., 2021).

The reduction in inundation duration is hydraulically important because the consequences of flooding are influenced not only by maximum depth but also by the length of time during which water remains within residential, transportation, and industrial areas. Prolonged inundation can disrupt mobility, extend business interruptions, accelerate deterioration of infrastructure, and increase community exposure to contaminated floodwater. Previous studies of retention facilities have similarly demonstrated that storage and controlled discharge can modify the timing of flood propagation even when reductions in maximum water level remain moderate (Herath et al., 2023; Murphy et al., 2025). The three-hour improvement observed in Terboyo therefore represents a meaningful component of the pond's overall performance despite its relatively limited influence on peak inundation depth.

A comparable improvement was observed in the post-peak recession process. In the baseline simulation, approximately 30 hours were required for water levels to decline from the flood peak to the specified recession threshold, whereas the retention-pond scenario shortened this period to 27 hours. The resulting 3-hour reduction corresponds to a recession-time effectiveness of 10.00%, which was the highest positive performance value among the indicators evaluated in this study. This result is consistent with the principle of sustainable urban drainage, in which temporary storage and controlled conveyance are intended to regulate the temporal distribution of excess stormwater rather than merely remove water instantaneously (Suripin, 2004; Khoiri et al., 2022).

The improvement in recession behavior can be attributed to the ability of the retention pond to provide temporary storage while the pumping system continues evacuating water after the rainfall peak has passed. In low-lying coastal areas, such a function is particularly important because gravity drainage may become inefficient when receiving-water levels are unfavorable or when land elevation has been reduced by subsidence (Pujiastuti et al., 2016; Taufiq et al., 2022). The hydraulic benefit of pumping is therefore expressed not only during the peak stage but also during the declining limb of the flood hydrograph. Similar evaluations of retention systems indicate that outlet and pump operations can substantially affect the time required for a flooded system to recover after extreme rainfall (Suryadinata et al., 2013; Hosseinzadeh et al., 2023).

The comparative temporal indicators are summarized in Table 3. Both indicators improved by exactly 3 hours, but their relative effectiveness differed because their initial durations were different. Inundation duration declined by 9.38%, while recession time declined by 10.00%, indicating that the strongest simulated benefit of the Terboyo Retention Pond was associated with accelerating post-flood recovery. Evaluating these temporal parameters alongside depth and area provides a more comprehensive representation of infrastructure performance than relying on a single hydraulic variable (Agonafir et al., 2023; Xu et al., 2023).

Table 3. Comparison of Inundation Duration and Recession Time

Performance indicator	Without pond	With pond	Absolute change	Effectiveness
Inundation duration	32 h	29 h	−3 h	9.38%
Recession time	30 h	27 h	−3 h	10.00%

The stronger temporal improvement compared with the 4.91% reduction in peak depth suggests that the primary contribution of the retention pond is to regulate water over time rather than substantially suppress maximum inundation. From a hydraulic-system perspective, this pattern indicates that storage is available but cannot be utilized instantaneously at a rate sufficient to eliminate surface flooding during the most critical stage of the storm. A system-balance interpretation requires simultaneous consideration of incoming rainfall volume, temporary storage, conveyance capacity, and outgoing discharge, because restrictions at any component can control overall performance (Brunner & Rechberger, 2016). This interpretation is also consistent with modern urban flood modeling, which treats rainfall, surface routing, storage, drainage, and discharge as interconnected processes rather than independent components (Guo et al., 2023; Luo et al., 2022).

The simulation results indicate that the limitation is likely associated with hydraulic access to and evacuation from the retention pond rather than with pond surface area alone. The modeled pond covers approximately 189 ha, while the simulation represents only one pumping unit with a discharge capacity of 0.5 m³/s; consequently, runoff generated rapidly during the design storm cannot necessarily be transferred through the inlet and outlet system at the same rate at which it accumulates on the surface. The original model also indicates that runoff is concentrated toward the retention facility through the Sringin and Tenggang inlet structures, making their conveyance characteristics critical to overall system response. Studies of urban drainage and detention systems similarly show that increasing storage without corresponding improvements in inlet, outlet, and conveyance capacity may produce only limited reductions in surface flooding (Hosseinzadeh et al., 2023; Khatooni et al., 2025).

The magnitude of the rainfall input further illustrates the hydraulic challenge imposed on the system. A design rainfall depth of 154.82 mm applied over the approximately 22.802 km² computational domain corresponds to a gross precipitation volume of roughly 3.53 million m³ before accounting for infiltration, surface losses, and other hydrological processes. Under such loading, the timing at which rainfall is converted into overland flow and transferred toward the drainage network becomes as important as the nominal capacity of the retention facility itself. HEC-RAS 2D *rain-on-grid* modeling is particularly suitable for examining this behavior because rainfall is applied directly to computational cells, allowing surface accumulation and flow routing to develop spatially across the terrain (Ennouini et al., 2024; U.S. Army Corps of Engineers, 2023).

The reliability of these temporal results also depends on the capability of the two-dimensional model to reproduce flow pathways across the heterogeneous Terboyo landscape. Previous comparisons between one-dimensional and two-dimensional approaches have shown that 2D models provide greater detail when water leaves drainage channels and spreads across floodplains or urban surfaces (Mashuri et al., 2023; Vashist & Singh, 2023). Nevertheless, simulated duration and recession remain sensitive to DEM accuracy, mesh configuration, surface roughness, infiltration assumptions, and hydraulic boundary conditions (Alipour et al., 2022; Arash & Yasi, 2023). The findings should therefore be interpreted as a scenario-based hydraulic evaluation that provides a comparative measure of pond performance under identical modeled rainfall conditions rather than as an exact prediction of every future flood event.

The four evaluated indicators demonstrate that the Terboyo Retention Pond provides uneven but identifiable flood-control benefits. Peak inundation depth decreased by 4.91%, inundation duration declined by 9.38%, and recession time improved by 10.00%, whereas the total inundated area increased slightly by 0.44%, indicating that water redistribution remains an important concern. From a practical perspective, improving inlet conveyance, increasing or optimizing pumping capacity, and strengthening integration between the pond and surrounding drainage network may enhance the utilization of the available storage volume; such improvements are particularly important in flood-prone urban areas where recurring inundation continues to generate social and economic disruption

(Nasri et al., 2023; Badan Nasional Penanggulangan Bencana [BNPB], 2023). The overall results therefore indicate that the performance of the Terboyo system should be understood as the combined outcome of storage capacity, hydraulic connectivity, pump operation, terrain conditions, and distributed urban runoff rather than the physical presence of the retention pond alone.

CONCLUSION

The HEC-RAS 2D simulation demonstrates that the Terboyo Retention Pond provides measurable but uneven flood-control benefits under the 10-year return-period rainfall scenario. The pond reduced peak inundation depth from 0.489 m to 0.465 m, corresponding to an effectiveness of 4.91%, while inundation duration decreased from 32 to 29 hours with an effectiveness of 9.38%. Recession time also improved from 30 to 27 hours, producing the highest effectiveness value of 10.00%. However, the inundated area increased slightly from 13.25 ha to 13.31 ha, resulting in a negative effectiveness of 0.44%, which indicates that the intervention altered the spatial distribution of floodwater without uniformly reducing the total flooded surface.

Overall, the findings indicate that the performance of the Terboyo Retention Pond is determined not only by its storage capacity but also by the hydraulic efficiency of the supporting drainage infrastructure. The relatively small reduction in peak depth and the slight expansion of inundated area suggest that inlet conveyance and pumping capacity remain important system constraints. Improvements in inlet configuration, pump capacity, and hydraulic connectivity between the surrounding drainage network and the retention pond are therefore required to optimize flood attenuation. The study also confirms that retention-pond performance should be evaluated through multiple hydrodynamic indicators because changes in flood depth, extent, duration, and recession time may produce different responses under the same rainfall event.

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