

Reviewer#1

General comment: The authors presented a relatively well-structured and relevant manuscript addressing the increasingly complex interplay between reservoir operation, rainfall and downstream flooding, taking the Sai Gon – Dong Nai basin as a deep dive section. The paper has a clear and relevant overall structure, moving logically from reservoir operation, to hydrodynamic modelling, to optimization, and finally to compound flooding and the basin case study. The literature overview and connection between traditionally separate strands of literature on how to model compound floods address an important gap and would likely be appreciated by the modelling community.

Response: We sincerely thank the reviewer for the positive evaluation and for recognizing the value of our manuscript. We are glad that the logical structure, the synthesis bridging traditionally separate disciplines (reservoir operation, hydrodynamic modeling, optimization, and compound flooding), and the deep dive into the Sai Gon–Dong Nai basin resonated well and will be appreciated by the broader modeling community. Below, we address the specific comments and suggestions one by one in detail.

Comment 1: The MS tends to address compound floods driven by combined rainfall-triggered high flows with storm surge/tidal backwater. It would be good and complete to frame compound flooding as an interplay of not only these two factors, but also multiple reservoirs, draining into one downstream catchment. This is coming though here and there in the MS, but could also be more prominent. Also see Section 05 in Figure 2 and revise if you agree.

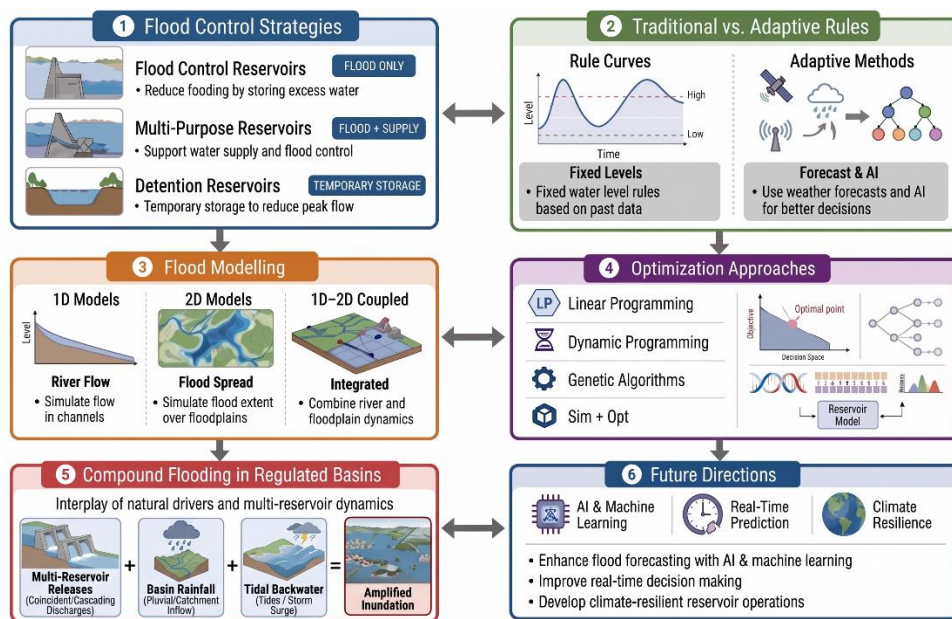
Response 1: We completely agree with the reviewer on the raising issue. In heavily regulated river basins, compound flooding cannot be adequately framed solely as a three-way interaction among meteorology (rainfall), hydrology (catchment runoff), and oceanography (storm surge/tides). The upstream fluvial boundary itself is frequently an anthropogenic compound system governed by the coincident, uncoordinated, or synchronized releases from multiple upstream reservoirs draining across converging tributaries into a shared downstream receiving floodplain.

To address this comprehensively, we have made the following revisions across the manuscript:

1. *Revised Figure 2 (Panel 5 and caption):* We have updated Panel 5 to explicitly incorporate multiple reservoir releases alongside extreme precipitation and tidal/surge backwater, changing the formulation from a simple Rain + River Flow + Tides to a multi-source compound driver including Multiple Upstream Reservoir Releases + Catchment Rainfall + Tidal Backwater/Storm Surge.

Panel title revised: Compound Flooding in Regulated Basins

Subtitle revised: Interplay of natural drivers and multi-reservoir dynamics



Caption revised: **Figure 2.** Integrated framework of reservoir operation for floodplain risk mitigation, illustrating the evolution from traditional rule-curve methods to adaptive, forecast-informed strategies, supported by hydrodynamic modelling (1D–2D), optimization techniques, and the interplay of multi-reservoir operations with compound coastal-pluvial-fluvial flood drivers, alongside future AI-driven solutions.

2. *Introduction (Section 1)*: Explicitly redefined the concept of compound flooding in regulated deltaic catchments to include multi-reservoir release interactions.

Our text revised (Paragraph 3): *“The problem is further complicated by compound flooding, traditionally characterized by the co-occurrence of high fluvial discharge, intense pluvial precipitation, and oceanic storm surge or tidal backwater effects (Green et al., 2025). In heavily engineered basins, however, this phenomenon extends beyond natural hydro-meteorological interplay to encompass an anthropogenic-hydrological compounding dynamic, in which the simultaneous or uncoordinated discharges from multiple upstream reservoirs drain across convergent sub-catchments into a single downstream receiving area. Today, near-coastal zones and low-elevation coastal zones—subject to flooding from a range of drivers—are home to approximately 2.15 billion and roughly 900 million people globally, respectively (Reimann et al., 2023). In coastal and deltaic basins, spillway releases from multi-reservoir systems, lateral tributary runoff, and tidal backwater do not act independently; rather, their non-linear hydro-mechanical superposition produces downstream flood stages and durations that far exceed single-driver estimates (Green et al., 2025). The 2017 Hurricane Harvey event illustrated this vividly, as record-breaking rainfall, river discharge, and runoff combined with prolonged storm surge to cause catastrophic flooding in Houston, Texas—becoming the second-costliest natural hazard in U.S. history at USD 152.5 billion in damages (Valle-Levinson et al., 2020). Despite these compounded realities, traditional reservoir optimization frameworks typically reduce downstream boundaries to simplified stage-discharge relationships. Consequently, most existing flood risk assessments continue to evaluate drivers in isolation, neglecting the non-linear interactions inherent to coastal–estuarine systems (Green et al., 2025).”*

3. *Methodology & framework description (Section 2.4)*: Updated text describing Panel 5 revised in Figure 2.

“...Crucially, the framework accounts for the heightened risks of compound flooding (Panel 5), broadening the paradigm to illustrate how the simultaneous convergence of multiple upstream reservoir releases across sub-basins, localized pluvial runoff, and ocean tides/surges amplifies severe downstream inundation...”

4. *Mechanisms of compound flooding (Section 6.1)*: Added theoretical depth on how multi-reservoir operations across sub-catchments create compound flood hazards when discharge waves converge with tidal locking.

“...In highly regulated deltaic and estuarine networks, this phenomenon is primarily driven by the intersection of five critical components: (i) upstream release dynamics from multiple parallel or cascading reservoirs, where coincident emergency spillway operations across distinct sub-catchments synchronize flood peaks downstream; (ii) natural fluvial runoff generated across intermediate, uncontrolled catchments; (iii) intense local pluvial events that exceed urban drainage capacity; (iv) tidal backwater that elevates base water surface profiles and physically restricts channel conveyance; and (v) storm-surge anomalies pushing coastal waters inland (Green et al., 2025). When multiple upstream dams operate under independent rule curves without basin-wide synchronization, their cumulative discharge waves can coalesce at downstream river confluences. If this hydrologic peak arrives concurrently with astronomical high spring tides or surge-induced coastal locking, channel drainage capacity collapses, producing devastating overbank flooding even if individual dam releases remained within downstream non-damaging thresholds under free-flowing conditions.”

5. *Case perspective of Dong Nai–Sai Gon Basin (Sections 6.3.1 and 6.3.2)*: Highlighted the critical compound confluence between the Dau Tieng reservoir (Sai Gon River sub-basin), Tri An reservoir (Dong Nai River sub-basin), and the trans-basin connection from Phuoc Hoa reservoir, demonstrating how their simultaneous operations interact directly with marine tides to dictate downstream flooding in Ho Chi Minh City and Binh Duong.

“The Dau Tieng reservoir, with a storage capacity of approximately 1.58 billion m³, is the largest reservoir in the Sai Gon sub-basin and plays a pivotal role in regulating dry-season water supply and mitigating monsoon-season flood peaks along the Sai Gon River (Figure 3A). The water level of the Sai Gon River from its upper reaches to the Thu Dau Mot gauging station is directly dependent on Dau Tieng reservoir releases, with the reservoir's outflow regime exerting the dominant hydrological control on channel water levels throughout the tidal transition zone (Markova et al., 2023). To meet water supply requirements for irrigation and flushing saltwater intrusion in the dry seasons, Dau Tieng reservoir receives a supplemental transfer of 30–40 m³/s in average annually from the Phuoc Hoa reservoir on the Be River. In parallel, the Tri An reservoir on the Dong Nai River (2.76 billion m³) regulates the upper Dong Nai River. Recent research underlines that upstream runoff in the Dong Nai basin is subject to extreme orographic precipitation events and rapid flood peaking, demanding advanced data-driven runoff forecasting frameworks to capture inflow surges into Tri An (Le et al., 2025). Downstream, the confluence of the Sai Gon and Dong Nai rivers discharges through a heavily modified estuarine complex into the East Sea, where pervasive riverbed morphodynamic changes and sand mining have systematically altered tidal wave propagation and amplified estuarine flood peaks (Le

et al., 2025). The strong bidirectional flow regime means that downstream flood severity in HCMC is dictated by the precise temporal synchronization between upstream reservoir release waves and peak tidal phases (Le et al., 2026).

Consequently, compound flood risk across downstream Binh Duong and HCMC represents an archetypal multi-reservoir, multi-driver problem. Extreme inundation is driven not merely by an isolated dam release, but by the compound interplay among: (i) coordinated or coincident spillway discharges from both Dau Tieng (up to 1,650 m³/s and Tri An (discharges of 160–1,400 m³/s or higher during extremes) draining into their respective channels; (ii) high unregulated tributary inflows and pluvial cloudbursts over the urban core; and (iii) semi-diurnal spring tides exceeding +1.6–1.7 m at Phu An and Nha Be stations (Couasnon et al., 2022). When emergency spillway releases from both Dau Tieng and Tri An coincide with peak high tides at the downstream confluence, tidal backwater acts as a hydraulic dam, preventing fluvial evacuation and forcing water over urban floodplains. Hydrodynamic simulations using MARINE rainfall-runoff and TELEMAC-2D inundation models confirm that during such compound occurrences—such as the July 2009 storm event—inner-city inundation in Binh Duong and HCMC expands significantly when elevated releases coincide with high coastal boundaries (Dinh et al., 2019). This reinforces the conclusion that compound flood management cannot treat upstream dams as isolated single-source regulators; optimization must explicitly coordinate multi-reservoir releases to stagger flood arrivals at the tidal confluence zone.”

6. Conclusions (Section 7): Positioned multi-reservoir coordination under compound downstream forcing as a core frontier in compound flood modeling.

“...Second, insufficient representation of compound flood drivers: existing optimization frameworks treat downstream boundaries as simple flow-routing elements, failing to capture the non-linear compound interactions between synchronized multi-reservoir releases, intense localized pluvial runoff, and dynamic astronomical or storm-driven tidal backwater (Green et al., 2025; Giuliani et al., 2021)...”

Comment 2: The review brings together hydrodynamic modelling, AI/ML, forecasting and optimization, but the distinction between these functions could be stronger. In particular, it would be useful to clarify what exactly is being optimized, what information is predicted, and how the predicted information feeds into reservoir decisions. For example, are the primary objectives minimizing downstream flood extent/depth/duration, reducing peak discharge, maintaining reservoir safety, maximizing water supply/hydropower, or some combination of these?

Response 2: We agree with the reviewer that clearly delineating the distinct functional roles of forecasting, hydrodynamic simulation, and optimization is essential for readers navigating this interdisciplinary topic. At the same time, we would like to clarify that providing exhaustive mathematical formulations, governing equations, or algorithmic code structures for each specific optimization and prediction function is beyond the primary aim and scope of this review. Our core objective is to synthesize the state-of-the-art integration across reservoir operations, hydrodynamics, optimization, and compound flooding science, rather than providing a detailed treatise on operational research mathematics.

However, to address the reviewer’s comment directly without overextending the scope of the paper, we have added a concise conceptual clarification in Section 5.3 (and referenced it in Section 6.3.2):

“Simulation–optimization frameworks advance riverine flood risk management by coupling a physically based hydrodynamic simulation model directly with an optimization algorithm to iteratively search for superior reservoir operating policies. To conceptualize this coupled workflow without delving into exhaustive mathematical formulations beyond the scope of this review, the operational cycle relies on three distinct but interacting functions: (1) predictive modules (hydrologic and weather forecasting) predict forward-looking boundary conditions, such as reservoir inflows and coastal tidal stages; (2) optimization algorithms adjust operational decision variables—principally time-series reservoir release rates and dynamic rule-curve thresholds; and (3) hydrodynamic models (or fast AI/ML surrogate emulators) simulate how those candidate releases propagate downstream. In modern multi-objective flood control, the optimizer iteratively evaluates Pareto trade-offs among competing objectives: mitigating downstream flood hazards (traditionally reducing peak discharge, and increasingly minimizing spatial inundation extent, depth, and duration), safeguarding dam structural integrity (minimizing peak reservoir water levels), and maximizing post-flood conservation storage for dry-season water supply and hydropower. The resulting multi-dimensional flood metrics are then fed back into the optimization routine as objective function values to guide the next iteration of the heuristic search (Bhargav et al., 2025)...”

Comment 3: Physics–AI approaches: please specify what do we mean with AI approaches.

Response 3: We agree that the term “AI approaches” should be clearly defined within the context of physics–AI frameworks. In the revised manuscript, we explicitly specify that AI approaches refer to three key tools:

- Deep learning surrogates/emulators (e.g., Convolutional Neural Networks [CNNs], Physics-Informed Neural Networks [PINNs]) that emulate 2D hydrodynamic inundation physics near-instantaneously to bypass numerical computational bottlenecks.
- Time-series sequence forecasting models (e.g., Long Short-Term Memory [LSTM] networks and Transformers) for hydrologic inflow and coastal tidal level prediction.
- Deep Reinforcement Learning (DRL) algorithms for closed-loop, adaptive reservoir release policies under dynamic conditions.

We have incorporated these specific definitions into Section 4.2 and Section 7:

“Despite these advanced diagnostic capabilities, a major barrier prevents the direct integration of high-fidelity 2D physics into real-time operational workflows. High-resolution 2D simulations over extensive spatial domains remain computationally expensive, which restricts their utility during active, rapid-response decision-making cycles. To bridge this gap between physical fidelity and real-time necessity, surrogate-model approaches are rapidly emerging as a practical alternative in contemporary research. Machine learning and deep learning architectures—specifically Convolutional Neural Networks (CNNs) and Physics-Informed Neural Networks (PINNs)—are increasingly deployed as hydrodynamic surrogate emulators to substitute for the heavy computational load of the underlying 2D numerical engines. By embedding governing physical laws into network loss functions, these physics–AI surrogates estimate 2D spatial depths and inundation extents near-instantaneously while preserving mass and momentum balance. While deep learning models often demonstrate impressive predictive accuracy, they still face notable hurdles, particularly regarding a lack of embedded expert physical knowledge and a relative scarcity of comprehensive benchmark data for rigorous testing (Karim et al., 2023).”

“Future research directions should prioritize three interconnected advances. First, hybrid physics–AI frameworks and Explainable Artificial Intelligence (XAI) offer both the computational efficiency and operational transparency required to close the gap between optimization, dam safety governance, and full floodplain impact assessment. Here, AI encompasses three specific functional tools: (i) sequence-learning models (e.g., LSTMs and Transformers) for reservoir inflow and storm surge forecasting, (ii) physics-informed neural networks (PINNs) surrogates that emulate 2D flood inundation in real time, and (iii) deep reinforcement learning (DRL) algorithms that map forecast states to multi-reservoir release decisions under non-stationary conditions (Bhargav et al., 2025)...”

Comment 4: Unpredictability of precipitation and associated runoffs: What about cascading system and inter-dependency amongst reservoirs on the same stream. See main comment 1.

Response 4: In cascading systems along the same river, precipitation and runoff unpredictability is further compounded by hydraulic inter-dependencies, where an upstream dam's release directly becomes the sudden, unmanageable inflow of the next downstream reservoir. We have added a concise statement in Section 1 (Introduction) to explicitly capture this cascading dynamic and clarify “unpredictability of precipitation and associated runoffs” in the earlier sentence of the paragraph:

“...Furthermore, in cascading systems along the same stream, strong hydraulic inter-dependencies mean that upstream releases directly amplify inflows to downstream reservoirs; without coordinated multi-reservoir control, these sequential releases propagate and exacerbate downstream flooding even when individual reservoirs operate within their own design parameters (Argoubi and Mili, 2025).”

Comment 5: Lack the feedback information: What do we mean with this?

Response 5: By “lack the feedback information”, we mean that conventional rule curves operate as open-loop policies that rely strictly on pre-determined calendar dates and current reservoir storage, without assimilating real-time state observations or predictions—such as short-term inflow forecasts, downstream water stages, tidal backwater levels, or the release status of interconnected dams. We have clarified this phrase in Section 1 (Introduction, Page 2).

“...The performance gap is evident under changing conditions as studies have shown that conventional operating rules yield highly suboptimal performance under non-stationary regimes because they operate as open-loop policies that lack real-time feedback information—such as hydrologic inflow forecasts, downstream channel water levels, and operational states of neighbouring reservoirs—which is required to enable adaptive and coordinated strategies (Giuliani et al., 2021)....”

Comment 6: High-resolution hydrodynamic models: Spatially, or temporally?

Response 6: We refer to both spatial and temporal resolution: spatial resolution via fine-scale computational meshes and high-accuracy digital elevation models (DEMs) to capture subtle topographic controls and overland flood extents, and temporal resolution via fine, adaptive time-stepping (seconds to minutes) necessary to ensure numerical stability and accurately resolve rapid flood wave propagation and tidal dynamics. We have clarified this explicitly in Section 1 (Introduction, Page 3).

“...Spatially and temporally high-resolution hydrodynamic models—resolving fine topographic grids alongside sub-minute numerical time-stepping can now simulate water movement across complex terrain with considerable precision, while sophisticated optimization algorithms are capable of navigating inherent multi-objective trade-offs, principally between evacuating storage to mitigate downstream flood hazards and retaining water for hydropower, municipal supply, and ecological base flows...”

Comment 7: Difficult trade-offs: Please specify what do you mean with this.

Response 7: By using “difficult trade-offs”, we referred to the inherent conflicts in multi-purpose reservoir operations—most notably the competition between maintaining empty buffer storage to attenuate downstream flood peaks and conserving stored water volumes to guarantee municipal/irrigation supplies, hydropower generation, and ecological base flows, all while strictly adhering to dam safety thresholds.

We have revised the sentence in Section 1 (Introduction, Page 3) to specify these competing objectives directly.

“...Spatially and temporally high-resolution hydrodynamic models—resolving fine topographic grids alongside sub-minute numerical time-stepping can now simulate water movement across complex terrain with considerable precision, while sophisticated optimization algorithms are capable of navigating inherent multi-objective trade-offs, principally between evacuating storage to mitigate downstream flood hazards and retaining water for hydropower, municipal supply, and ecological base flows...”

Comment 8: Figure 1: Please specify if this is for Sai Gon – Dong Nai, or globally.

Response 8: We thank the reviewer for pointing this out. Figure 1 outlines a generalized, globally applicable methodological framework for reviewing and integrating reservoir operations, hydrodynamic modeling, optimization, and compound flood dynamics across regulated river basins globally. The Sai Gon–Dong Nai river basin is introduced in Section 6.3 as an illustrative, focal case study to contextualize and ground this global framework.

To make this distinction clear, we have updated both the text in Section 2 (Page 3):

“A generalized methodological framework of five steps, applicable globally to regulated river basins and shown in Fig. 1, was used in this review paper to synthesize reservoir operations and floodplain risk. It outlines the workflow from literature search and screening to thematic classification and synthesis...”

and the caption of Figure 1:

“Figure 1. Generalized methodological framework applicable globally to regulated river basins, illustrating five steps of literature search, screening and selection, literature clarification, synthesis and analysis, and developing conceptual integration framework for downstream floodplain risk management under upstream reservoir operations.”

Comment 9: Table 1 can be made more compact by reducing line spacing, please introduce the abbreviations.

Response 9: The constructive suggestion is highly appreciated. We have tightened the line spacing and typography of Table 1 to make the table substantially more compact. Additionally, we have introduced a comprehensive footnote directly beneath Table 1 defining all thematic codes and methodological abbreviations used.

Below Table 1:

“Note: Thematic categories: RS = Reservoir Operation Strategies; HD = Hydrodynamic Modelling; OP = Optimization Methods; CF = Compound Flooding and Basin-Scale Studies. Abbreviations: AI = Artificial Intelligence; CMIP6 = Coupled Model Inter-comparison Project Phase 6; DEM = Digital Elevation Model; DL = Deep Learning; EMODPS = Evolutionary Multi-Objective Direct Policy Search; (E)NSGA-II/III = (Enhanced) Non-Dominated Sorting Genetic Algorithm II/III; HEC-RAS = Hydrologic Engineering Centre’s River Analysis System;

ML = Machine Learning; MOEA/D(-DE) = Multi-Objective Evolutionary Algorithm based on Decomposition (with Differential Evolution); RL = Reinforcement Learning; SWAT = Soil and Water Assessment Tool.”

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