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Editorial

Beyond infrastructure: Re-conceptualizing flood resilient governance through systems thinking, Indigenous knowledge, and proactive planning

1. Introduction

Floods can no longer be conceived as natural events that occur within a conventional system. On the backdrop of “climate change”, “altered” rainfall patterns, and “incremental” growth of settlements in low-lying areas, flooding has become a critical concern for urban and territorial resilience. Climate change is not merely increasing rainfall intensities; it is changing the distribution of the probability of extreme events (Lee & Zhao, 2021). Owing to this panoply of climate change effects, floods are no longer confined to coastal and riverine areas; even arid regions around the globe are experiencing an increased frequency of flooding events, often with significant loss of life and extensive infrastructural damage (Rahman et al., 2016). In doing so, it is reconfiguring the fundamental understanding upon which traditional risk calculations have historically been based.

Flood governance structures, especially in regions like the Province of British Columbia (BC) in Canada, continue to overwhelmingly rely on structural protection measures, including dikes, levees, embankments, and control systems, among others. While necessary, such dominance of structural protection can be seen as a symptom of a vivid and more insidious problem: an epistemological bias that treats uncertainty as something to be physically contained. Structural measures are inherent and provide vital defense but often foster a weak sense of security. The infrastructural measures, integral to the region's operational framework, were extensively compromised during the floods, thereby imposing an additional, multifaceted burden on the local governments (Rahman et al., 2016). Structural measures are grounded in the belief that extreme events will follow a predictable recurrence based on historical data (Kundzewicz et al., 2018). The question that arises is: if climate change is structurally changing risk patterns, can flood governance continue to rely primarily on structural defenses designed to address a historical past?

‘Resilience’ can no longer simply mean built-infrastructural robustness (Chester et al., 2021). It adjoins with governance that is expected, adaptive, and incorporates inter-generational wisdom popularly known as Indigenous knowledge systems. Governance that merely reacts to climatic disruptions by launching post-disaster response efforts fails to mitigate the underlying vulnerabilities; instead, it perpetuates the existing risks without affecting meaningful change in the structural factors that contribute to those vulnerabilities. Flood governance as a continuous process is, therefore, a necessary reconceptualization. To move from “structural” to “systemic” resilience, it is necessary to recognize that climate change is not a temporary alteration but a permanent state of uncertainty. The question is no longer how to control floods, but how to govern in a reality where the extreme turns out to be a “new” norm. Viewing flood governance as an interconnected process instead of a series of isolated events unleashes opportunities for anticipatory, inclusive, and climate-resilient approaches to both flood adaptation and mitigation.

2. Non-structural interventions for flood resilience

The predominant assumption that physical structures are capable of mitigating the unpredictable impacts of floods is no longer valid. While climate change is at its accentuating dynamics, floods are no longer the unexpected events, while their occurrences are getting irregular, uncertain, and the impacts turn out to be stronger. While structural measures are important for flood mitigation, they are rather overwhelmingly focused on mitigating immediate risks and associated damages, leaving the long-term adaptation to these events almost neglected and untouched.

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Given the current status quo, there is a pressing need to also understand the importance and appreciate the value of non-structural approaches to both flood mitigation as well as adaptation. The overwhelming hegemony for structural intervention needs to be adjoined by a greater recognition of the value and effectiveness of non-structural treatments, notably proactive planning interventions and adaptive tools, including land-use regulations, floodplain mapping and insurance for disaster (Kaur et al., 2025). Shifting the approach away from “reactive” or “corrective” to “proactive” response would essentially embed non-structural approaches to mitigate looming damages and help adapt to the dynamic impacts of flood events.

To articulate it differently, floods are regressing towards the tail (Flyvbjerg, 2021). In such a quagmire, the real question is not the height of the levees or the strength of the pumps. Rather, the core focus lies in the preparedness and the capacity of the system to adapt to the changing nature of floods. Structural and non-structural approaches are two facets of the same coin. Together, these interventions are the key to creating a flexible, anticipatory governance framework capable of navigating the uncertainty of floods. In the era of climate change, “irregularly” regular floods are the new normal. The question of resilience is no longer about the capacity to deal with the impacts. Rather, it is the capacity of the flood governance to adapt to the “new” normalcy.

3. Translating the 2021 BC floods into action

The 2025 BC atmospheric floods brought severe weather, including heavy rainfall, rockfalls, and a high avalanche risk, which resulted in the closure of all highways out of the Lower Mainland (Chan, 2025). These disruptions affected infrastructure and led to evacuations, particularly in the Fraser Valley. The floods and corresponding hazards made rescue operations challenging, analogous to the extreme weather events that caused similar disruptions in late 2021. Apparently, lessons from the 2021 BC floods have not been adequately translated into follow-up adaptation and mitigation actions.

Comprehensive and data-driven assessment: Flood governance in flood-risk communities, including BC, can no longer be based entirely on historical flood frequencies and traditional return period calculations. Climate change has altered the baseline, making rare events plausible, and compound hazards such as concurrent atmospheric flooding, coastal surge, and infrastructure failure are no longer hypothetical. Yet many flood assessment approaches still assume statistical stability and only gradual change. The disconnect between climatic reality and planning rationale creates a gap in flood governance. A detailed flood risk assessment involves the forecast of expected climate changes, the interdependencies of infrastructure with other elements, the population size and its distribution, as well as the quality of settlement options with the possibility of service disruption. The risk is not just hydrologically modelled; it is socially constructed through community structure, economics, and the interplay of essential services under stress. A flood risk assessment that does not consider these interrelated vulnerabilities will be systematically incomplete, even though technologically sophisticated. Therefore, relying on a single composite index is inadequate; flood governance requires a multidimensional and systems-based assessment (Del-Rosal-Salido et al., 2025). To improve resilience and adaptability, it is essential to enhance the predictability of extreme events and their subsequent impacts on urban areas and territories. Novel and innovative data-driven spatiotemporal approaches can offer valuable analytical frameworks that help in planning, managing, and advancing urban and territorial planning systems (Laghari et al., 2025). It is critical to note in this exercise that flood governance can no longer be based on “regression-to-mean” intelligence. The emerging climate change reality suggests that extreme events are not returning to the mean; they are escalating over time (Flyvbjerg, 2021). While planning around "average" scenarios may be administratively attractive, it is also systematically incorrect. It misjudges "tail" risks, those scenarios that cause catastrophic damage. In a high-capacity context like BC, it is a matter of insufficient precautionary orientation. A forward-looking, and data-driven flood risk assessment that considers extreme and compound scenarios is, therefore, not alarmist; it is responsible governance. Excluding it, future flood impacts will be unforeseeable because they were not adequately anticipated.

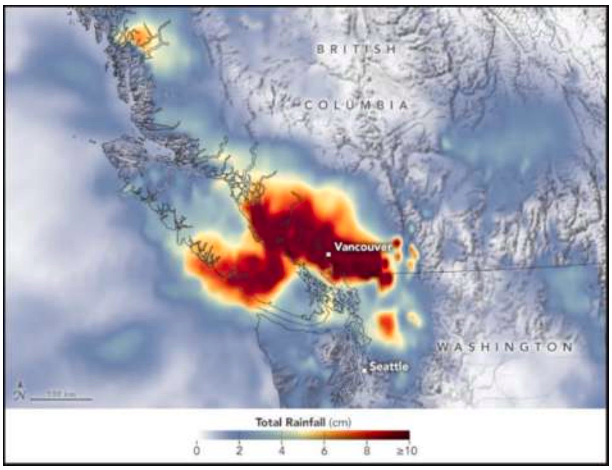

Fig. 1. Rainfall levels in the flooded areas of Vancouver.
Source: Dauphin & Stevens, 2021.

Re-assessing Flood Risk Maps – Beyond Conventional Practices: Let's assume that a community has developed its basic infrastructures, including highways, hospitals, schools, water pump stations, power plants, etc., without an outlook on the potential flood risks. Such omission could cause heavy damage to these infrastructures and properties along with significant death tolls (Sharma, 2024). The contemporary flood risk management practices have been infrastructure-led with a sheer neglect of non-structural measures, i.e., floodplain maps – one of the most pivotal mitigation tools. Many of the available flood maps of the communities are outdated, and they have not been able to capture recent changes in climate, urbanization, and river behavior. Recent changes in climate reflected in rainfall don't necessarily reflect the historical trend. These recent and relevant developments should have been systematically documented to inform follow-up actions, including non-structural cost-effective investments (e.g., updated floodplain mapping) within the broader framework of flood governance. When updating floodplain maps, local authorities must recognize that less accurate results are often a consequence of not incorporating relevant tools, including machine learning and deep learning, among others. Traditional floodplain mapping methods, which depend on simplified assumptions, manual processing, and limited data capabilities, are prone to overestimating or underestimating flood risks, as they lack the sophistication needed to handle complex and high-dimensional datasets and dynamic flood patterns (Bentivoglio et al., 2022).

The BC municipal, regional, and Indigenous governments hold the key responsibility to prepare and update floodplain maps. However, those governments have limitations in terms of funding and relevant in-house expertise (Nahiduzzaman et al., 2021). Moreover, the flood risk maps are outdated i.e., more than 10 years old (Ministry of Forests, 2023). Incoherent land use plans and not-so-thoughtful settlement placement choices are found to ramp up the adverse consequences of floods (Sarkissian et al., 2022). Fig. 1 highlights the areas affected by flooding in 2021, along with the rainfall intensities. In parallel, Fig. 2 identifies regions that are at risk from sea level rise. However, it failed to accurately delineate the flood-prone areas due to a lack of integration of the critical variables, including rainfall, land elevation, slope, etc. Residents living in these areas confront a persistent risk of seasonal flooding, and living through the rainy season turns out to be a significant challenge for them. Evidently, similar impacts were experienced in 2025, mirroring the flooding experienced in 2021 within the same areas. Actual resilience is not entirely about infrastructure; it is also about planning, and one cannot plan without empirical knowledge. Therefore, knowledge of flooding, being a living resource, can help plan and prepare for potential flood risks. Thus, by recognizing flood knowledge (a weighted average of the historical and recent pasts) as a central pillar of flood risk management, governance can move resilience strategies from a reactive stance to a more proactive approach.

Moving Beyond Single Flood Events – Understanding Cascading Impacts: Flood can no longer be seen as a siloed event; instead, it needs to be viewed as part of a complex system of cascading events. Secondary hazards, such as landslides, infrastructure failures, water contamination, and fires, can emerge both concurrently with and in the immediate aftermath of flooding, as the flood exacerbates pre-existing vulnerabilities, triggers soil instability, and damages critical infrastructures (Aguirre, 2020). The catastrophic floods in Europe in 2021, affecting Germany, Belgium, and adjacent countries like Luxembourg and the Netherlands, highlight the broader consequences of such natural disasters on both local and international scales. In BC, however, flood governance is still largely constructed on planning for and managing floods as a single and isolated hazard with limited consideration of forward linkages to the secondary consequences (e.g., landslides) or backward connections to related hazards including drought and wildfires. As a result, communities experienced significant landslides as a secondary hazard during 2021 floods, an outcome that had not been well anticipated in existing planning and management approaches (Gillett et al., 2022). Thus, planning and managing the risks associated with events like wildfires, landslides, and so forth operate in silos with little or no coordination. This affects the type, scale, and nature of infrastructure that needs to be developed, as well as the adequacy and preparedness of emergency response measures that must be in place. Flood governance in BC appears to inadequately recognize the critical interconnections between flooding and other concurrent events, despite the extensive damage caused by the 2021 and 2025 floods. Furthermore, the "Flood Risk to Resilience: A B.C. Flood

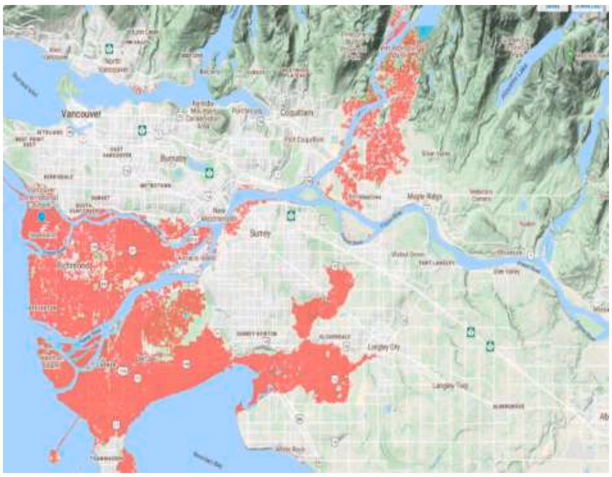

Fig. 2. Predicted floodplain map considering potential level rise.
Source: Little, 2019.

Strategy to 2035", released after the major flood in 2021 (Government of British Columbia, 2024), also overlooked the significance of secondary hazards, despite the clear evidence of their impacts, and continues to treat floods as isolated events instead of addressing the broader and interconnected risks. Flood governance in BC, therefore, appears to be reactive rather than anticipatory. Cascading events are still not sufficiently recognized as increasingly common occurrences. Therefore, flood governance must move towards a more systemic, anticipatory, and integrated management approach – one that recognizes floods as interrelated events with cascading impacts on communities.

Flood Resilience through Systems Thinking: Floods need to be addressed using a systemic approach. It is necessary to transition from narrow and one-dimensional "linear" thinking to an integrated "circular" approach that embraces the broader and interconnected dynamics of flood risks (Awah et al., 2024). This further stresses on the growing need to adopt a systems thinking approach to flood mitigation and adaptation. Effective flood management strategies require interventions that go beyond administrative and sectoral boundaries, engaging communities, regional districts, cities, provinces and transboundary regions (e.g. across the border of Canada and the USA) to address flood risks. A key factor undermining both flood adaptation and mitigation in the region is the lack of coordinated multilevel governance among the provincial governments, First Nations governments, regional districts, and municipalities (Brody et al., 2009).

Flood resilience can be strengthened through systems thinking, an analytical paradigm that comprehends complex issues as interrelated, emphasizing the dynamic interactions and feedback loops within a system. Tools such as "Causal Loop Diagrams (CLD)", the "Driver-Pressures-States-Impacts-Responses (DPSIR) framework", and "System Dynamics (SD)" facilitate the visualization of these interdependencies and the exploration of the multifaceted environmental, social, and institutional determinants of flood risks (Rehman et al., 2019). CLDs delineate feedback mechanisms that perpetuate flood vulnerabilities, DPSIR categorizes the causative factors and responses to inundation, and SD models simulate the long-term consequences of varied flood management interventions. By integrating these system thinking tools, BC can devise a comprehensive and adaptive flood management framework that anticipates emerging threats, optimizes policy interventions, and promotes synergistic collaboration among stakeholders, thereby enhancing sustained flood resilience and preparedness.

Extreme weather events, such as floods, cannot be effectively managed through fragmented planning and implementation strategies. Effective flood management strategies require all elements of the system to be actively involved to ensure an anticipatory and resilient approach. Communities contribute to flood management by providing essential lived experiences of flood risks and vulnerabilities; cities are responsible for managing critical infrastructure and daily operations; regional districts are responsible for resource management and coordination; Indigenous and First Nations governments contribute to flood management by providing geographical intelligence and expertise; provinces provide funding and regulatory management; and emergency management provides a quick response to flood risks. Moreover, the systems thinking approach should be aligned with global frameworks, such as the "Sendai Framework for Disaster Risk Reduction (2015-2030)", to ensure a cohesive approach to flood risk management that integrates resilience, prevention, and cross-sectoral collaboration. BC still lacks a guiding policy at the provincial level that aligns with the Sendai Framework (Ebbwater Consulting Inc., 2021).

Each of these elements is critical to effective flood management strategies that go beyond "reacting to floods" to "proactively engaging" with flood risks. Systems approaches must also account for critical constraints which often present significant barriers to both the development and revision of floodplain maps. The most common challenges identified in this regard include less-than-sufficient funding, technical expertise, accurate data, stakeholder engagement, and strategic planning (Nahiduzzaman et al., 2021). Therefore, by applying systems thinking and incorporating mechanisms for collaboration and cross-scale coordination, flood management can be shifted toward more proactive and adaptive approaches, which will strengthen resilience and reduce vulnerabilities to extreme weather events, including floods. This could be accomplished by addressing flood risks through comprehensive and integrated strategies as opposed to fragmented approaches.

Rethinking Indigenous Knowledge in Flood Governance: The importance of Indigenous knowledge cannot be overstated when it comes to flood governance. The Indigenous view is a foundational principle for flood governance, as multiple studies showed that Indigenous knowledge offers effective, and community-rooted techniques to flood risk mitigation and long-term resilience (Markolinda et al., 2025; Obi et al., 2021). The integration of science-based flood governance and Indigenous knowledge systems (which have been in existence for centuries) is a critical step towards a balanced and more effective flood governance. The Indigenous knowledge systems that have been developed over the years are not just ceremonial; instead, these knowledge systems have been practical and adaptive to the needs of Indigenous communities who have faced manifold natural hazards. For instance, Uganda's Rwenzori Mountains, traditional ecological knowledge played a vital role in flood risk management, with practices such as flood prediction, mountain cleansing rituals, and planting native plants to improve ecological systems and manage flood risks (Bwambale et al., 2018). Similarly, the knowledge held by Indigenous communities of the mountains, riverine, and coastal areas of BC can be integrated into flood management strategies, as it offers place-based intelligence and practices that can strengthen flood resilience. The marginalization of Indigenous knowledge systems in BC's flood governance represents more than a policy shortcoming; it is a broader failure to foster resilience for these communities, who continue to confront climate-related hazards that cannot be addressed solely through modern infrastructure.

Toward Proactive and Preventive Flood Governance: A fundamental change from "reactive" to "proactive" and "preventive" flood management is urgently needed. "Proactive" flood mitigation emphasizes anticipating and preparing for flood risks before they materialize through foresight-driven actions while "preventive" mitigation focuses on direct actions to reduce flood damage, implementing zoning restrictions in hazard zones, flood proofing buildings, or restoring wetlands as natural barriers. Resilience in flood management is generally stronger during the pre-flood compared to the post-flood phase (Chapagain et al., 2025). The reactive approach, where flood management is mobilized only after floods have occurred, locks communities in a repetitive pattern of damage,

Fig. 3. Disaster management cycle.
Source: Adapted from Rana et al., 2021.

rebuilding, and reconstruction. Such approaches treat floods as isolated crises rather than as manifestations of deeper vulnerabilities embedded in infrastructure, land use, and societal systems.

In contrast, proactive approaches to flood management reconceptualize governance as anticipatory and adaptive. Cost-benefit account through life cycle assessment (LCA) could take center stage in this transformation, not just as an economic instrument but as a means of unlocking the long-term social benefits of foresight, saved lives, minimized social disruption, and preserved public investments (Sevigné-Itoiz et al., 2021). Incorporating LCA based cost-benefit analysis into the disaster management cycle enables evaluation of mitigation, preparedness, response and recovery phases, helping decision makers allocate resources more efficiently and prioritize investments that strengthen long-term resilience. By aligning LCA based cost-benefit analysis with the disaster management cycle (Fig. 3), the cost of each phase i.e., mitigation, preparedness, response, recovery and adaptation can be evaluated in currency values. This monetary alignment helps decision-makers prioritize investments in flood management, ensuring that resources are allocated effectively to minimize long-term costs and maximize the benefits of building resilience, reducing flood damage, and speeding up recovery.

Proactivity emphasizes preparation and risk reduction before the floods occur, rather than reaction and reconstruction afterward. This shift is not only operational but conceptual. It means moving beyond conventional assumptions that floods are episodic "shocks" and, instead, seeing them as recurring phenomena that are intertwined with urbanization, climate change, and socio-environmental processes. In this sense, proactive flood governance represents a deeper transformation change in how communities and institutions understand risks and pertaining responsibility. Anticipatory instruments such as LCA-driven cost-benefit analysis are not optional but essential to resilience. The question is no longer whether floods will come, but whether our systems are ready to act in advance.

4. Conclusions

The integrated flood management framework (Fig. 4) exemplifies a proactive and holistic flood model for BC. It meets the four key principles that can effectively mitigate risks in the modern world, which is marked by "regression to extreme events". First, the framework reduces risks by anticipating extreme flood events beyond averages and preparing communities before the disaster strikes, and through LCA based cost-benefit analysis that influences the investment decision about the nature and types of relevant infrastructures. Second, it adheres to the precautionary principle by adopting forward-thinking policies, early warnings, and natural flood management to prevent cumulative risks. Third, it ensures that the required contingencies are in place through concerted efforts by different entities, including the government, Indigenous communities, emergency services, and the communities to ensure redundancies when extreme events occur.

Fourth, it adopts immediate pertinent actions through constant monitoring, community engagements, and infrastructural planning to reduce vulnerability to flood risks. This framework appears to be a robust model of flood management that can change the paradigm of flood governance from reactive responses to proactive approaches. Communities adopting this comprehensive framework expect to

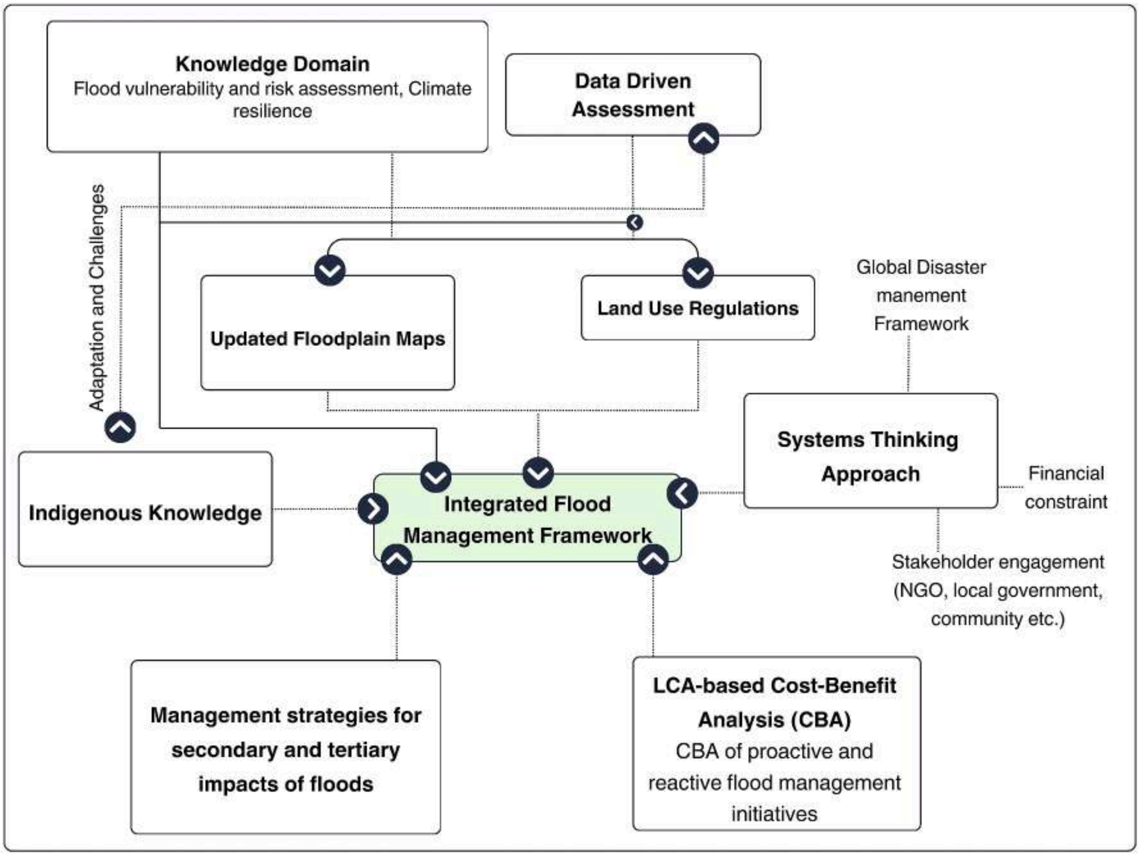

Fig. 4. Integrated flood management framework.

be better-off in preparation, less vulnerable, and have enhanced resilience in the face of increasingly severe and uncertain flood events. As such, it offers a governance framework that is better aligned with the complex realities of climate change.

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