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Integrating Participatory Visualization Methods to Explore Drivers of Change Within Flood Risk Management Systems

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Abstract

Flood risk is a wicked problem, characterized by non-linear dynamics, cross-scale interdependencies, and contested responsibilities. Disentangling who or what has the capacity to drive change in flood risk management (FRM) systems is a critical step for designing inclusive and sustainable risk-reducing interventions. Given the diverse range of actors often involved in FRM decision-making, it is necessary to consider different interpretations of what system features are important. Using participatory visualization methods this study applied a systems-thinking lens to examine how experts visualize the FRM system and its drivers of change in British Columbia (BC), Canada. Workshop one participants undertook group timeline mapping to visualize their understanding of the events and processes that have driven BC FRM system development. Workshop two participants completed open-ended concept maps, producing personal mental models of the features and relationships that make up the present-day FRM system. Data from both workshops were synthesized into a 'master' timeline and concept map, and the experts' perceived drivers of system change were identified. Our results revealed decentralizing governance shifts and past flood events as drivers of historic system development in the minds of our experts. Our results also indicated leverage points that experts had included as drivers of system improvement in their concept maps, with frequently named and connected features, such as the most interconnected feature: 'flood mapping', offering potential opportunities for cross-sector collaboration and cascading risk-reduction action. Possible gaps in the FRM system were also revealed by system features that were acknowledged as important by participants but were represented as disconnected, including themes of 'climate change impact' and 'reconciliation'. Participatory visualization methods, especially when used in combination, offer a practical approach for representing experts' mental models of FRM systems, revealing expert-identified leverage points for practical FRM improvement that can contribute to sustainable flood risk reduction goals.

Keywords: flood risk management; systems thinking; concept mapping; timeline mapping; participatory methods; governance; sustainability

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1. Introduction

Flood risk is increasingly being embraced as a wicked problem, in that it can be defined as a social issue that is multi-dynamic, interconnected, and difficult to manage [1,2]. As climate change intensifies hydrometeorological variability, many locations will see increases in flood damage [3] and the limitations of managing isolated components of wider flood risk systems will become more apparent. For instance, the past overemphasis on preventative, hard engineered Flood Risk Management (FRM) solutions over more holistic portfolios of risk-reducing options has been considered unsustainable and a contributing factor in the repetitive flood damage being faced by many communities [4]. Instead, authors are emphasizing the need for a shift towards a 'systems-thinking' approach that stresses the non-linear dynamics and linkages that are integral to flood risk [5,6]. An approach that views a system as an interconnected whole can afford decisions that better account for the interaction of physical, social, political, and economic processes that impact, and are impacted by, risk management decisions [7]. Such systems-oriented approaches are also closely aligned with broader sustainable flood management objectives, in that they emphasize the long-term coordination of environmental protection, social wellbeing, institutional capacity, and economic resilience within complex and interconnected human–environment flood systems [8,9].

Flood systems can be understood broadly to include all physical and organizational structures that influence or are influenced by flooding [10]. It is desirable to understand the dynamics underlying the system so that the components that have the greatest capacity to drive change in a sustainable manner can be identified [5,11]. Hall et al. [12] define a 'driver' as a phenomenon that may change the state of a flooding system. Drivers of change are crucial to recognize because they represent factors that may have large cascading effects if altered. For instance, in a flood system the enactment of floodplain management policy is a common driver of change as it is likely to impact many actors and activities in flood exposed areas. It is helpful to consider both current and historic drivers of change, as the identification of historic drivers can help reveal institutional inertia within current FRM systems [13,14].

Identification of drivers of change within FRM systems can be a difficult task. FRM decision making has become increasingly decentralized in many countries, with accountability devolving to a broad set of actors, each with their own (often conflicting) understandings of their FRM system [15]. Research has shown that the diversity of interpretations of FRM systems between flood management actors can hinder effective decision making, and that time needs to be spent to construct system interpretations that are meaningful to all involved [16]. When taking a systems-approach to FRM, eliciting expert participant knowledge can help uncover crucial factors that underpin the effectiveness of a FRM system, factors that may otherwise go missed through top-down, researcher-led modeling or review approaches that exclude diverse expert perspectives [17,18].

An intuitive way to represent experts' understanding of a FRM system is through visualization methods. Authors working on FRM have previously used methods such as causal loops diagrams [19], systems dynamics modeling [20], and group concept mapping [21] to visualize flood systems. However, when the goal is to represent expert knowledge as the primary data source, the visualization methodology also needs to be participatory in nature. Concept mapping (qualitative/open-ended) is a graphical elicitation tool and form of mental modeling that efficiently represents participant understanding of a prompted topic [22], producing a map that represents their personal knowledge structure while preserving their individual worldview [23,24]. While variations of open-ended concept mapping have occasionally been used to assess flood risk topics previously, e.g., [21,25–28], participatory concept mapping has been underutilized in the construction of FRM systems.

Timeline mapping is another participatory graphic elicitation tool, focused on aiding participants in their reflection and consideration of temporal events [29]. Timeline mapping can be especially useful for assessing causal pathways and isolating drivers [30] and has been used in hazard and disaster research to examine the development and success of risk management systems [31–33]. Once participatory data on a FRM system have been gathered, these data can be paired with other findings from sources such as policy assessment or other modeling outputs to provide a more complete understanding of a system [17].

This qualitative study evaluates how expert participants visualize a FRM system, and what factors they understand to be key drivers of change within it, both historically and currently, using the case of BC, Canada. Our objectives were to (1) characterize diverse expert perceptions of a present-day FRM system and (2) to isolate the historic and present-day drivers of change that experts believe are influencing the FRM system. To achieve these objectives, we undertook two participatory workshops in late 2023 and early 2024, utilizing concept mapping to capture experts' understandings of the present-day BC FRM system, and timeline mapping to ascertain what factors experts believe have driven the development of BC's FRM over time. The combination of participatory visualization methods presented in this study provide a practical approach for researchers and practitioners seeking to represent diverse stakeholder understandings of disaster management systems and identify perceived leverage points for advancing sustainable risk reduction action.

2. Materials and Methods

2.1. Study Context

The province of BC is situated along the Western coast of Canada and is exposed to coastal flooding from the Pacific Ocean, and riverine and pluvial flooding inland. The province typically receives consistent winter precipitation, often combined with higher magnitude events in the form of atmospheric rivers and storms, alongside the potential for rapid snowmelt during spring months [34]. Several major floods have impacted the province in the past, including the 1894 and 1948 Fraser River floods, and the 2021 atmospheric river flood events, all of which mainly impacted the lower mainland region of the province (Figure 1). Under climate change, it is predicted that the province will undergo alterations in the timing, magnitude and frequency of runoff and that flood severity will increase [35]. Flood damage estimates are also expected to rise with growing populations and urban development in flood-exposed settlements [36].

BC now has some of the most decentralized and complex flood risk governance of any Canadian jurisdiction. Flood management has a long history in BC, with First Nations communities speaking of ancient floods and traditional adaptation measures, before colonial settlers rapidly altered waterways in the name of flood prevention from the late 1800s onwards [37]. BC's FRM was historically overseen by both federal and provincial governments until the devolution of flood management to the provincial government in 1996 [38]. In 2004 the management of flood hazard land use decisions further devolved to the municipal government level [39]. In recent years the province has adapted its legislation to be in line with the United Nations Declaration on the Rights of Indigenous Peoples Act (DRIPA), seeking to provide Indigenous communities with more opportunity for their rights and worldviews to be reflected within disaster management practices [40]. Reconciliation is the ongoing action of establishing and maintaining respectful and equitable relationships between Indigenous and non-Indigenous peoples. These relationship-building principles are formally incorporated into BC's provincial disaster legislation, and reconciliatory ac-

tion, therefore, underpins the work of Indigenous and non-Indigenous flood management stakeholders alike in the region.

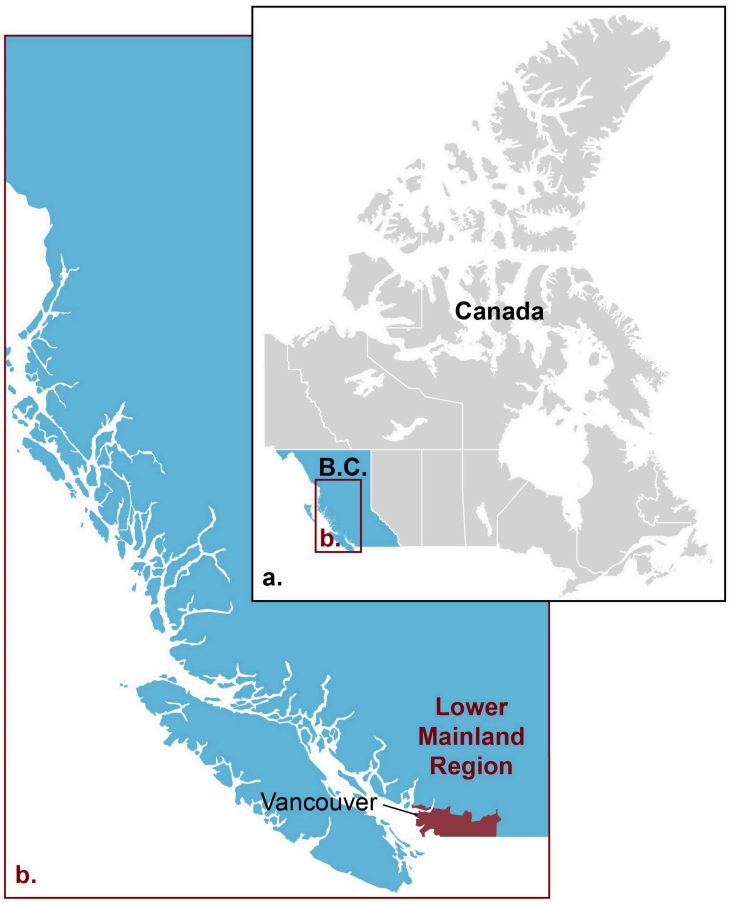


Figure 1. The lower mainland region (highlighted red) that is a notable example of an area that has been drastically impacted by major flood events in the past (**a**) within the wider province of BC (highlighted blue) which is the study area for this research (**b**).

Past research suggests "the current model for flood risk governance in BC is broken" [41] (p. 118) and recent severe flooding has brought the unsustainable nature of BC's current FRM system into the spotlight. The November 2021 floods that hit the lower mainland region saw a spike in flood-related policy and research in the province, with the creation of the new Ministry of Emergency Management and Climate Readiness in 2022, modernization of the province's Emergency and Disaster Management Act, and the release of the BC Flood Strategy. Despite this progress, to date limited funding has been allocated for FRM improvement [42], and floods, while remaining the most frequent disaster-causing hazard type in the province, continue to be under-researched when compared to other hazards in the region [43]. There is a gap for expert participants to share their knowledge of the BC FRM system.

2.2. Data Collection

Data for this research were collected across two participatory workshops, led by the Living With Water (LWW) research group, an interdisciplinary team of researchers and practitioners investigating flood resilience and coastal adaptation in BC.

The purpose of Workshop One (i.e., timeline mapping) was to capture experts' understandings of the historic drivers of change in the BC FRM system. Workshop Two (i.e.,

concept mapping) aimed to establish participants' perceptions of the present-day BC FRM system and current drivers of change.

Workshop sampling and data collection approaches differed substantially, with Workshop One consisting of an in-person grouped pool of seventy participants, while Workshop Two was made up of a smaller number of fourteen participants who worked individually but did discuss their maps in groups. The two workshops, therefore, had variability in group dynamics, elicitation environments, and levels of group consensus. Differences in sampling approach were in part, a result of the methodological requirements, with concept mapping needing a smaller number of participants in relation to facilitators, while the timeline mapping activity was simpler and could accommodate more participants. The differences were also a result of the data collection situation, with the timeline mapping workshop being designed to cater to conference attendees who were looking to collaborate and have discussions with one another.

The participatory methods were designed to be used in one-off, short workshop settings where participants have limited time. Therefore, reflective discussion and revision opportunities were incorporated throughout the data collection process. Semi-structured questions were asked to participant groups in both workshops to act as triangulation sources during data analysis [44,45]. Discussions at both workshops were audio recorded, and workshops operated under UBC Research Ethics Board approval (project H21-02199).

2.2.1. Timeline Mapping Data Collection

Workshop One took place in person at the Understanding Risk in BC (URBC) conference in October 2023, which brought knowledge holders, practitioners, and leaders from private, public and NPO sectors together to share multihazard understandings of the BC context. The workshop participants (n = 70) were attendees of the conference and were invited to self-select to participate in the workshop via email and during conference registration. As the goal of this research was to represent as many experts' experiences and perceptions of the BC FRM system as possible in a short amount of time, demographic screening did not inform participant selection beyond the requirement that they were attending URBC. There was a diverse range of institutions that were represented at the conference, including academia, local government, international representatives, and First Nations peoples. Participants were randomly placed into five groups (n = 14 per group) for appropriate facilitation size [46].

Participants had one hour to create their group timeline and were asked the operative question: "what events and processes have impacted and continue to impact BC's flood management?" Participants wrote down and noted the scale of events and/or processes individually first, before coming together in their group to place them chronologically along a timeline. Participants were asked to discuss their decisions with each other and with facilitators. Participants were then given five 'importance markers' to place on the events/processes they felt had the greatest influence on BC's flood management system. Participants were not asked to reach consensus on their group timelines, with individuals able to place their own events and processes as they saw fit. However, we acknowledge that the group workshop setting may have resulted in the dominance of certain participant voices with possible professional hierarchies and the potential for under-representation of minority voices. More details on the exact method used are covered in the LWW timeline report [47].

The result of the Workshop One data collection process was five timelines, with a total of 224 individual events/processes.

2.2.2. Concept Mapping Data Collection

Workshop Two took place online in January 2024. Fifty experts across academic, industry, government and First Nation groups were identified as holding high levels of knowledge about the BC FRM system and were invited to participate in the workshop. Fourteen experts accepted the invite and attended the workshop. Attending experts were from private industry (n = 5), the Government of BC (n = 4), flood-related NGOs (n = 2), academia (n = 1), Regional District Boards (n = 1), and First Nations Government (n = 1). The workshop took place over Zoom, using the software Miro (https://miro.com) [48]. We employed individual concept mapping as we wanted to make space for each participant to share their own unique perspective of BC's FRM system.

Participants were asked to complete a concept map, prompted by the questions:

- How do you understand flood management in BC?
- What makes up the flood management system in BC?

We followed an open-ended concept mapping procedure. There were four steps to the concept mapping process. (1) Participants placed concepts onto notes to form 'nodes' on individual boards. (2) Participants identified 'links' (directional arrows) between nodes, labelling links to describe the relationship. (3) Participants discussed their first map in small groups [49]. Participants then repeated steps 1 and 2, adjusting their maps [50]. (4) Participants reflected on their final maps and noted what was missing from the system they had visualized. Participants were encouraged to select their own nodes, links, and link labels [51], following the prompts provided by facilitators [49,52]. While the maps themselves were individually constructed, all participants discussed their maps with each other, which introduced the potential for group think issues (e.g., participant convergence on a smaller set of narratives), and the over-representation of dominant voices. We sought to limit these issues by reminding participants to ground their maps in their own personal experiences throughout the workshop.

The final 14 maps included 422 nodes and 437 linking relationship lines.

2.3. Data Analysis

2.3.1. Timeline Mapping Data Analysis

Following Workshop One, the 5 timelines were transcribed, noting original events/process titles, dates and associated notes. A final 'master list' was produced to create a summary timeline. It was necessary to validate the timings of the events/processes [53], so three members of the research team validated all events/processes. Events/processes referencing pre-colonial Indigenous activities were not 'validated' as we felt it is not the role of our research team to prove Indigenous histories [54].

To ascertain the relevance of each event/process to the BC FRM system, triangulation was undertaken, comparing participants' writing, notetakers' notes, workshop audio recordings of participants' explanations, and the researchers' findings while validating dates.

In total, we excluded 55 events that lacked participant explanation as to why they were relevant to the BC context in either the timelines themselves or any of the accompanying triangulation sources. The majority of these 55 events were international disasters (e.g., the 2011 Tōhoku earthquake and tsunami) that were raised by participants, but where no explanation for their relevance was offered. Other excluded events included technical advancements in flood modeling and management that lacked explanation, policy changes where no name or date were provided for the researchers to identify the particular instrument being referenced, and local flood events that once again, the researchers were unable to identify due to a lack of detail. An additional 31 events were also excluded because the timing/dates could not be validated by the research team, even if the relevance of the event/process was described by a participant. Most of these events were technical

advancements in flood modeling and management that were poorly recorded online (e.g., gauge measurement installations), and local policy and funding changes that were unable to be traced to any official documentation. Our exclusion process privileged events and processes that have an online dated record, except for events referencing Indigenous histories (all of which were included).

A total of 139 events/processes were included. Repeat events/processes across the 5 timelines were then collapsed and final event/process titles were discussed between three researchers, a total of 70 events/processes made up the final dataset. Any importance markers were summed for repeating events/processes.

Common themes that emerged inductively across the 70 final events and processes were coded and reviewed by two of the research team. Emergent coding was undertaken by both researchers, with discussion and reflection of the codes over an iterative process [55]. Thirteen final categories across the 70 events/processes were finalized for discussion and are elaborated on below.

2.3.2. Concept Mapping Data Analysis

Following Workshop Two, the 14 concept maps were transcribed and cleaned to produce a master concept map dataset and visualization [27,56]. During data collection, participants were encouraged to embrace the intricacy of their systems, and as a result many of the final concept maps featured complex net-type structures [57] with varying numbers of nodes and links. We felt that all maps represented expert constructions of experience were, therefore, important to include [58].

While the focus of the study was on the qualitative nature of concept maps, basic descriptive statistics were employed alongside experts' statements to assist in discerning nodes of particular importance from the perception of our participants. The number of outgoing and incoming links (outdegree and indegree), along with total number of connections (centrality) were recorded for each node [59]. Occasionally it wasn't possible to discern the nature of a link (n = 62, 14.2%), and in those cases, the link only counted towards final centrality score. It was essential to reduce the high number of nodes into a manageable dataset for production and interpretation of a master visualization, and to remove duplicated or highly similar nodes. Across the 422 nodes, similar nodes were collapsed under a common cleaned node name. A final list of 78 'cleaned' nodes was created by three members of the research team over four rounds of review, seeking the most appropriate overarching terms. Examples of this cleaning process and rationale for cleaning decisions are shown in Table 1.

The outdegree, indegree, and centrality scores of repeating nodes were combined to give an indication of what participants, after cleaning, felt to be influential nodes within the current system. Twenty-nine of the original 422 nodes (and their associated links) were excluded due to: a lack of clarity over what a node meant in either the map or accompanying audio recordings (n = 8); multiple concepts being included in a single node (n = 5); node title terminology that was too general and failed to be linked to the BC context (e.g., "disaster" or "solution") (n = 5); or node title terminology that stipulated that the node was lacking/not present which complicated other analysis steps (n = 11).

The final 78 'cleaned' nodes were emergently coded for overarching category themes and were reviewed by two of the researchers following the same approach as the timeline mapping. Categories were based on the content offered by participants, with the workshop audio recordings cross-checked to ensure interpretation of the experts' intentions behind their node meaning were correct [60]. Additionally, categorization relied on the deep knowledge of the local FRM landscape held by the two researchers undertaking the coding that helped connect the meaning of participants' nodes to their wider themes.

Table 1. Select examples of the concept map node cleaning and thematic grouping process. A simple example from the 'Flood hazard factors' category is shown, while all other examples relate to First Nations and their rights and knowledge to show how meaning was preserved or aggregated across similar node concepts.

Example Nodes from Individual Maps	Grouped Node Title After Four Rounds of Cleaning	Thematic Category of Cleaned Node	Rationale for Node Cleaning and Categorization
"Wildfire and logging worsen floods"; "Impacts from wildfires/logging"; "Wildfire"; "Forestry"; "Impacts of fires"	Wildfire and logging	Flood hazard factors	Wildfire and logging were grouped together as participants discussed the impact of loss of forest coverage on flood run-off potential (worsening flood hazard)
"First Nations"; "Indigenous governing bodies"; "Indigenous communities"	First Nations	Governance	These nodes referred to Nations as a key body or community within the governance system of FRM
"First Nation rights and title is a core consideration"; "First Nations title and rights"; "Canada inherent rights policy"; "Historic and modern day treaties"	First Nations Rights and Titles	Governance	Here the nodes refer directly to Nation rights to self-governance of disaster management and management of their reserve lands broadly
"Indigenous knowledge"	Indigenous Knowledge	Flood-understanding activities	Indigenous knowledge was discussed by participants in relation to understanding of past flood activity, so was grouped within this theme
"DRIPA"; "UNDRIP"; "UNDRIP/DRIPA"; "United Nations Declaration on the Rights of Indigenous Peoples"	DRIPA	Policies	DRIPA was referenced as its own key piece of international policy by many participants, so was preserved as a separate node rather than being grouped with other international policies
"Where risk reduction meets reconciliation"	Reconciliation	Resilience & Capacity	While reconciliation may relate to the 'First Nations Rights and Title' node, it was interpreted to instead refer to the improvement of flood management to be in line with the needs of Nations in BC, and therefore the resilience and capacity of communities
"Case Law: Delgammuu k/Tshelhqoti n/Yahee etc. Case law"	Case law	Policies	Case law was preserved as its own node as it was distinct from other non-Indigenous government legislation, while still relating to policy creation

Frequency of node mention [27,61] and node centrality [62] were used as general indicators of potential nodes of importance from the perspective of participating experts. Expert-elicited drivers of change were additionally identified as those nodes that had the

highest outdegree relative to indegree scores [11]. Given that 14.2% of node connection directions were unclear, outdegree and indegree scores provide only a cautious representation of participant identified drivers, while node frequency and centrality remain the focus of our results. Additionally, certain factors likely influenced participants' capacity to represent all drivers and linkages as they truly exist within their minds, including task interpretation, ease of Miro use, and how easily a particular node lends itself to linked causality.

Matrices from each of the 14 original concept maps were produced using the final cleaned node list, utilizing a binary linking system to represent a connection between two nodes. These 14 matrices were combined to produce a final matrix of all 78 nodes and links and was imported into the NodeXL Pro (version +1.0.1.559+) software to produce a 'master' concept map visualization [28,63].

3. Results

3.1. Visualizing the FRM System

To achieve our first objective of characterizing the expert understandings of the current BC FRM system, we produced a master concept map containing nodes from all 14 cleaned individual maps (Figure 2). Node frequency and centrality scores of both the final 78 nodes and their eight overarching thematic categories helped determine key features and topics of importance within the system, as it currently existed during the workshop. The results below discuss some of the nodes and categories that fell at the extremes of node frequency and centrality, assessing system features that were mentioned by all or many participants, along with their system connection patterns.

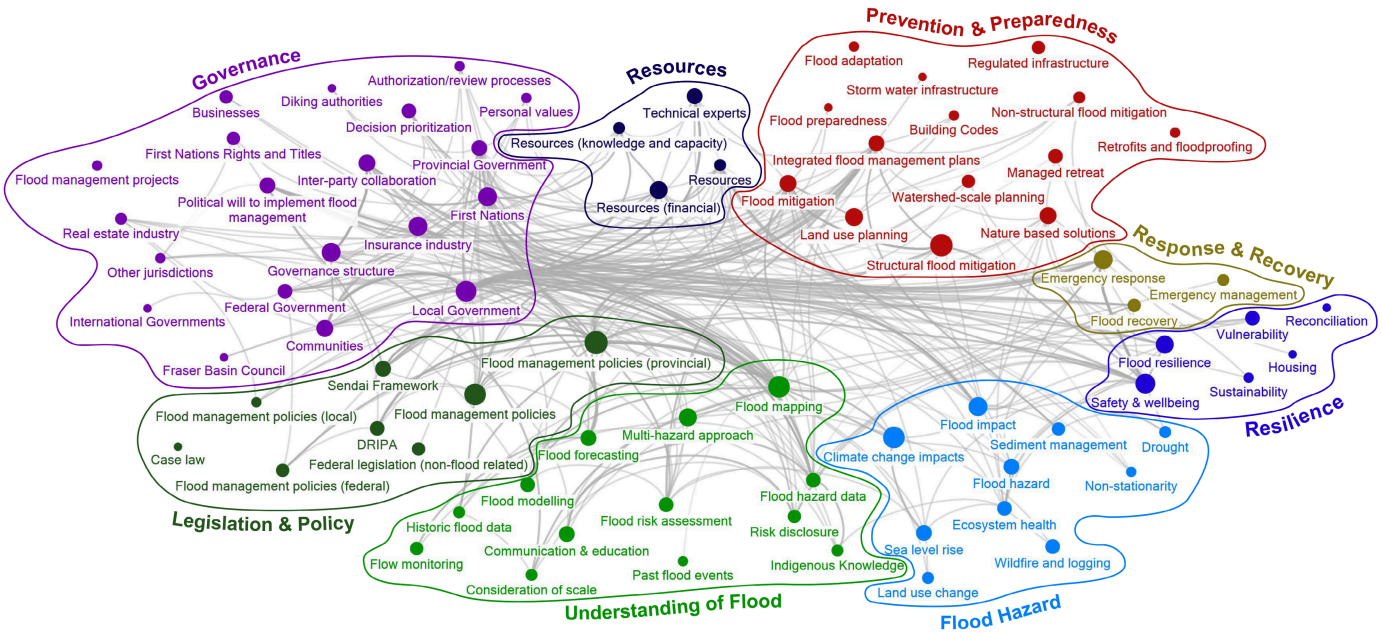


Figure 2. Master concept map showing the results of the 14 individual aggregated maps produced by experts from different FRM sectors in BC. Node size and link darkness correlates to the frequency of node mention and link identification across the 14 maps. The different colored zones represent the thematic categories that nodes were assigned during data analysis.

The largest category was 'Governance', with 24.4% (n = 96) of individual nodes aligning to this theme (Table 2). Unsurprisingly, Governance also had the highest centrality score, with 27.7% of all original links made by participants linked to nodes within this category, most commonly being connected to other nodes within the Governance category, and then the 'Understanding of Flood and 'Prevention and Preparedness' categories. Within

the Governance category, 'Local Government' was the most frequently mentioned node with the highest centrality score and ranked fourth for frequency of mention and second for centrality across all 78 final nodes (Table 3). The centrality of many of the nodes within the Governance category aligned with the participant assertions of the complexity of roles and responsibilities that currently make up BC's flood management system, with one participant noting:

> *"they have pages and pages and pages of all the different roles that these different bodies share and. . .it's a very complicated matrix. It would be really nice if we could clean that up a little bit, but that's major heavy lifting"*
>
> (Concept mapping participant).

Table 2. Node number, indegree, outdegree, and centrality scores for the eight concept map categories. Total centrality scores are higher than the sum of outdegree and indegree due to the presence of links where incoming or outgoing nature could not be discerned (n = 62).

Node Category	Frequency of Node (Count)	Frequency of Node (%)	Total Outdegree	Total Indegree	Total Centrality
Governance	96	24.4	101	96	242
Understanding of Flood	66	16.8	70	71	157
Prevention and Preparedness	65	16.5	49	57	108
Flood hazard	55	14.0	36	34	79
Legislation & Policy	48	12.2	53	31	101
Resilience	27	6.9	4	30	50
Resources	20	5.1	31	23	64
Response and Recovery	16	4.1	14	15	37

Table 3. Frequency of mention (may include multiple mentions within an individual's map), indegree, outdegree, and centrality scores for the ten most central concept map nodes. Total centrality scores may be higher than the sum of outdegree and indegree due to the presence of links where incoming or outgoing nature could not be discerned.

Cleaned Node Title	Frequency of Mention	Indegree	Outdegree	Centrality
Flood management policies (provincial)	14	25	13	42
Structural flood mitigation	13	7	12	19
Flood mapping	12	11	25	45
Flood management policies (non-provincial)	12	11	9	23
Climate change impacts	12	10	2	13
Local government	11	18	20	42
Safety & wellbeing	10	2	19	27
First Nations	9	9	15	30
Emergency response	9	10	11	25
Flood impact	9	4	10	20

'Understanding of Flood' was the second largest and most central theme that nodes were categorized into. Within this category, 'Flood Mapping' was the node that was most frequently referred to, scoring third-equal overall, and having the highest centrality score of all 78 nodes, suggesting the expert participants understood this node to be innately interconnected with the rest of the system.

Only two nodes: 'Flood Management Policies (Provincial)' and 'Climate Change Impacts' were mentioned by all participants in their individual maps. Interestingly, despite scoring third-equal in frequency of mention across all maps, 'Climate Change Impacts' did not score highly for centrality, possibly meaning that while participants recognize the

relevance of climate change, they do not believe it to be well-linked to the rest of the current system. Another possible explanation is that participants did not have the capacity to show how this node was connected due to factors such as time pressure or limitations with the Miro platform. Other nodes that were frequently mentioned by participants but were not well connected included 'Federal Legislation (Non-flood Related)' and 'Managed Retreat'.

It was not only the most frequent and central nodes that were of interest in characterizing expert interpretations of the present-day system, the isolated or infrequent nodes also reflected potentially interesting results. Several nodes such as 'Non-stationarity' and 'Reconciliation' were brought up, but participants failed (or chose not) to connect them to the wider system within the time provided. The role of First Nations in BC's FRM system was acknowledged in nine of the fourteen concept maps, but reconciliation was only raised by those in private industry, and was not raised by the First Nation government representative, although it is impossible to say whether this is because reconciliation is truly missing from the system, or because the predominantly non-Indigenous group found it to be a challenging concept to integrate within the time and methodological constraints of the workshop.

Other nodes were identified by participants from only one sector; for instance, only provincial government representatives included 'Diking Authorities' in their concept maps, while our First Nation Government representative was the only one to include the feature of 'Case Law'. These variations highlight the different actors' mental models of who and what is important in BC's FRM system, and the benefits of individual concept mapping as a first step for capturing system components that may be missed if only consulting one group of FRM actors.

3.2. Expert-Identified Drivers of Change

3.2.1. Historic Drivers of FRM Change

Timeline mapping results revealed information about key drivers of change in BC's FRM system historically. The 'master' timeline visualization can be found on pages 16–17 of the LWW timeline report [47]. Frequency of mention and ranking of importance were used to highlight the importance of various factors. Twelve (17.1%) of the final 70 cleaned events/processes were past flood events that have occurred in BC (Table 4). The category of 'Past Flood Events' had the second highest number of importance markers (n = 26), surpassed only by 'Treaty, Agreement or Legislation' (n = 28). Eighteen of the final 26 importance markers in the 'Past Flood Event' category were associated with the 2021 atmospheric river floods in BC, which had the highest importance ranking of any event or process that was identified by participants.

Enactment of 'Treaty, Legislation, or Policy' events/processes received the highest number of importance markers from participants. Provincial-scale legislation, such as the 2023 BC Emergency Management Act, National-scale legislation, such as the Indian Act, and International-scale policy, such as the Sendai Framework, were all brought up across multiple groups and received high importance rankings as drivers of change. Events/processes associated with governance change were also frequently identified by participants, with the shifting of management from provincial government level to the local government level receiving the second highest number of importance markers by participants (n = 9).

Only 6 of the final 70 events/processes were related to 'Anthropogenic Development', and these events didn't receive many high importance markers; however, 'Population Growth in BC' was the single most frequently mentioned event or process across all five groups, suggesting that while the process wasn't currently considered as important as other events, it was clearly influential in how the FRM system has grown.

Table 4. Total event/processes within each of the timeline map categories. Importance markers (provided by participants) were summed within each category.

Final Category	Frequency of Event/Process (Count)	Importance Marker Total
Past flood events	12	26
Treaty, legislation, and policy	9	28
Governance change	7	21
Other local hazard event	7	2
Anthropogenic development	6	11.5
Framework or guideline	6	11
Flood mitigation decision	5	11.5
Funding stream	4	7
Indigenous history	4	2
Climate or environmental impact	3	8
Other water management	3	1
International disaster event	2	2
New data capacity	2	1

3.2.2. Drivers in the Present-Day FRM System

Within the concept mapping phase of the study, drivers of change were defined as those nodes or categories of nodes that had relatively high outdegree compared to indegree centrality. That is, these are the nodes or categories of nodes that were perceived by participants to be influencing more of the system than the parts they were influenced by. A limitation of this approach to defining drivers of change was that 14.2% of the 437 participant-provided links (n = 62) could not be classified as outgoing or incoming because participants omitted directionality from their links. Indegree and outdegree ratios may also have been influenced by factors such as time pressure, or methodology misunderstanding meaning experts were unable to add all the directional arrows that they wished to. However, we still have included those categories with the strongest ratios for discussion to represent high-level and cautious insight into the experts' maps.

The legislation and policy category was the only category that clearly stood out as a driver of change, according to participant perceptions, with substantially more outdegree connections than indegree. Within this category both the 'Sendai Framework' and the 'Declaration for the Rights of Indigenous Peoples Act' were mentioned as key international policies that had notable influence over parts of the flood management system, with the Sendai Framework having no incoming connection, and the Declaration having an outdegree vs. indegree ratio of 3:1. Individual nodes with high levels of perceived influence over other nodes were 'Technical Experts', the 'Federal Government', and 'Climate Change Impacts', with outdegree vs. indegree ratios of 9:1, 7:1, and 5:1, respectively.

4. Discussion

4.1. Expert-Identified Drivers for FRM System Improvement

From two separate participatory workshops, we gathered a wealth of data on the BC FRM system from participants across diverse stakeholder groups. This data shows experts' perspectives of present-day system behavior and their understandings of the past events/processes that have driven the development of the FRM system. Here, we isolate which system factors have the greatest driving influence within the system from the perspective of our participating experts. While we consider both the current and historical factors of influence recorded by workshop participants, we acknowledge that the variation in workshop design makes direct comparison of the results imperfect. However, a qualitative assessment of the similarities and differences between workshop results still

affords interesting starting points for FRM system improvement in BC that add to other recent recommendations [41,64].

Consideration of who bears the responsibility for flood management in BC was clearly top of mind for participants in both workshops, with 'Governance' being the largest node category across the concept maps, and 'Change in Governance' being the second largest category of events/processes brought up by timeline mapping participants. The Canadian federal government was recognized as being a driver of change both historically and in the present-day BC FRM system, when it is involved. Within their constructions of the current system, participants attributed far more outgoing than incoming links to the 'Federal Government' node, suggesting its role as a potential 'driver' in the minds of the experts [11]. However, this driving nature is at direct odds with the 'Federal Government' node's lack of overall centrality or frequency of mention, suggesting participants may feel that, when involved, the federal government has the direct power to influence change within the BC FRM system, but that it is currently not doing so. The significance of the federal government and the importance of decentralization in BC was also reflected in the minds of the timeline mapping participants, with the events of the exit of the federal government from BC flood management, and the further devolvement to local government management in 2004 receiving amongst the highest number of 'importance markers' from participants.

Whether it is better to handle FRM at the central or decentralized level is not a simple question, but previous scholars have asserted that for decentralization to be effective and allow for locally relevant management decisions to prosper, appropriate resourcing and support are essential [65,66]. While participants recognized the value of different funding streams, financial resources were some of the least identified topics across both the concept mapping and timeline mapping activities. Indeed, many participant discussions in both workshops focused on the lack of funding and resource, attributing the issue in part to the decentralized system. One timeline mapping participant stated:

> *"Funding shifts to local government. . .pushed onto local authorities who don't have the same tax base to pull from. . .that's why you're seeing a lack of updates in the last 20 years"*
>
> (Timeline mapping participant).

Authors argue that a decentralized governance approach may be effective under certain disaster management conditions, but this needs to be accompanied by additional collaboration solutions [67]. The most central concept map node through this work: 'Flood mapping' could act as a potential collaboration driver in BC. Participants recognized how flood mapping was both impacted by governance and funding changes but also had the power to pragmatically drive improvements across management decisions, an opinion that has previously been communicated in Canada [68]. One participant asserted:

> *"I think the flood hazard mapping, or accessibility to consistent and trusted data, is a really good place to start because it's one place where I think we can get everyone on the same page and then moving forward"*
>
> (Concept mapping participant).

Flood mapping is intrinsically linked to the effective function of many FRM tools, providing spatial information that can support decisions at prevention, preparedness, and response stages [69]. Participants pointed to the ability of something as data-driven as flood mapping to act as a bridge-building point of agreement between diverse actors and institutions involved in FRM, acting as a catalyst to bring back some of the more centralized FRM governance that was once praised in the province [38].

Examples of flood map activities fueling collaborations in BC have been seen in recent years, with the arrival of new federal cost-sharing programs providing resources for

mapping to take place, and for cross-organization collaboration to occur [70]. The Fraser Basin Council in BC directly collaborates with federal, provincial, and local government partners in their watershed-scale flood mapping activities, while also engaging First Nations in the mapping process [71]. Authors have shown that exposure to flood information can trigger stakeholders to be more pragmatic in seeking further information and solutions [72]. Additionally, if a finalized flood map is collectively agreed on by multiple parties, the use of map information to authorize other risk reducing decisions (e.g., land use planning, new flood infrastructure installation) should, in theory, progress more smoothly.

Of course, flood maps are not politically neutral and can act as sources of contestation even as they drive collaboration [73]. Flood maps typically involve the encoding of flood behavior assumptions and uphold the engineering-centered definition of flood as the singular correct approach to understanding flood hazard and risk. Additionally, as maps are used in financially impactful decisions, such as the setting of insurance premiums and land use restrictions, caution must be taken to ensure maps don't exacerbate pre-existing inequalities [74]. However, if early collaboration with diverse stakeholder groups during map production can be achieved, the resulting map uses can be more equitable and sustainable in nature, aligning with the interests of multiple stakeholder groups [75].

4.2. Expert-Identified Gaps in the FRM System

By employing and comparing participatory methods that allow individuals with diverse experiences to represent their own FRM system interpretations, surprising outliers and system gaps that may otherwise be missed can be recognized [21]. In general, disconnected concept mapping nodes that participants failed to connect to the wider system (e.g., 'Non-stationarity'), or that were only brought up by participants from a single sector (e.g., 'Land use changes') may represent features that are under-considered in the current FRM system. Additionally, features recognized as important in the timeline mapping workshop but that failed to be identified in the present-day system may represent areas of inaction or that are perceived as unsustainable, although the differences in data collection setting between the two workshops makes this direct comparison challenging. We also acknowledge that things like time restriction, Miro usability restrictions, and the level of method or concept understanding amongst participants likely played a role in influencing the ability of experts to bring up or link all factors that they may have wanted, although the accompanying interview questions specifically created space for participants to raise anything they felt was flawed or missing in their maps.

In our results, 'Reconciliation' (the ongoing process of building respectful, equitable relationships between Indigenous and non-Indigenous peoples in Canada) emerged as a potential gap based on our experts' representations of the current FRM system. Recognition of the role of 'First Nations' was included in most of the concept maps, but 'Reconciliation' was notably largely absent and was left entirely disconnected from the system when mentioned. There are many reasons why this might be, including that participants are unaware or unconvinced that reconciliation has had an impact on BC FRM, but also possibly that participants lacked time to connect such a complex concept within their maps, or did not feel comfortable discussing the concept amongst the primarily non-Indigenous group. Only one participant was a First Nations representative so assessment of the true impact that reconciliation is having on BC's FRM system cannot be discerned from this study. However, reconciliatory action is, by definition, a two-way process that requires active participation by decision-makers across non-Indigenous institutions to be effective, and our non-Indigenous participants primarily worked for institutions with stated reconciliation values and goals. Given this, and the Government of BC's efforts to increase reconciliatory disaster policy [76] we were surprised by the lack of reconciliation connection within the

participants' system visualizations, although the concept was raised as important during breakout discussion:

> *"I think. . .everybody's got this, where risk reduction meets reconciliation in BC is so crucial. . . really working with our host nations to change the flood risk governance models and work on what needs to happen for risk reduction"*
>
> (Concept mapping participant).

The lack of connection between reconciliation and the wider current system was in contrast with the multiple Indigenous history events/processes that were identified by timeline mapping participants as being important in the development of the BC FRM system. These findings align with comments from the wider literature on the ambiguity of reconciliation in research and practice [77,78]. Based on the workshop findings, experts in BC are aware of how important Indigenous peoples have been in past disaster management, and that First Nations remain central to current management practice, but the concept of reconciliation and the deeper advancement of FRM to be in line with Indigenous needs was not well represented. Participants expressed concern over how to better include Indigenous peoples in the governance of BC FRM, with one timeline mapping participant suggesting:

> *"Incorporating Indigenous knowledge in flood planning is really important. . .how do we listen to their voices, have their perspectives at the table and make sure that those solutions are being brought forward, rather than taking an umbrella approach to flood risk management?"*
>
> (Timeline mapping participant).

Another gap that was highlighted in the experts' representations of the present-day system was the role of past flood events. Past floods were the most frequently mentioned type of event/process in the timeline mapping activities. Participants felt that these events have had an essential role in shaping the BC FRM system, with the 2021 BC flood event receiving the greatest number of 'importance markers' of any of the events/processes. On the other hand, 'Past flood events', while brought up in the present-day concept maps, was one of the least frequent or connected nodes of the entire set. This could suggest, once again excluding methodological issues, that experts in BC believe there is a pattern of not accounting for the lessons of past disasters [79] in the present-day BCFRM system. A lack of consideration of past events in the current system may be in part encouraging the path dependent systems and general inertia on FRM action that has been criticized in BC in the past [80,81]. Previous authors have pointed to the value of taking advantage of the policy windows that open following disaster events to enact quick and enforceable action that can support sustainable risk reduction moving forwards [82]. There needs to be opportunity for better recognition of the value of flood events when they occur, and embedded governance processes that enable decision makers to adapt the system when these 'windows of opportunity' present themselves.

4.3. The Value of Participatory Visualization Methods in FRM Systems Thinking

Expert participatory input is an essential step in the creation of effective FRM solutions and the enhancement of sustainable and livable societies [28]. Western flood management is inherently siloed [83] and FRM actors experience flood systems differently [16]. Given this, participatory methods that can allow participants to freely express their individual world-views and lived experiences should be sought out. Such methods need to be accessible and transparent for participants who are unfamiliar with technical elicitation procedures [84].

The open-ended concept mapping and timeline mapping methods described in this article provide an intuitive approach for participants to represent their mental models of a FRM system, offering a way to legitimize the knowledge of diverse participants [85].

The visualization process allows for the collection of otherwise inaccessible data that can complement other modeling and assessment sourced datasets to provide as accurate as possible a representation of a FRM system [20]. As climate change alters flood behavior it becomes increasingly difficult to work from historic data to predict patterns within systems [86]. As shown in this paper, participatory visualization methods can reveal perceived causal relationships and system gaps that actors hold knowledge of, but that may not have been readily revealed through other methods such as survey or interview. This is especially true when cross-comparing multiple methods as we did here [87,88], providing an opportunity to discuss similarities and differences between historic and current day system drivers in a qualitative manner.

Beyond more holistic system portrayal, the process of participatory system-construction can allow for sharing of participants' individualized causal assumptions and help them render or even broaden who or what they consider to be important within a FRM system [89,90]. This process produces management solutions that can be more mutually agreeable to all parties involved [91], prompting sustainable decisions that can drive risk reduction into the future. Past research into water management has shown that different sectors perceive decision-making and uncertainty differently [92], and indeed, that actors within FRM systems can have entirely different constructions of what FRM entails [16]. It is, therefore, important to consider the use of methods that can uphold unique individual perceptions, even as you seek to formulate a consolidated system construction [7].

There is a tendency towards simplification when addressing disaster issues [79], with a desire to attend to only a sub-set of the important facts of a risk system when making decisions. Instead, embracing the messiness of a system in the earliest phases of its depiction, by inviting diverse perceptions on what is important to consider, can unlock key insights into who or what is most capable of driving change. In turn, practical visualization tools, like the ones presented here, can ultimately support sustainability across flood-impacted social, ecological, and economic systems by promoting long-term institutional change, social inclusion, and adaptive capacity building [28].

4.4. Future Research Opportunities

We recognize opportunities to build upon the insights and methods presented in this paper. The visualizations produced here represent only a single snapshot of the perceptions of the experts who participated in our workshops. In the case of our concept map, this means our final visualization represents predominantly settler institutional perspectives of BC's FRM system as of 2023. Further work is needed to understand how flood management experts from First Nations across BC experience the province's FRM system.

In general, the final interpretations of our concept and timeline mapping visualizations were influenced by the methodological limitations that we have described throughout this paper, including data collection constraints and challenges associated with the necessary cleaning and grouping of large numbers of concepts and events/processes into 'master' datasets. Open-ended concept mapping remains an under-explored method in relation to FRM system understanding, with only a few examples in the literature, e.g., [21]; further investigations into appropriate standardization of the method would be beneficial. Future studies seeking to use open-ended concept or timeline mapping methods should consider adding a follow-up session for participants to review the master visualizations to further validate final interpretations, although our in-built review sessions were a promising approach for contexts that demand a single engagement session (e.g., conferences).

Finally, while our methods offer a proof of concept for the gathering and representation of expert perceptions of a localized FRM system by combining visualization methods, to accurately represent a FRM system in its entirety, these participatory results should

be considered alongside other data. As authors have previously noted, participatory mental modeling approaches work best as social learning tools [93], and as a solution for ensuring diverse participant perspectives are included [85]. Participatory visualization tools have their shortcomings, being typically a static representation of perceived system components, while also failing to account for things like uncertainty [94]. Further systems data sourced from analysis of relevant policy [95], published literature [5], non-visual participatory methods [96], combining of timeline data into the system model [97], and other flood systems modeling based on researcher-led feature inputs [98], can all provide additional system understanding and validation opportunities. Additionally, modeling of the quantifiable effect of the different drivers identified through participatory methods may also be useful to explore [99]. Nevertheless, the results of participatory visualization approaches offer excellent qualitative baseline data that can be inclusive of a wide range of actor perspectives, and that can then be used in weighting and simulation of potential FRM decisions [17].

5. Conclusions

As flood damages rise globally, stakeholders require tools that help visualize the complex system interactions driving flood risk to identify solutions that support the long-term sustainability of social, environmental, and economic systems. This qualitative study aims to characterize experts' perceptions of the FRM system of BC, Canada by employing two separate participatory visualization methods. We drew on a systems-thinking approach and employed participatory concept and timeline mapping across two workshops with different groups of expert participants. Our results revealed the factors that experts believe have driven change in the BC FRM system in the past, and the drivers that currently shape the system. Participants in the timeline mapping workshop selected past floods, the enactment of treaty and policies, and major decentralizing governance shifts as the main events/processes that were responsible for driving change in BC's FRM system historically. On the other hand, participants in the concept mapping workshop highlighted factors, such as Local Governments and Flood Mapping, as major central forces within the present-day system. Additionally, our results revealed several potential weaknesses in the current FRM system where factors were frequently mentioned by the participating experts but were poorly connected (e.g., climate change impacts) or were largely excluded and entirely disconnected (e.g., reconciliation). Such features were raised as important, but due to a variety of possible reasons, participants failed to identify how the features were impacting or being impacted by the rest of the system.

This study adds to the growing body of literature seeking to engage participants from diverse decision-making groups in the construction of flood system understanding. Participatory methods must be intuitive and adaptable enough to allow participants to represent their own unique worldviews and lived experiences if holistic and inclusive FRM system understanding is to be achieved. Such participatory approaches can inform decisions that support more sustainable risk reduction as they align to the needs of a wider range of interested parties.

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Data Availability Statement: The cleaned dataset generated and analyzed during this study is publicly available at https://figshare.com/s/6a1531adc1583a9832af (accessed on 25 May 2026). The final visualization of the timeline material can also be found in the LWW timeline report [47]. The raw data associated with this study is not available due to privacy and confidentiality considerations.

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Abbreviations

The following abbreviations are used in this manuscript:

FRM	Flood Risk Management
BC	British Columbia
LWW	Living With Water

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