DOCTORAL CONSORTIUM

AN INTEGRATED DECISION SUPPORT FRAMEWORK FOR MULTI-PHASE FLOOD EVENT MANAGEMENT

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Effective flood event management requires coordinated decision-making across preparedness, response, and recovery. Current decision support systems (DSS) handle these phases separately, leaving operational managers without a unified informational picture when it is most needed. This doctoral research develops an integrated DSS framework that unifies heterogeneous data sources - from hydrological models and IoT sensors to satellite imagery and social media - following a Design Science Research (DSR) approach. In this paper, we present the results of a preliminary literature review aimed at identifying the research gap. The review confirms that no published work integrates data across the full risk management cycle - from early warning through response to recovery. Building on this gap, the paper outlines the research design and expected contributions: (1) a DSS framework addressing cross-phase decision support, and (2) a methodology for heterogeneous data integration in flood management. The research addresses both technical and institutional dimensions of fragmentation.

Keywords:
decision support system,
flood management,
heterogeneous data
integration,
interoperability,
disaster response,
design science research

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1 Introduction

Floods are one of the most common and destructive natural disasters in the world, requiring rapid, informed decisions across multiple organizations. Effective flood event management comprises three phases: preparation (before the event), response (during the event), and recovery (post-event). Each phase involves different actors, data requirements, and decisions.

These decisions are currently supported by a disjointed set of tools. Meteorological forecasts, satellite imagery, IoT sensor data, hydrological models, and logistical data are all maintained in distinct systems that were not designed for interoperability. Under time constraints, operational managers are required to integrate data from multiple heterogeneous sources without access to a fully coherent situational overview.

Slovenia's August 2023 floods made the problem visible. They ranked among the most damaging in the country's recent history, sweeping through buildings, infrastructure, and farmland across several river basins (Bezak et al., 2023). Existing tools could not handle an event of that magnitude. As recovery demands accumulated, fragmented systems fell behind, and decision-makers operated without a unified picture of conditions on the ground.

The research question motivating this doctoral project is, *"How can heterogeneous data sources be integrated into a unified DSS architecture that supports decision-making across all phases of a flood event?"*

This proposal presents the research design, expected contributions, and current progress toward answering that question.

2 Problem Definition

2.1 Organizational and Institutional Dimensions

The fragmentation is not solely technical. Sensor systems often fail to integrate because of how agencies handle the data – not because of the technology itself. One agency may treat a reading as reliable, another may discount it, and a third may interpret the same value under its own protocol (Hong & Shi, 2023).

The main obstacle to next-generation operational flood DSS is the absence of cross-agency collaboration on shared frameworks (Schwanenberg et al., 2018). Recent empirical work identifies three structural barriers behind this gap. First, flood management is institutionally fragmented, split across several sector mandates. Second, incompatible datasets prevent agencies from forming a common operational picture. Third, capability injustice persists: access to advanced tools is unequal, leaving local responders with limited operational information.

This research addresses both the technical and organizational dimensions of integration.

2.2 Research questions

RQ1: What are the documented gaps in existing DSS approaches for flood management, across data sources, supported phases, and architectural design?

RQ2: What data integration approach can consolidate heterogeneous flood management data sources into an interoperable format for operational decision-making?

RQ3: What DSS framework supports decision-making across all three phases of a flood event, and how does it address the identified gaps?

3 Methodology

The research follows a Design Science Research (DSR) approach, grounded in the foundational framework for information systems research by Hevner et al. (2004) and operationalized through the process model of Peffers et al. (2007). This DSR approach is selected because it combines methodological rigor with practical utility — it demands both theoretical grounding and a demonstrable artifact validated against the needs of operational decision-makers. Steps are visually explained in Figure 1.

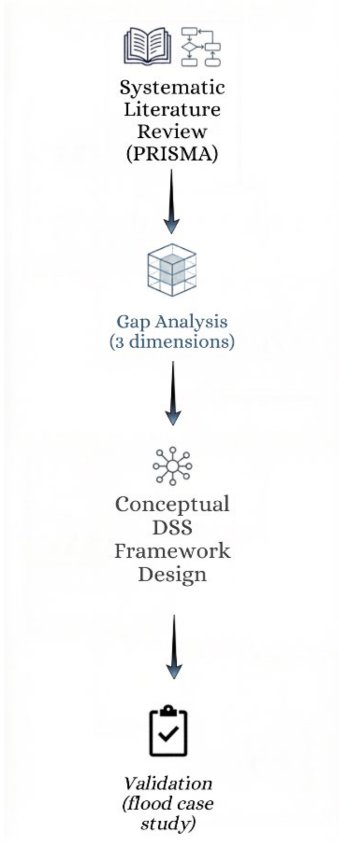

Figure 1: Research Design Following a DSR approach
Source: Own

3.1 Phase 1: Systematic Literature Review

The review performs a structured search across Web of Science, SCOPUS, and ProQuest, using keyword combinations covering DSS, flood management, data integration, interoperability, real-time operation, and heterogeneous data sources. The search strategy is supplemented by snowball sampling following key references (Wohlin, 2014; Snyder, 2019).

Results will be organized in a comparative matrix showing, for each reviewed work, data sources used, flood management phases supported, architectural approach, and documented limitations. This matrix is the primary input for gap analysis.

3.2 Phase 2: Gap Analysis

The gap analysis proceeds across three dimensions:

1. Data sources — which sources are systematically absent from integrated approaches;
2. Phase coverage — which flood management phases lack adequate decision support;
3. Architectural gaps — which interoperability and semantic alignment challenges remain unresolved.

The output is a gap taxonomy serving as the design specification for Phase 3.

3.3 Phase 3: Conceptual DSS Framework Design

The conceptual DSS framework will specify:

- Which data sources to integrate (hydrological models, IoT sensors / Internet of Things, satellite imagery, meteorological forecasts, social media data, logistics data);
- What architecture supports consistent data exchange and semantic interoperability across these sources?
- How the system structure supports different decision types in each flood management phase.

The framework is the primary scientific artifact of the research.

3.4 Phase 4: Validation

The framework will be validated through a case study of the August 2023 Slovenia floods (Bezak et al., 2023), with semi-structured interviews with domain experts providing operational perspective. Two questions guide validation: Would the framework have given decision-makers a more integrated picture than tools available in 2023, and does it address the specific decision points where information was missing or delayed?

4 Preliminary and Expected Results

4.1 Systematic Literature Review

A systematic keyword search across Web of Science, SCOPUS, and ProQuest Dissertations & Theses confirms that existing DSS research for flood management is extensive but partial. The closest matching search string - *"decision support tool AND flood AND web-based AND forecast AND operational AND real-time AND river"* - returns zero results in Web of Science, confirming that no published work addresses the full problem scope. The literature clusters around five distinct areas.

Early warning systems. The strongest concentration of research addresses flood early warning. Multiple studies confirm that IoT sensor networks, machine learning algorithms, and web-based forecasting interfaces can reliably detect flood risk and alert decision-makers (Ilukkumbure et al., 2021; Lin et al., 2022). The technical performance of these systems has improved substantially over the past decade. Yet a consistent operational gap persists: early warning tools function as standalone applications. They generate alerts but do not feed those alerts into the logistics and coordination systems that emergency managers need to act on them. The practice, the warning reaches the right channels, but converting it into coordinated action still depends on manual handoffs between disconnected systems (Hong & Shi, 2023; Pantalona et al., 2021).

Hydrological forecasting models. Flood forecasting has matured technically. Hybrid approaches now blend numerical weather prediction with remote sensing and in-situ data, producing compound flood impact estimates that go beyond simple river-stage prediction (Láng-Ritter et al., 2022; Refadah, 2025). The challenge that remains is operational forecasts are probabilistic outputs, but emergency managers must usually act on a single, readable risk picture. Even an accurate model loses practical value when its confidence cannot be delivered alongside the forecast (Yu et al., 2025; Adler et al., 2025).

Social media and crowdsourcing. Citizen-generated data is gaining traction in flood monitoring research. Geo-referenced social media posts capture real-time flood conditions at a level of detail that fixed sensor networks cannot reach (Dujardin et al., 2025). Pairing crowdsourced observations with remote sensing improves damage assessment (Akhtar et al., 2024), and feeding them into hydrological models yields measurable gains in forecast performance (Songchon et al., 2023). The gap is structural rather than technical: these data are still treated as research inputs and rarely make it into the real-time tools that emergency managers actually use during an event. Their value sits mostly in post-event analysis.

Coupled agent-institution models. A smaller but theoretically significant body of research moves beyond technical components to examine how institutional factors shape flood response. The CLAIM framework (Abebe et al., 2019) couples hydrological simulation with agent behavior and institutional rules, modeling how organizational protocols and inter-agency mandates influence response effectiveness. This line of work is valuable because it names what purely technical DSS approaches tend to assume away: that institutions will coordinate smoothly if given good data. In practice, coordination depends on shared procedures, compatible authority structures, and agreed-upon definitions of critical concepts. Despite its relevance, this modeling tradition has not been integrated into operational tools.

Recovery-phase systems. Recovery represents the most significant gap in the DSS literature. Existing systems are designed to support the active event phase and are not built to carry information forward into reconstruction decisions. When a flood event ends, the data generated during response — damage locations, affected populations, and resource allocations — is rarely aggregated in a form that supports structured recovery planning. Socioeconomic dimensions are consistently underrepresented in this literature. Community-level vulnerabilities shape the speed and fairness of recovery (Park et al., 2024; Mendis et al., 2024), yet DSS tools rarely capture either dimension. The build-back-better principle, although prominent in policy texts, sees little concrete implementation (Birkmann et al., 2023).

The pattern across these five areas is consistent. Each domain has produced technically capable, well-validated tools that address one component of flood management effectively. What the literature has not produced is an artifact that connects these components — carrying information from early warning through active response into recovery, across the institutional boundaries that separate the agencies involved. Most existing DSSs handle single decision points and stop short of supporting the full risk management cycle (Pantalona et al., 2021). The only doctoral study addressing all three flood management phases does so exclusively in a developing-country context, making direct transfer to institutional systems such as Slovenia's unreliable (Thomas, 2017). A summary is provided in Table 1.

Table 1: Summary of DSS Research Areas — Key Capabilities and Documented Gaps

Research Area	Key Capability	Documented Gap	Source
Early Warning Systems	Real-time detection, IoT alerts	No integration with response logistics	Ilukkumbure et al. (2021); Lin et al. (2022); Hong & Shi (2023); Pantalona et al. (2021)
Hydrological forecasting	Compound flood models	Uncertainty not communicated operationally	Láng-Ritter et al. (2022); Refadah (2025); Yu et al. (2025); Adler et al. (2025)
Social Media & Crowdsourcing	Granular real-time data	Not integrated in operational tools	Dujardin et al. (2025); Akhtar et al. (2024); Songchon et al. (2023)
Coupled agent-institution models	Institutional behaviour modelling	Not integrated into operational DSS	Abebe et al. (2019)
Recovery-phase systems	-	No cross-phase data continuity	Park et al. (2024); Mendis et al. (2024); Birkmann et al. (2023)

Source: Own

4.2 Expected Scientific Contribution

Contribution 1 - Methodology for heterogeneous data integration in flood management. The methodology details a procedural sequence for unifying five heterogeneous source types – hydrological models, IoT sensors, satellite imagery, meteorological forecasts, and social media data – into a single interoperability layer that operational decision-makers can directly use. The methodology will address both technical interoperability (data standards, APIs, update frequencies) and semantic interoperability (ensuring shared meaning of key operational concepts such as "risk level" across agencies).

Contribution 2 - DSS framework for integrated flood management. A specification covering all three flood management phases, with defined components, data flows, and adaptation mechanisms for different stages of event development - from early warning through active crisis management to recovery coordination.

Together, these contributions address a documented gap at the intersection of information systems design and disaster management practice. The research extends the DSR tradition in information systems (Hevner et al., 2004) into the domain of multi-phase, multi-agency crisis management.

4.3 Expected Practical Contributions

The practical value of the research is direct. Emergency management organisations - civil protection services, hydrological agencies, and local authorities - currently coordinate across multiple disconnected systems. A DSS framework would:

- Enable a Common Operational Picture (COP) accessible to all involved agencies in real time;
- Reduce the capability injustice between national and local responders by providing a shared informational baseline;
- Support recovery planning by making response-phase data (damage extent, affected areas, priority needs) continuously available, without requiring manual re-aggregation.

Data uncertainty remains a poorly addressed problem in flood decision-making (Yu et al., 2025). The framework tackles this by attaching reliability and provenance markers to each integrated data stream. Decision makers can then judge both what the data shows and how much to trust it.

5 Future Development

Phases 1 and 2 – the systematic literature review and gap analysis – are scheduled for completion by early 2027.

Following the validation phase, the research opens several directions for future development:

- Empirical validation and potential implementation of the conceptual artifact in collaboration with operational flood management organizations, such as the Administration for Civil Protection and Disaster Relief (URSZR), as a direction for follow-on research beyond this doctoral project;
- Extension to other disaster types where similar data fragmentation problems exist (wildfires, earthquakes, industrial accidents), testing the generalisability of the integration methodology;
- Development of open data standards for interoperability in emergency management systems, informed by the gap taxonomy;
- Deeper integration of socioeconomic vulnerability data into recovery-phase decision support, addressing the finding that marginalized communities are consistently underrepresented in post-flood reconstruction decisions (Park et al., 2024; Mendis et al., 2024).

The research is positioned to contribute to both the academic literature on information systems design and practical improvements in how flood events are managed — reducing the informational gaps that slow response and increase damage.

AI Usage Statement

The authors used artificial intelligence tools during the preparation of this manuscript. Specifically, Claude (Anthropic) was used to support drafting, language refinement, and paraphrasing of the text. Scribbr AI Proofreader was used for grammar checking. The authors verified all AI-generated content against primary sources, conducted independent literature searches, formulated the research questions and methodology, selected and evaluated the cited works, and reviewed and revised all AI-assisted text to ensure accuracy and academic integrity. The intellectual contributions presented in this paper — including the identification of the research gap, the proposed DSS framework concept, and the research design — represent the authors' original work. The authors take full responsibility for the content of this submission.

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