

Examining the Experiences in Developing Flood Disaster Database System From a Full-Cycle Management Perspective

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ABSTRACT

Flood disaster databases constitute a critical foundation for enhancing disaster risk reduction (DRR) capacities. Although China has achieved initial progress in developing the National Comprehensive Natural Disaster Risk Database, the fine-grained construction of its data systems and the efficacy of its comprehensive service applications require further exploration and refinement. Given the relatively mature disaster database systems in some developed countries, which offer valuable reference, this study adopts a full-cycle management perspective to construct a novel comparative research framework on the differences. The article points out that the development of China's flood disaster databases faces bottlenecks: inaccuracies in pre-disaster risk forecasting, lags in mid-disaster emergency response, and difficulties in institutionalizing post-disaster experiences. These challenges expose a full-cycle data fragmentation issue. Conversely, countries like the USA and the Netherlands have accumulated extensive pioneering experience in data standardization, dynamic simulation, collaborative governance, and societal application. Simultaneously, its practical bottlenecks regarding data coverage, response timeliness, and equity in resource allocation provide critical reflections for China's localized exploration. Accordingly, this study proposes a localization pathway for China's flood disaster database system construction:

institutionally, it is imperative to accelerate the establishment of a government-led, multi-departmental collaborative management mechanism; technologically, priority should be given to advancing flood risk mapping and developing multi-source data integration platforms; in terms of social aspect, regional pilot programs should be conducted in key river basins to evaluate strategic feasibility. These strategies aim to steadily enhance the comprehensive efficacy of China's flood disaster databases, thereby facilitating their progressive optimization.

KEYWORDS

Disaster Database; Disaster Management Cycle; Localization Strategy; Flood Disaster; Comparison Study

HIGHLIGHTS

- Disaster database development plays a crucial role in decision support for comprehensive disaster mitigation
- Adopts a full-cycle perspective to diagnose local issues and analyze the global experiences and shortcomings
- A localized institutional-technological-social strategy turns scale advantages to mitigation efficacy

1 Introduction

Driven by climate change, hydrometeorological events currently account for over 90% of all global natural disasters^[1], with floods standing out as exceptionally destructive hazards. In China, spatial

exposure to varying degrees of inundation affects roughly two-thirds of the national territory, making flood mitigation a critical imperative within contemporary disaster risk reduction (DRR) agendas^[2]. Guided by the Sendai Framework for Disaster Risk Reduction 2015–2030^[3], the global community has identified the

substantial mitigation of disaster risks and socio-economic losses as a primary objective^[4]. Consequently, rigorous disaster data compilation and loss accounting serve as foundational pillars for comprehensive risk assessment, climate adaptation planning, and the optimization of emergency response and relief fund deployment. By equipping policymakers with high-resolution, precise risk intelligence^[5], robust disaster databases significantly amplify the effectiveness of DRR interventions and post-disaster resilience-building.

Within the global DRR framework, nations such as Japan and the USA^[6] have, through protracted operational experience, established standardized disaster database systems characterized by extensive spatial coverage and robust data interoperability^[7]. By contrast, the development of China's flood disaster databases remains in its nascent stages^[8], currently navigating a critical transition from fragmented, localized initiatives toward systematic, integrated architectures. Constrained by these early-stage characteristics, there remains substantial room for optimization and top-level coordination regarding data consolidation, the standardization of archiving protocols, and full-cycle coverage capabilities. Currently, dedicated thematic research on disaster databases remains relatively scarce^[9], with existing literature predominantly focusing on empirical application cases and specific database technologies. While a minority of scholars have conducted comparative analyses on domestic and international databases, examining metrics such as data coverage^[10], developmental objectives^[11], and archiving criteria^[12] to recommend enhancements in documenting post-disaster contexts and loss inventories, few have systematically deconstructed China's disparities with international counterparts such as the USA through the lens of institutional and technological synergy^[13]. Instead, some researchers adopt a reductionist approach, concentrating on specific technical facets, such as pre-disaster forecasting^[14] and efficient data acquisition^[15], within isolated temporal phases. Although technological advancement is a crucial component of database development^[16], flood disaster management must be treated as an integrated continuum. Data voids or managerial silos at any juncture inevitably degrade the overarching systemic efficacy^[17].

Consequently, this study innovatively introduces the "full-cycle management" perspective, encompassing pre-disaster prevention, mid-disaster emergency response, and post-disaster recovery, to dismantle compartmentalized management barriers. Grounded in China's specific national context, this research examines the operational advantages and potential limitations of the existing database system, moving beyond a unilateral benchmarking of

its experiences. By systematically reviewing current domestic bottlenecks alongside global practices, this paper aims to explore mechanisms for selectively assimilating international lessons and formulating a localized pathway for flood disaster database development of China, providing robust theoretical and methodological scaffolding for optimizing China's disaster governance framework.

2 Current Status and Challenges of China's Flood Disaster Database Development From a Full-Cycle Management Perspective

2.1 Disaster Data Monitoring and Collection Capabilities: Leading Hardware Scale Versus Imbalanced Efficacy

Flood data monitoring and collection constitute the foundation of flood disaster mitigation in China. Currently, although China leads globally in the scale of data monitoring and collection hardware, the overall efficacy of these data remains suboptimal. China has established the world's largest hydrological monitoring network, comprising 155,000 stations and forming a "satellite-radar-ground station" integrated monitoring system^[18], which primarily targets forecasting and early warning^[19]. According to the 2024 China Flood and Drought Disaster Prevention Bulletin^[20], minute-level data transmission has bolstered flood early warning efficiency. For example, in Qinghai Province, early warning SMS capacity increased from 150 to 1,700 messages per minute, achieving an efficiency improvement of over 10 times^[19], and the automatic flow monitoring rate has increased from 30% in 2020 to 53% in 2024^[18]. However, significant spatiotemporal imbalances in monitoring efficacy persist, as evidenced by recent extreme events—during the 2023 Haihe River Basin mega-flood^[21], data deficiencies led to a 32% forecasting deviation; similarly, emergency responses were delayed by over one hour during the 2021 Henan extreme rainstorm^[22]. Spatially, the coverage of monitoring nodes is unevenly distributed: the monitoring density for small- and medium-sized basins is merely one station per 500 km², and stations in the arid Northwest region remain sparse, with radar coverage in heavy rainfall centers falling below 40%^[23]. Consequently, the majority of flood storage and detention basins lack real-time water level monitoring^[20]. Furthermore, severe discontinuities exist within historical data archives. According to a 2022 survey by the Ministry of Water Resources, 78% of county-level flood archives have not yet been digitized^[24]. Furthermore, severe discontinuities exist within historical data archives. As Taoru Liu has critically noted, China's efforts in the literature collation and datafication

of historical disaster records since 1949 remain constrained by significant bottlenecks and deficiencies^[25].

2.2 Data Translation Capabilities: Comprehensive Archiving Versus Underdeveloped Utilization

The development of China's flood disaster data systems exhibits a transitional characteristic defined by "robust foundations but underdeveloped applications." In terms of data accumulation, systematic flood event databases spanning from 1954 to the present have been established across the seven major river basins^[26], providing fundamental support for post-disaster assessments. Breakthroughs have also been achieved in the innovation of knowledge platforms. For instance, the Dayu platform, China's first AI-driven flood control platform, introduced by China Three Gorges University in 2025^[27], facilitates flood routing simulation and the intelligent formulation of dispatch schemes. This advancement propels a paradigm shift in decision-making models from traditional human-computer interaction toward intelligent assistance. Furthermore, indigenous modeling technologies have demonstrated substantial international influence. The Xin'anjiang model, developed by Hohai University^[28], has been widely adopted by numerous research institutions, and its global hydrometeorological simulation platform provides technical support for flood mitigation across multiple regions along the Belt and Road Initiative.

Despite these achievements, the overarching efficacy of data utilization remains severely constrained—this is a systemic challenge widely recognized in global disaster management^[4,29], primarily manifesting in two dimensions: data application and engineering practices. Data applications are disproportionately concentrated within governmental emergency dispatch operations; the absence of market-oriented tools consequently leads to lagging societal services^[30]. Meanwhile, there is a profound deficiency in integrating data into engineering practices, as historical loss and post-disaster reconstruction data are rarely standardized or structurally archived^[31]. For example, flood events occurring in the Yangtze River Basin over the past two decades have not been systematically recorded^[32], and the completion rate of data fields pertaining to post-disaster reconstruction remains critically low. Consequently, historical lessons fail to effectively inform and guide contemporary engineering practices^[33].

2.3 Systemic Architectural Capabilities: Local Initiatives Versus National Fragmentation

The development of China's flood disaster databases exhibits a pronounced dualistic paradigm characterized by "local initiatives

and national fragmentation." Throughout the nation, various provinces and municipalities have cultivated highly specialized operational systems, and currently provincial-level emergency management platforms have achieved comprehensive coverage. For instance, the Beijiang River flood control system in Guangdong has integrated multi-source data via the WPD platform^[34]; Hunan's flood control cloud platform has consolidated 110 county-level flash flood early warning systems, significantly driving down flash flood mortality rates compared with the 2010 levels^[35]. Conversely, at the national level, top-tier databases, such as river basin flood control databases and meteorological disaster databases, suffer from an over-reliance on single administrative entities. The development of these databases is predominantly monopolized by the Ministry of Water Resources, the Ministry of Emergency Management, and the China Meteorological Administration, with critically insufficient participation from market forces and societal stakeholders. Although China has recently established the National Comprehensive Natural Disaster Risk Database to initially consolidate risk data, it lacks vertical integration with local systems. This disconnect has resulted in a highly fragmented standardization framework, which manifests in the low standardization of data fields within local databases, the proliferation of unstructured historical data, and inadequate capabilities for data sharing and interoperability.

2.4 Core Issues in Flood Database Development From a Full-Cycle Management Perspective

Although the concept of full-cycle management has been discussed in comprehensive disaster prevention research^[36], it primarily serves as a procedural reference for disaster relief and administrative management. In contrast, this study adopts the full-cycle perspective specifically to examine database construction, emphasizing that data continuity across these phases is a critical prerequisite for effective mitigation. However, the pronounced data fragmentation within China's flood disaster databases manifests the intertwined dilemmas of "inaccurate forecasting, inefficient resource mobilization, and rigid institutional adaptation" (Fig. 1). Specifically, within this cyclical mechanism, inaccurate forecasting is characterized by prior deviations in disaster loss forecasting that systematically manifest as imbalanced pre-disaster monitoring efficacy, due to inadequate monitoring coverage and limited data precision. Furthermore, ineffective mid-disaster decision-making, stemming from cross-departmental data silos and the absence of collaborative mechanisms, leads to inefficient resource mobilization, manifesting as delayed emergency responses and

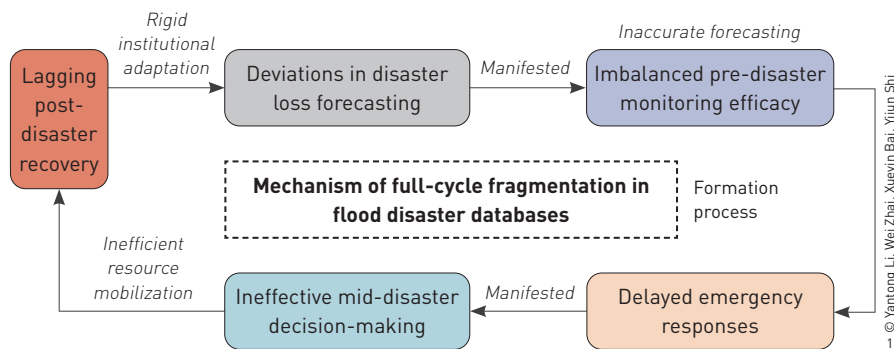


Fig. 1 Intertwined dilemmas in China's flood disaster database development from a full-cycle management perspective.

sub-optimal dispatch efficiency; while rigid institutional adaptation emerges from lagging post-disaster recovery, where fragmented post-disaster data impedes the translation of historical experiences into institutional optimization. The fundamental root causes lie in incomplete monitoring frameworks, deficient data-sharing mechanisms, and weak data utilization capabilities. Consequently, these systemic bottlenecks prevent China's hardware advantages from being effectively translated into comprehensive, full-cycle management efficacy.

3 Experiences and Limitations of the Existing Flood Disaster Databases From a Full-Cycle Management Perspective in Developed Countries

3.1 Overview of the Global Flood Disaster Database System

The USA has progressively established a multi-layered, multi-stakeholder collaborative flood disaster database system (Fig. 2). This comprehensive framework encompasses diverse contributing stakeholders, core data spanning the full management cycle, versatile storage modalities, and standardized data formats^[37]. Within this architecture, the Federal Emergency Management Agency (FEMA)^[38] and the National Oceanic and Atmospheric Administration (NOAA)^[39] serve as the core agencies, undertaking the critical functions of emergency management and monitoring and early warning, respectively^[40].

Specifically, FEMA orchestrates a comprehensive suite of databases—including the National Flood Insurance Program (NFIP)^[41], the Hazus Multi-Hazard (HAZUS-MH)^[42] modeling program, Flood Insurance Rate Maps (FIRMs)^[43], and the Disaster Declarations Database (DDD) (Table 1)^[44]. These platforms encompass a diverse array of datasets covering economic losses, insurance records, risk assessments, disaster declarations, and

post-disaster recovery fund allocations, thereby seamlessly spanning the entire disaster management cycle. Concurrently, NOAA^[16] leverages platforms such as the National Weather Service (NWS)^[45], the National Centers for Environmental Information (NCEI)^[46], the Advanced Hydrologic Prediction Service (AHPS)^[47], the Storm Events Database (SED), and Flood Frequency Data (FFD)^[45]. By systematically integrating hydrometeorological monitoring, historical disaster archives^[48], and real-time forecasting intelligence^[49], NOAA provides robust data scaffolding for flood trend analysis and disaster response operations.

3.2 Experiences in Flood Disaster Database Development

3.2.1 Full-Cycle Management and Multi-Scenario Application System

FEMA places significant emphasis on pre-disaster assessment and forecasting as well as post-disaster recovery management. Nevertheless, its archival systems for disaster event records and mid-disaster response data require further development. It encompasses four primary databases (including the NFIP and FIRM), which collectively cover 18 natural hazard data types^[38], such as flood insurance coverage^[50], disaster declarations^[10], federal relief funds^[51], and flood risk zones^[52]. These data are applicable throughout the pre-, mid-, and post-disaster phases^[53] and are practically deployed across 10 specific aspects^[54], including pre-disaster customized insurance, flood risk assessment, land use planning, and risk simulation modeling; mid-disaster emergency declaration, response handling, data handling and rescue operation; and post-disaster losses, federal assistance operation, and

Fig. 2 The structure of the USA's flood disaster database system.

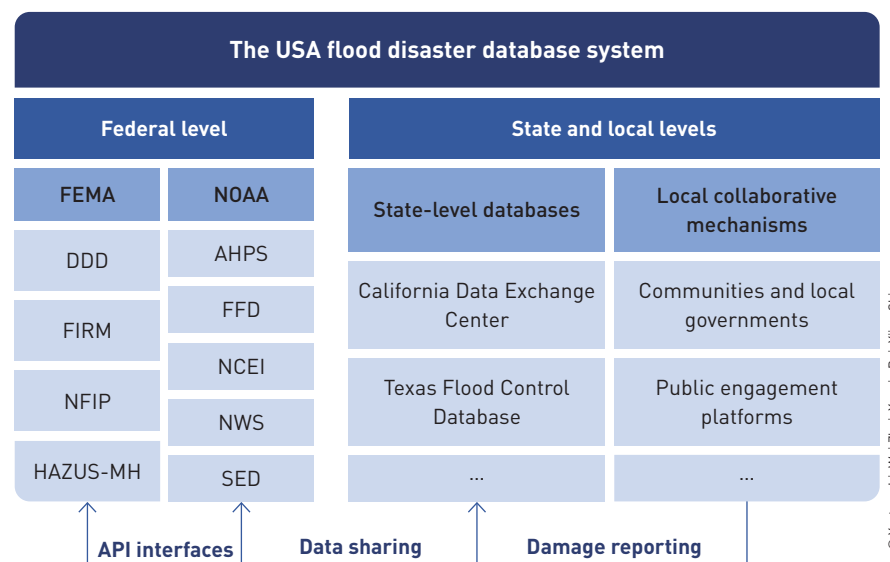


Table 1: Characteristics of the USA flood disaster databases

Database	Spatial coverage	Data precision	Update frequency	Standardization level	Data accessibility
AHPS	National flood risk forecasting	Dynamic forecasting via hydrological models; precision relies on model parameters	Real-time updates of forecasting data with high timeliness	Standardized forecasting data and outputs	Fully accessible
DDD	National disaster declarations since 1953	Detailed event records (i.e., time, location, federal response), but lacks specific loss data	Updated in real-time with the latest declarations	Unified event classification and recording formats	Fully accessible
FFD	National flood occurrence probabilities and risk zones	High precision in statistical analysis, but constrained by historical data completeness	Updated irregularly alongside new data or model developments	Highly standardized	Fully accessible
FIRM	National flood risk zoning maps	High precision based on topographic data and hydrological models	Slow update cycles; fails to reflect timely risk dynamics in some regions	Highly standardized map data formats	Fully accessible
HAZUS-MH	National flood risk forecasting and loss assessment data	Refined precision via GIS modeling; relies on input data granularity	Updated irregularly; subject to model and input data variations	Unified standards for risk assessment and calculation	Partially accessible
NCEI	National historical disaster records and hydrometeorological data	High data quality, though older records may exhibit missing data or anomalies	Limited historical updates; ongoing updates for recent disaster records	Highly standardized	Partially accessible
NFIP	National flood insurance risk zones	High precision, yet limited to participating areas	Updated periodically; supplemented post-flood events	Unified standards for insurance and loss assessment	Partially accessible
NWS	Nationwide real-time flood monitoring data	High precision; collected via advanced real-time equipment	Updated in real-time with high timeliness	Unified data formats	Fully accessible
SED	Nationwide flood events and their impacts since 1950	High precision; details event time, location, losses, and casualties	Updated periodically; supplemented post-flood events	Unified data recording formats	Fully accessible

NOTE

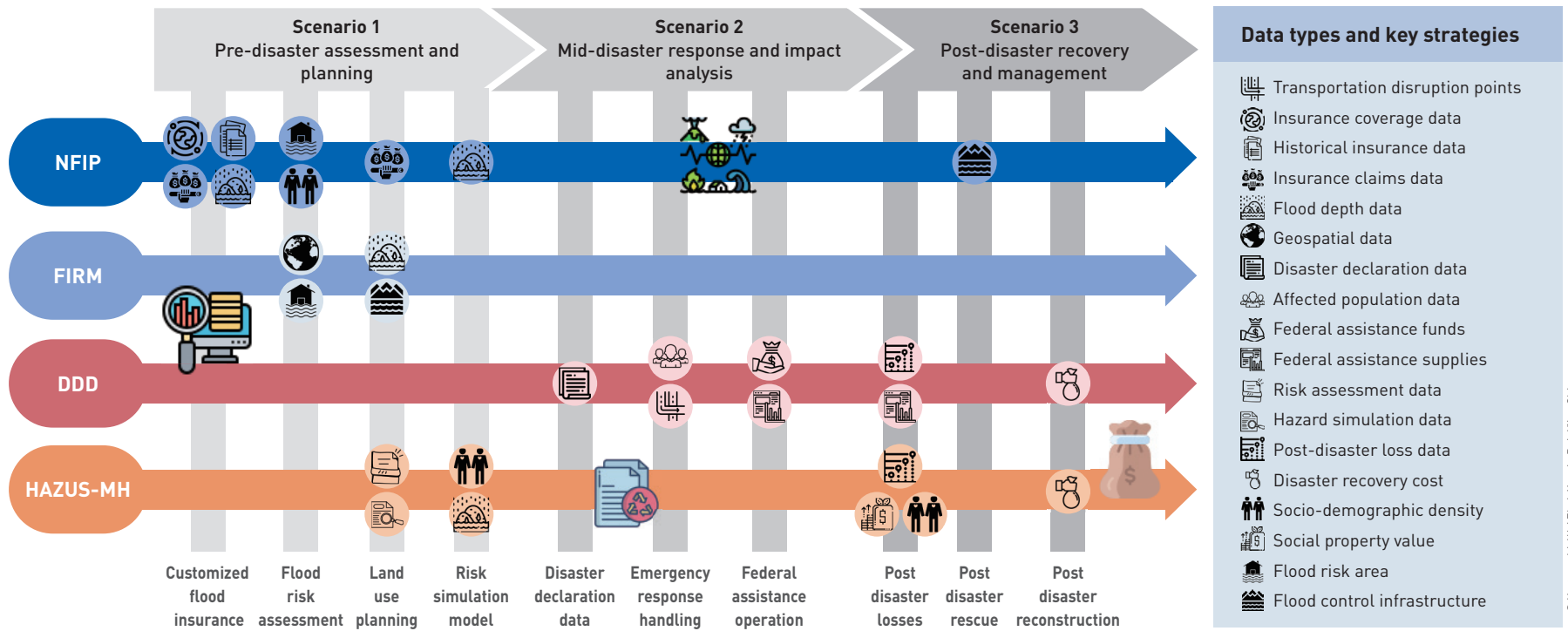
The information of the included databases was sourced from Refs. [18–23,25–28,34–35,37–49].

reconstruction (Fig. 3). For instance, within the context of flood insurance formulation, the NFIP supplies critical data^[55] (e.g., insurance coverage metrics, flood depth records) to facilitate pre-disaster vulnerability assessments and preventative preparedness; in risk assessment scenarios, it provides data on flood risk zones and socioeconomic indicators to support flood risk projection and spatial zoning initiatives^[50].

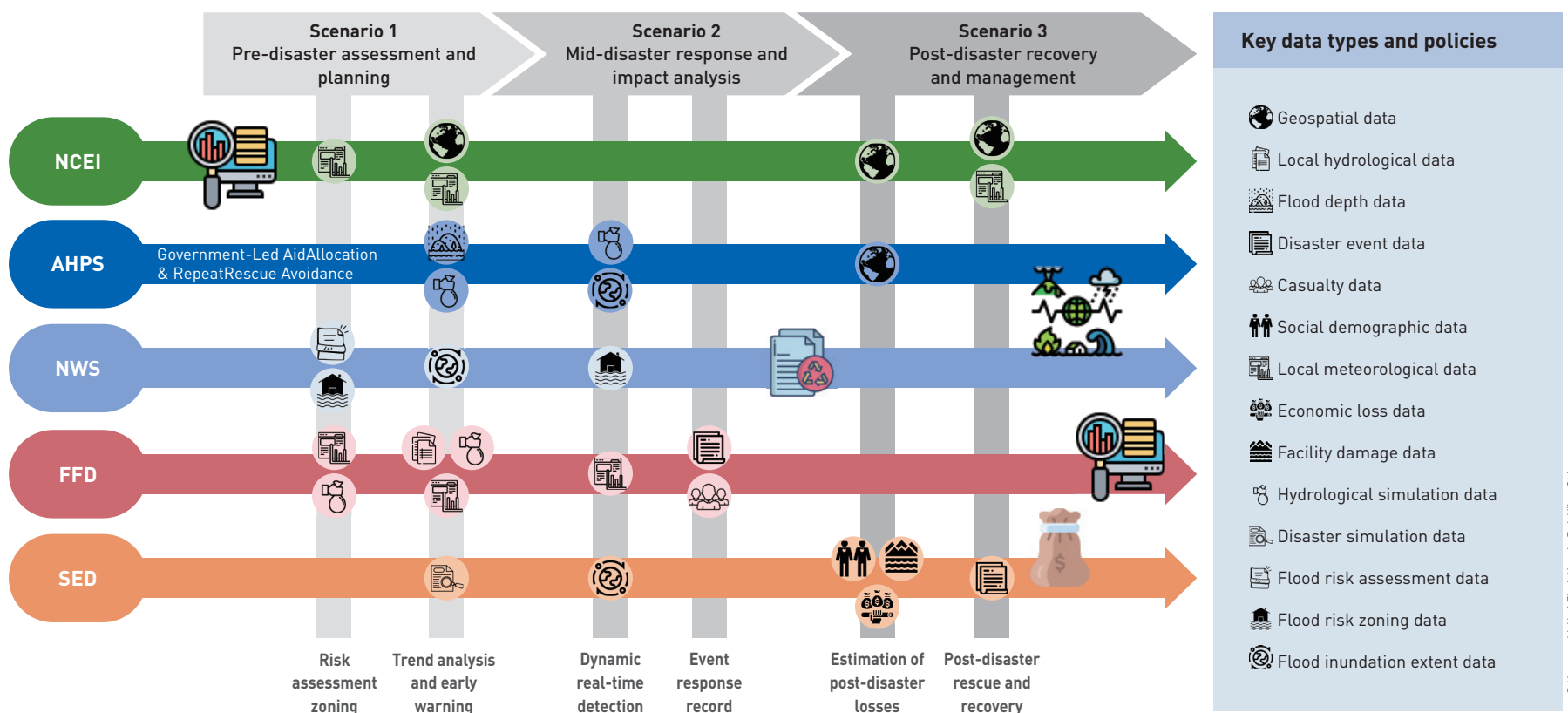
Conversely, NOAA manages five core databases (including NCEI and AHPS), which encompass 14 disaster data categories, such as geospatial, local hydrological^[56], and local meteorological data^[57]. This repository spans the entire disaster

management cycle and is operationalized across eight practical scenarios. For example, 1) pre-disaster risk assessment zoning and trend analysis for early warning; 2) mid-disaster dynamic real-time detection and event response record; 3) post-disaster loss estimation, rescue operations, and recovery planning (Fig. 4). In addition, the NWS provides crucial datasets, such as disaster inundation extents and flood risk demarcations^[58]. These inputs are instrumental in sustaining robust pre-disaster early warning mechanisms and facilitating dynamic, real-time monitoring during disaster events.

The databases managed by NOAA, FEMA, and other affiliated



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Fig. 3 The full-cycle multi-scenario application system of FEMA's flood disaster databases.

Fig. 4 The full-cycle multi-scenario application system of the NOAA's flood disaster databases.

agencies collectively constitute a comprehensive, dynamic, and multi-dimensional flood disaster management database system. By facilitating data integration and inter-agency collaboration

across the three primary disaster phases, this integrated architecture synergistically supports the entire continuum of comprehensive DRR.

3.2.2 Unified Standards for Database Construction

Although the FEMA flood databases possess diverse data storage formats and multi-scale datasets, challenges in data harmonization remain. To better serve the requirements of flood disaster policy and decision-making, researchers such as Zhi Li^[37] have attempted to unify the construction standards across various databases. These ongoing standardization efforts are primarily reflected in three dimensions as follows.

1) Disaster classification standards. The FEMA has formulated classification protocols encompassing disaster types, response tiers, and post-disaster recovery parameters. This framework attempts to ensure the systematization and uniformity of flood disaster information^[59].

2) Unification of database formats. The FEMA has preliminarily developed a comprehensive repository known as the United States Flood Database (USFD). Integrated from seven independent data sources (Fig. 5), the USFD^[37] covers the most extensive historical flood records in the US, featuring a broad spatiotemporal span. It is designed to offer both discrete datasets and uniformly integrated data to accommodate diverse user demands. Analytically, the USFD supports multiple research domains, including the validation of hydrological and hydraulic simulations, climate research on spatiotemporal flood patterns, and flood susceptibility analysis in vulnerable geophysical regions^[37].

3) Inclusion criteria for disaster events. While both FEMA and NOAA have established explicit criteria for archiving disaster events, their focal points and specific standards remain distinct^[60]. FEMA's inclusion protocols are primarily aligned with disaster severity assessments and the mobilization of federal assistance^[61]. Conversely, NOAA's criteria are predominantly oriented toward hazard monitoring, early warning, and immediate emergency response^[62].

3.3 Application Implications From the Flood Disaster Databases Development

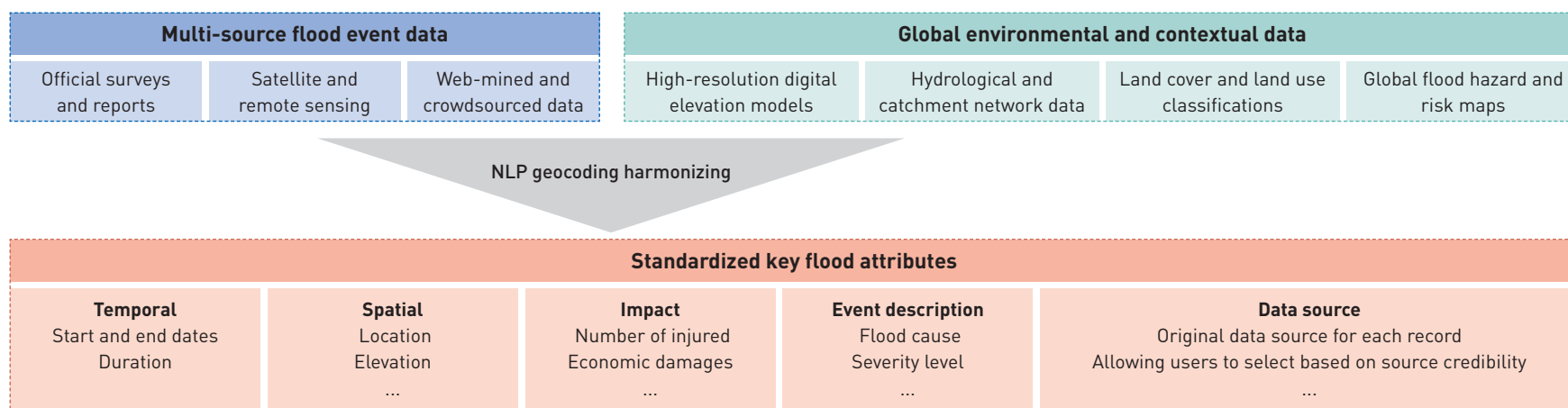
3.3.1 Practical Applications: Databases Supporting the Full-Cycle DRR Process

(1) Pre-disaster early warning and risk identification

During the flood preparedness phase, local agencies utilize databases such as NOAA's AHPS and NWS to facilitate disaster early warning and risk identification. By leveraging real-time water level monitoring and hydrological simulation models, the AHPS provides government agencies with targeted flood risk forecasts, thereby supporting pre-disaster evacuation and emergency preparedness^[63]. For instance, during Hurricane Harvey in 2017, real-time water level data supplied by the AHPS assisted emergency managers in making rapid decisions and organizing preemptive evacuations, which contributed to a reduction in casualties^[64]. Simultaneously, the NWS enables the early identification of impending flood events based on meteorological models^[65]; its track forecasts indicated that Harvey would bring 40 to 50 inches (approximately 100–130 cm) of precipitation^[66], providing a scientific basis for local governments to formulate proactive DRR measures. Similarly, during the 2014 flood events in Oklahoma^[67], the NWS projected meteorological data of persistent heavy rainfall exceeding 12 h^[68], enabling the issuance of severe storm warnings hours in advance and assisting local authorities in implementing timely emergency interventions^[69].

(2) Mid-disaster emergency response and rescue

During the occurrence of flood events, databases managed by FEMA and other agencies play a crucial role in emergency rescue operations and resource allocation. During the 2008 Missouri floods, FEMA issued three disaster declarations and activated the Individual Assistance (IA) program, receiving 31,022 disaster assistance applications from residents. During the emergency



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response to Hurricane Ian in Florida in 2022, FEMA leveraged modern database systems to efficiently process over 910,000 IA applications within months^[70]. The agency mapped the residential locations alongside tornado distribution patterns^[71], thereby achieving a spatial visualization analysis of the aid recipients^[69] (Fig. 6). By integrating FEMA's risk assessment and disaster declaration databases, the government conducted tasks such as eligibility verification for disaster victims and compensation assessment, which structurally improved overall rescue efficiency. Furthermore, the DDD consolidated multi-dimensional data—including affected populations and infrastructure damage—to support emergency departments in rapidly identifying areas requiring emergency housing assistance. The NFIP database recorded the insurance coverage and claims of victims, assisting FEMA in verifying post-disaster insurance information to avoid the duplication of benefits. Combined with FIRMs, emergency departments were able to more accurately determine the relief eligibility of residents in high-risk zones, aiming to ensure timely rescue operations and the rational distribution of resources.

(3) Post-disaster recovery and reconstruction management

Following flood events, local agencies leverage the NCEI and FEMA databases to conduct post-disaster loss assessments and determine reconstruction prioritization levels. This mechanism ensures that resources are strategically allocated to infrastructure and communities in critical need, thereby facilitating a tiered prioritization of recovery targets. For instance, following Tropical

Storm Irene, historical flood data and disaster impact analyses provided by NOAA assisted FEMA and state agencies in delineating the reconstruction hierarchy for approximately 800 km of roads and hundreds of bridges, ultimately optimizing targeted resource deployment^[72]. Similarly, in the aftermath of Hurricane Harvey in 2017, the NCEI data supported the Texas state government in evaluating economic damages. The assessments revealed that the flooding inflicted over USD 125 billion in direct economic losses, serving as the robust empirical basis for the government to formulate equitable fund allocation and comprehensive reconstruction plans^[73].

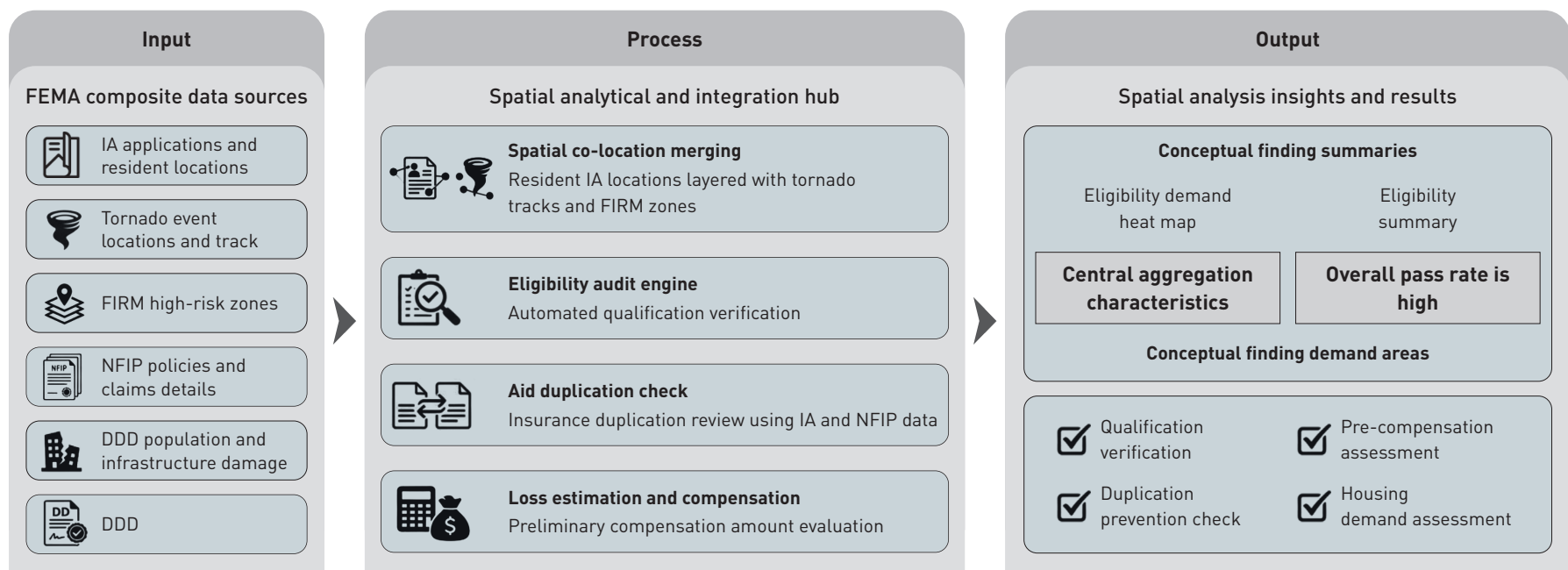
3.3.2 Academic Research Applications: Databases Facilitating the Enhancement of Comprehensive DRR Capacities

Flood disaster databases play a vital role in flood risk management. They not only support pre-disaster risk identification and the construction of early warning models but also provide essential data scaffolding for mid-disaster dynamic risk assessment, as well as post-disaster recovery and reconstruction. Research conducted by utilizing various databases encompasses the entire DRR spectrum—from risk assessment to social equity analysis—thereby providing a scientific basis and technical support for flood mitigation.

(1) Pre-disaster risk assessment and supplementary validation

Prior to the occurrence of floods, research predominantly focuses on hazard risk identification, disaster simulation, and

Fig. 6 Spatial distribution map of aid recipients' information.



model validation. For example, when investigating the flood impacts during Hurricane Maria, researchers combined FEMA's 500-year flood probability maps with data from NOAA's AHPS portal^[74]. This integration effectively mitigated the uncertainties arising from missing remote sensing data, thereby improving the accuracy of flood extent simulations and soil moisture verification. Furthermore, comparative studies utilizing NFIP and Spatial Hazard Events and Losses Database for the United States (SHELDUS) data nationwide^[10] have elucidated the spatial distribution characteristics of flood losses and verified the spatial correlation between flood damage and underlying risks. These studies indicate that flood disaster databases can provide high-resolution data support for pre-disaster risk identification, forecasting, and model validation, which is of great significance for enhancing comprehensive DRR capabilities.

(2) Mid-disaster dynamic risk assessment and emergency decision support

During flood events, databases are widely applied in domains such as real-time risk monitoring, flood risk mapping, and the optimization of insurance pricing. By integrating FEMA flood risk maps with NOAA storm data, researchers have constructed more precise flood risk maps, providing an important basis for insurance companies to optimize pricing models and risk assessments^[52]. Some scholars suggest that the FEMA data should be updated periodically to accommodate the dynamic nature of flood risks^[75]; this would enable insurance providers to access the latest risk distributions for dynamic pricing and real-time responses. These studies demonstrate that, during the mid-disaster phase, flood disaster databases not only support science-based emergency decision-making by governments and enterprises but also supply foundational risk management data for the insurance sector, thereby enhancing the precision and timeliness of mid-disaster relief efforts.

(3) Post-disaster recovery strategies and management optimization

In the aftermath of floods, research largely centers on post-disaster loss assessment, the optimization of resource allocation, and issues of social equity. Based on flood data provided by the FEMA and the HAZUS-MH model, researchers conducted systematic evaluations of post-disaster losses, thereby optimizing resource allocation schemes for recovery and reconstruction^[76]. Additionally, by utilizing extensive claim datasets of the NFIP and advanced spatial models, scholars have further unraveled the spatial distribution patterns of flood damage, validating the strong spatial correlation between actual flood losses and associated

environmental risks^[77]. This provides a precise basis for identifying high-risk zones and formulating reconstruction decisions in post-disaster management.

Furthermore, during the post-disaster recovery and reconstruction phase, scholars emphasize the imperative of maintaining social equity. Utilizing big data from the NFIP, researchers have analyzed the inequalities among different socioeconomic groups in the USA regarding flood insurance participation rates, pricing, and compensation, subsequently proposing recommendations to enhance insurance equity^[50]. Evaluations of the spatial distribution of post-disaster recovery and resource allocation have highlighted issues concerning unequal resource distribution and disparate relief efficiencies across different regions^[40]. Studies have also explored the role of FIRM in rescue and recovery operations, analyzing the disparate assistance needs across communities—particularly addressing the post-disaster recovery challenges faced by low-income and impoverished neighborhoods^[78]. These collective studies underscore the critical importance of integrating equity considerations into the post-disaster recovery process.

3.4 Limitations of the Flood Disaster Database Development

Although agencies such as FEMA have constructed a full-cycle database system that plays a significant role in risk identification, insurance formulation, and post-disaster reconstruction, certain limitations remain. These limitations are primarily manifested in uneven data coverage across different regions, delayed data updates, and disparities in rescue and compensation between urban and rural areas, as well as across different socioeconomic groups.

Regarding data coverage, while the FEMA flood disaster databases have achieved national spatial coverage, the data precision and accessibility in non-high-risk insurance zones remain inferior compared with high-risk areas. High-resolution loss data within the NFIP is largely confined to participating insured regions. Flood risk information for uninsured areas—particularly low-income communities and rural regions—is severely lacking, resulting in significant biases in risk assessment and pre-disaster prevention strategies. For instance, high-resolution empirical modeling reveals that the actual USA population exposed to a 100-year return period flood is approximately 3.1 times higher than official federal estimates, meaning nearly 28 million people reside in unmapped or under-assessed high-risk zones^[52,75], reflecting the spatial imbalances inherent in data collection mechanisms driven by the insurance system.

In terms of data updates, some databases suffer from extended

update cycles and the failure to digitize and archive older paper-based records. The update cycle for FEMA's FIRMs exceeds 10 years in certain regions, and NOAA's NCEI historical disaster data also exhibits temporal gaps, leading to inaccuracies in risk evaluation. During the 2017 Hurricane Harvey in Houston, for instance, one-third of the inundated areas were not covered by the latest risk maps. This discrepancy between the risk assessment results and the actual disaster context structurally weakens the predictive accuracy of the databases.

Regarding equity in DRR, although the database system has enhanced the scientific rigor of disaster rescue and the formulation of post-disaster recovery plans, systemic imbalances persist at the societal level. Following Hurricane Katrina in Louisiana, for example, a subset of low-income households was not incorporated into the assistance rosters in a timely manner^[79]. Furthermore, the scarcity of monitoring stations in rural areas contributed to an average delay in rescue response times exceeding 48 h^[80].

In summary, while the FEMA flood disaster database system has significantly advanced the scientific foundation and timeliness of DRR across the full disaster cycle, its capacity to ensure DRR equity, comprehensive data coverage, and update timeliness requires further optimization.

4 Implications for the Localized Development of China's Flood Disaster Database

The aforementioned experiences and limitations associated with the global flood disaster database system offer valuable references and critical reflections for database development in China. However, profound disparities between the two nations regarding institutional environments, technological frameworks, and social structures dictate that the USA model cannot be directly transplanted. Therefore, grounded in a comprehensive understanding of these global contextual differences, it is imperative to selectively assimilate the successful experiences and facilitate the construction of a localized development pathway for flood disaster databases of China.

4.1 Comparative Analysis of Contextual Differences

4.1.1 Institutional System

The Netherlands relies on a mature framework and mandatory data integration mechanisms, whereas China's database development is fundamentally administrative-led, currently lacking robust sharing mechanisms and unified standards. The USA utilizes federal legislation such as the Freedom of Information Act (FOIA)

and the Stafford Act as top-level frameworks, which mandate the integration of multi-source data and clearly delineate institutional responsibilities. This forms a governance model characterized by decentralized collection and centralized management. However, this model possesses a dual nature: on the one hand, legislation safeguards data standardization and accessibility; on the other hand, the decentralization of power between federal and local governments can lead to spatial disparities in data updates and execution standards. In contrast, China's flood disaster database construction remains centered on executive leadership. Data resources are dispersed across meteorological, emergency management, water resources, and natural resources departments. A legally binding sharing mechanism and unified standards have yet to be fully established, making cross-departmental synergy heavily reliant on policies and top-down directives. Recently, China has issued policy documents such as the National Emergency Management System Plan During the 14th Five-Year Plan Period^[81] and the Guiding Opinions on Vigorously Promoting the Construction of Smart Water Conservancy^[82], which stipulate the development of unified informatization platforms and cross-departmental data-sharing mechanisms. Therefore, China could adopt a "regulation-administration" synergy to progressively establish a comprehensive data governance framework.

4.1.2 Technological Frameworks

Although China currently faces gaps regarding long-term data accumulation, standardization, and update frequency, it already possesses the technological potential and systematic foundation to construct high-precision, structured, multi-tiered, dynamic flood databases. Represented by NOAA's AHPS, the USA achieves dynamic flood monitoring and forecasting by coupling real-time hydrological monitoring data with high-resolution meteorological models. Concurrently, the FEMA's FIRMs utilize GIS spatial analysis techniques to generate flood inundation zones across various return periods, making them accessible to local governments and social institutions via open API interfaces. The parallel operation of these systems provides robust technical support for the flood databases. Conversely, although China has established the world's largest hydrological monitoring network, deficiencies remain regarding the monitoring density for small- and medium-sized basins, real-time data transmission capacities, and the construction of dynamic simulation platforms. In recent years, the establishment of intelligent platforms—such as the Dayu platform—has served as a strong catalyst for advancing the technological capabilities of China's database construction.

4.1.3 Social Structure

The Netherlands and the USA link flood risk data with the insurance market, fostering an environment of public participation and societal co-governance. In contrast, China's flood insurance market is not yet fully mature, resulting in lower societal data contributions and public participation. Through the NFIP, the USA has successfully connected flood risk data with the insurance sector. Based on FIRMs, residents and enterprises can clearly understand their flood risk levels, insurance agencies can formulate differentiated premiums, and the government can use this basis to allocate infrastructure resources and distribute subsidies. This mechanism not only promotes the application of flood data in actuarial science and post-disaster reconstruction but also strengthens public risk awareness and societal governance. Currently, flood insurance and related products in China remain underdeveloped. The participation of social institutions and the public in the collection, feedback, and application of flood data is relatively low, and a mechanism for societal data contribution has yet to take shape. At this stage, data sharing in China is predominantly government-driven, indicating that the database's potential value in DRR remains largely untapped.

4.2 Localization Strategies for China's Flood Disaster Database Development

By assimilating the successful experiences while mitigating its shortcomings regarding spatial equity, dynamic updating, and social inclusivity, several phased, localized implementation strategies for China to establish its flood disaster databases are proposed in this article. These localization strategies are categorized into three pathways: directly applicable strategies, strategies requiring pilot verification, and alternative solutions (Fig. 7).

4.2.1 Directly Applicable Strategies: Prioritized Promotion of Foundational Databases

China possesses a relatively mature technical foundation for database construction. Areas suitable for direct promotion include flood risk mapping and the development of multi-source data fusion platforms. Aligning with policy mandates such as the Top-Level Design for Smart Water Conservancy Construction, national-level methods and standards for flood risk zoning should be established. This aims to achieve the standardization, dynamic updating, and visualization of risk maps, providing scientific scaffolding for flood control planning and urban space management. Furthermore, by fostering cross-departmental collaborative awareness, multi-dimensional data—including

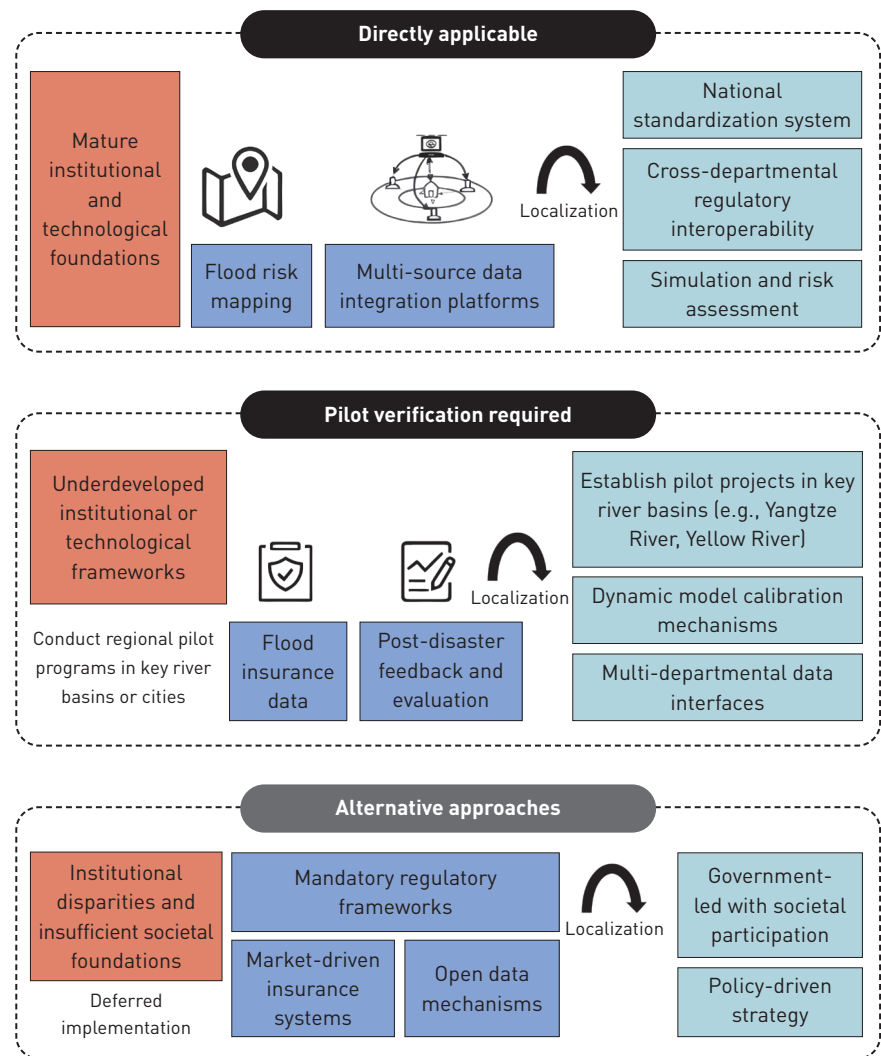


Fig. 7 Localization strategies for the development of China's flood disaster databases.

meteorological, hydrological, geospatial, and socioeconomic information—should be integrated to build a nationwide, multi-source, heterogeneous data fusion platform, gradually forming unified data standards and interface protocols among government agencies. This platform can support the cross-departmental sharing of full-cycle information, from pre-disaster early warning and mid-disaster dispatching to post-disaster recovery. With robust foundational conditions and relatively low implementation difficulty, this strategy can be pioneered nationwide, laying the institutional and technological groundwork for the comprehensive upgrading of the flood disaster database system.

4.2.2 Strategies Requiring Pilot Verification: Demonstrations of Mechanism Innovation and Technological Integration Referencing the “decentralized collection and centralized management” model of the USFD, regional pilot projects could be

launched in key basins or cities to verify feasibility. First, regarding flood insurance data, the NFIP provides a paradigm for leveraging insurance data in disaster governance. However, as China's flood insurance system is not yet mature or widely adopted, insurance data currently serves primarily as supplementary information for risk assessment and disaster loss grading. Therefore, attempts to promote the application of insurance data in governmental decision-making could be initially piloted in key watersheds such as the Yangtze and Yellow River basins. Second, regarding post-disaster feedback and evaluation mechanisms, China should establish a model-calibration mechanism based on post-disaster loss data, enhancing the capacity for real-time information updates to assist pre-disaster risk assessment and emergency decision-making. Furthermore, in constructing regional database demonstration projects, cross-departmental joint pilot programs can be initiated to establish a collaborative platform among water resources, meteorological, and emergency management departments, thereby verifying the feasibility of multi-source data fusion platforms and dynamic model updating.

4.2.3 Alternative Solutions: Tailored to Actual Conditions

Due to disparities between China and other countries regarding institutional system, market maturity, and social structures, certain experiences of Japan, the Netherlands, and the USA are difficult to promote and apply directly in China in the short term, necessitating the exploration of alternative solutions tailored to China's actual conditions. Specifically, rather than the disaster governance model that relies heavily on a market-driven insurance system, China, under the government-led governance framework, should explore public participation mechanisms centered on government guidance and financial subsidies to strengthen public risk awareness. Additionally, while the USA implements an open data-sharing system, China maintains stricter requirements for data security and privacy protection. Therefore, priority should be given to facilitating data linkage and sharing strictly among government departments, exploring methods for collecting multi-source societal disaster information, and prudently promoting the utilization of social data.

5 Conclusions and Outlooks

From a full-cycle management perspective, this article has examined the challenges of database construction in China, alongside the insights from the review on the development, application experiences, and limitations of the global counterpart. The article points out three core issues in China's flood disaster

database construction—inaccurate forecasting, difficult cross-agency synergy, and a lack of mandatory constraints—which fundamentally manifest as a data fragmentation dilemma characterized by pre-disaster risk prediction biases, mid-disaster emergency response lags, and the inability to institutionalize post-disaster experiences. The paper summarizes pioneering the successful experiences in data standardization, multi-source fusion, cross-departmental collaboration, and societal applications, while highlighting its limitations regarding data coverage disparities, timeliness issues, and equity in DRR.

The study emphasizes the global differences regarding institutional system, technological frameworks, and social structure, and suggests that China must establish localization strategies tailored to its actual conditions. Specifically, China should prioritize the nationwide promotion of standardized flood risk maps and multi-source data fusion platforms to consolidate its data foundation; regional pilot programs should be launched in key areas such as the Yangtze and Yellow River basins to explore flood insurance applications and cross-departmental collaborative mechanisms; while building a government-led, subsidy-oriented management framework should also be put attention.

Looking forward, China should focus on enhancing technical capabilities and realizing cross-departmental collaborative mechanisms. By promoting the integrated application of technologies such as artificial intelligence (AI) and digital twins, the capacity for disaster perception and dynamic simulation can be significantly elevated. Institutional guarantees for cross-departmental collaboration and data sharing must be established to dismantle data silos between agencies. Furthermore, promoting flood insurance will strengthen public participation awareness, thereby gradually establishing a flood disaster database system that emphasizes full-cycle management and enhances the capacity to support precise, data-driven decision-making.

Competing interests | The authors declare that they have no competing interests.

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全周期管理视角下洪涝灾害数据库系统建设回顾

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摘要

洪涝灾害数据库是提升防灾减灾能力的重要基础。尽管中国在国家自然灾害综合风险基础数据库的建设基础上已取得初步成效,但在数据系统的精细化建设及综合服务应用的能效方面尚处于探索阶段。一些发达国家具备相对完善的灾害数据库系统,具有一定借鉴意义。本文创新性地提出全周期管理视角下的国际差异研究框架。本文指出,中国洪涝灾害数据库建设存在灾前风险预测偏差、灾中应急响应滞后、灾后经验难以制度化等问题,导致全周期数据断裂。相反,发达国家(例如美国和荷兰)在数据标准化、动态模拟、协同治理和社会化应用等方面积累了丰富的先行经验。同时,其在数据覆盖度、响应及时性和资源分配公平性等方面的实践瓶颈,也为中国探索本土化路径提供了参考。基于此,本文提出中国洪涝灾害数据库系统建设的本土化策略:制度层面,加快构建政府主导,多部门协作的管理体系,稳步提升数据库的综合能效;技术层面,优先推广洪水风险图绘制和多源数据融合平台建设;社会层面,在重点流域开展区域性试点以探究策略可行性,从而逐步完善中国洪涝灾害数据库系统建设。

关键词

灾害数据库; 灾害全周期管理; 本土化策略; 洪涝灾害; 对比研究

文章亮点

- 灾害数据库建设在综合防灾辅助决策中至关重要
- 首次提出以全周期管理视角系统诊断本土问题并解构美国建设经验
- 设计了制度-技术-社会本土化路径,推动建设从规模优势向防灾效能转化