



# Assessing flood resilience through the plan quality evaluation: The City of Miami, Florida, USA

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## Abstract

Miami, Florida, faces increasing flood risks from climate change, sea-level rise, and urban development, necessitating effective planning frameworks to enhance community resilience. This study evaluates the extent to which flood resilience principles are integrated into two key planning instruments in Miami: the Local Mitigation Strategy (LMS) and the Comprehensive Plan (CP). Using a plan-quality evaluation framework, the study assesses the extent to which these plans incorporate fact-based, goals and objectives, policies and strategies, inter-organizational coordination, and implementation mechanisms. The findings reveal that both plans contribute to flood resilience planning but emphasize different dimensions of resilience. The LMS demonstrates stronger integration of risk assessment, coordination, and implementation components, while the CP provides a stronger strategic vision and policy framework for guiding future development. Overall, the LMS achieved a higher plan-quality score, suggesting a greater emphasis on the operational aspects of resilience planning. The results highlight the complementary roles of hazard mitigation planning and comprehensive planning in addressing flood risks. The study suggests that greater integration between these planning frameworks could strengthen resilience outcomes by linking long-term policy objectives with actionable implementation mechanisms. These findings contribute to the broader understanding of flood resilience planning and provide practical insights for planners and policymakers seeking to strengthen resilience to climate change, sea-level rise, and future flood hazards.

**Keywords:** Flood resilience, Local mitigation strategy, Comprehensive plan, Policy integration, Plan quality evaluation

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## 1 Introduction

Miami, officially known as The City of Miami, is located on Florida's (USA) southeastern coast and serves as the administrative center for Miami-Dade County (City of Miami, 2020). As of the 2020 census, its population was 442,241, making it the second-most populous city in Florida, after Jacksonville. The population density increased from 11,135.9 per square mile in 2010 to 12,285.8 per square mile in 2020. Covering 55.25 square miles, Miami is commonly known as the 'Magic City' and serves as a central hub within the expansive Miami Metropolitan area (U.S. Census Bureau, 2020; City of Miami, 2020).

Miami faces significant flooding challenges, primarily due to its low-lying topography, susceptibility to tropical storms and hurricanes, heavy rainfall, and the ongoing

threat of sea-level rise associated with climate change (City of Miami, 2020). Notable historical flood events, such as the 1926 Great Miami Hurricane, Hurricane Andrew in 1992, Hurricane Katrina in 2005, Tropical Storm Fay in 2008, periodic 'king tide' events, Tropical Storm Eta in 2020, Hurricane Ian in 2022, and Hurricane Idalia in 2022, underscore the city's vulnerability to flooding from hurricanes, tropical storms, and heavy rainfall (Florida Division of Emergency Management, 2018). According to the Southeast Florida Regional Climate Change Compact Sea Level Rise Work Group (Compact) (2020-02), sea levels are projected to rise by 2 feet above 2019 levels over the next 40 years and continue to rise thereafter. This poses a significant threat to property and the safety of human communities (Kousky, 2014; National Weather Service, 2019).

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The United Nations, in its 2015 Sendai Framework for Disaster Risk Reduction, highlighted this pattern globally, declaring that integrating vulnerability reduction into local planning is a critical need (United Nations General Assembly, 2015). As a result, Miami has taken steps to improve its flood resilience and preparedness through policies, urban development plans, infrastructure improvements, and hazard mitigation plans to reduce the impacts of future flood events. Communities adopt multiple plans that address hazard mitigation, both directly and indirectly; integrating local plans can significantly affect future community vulnerability to flood hazards (Malecha et al., 2022). Vulnerability is exacerbated by continued development in flood-prone areas and a lack of coordinated hazard mitigation planning (Cutter and Finch, 2008; Moser et al., 2014), making land-use and built-environment planning critical for flood resilience (Malecha et al., 2022).

Various plans, including comprehensive, land-use, hazard mitigation, and transportation plans, influence the vulnerability of built and natural environments (Yu et al., 2021). The comprehensive plan (CP) has legal standing and is central to land-use regulation, linking the community's future vision to private property regulation (Berke and Godschalk, 2009; City of Miami, 2019). The hazard mitigation plan is a widely adopted special-purpose plan in the United States that focuses on minimizing the impact of natural and human-caused hazards, particularly floods (Federal Emergency Management Agency, 2023). Despite their essential role in flood mitigation, natural hazards have not always been a high priority in governmental policies across jurisdictions (Burby, 2005). Local plans may lack consistency and fail to address areas most vulnerable to flooding or sea-level rise (Berke et al., 2015). Given the increasing frequency of flood disasters, additional research and continuous attention are needed.

This study evaluates the quality of plans, specifically comprehensive and hazard mitigation plans, in Miami, Florida, to address the complexities of flood resilience. The primary research question is: 'To what extent are Miami's existing policies and plans for flood resilience effectively integrated, and what factors influence their integration?' The study employs a plan quality evaluation with five components (fact base, goals and objectives, policies, tools and strategies, inter-organizational coordination and capabilities, and implementation), using the coding protocol from Brody's book *Ecosystem Planning in Florida, Solving Regional Problems through Local Decision-making* (Brody, 2008). While the study modifies selected items for each plan component, the foundational framework for plan quality evaluation remains unchanged.

## 2 Literature Review

### 2.1 Plan Quality and Plan Evaluation

Plan content or plan quality is one way to measure policy learning because plans for the same jurisdiction change and adapt to new conditions over time (Brody et al., 2009a). The idea that a plan can serve as an indicator of both the quality of the planning process and the strength of implementation has gained prominence (Talen, 1996; Hoch,

2002). Baer (1997) introduces a conceptual model, 'plan evaluation,' that outlines criteria for the systematic evaluation of plans (Brody, 2003). Baer emphasizes viewing a plan as both a product or outcome of the planning process and a blueprint for future actions. Core characteristics of plan quality, identified by Kaiser et al. (1995), include a strong factual basis, clearly articulated goals, and appropriately directed policies.

Empirical studies, particularly those focused on natural hazard mitigation, have applied these core characteristics to assess the quality of local plans. Research by Burby and May (1997) examined the influence of state mandates on plan quality, prompting additional studies that advanced understanding of how to measure the quality of local comprehensive plans in addressing natural hazards (Burby and Dalton, 1994; Berke and French, 1994; Berke, 1996; Burby and May, 1997). Brody (2003) broadened the concept of plan quality evaluation by introducing characteristics such as inter-organizational coordination, capabilities, and implementation. Lyles et al. (2012) further refined these principles into direction-setting and action-oriented categories.

Brody (2008) applied five plan quality components directly to ecosystem approaches to management, offering insights into the contextual influences on plan quality. The identified plan quality components include Fact Base (summarizing current local conditions), Goals and Objectives (guiding plan implementation), Inter-Organizational Coordination and Capabilities (capturing collaborative abilities), Policies, Tools, and Strategies (actualizing community goals), and Implementation (ensuring responsibility and cost-bearing for proposed actions). These plan elements are assessed quantitatively using indicators or issues to gauge plan quality. The principles derived from these studies serve as a guide for creating effective plans, particularly in the realm of hazard mitigation.

### 2.2 Brief Description of Planning Documents

Miami has implemented various policies, plans, and programs to address challenges related to coastal protection, population movement, climate change, and disaster risk management. The following types of planning documents are typically important for flood management:

**Local Hazard Mitigation Plan (LHMP).** The LHMP, or Local Mitigation Strategy (LMS), of Miami-Dade County is a comprehensive community effort to minimize long-term risks to human life and property from hazards, including floods. The Disaster Mitigation Act (DMA) of 2000 requires all local governments to adopt a FEMA-approved mitigation plan to be eligible for federal pre- and post-disaster mitigation funds. LMSs are generally prepared at the county level and include their respective municipalities, including Miami. It is a dynamic document that is continuously updated to incorporate current and projected issues, monitor ongoing mitigation actions, and document completed measures. The July 2020 version of the LMS Plan represents a five-year update approved in 2015. It incorporates initiatives to address climate change and sea-level rise, as well as additional floodplain management measures through the Community Rating System (CRS). This plan typically in-

volves a comprehensive assessment of locality-specific risks, considering factors such as historical hazard data, current vulnerabilities, and future projections. The LHMP outlines a strategy for risk reduction and often includes initiatives to enhance community resilience (Miami-Dade County, 2020).

**Comprehensive Neighborhood Plan.** The Miami Comprehensive Neighborhood Plan (CNP) was adopted as Ordinance 10544 on February 9, 1989, and has been amended by the City Commission through October 24, 2019. The CNP plays a pivotal role in guiding and regulating urban development (Kaiser et al., 1995). It is essential to note that Miami and the surrounding areas in Miami-Dade County continually update and refine these plans to address evolving challenges related to coastal flood protection, climate change, and population movement. These initiatives are crucial for reducing the city's vulnerability to flooding and other climate-related risks. The CNP is the result of a collaborative, iterative planning process that incorporates input from community members, government agencies, and other stakeholders. It provides a vision for the community's future growth and development, outlining goals, policies, and strategies to realise it. In the context of flood planning, the CNP addresses coastal management and land-use patterns to avoid development in high-risk flood zones and to ensure that infrastructure projects consider potential flood impacts (City of Miami, 2019).

**Other Relevant Plans.** The Stormwater Management Plan, with a focus on flood-related hazards, delineates mitigation goals, assesses viable measures, and prioritizes them in an Action Plan for systematic implementation. The City of Miami Comprehensive Emergency Management Plan outlines procedures for city activities before, during, and after emergencies. The City of Miami Hurricane Plan oversees recovery, identifies mitigation opportunities, allocates recovery resources, and ensures coordination throughout the recovery process. A Floodplain Management Plan guides development in flood-prone areas, and cities within the county are working to establish such plans and participate in the Community Rating System. The National Flood Insurance Program recognizes the Local Mitigation Strategy as a potential floodplain management plan for its participants (Miami-Dade County, 2020).

### 2.3 Concept of Resilience

Within the context of flood resilience and the 'bouncing forward' concept, resilience refers to a city's ability not only to withstand, adapt to, and recover from the immediate impacts of flooding but also to use the experience as an opportunity for positive transformation, continuous improvement, and development in the face of adversity (Masterson et al., 2014). It involves the city's capacity to prepare for, respond to, and rapidly recover from flooding while reducing future flood vulnerability, maintaining essential functions, and minimizing damage to infrastructure, the economy, and residents' well-being (Beatley, 2009). In this study, 'resilience' will be assessed by examining how effectively the city's planning documents, strategies, and initiatives manage and mitigate the impacts of flooding, with a focus on the quality and effectiveness of these plans.

## 3 Research Questions

The main research question is: 'To what extent are Miami's existing policies and plans for flood resilience integrated, and what factors influence that integration?' The two sub-research questions are designed to address the main research questions.

1. What specific policies and strategies within Miami's flood resilience plans demonstrate the highest levels of integration and effectiveness?
2. What are the key challenges and barriers that affect the integration of policies and plans for flood resilience?

Together, these research questions provide a comprehensive framework for evaluating the city's flood-resilience efforts and their impact.

## 4 Methodology

This study assessed the quality of comprehensive and hazard-mitigation plans in Miami, Florida, using a framework of five plan-quality principles developed by Brody (2008) in his book *'Ecosystem Planning in Florida: Solving Regional Problems through Local Decision-making'*. The study followed a structured approach that included a data collection and coding protocol.

### 4.1 Data Sources

The relevant plans that influence flood resilience in Miami, including the Comprehensive Plan (CP) and the Local Mitigation Strategy (LMS), were collected online and reviewed. The CP was updated in 2019 and downloaded from the official website of The City of Miami, Florida - <https://www.miami.gov/My-Government/Departments/Planning/Comprehensive-Planning-Main-Page/Miamis-Comprehensive-Neighborhood-Plan-MCNP>, and the updated LMS from July 2020 was obtained from the Miami-Dade County, Florida website - <https://www.miamidade.gov/govaction/legistarfiles/Matters/Y2020/201798.pdf>.

The CP encompasses a broad range of considerations, including future land use, coastal management, capital improvement, transportation, education, housing, natural resource conservation, intergovernmental coordination, parks and recreation and open space, sanitary and storm sewers, solid waste management, ports, aviation, and related facilities, potable water, property rights, the concurrency management program, and a list of amending ordinances. Thus, this research evaluated all elements of comprehensive plans to assess how effectively local governments employ flood policies through local CPs. Flood hazards are primarily addressed in the CP's coastal management element (City of Miami, 2019).

The LMS, composed of seven volumes (Part 1–The Strategy, Part 2–The Projects, Part 3–Funding, Part 4–Appendices, Part 5–Meeting Notes, Part 6–Completed Projects, Part 7–Flooding: The National Flood Insurance Program and Community Rating System), details the planning process and outlines mitigation measures based on haz-

ard risk and vulnerability assessments specific to Miami-Dade County. All seven volumes were reviewed to assess flood resilience.

#### 4.2 Coding Protocol and Scoring the Plans

Brody (2008) examined the ability of local comprehensive plans across Florida to implement the principles of ecosystem management by developing a coding protocol for ecosystem plan quality. For this research, Brody's established protocol was adopted, and the list of indicators suitable for flood considerations was used to evaluate the plan quality of Comprehensive and Hazard Mitigation plans. Plan quality is thus conceptualized (and measured) through the five components: Factual Basis; Goals and Objectives; Inter-Organizational Coordination and Capabilities; Policies, Tools, and Strategies; and Implementation. Together, these five plan components assess the extent to which both plans support flood resilience.

A total of 96 flood-related indicators, distributed across five plan quality principles, were used to unpack the conceptual dimensions of plan quality. Each plan component and its indicators briefly show links to flood considerations. A planning protocol listing each plan component and indicator is provided in Appendix A. The fact base includes 22 items relevant to assessing flood hazards, vulnerability, risk assessment features, and data assessment. The goals and objectives consist of 18 indicators, organised into three headings: economic impacts, physical impacts, and public interests. The policies, tools, and strategies include 43 indicators under Development Regulations tools, Land Acquisition Program Tool, Density Transfer Provisions Tool, Financial Incentives and penalties tool/taxing Tool, Land use analysis and permitting process Tool, Public facilities and Infrastructure Tool, Post Disaster reconstruction decisions Tool, Capital Improvements Tool, Structural tool, Awareness/Educational tool, Insurance tool, General Policy, and Emergency preparedness. The Inter-Organizational Coordination and Capabilities include 7 indicators under two headings, Beyond jurisdictional boundary and within jurisdictional boundary. Finally, the implementation principle consists of 6 items and focuses on monitoring activities. These indicators within the plan component help operationalize and measure the resilience of the local comprehensive plan and local mitigation strategy in Miami to flood hazards. The compilation of pertinent indicators is drawn from various sources, including works by Berke (1996), Brody (2003), Brody et al. (2009b), Brody et al. (2010), Peacock et al. (2009), Berke and Godschalk (2009), Astray-Caneda III EE (2013), Lyles et al. (2012,1), Kim and Marcouiller (2018), Moxey (2017), Park et al. (2020), Feinberg and Ryan (2022), and the book by Masterson et al. (2014). Additionally, new indicators have been incorporated to assess overall flood resilience.

Plan quality scores were measured primarily using the approach commonly used in previous plan quality research (Brody, 2003, 2008; Tang et al., 2010). Each flood policy issue was scored on a 0-2 ordinal scale. A score of '0' means the item is not identified or mentioned in the plan. A score of '1' means the indicator is considered or identified, but with no detail; and a score of '2' indicates a fully

detailed or mandatory element in the plan. In the factual basis component of the protocol, items presented in lists, tables, figures, and maps, if applicable, were considered fully considered or mandatory. This procedure ensured that all plan quality items remained on a 0-2 scale while recognizing that a strong fact base relies on both textual and graphic descriptions. Together, these indicators capture the principles of flood resilience and translate them into elements that can be identified, measured, and compared across comprehensive plans and hazard mitigation plans. Once plans were coded using the flood resilience plan protocol (Refer to Annex A), two types of scores were calculated. First, an overall measure of flood resilience plan quality was derived by creating indices for each plan component and overall plan quality (Berke, 1996). Indices were constructed for each plan component based on three steps (Brody, 2003, 2008):

- First, the actual scores for each indicator were summed across each plan component.
- Second, the sum of the actual scores for each plan component was divided by the total possible score.
- Third, each plan component score (fractional) was multiplied by ten to make a scale from 0 to 10. The plan quality measurement processes are calculated by the following equations (Brody, 2003, 2008):

$$PC_j = \frac{10}{2m_j} \sum_{i=1}^{m_j} I_i,$$

where  $PC_j$  is the plan quality for the  $j^{\text{th}}$  plan component;  $m_j$  is the number of indicators within the  $j^{\text{th}}$  component.

- Finally, the scores for all five components (factual basis; goals and objectives; inter-organizational coordination and capabilities; policies; and implementation) were summed, yielding a total plan quality score on a scale from 0 to 50 (Brody, 2008). Thus, the maximum score for each plan is 50. That is,

$$TPO = \sum_{j=1}^3 PC_j$$

The score reflects the quality of the flood-resilience policies adopted in the local comprehensive plan and the local mitigation strategy. A higher score reflects a higher quality of flood resilience policy.

## 5 Results

The study conducted a comprehensive assessment of flood resilience in Miami, with a specific focus on comparing the Local Mitigation Strategy (LMS) and the Comprehensive Plan (CP) using five plan-quality principles: Fact base; Goals and Objectives; Policies, Tools, and Strategies; Inter-organizational coordination and capabilities; and Implementation. The results, shown in Table 1, provide an overall plan-quality score for each principle and plan, indicating how well Miami incorporates flood-resilience considerations into its planning frameworks.

**Table 1.** Plan quality score differences between LMS and CP for each plan component.

| Plan Quality Principles                            | Local Mitigation Strategy-Plan Quality Score | Comprehensive Plan Quality Score |
|----------------------------------------------------|----------------------------------------------|----------------------------------|
| Fact base                                          | <b>7.3</b>                                   | 1.7                              |
| Goals and Objectives                               | 5                                            | <b>9.4</b>                       |
| Policies, Tools, and Strategies                    | 2                                            | <b>5.8</b>                       |
| Inter-organizational coordination and capabilities | <b>9.3</b>                                   | 4.3                              |
| Implementation                                     | <b>5</b>                                     | 1.6                              |
| Total Plan Quality Score                           | <b>28.6</b>                                  | <b>22.8</b>                      |

Note: Maximum score by plan component is 10.00; Maximum score for total flood resilience plan quality is 50.00.

Under the Fact Base principle, the LMS outperformed the CP, with a significantly higher score of 7.3 compared to 1.7. This suggests a more detailed and comprehensive understanding of flood-risk information within the LMS, highlighting a potential knowledge gap in the CP. Conversely, the CP excelled in the Goals and Objectives principle, scoring 9.5 compared to the LMS's 5, indicating a clearer, better-defined strategic vision for flood resilience. The evaluation of Policies, Tools, and Strategies revealed another advantage for the CP, with a score of 5.8 compared to the LMS's 2. This suggests that the CP has a more comprehensive set of policies and strategies to address flood resilience, potentially indicating a more robust implementation framework. Inter-organizational Coordination and Capabilities favored the LMS significantly, with a score of 9.3 compared to the CP's 4.3, highlighting more effective collaboration within the LMS framework. In terms of Implementation, the LMS again scored higher at 5 compared to the CP's 1.6, indicating a more effective approach to translating plans into concrete actions. The total plan quality score, the sum of scores across all principles, favored the LMS with 28.6, compared to the CP's 22.8, suggesting stronger integration of flood resilience principles within the LMS.

Addressing the main research question, the evaluation of the LMS and CP against plan quality principles indicates stronger integration of flood resilience principles in the LMS than in the CP. The total plan quality score favors the LMS, with variations in the quality of flood resilience plans in Miami. Regarding the first sub-research question, the detailed analysis of the LMS and CP highlights specific strengths and weaknesses in policies and strategies within each plan. The LMS demonstrates notable strengths in the fact base, inter-organizational coordination, and implementation, reflecting a well-documented understanding of flood-related issues, effective collaboration, and a robust approach to plan implementation. On the other hand, the Comprehensive Plan excels in the clarity of its goals and objectives, as well as in the formulation of policies, tools, and strategies. The discussion of each principle provides insights into the strengths and weaknesses of specific policies and strategies within the plans, thereby addressing this sub-research question.

The second sub-research question is implicitly answered by identifying areas for improvement in both plans. The higher score in the fact base for the LMS suggests a more comprehensive understanding of flood resilience issues, crucial for informed decision-making. Its superior score in inter-organizational coordination indicates effectiveness at

fostering collaboration, which is essential for successful implementation. Additionally, the higher implementation score indicates more actionable strategies, which are critical for practical outcomes. The CP could benefit from enhancing its fact base, coordination, and implementation, contributing to a more comprehensive flood resilience strategy. While the CP excels in policies, tools, and strategies, ensuring a balance with a strong factual basis and effective implementation strategies is crucial. Clear goals and objectives provide direction, but success depends on comprehensive information and effective plans. Both plans demonstrate strengths and areas for improvement, suggesting a need for a holistic approach that combines their strengths while addressing weaknesses to build a more robust flood resilience strategy. Continuous monitoring and updating of plans are essential for adapting to evolving challenges and ensuring long-term sustainability.

Overall, the LMS achieved a higher total plan-quality score than the CP, although both plans demonstrated significant strengths across the different plan-quality principles.

## 6 Discussion and Implications

The observed differences between the LMS and the CP align with the distinct purposes of the two planning instruments. As a hazard mitigation document, the LMS is designed to identify risks, coordinate stakeholders, and support the implementation of mitigation actions. Consequently, its stronger performance in factual analysis, coordination, and implementation reflects its operational focus on reducing disaster risk and enhancing preparedness. In contrast, the Comprehensive Plan serves as a long-range policy framework that guides future growth and development. Its stronger performance in goals, objectives, and policy provisions highlights its role in establishing a strategic vision for resilience and integrating resilience considerations into broader land-use and development decisions. However, its relatively weaker performance in factual analysis and implementation suggests that resilience objectives may not always be supported by detailed hazard information or clearly defined implementation mechanisms.

The findings highlight the importance of aligning long-term policy objectives with operational implementation mechanisms. Effective resilience planning requires more than a strategic vision; it also depends on access to technical information, institutional coordination, and the capacity to translate planning objectives into action. Plans that clearly

define responsibilities, coordination structures, and implementation procedures are more likely to produce tangible resilience outcomes. This observation is consistent with the planning literature, which emphasizes that plan quality depends not only on policy content but also on implementation and monitoring capacity.

The importance of integrating hazard mitigation planning and comprehensive planning has become increasingly evident as Miami continues to face recurring flood hazards associated with extreme rainfall, sea-level rise, and climate change. The June 2024 flooding event, which severely affected Miami and the surrounding areas of South Florida, caused widespread transportation disruptions, infrastructure damage, and neighborhood flooding, highlighting the city's ongoing vulnerability to extreme precipitation events (National Oceanic and Atmospheric Administration, 2024). These impacts reinforce the need for planning frameworks that align long-term resilience objectives with effective implementation mechanisms.

As communities face increasing flood risks driven by climate change, population growth, and continued urban development, strengthening the connection between planning vision and implementation capacity will be critical to building long-term resilience. These findings provide practical insights for policymakers and planners seeking to strengthen local flood resilience. Rather than viewing hazard mitigation planning and comprehensive planning as separate processes, greater integration between the two planning frameworks may enhance overall resilience outcomes (Yu et al., 2020). Such integration can help ensure that actionable strategies, coordinated governance structures, and evidence-based decision-making processes support long-term resilience goals.

## 7 Conclusions

This study evaluated the quality of flood resilience planning in Miami by comparing the Local Mitigation Strategy and the Comprehensive Plan against established plan-quality principles. The findings demonstrate that flood resilience planning is multifaceted and requires integrating technical analysis, policy direction, institutional coordination, and implementation capacity.

The study highlights that effective flood resilience cannot be achieved by a single planning instrument alone. Rather, resilience depends on how well different planning frameworks work together to support informed decision-making, guide development, and facilitate the implemen-

tation of risk-reduction measures. Strengthening connections between hazard mitigation planning and comprehensive planning can create a more cohesive, adaptive approach to addressing current and future flood risks.

The findings have important implications for communities facing escalating climate-related hazards. As flood risks continue to evolve, planning efforts should prioritize not only the development of resilience policies but also the institutional capacity and implementation mechanisms needed to translate planning objectives into measurable outcomes. Continuous monitoring, periodic plan updates, and cross-sector collaboration will remain essential to long-term resilience planning.

Ultimately, this study contributes to the broader discourse on effective flood resilience planning and highlights the significance of a holistic, integrated approach to urban planning in the face of climate-related challenges.

## Declaration of AI-usage Statement

During the preparation of this manuscript, the author used ChatGPT (OpenAI) to assist with language editing, grammar, and readability. All scientific content, study design, data analysis, interpretation of results, and conclusions were developed by the authors. The authors carefully reviewed and edited all AI-assisted outputs and assume full responsibility for the content of this publication.

## CRedit Statement

**Chandra Hada:** Conceptualization, Methodology, Data Curation, Formal Analysis, Investigation, Visualization, Writing – Original Draft, Writing – Review & Editing; **Samuel D. Brody:** Supervision, Methodology, Validation, Writing – Review & Editing, Funding Acquisition (Institute for a Disaster Resilient Texas).

## Conflict of Interest Statement

The authors declare that there are no known competing financial interests, personal relationships, or affiliations that could appear to influence the work reported in this manuscript.

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## Appendix A List of items and measurements included in the plan quality protocol for the five principles of plan quality

| <b>Coding Protocol for Local Hazard Mitigation Plan and Comprehensive Plan</b>                                                                                                        |                                     |                                        |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------|----------------------------------------|
| <b>Fact Base Principles (22 items)</b>                                                                                                                                                | <b>Coding Categories</b>            | <b>Coding Categories</b>               |
| Coding Categories                                                                                                                                                                     | <b>Local Hazard Mitigation Plan</b> | <b>Comprehensive Neighborhood Plan</b> |
| 0 = not identified and mentioned,                                                                                                                                                     |                                     |                                        |
| 1 = suggested or identified but not detailed,                                                                                                                                         |                                     |                                        |
| 2 = fully detailed or mandatory in plan                                                                                                                                               |                                     |                                        |
| <b>Plan assesses flood hazards</b>                                                                                                                                                    |                                     |                                        |
| 1.1 Addressed flood hazards including hurricanes/tropical storms, sea level rise, climate change etc.                                                                                 | 2                                   | 2                                      |
| 1.2 Prioritized flood hazards                                                                                                                                                         | 2                                   | 2                                      |
| 1.3 Identifies factors used in prioritizing hazards                                                                                                                                   | 2                                   | 1                                      |
| 1.4 Delineates location and boundaries for flood hazards areas                                                                                                                        | 2                                   | 2                                      |
| 1.5 Delineates magnitude and severity of flood hazards                                                                                                                                | 2                                   | 0                                      |
| 1.6 Information on previous flood hazard (history)                                                                                                                                    | 2                                   | 0                                      |
| 1.7 Delineates likelihood of occurrence of flood hazard event (e.g. annual probability)                                                                                               | 1                                   | 0                                      |
| 1.8 Describes separate characteristics of flood hazards                                                                                                                               | 2                                   | 0                                      |
| <b>Plan assesses vulnerabilities</b>                                                                                                                                                  |                                     |                                        |
| 1.9 Number of current populations exposed to flood                                                                                                                                    | 1                                   | 0                                      |
| 1.10 Number of disadvantaged populations exposed to flood hazard (e.g. number of people, demographic groups, locations)                                                               | 1                                   | 0                                      |
| 1.11 Number and total value of Public infrastructures (water, sewer, roads, storm water drainage) exposed to flood hazard                                                             | 2                                   | 0                                      |
| 1.12 Number and total value of private structures exposed to flood hazard                                                                                                             | 2                                   | 0                                      |
| 1.13 Number of critical facilities such as hospitals, bridges, sewage treatment plants, water treatment plants, schools, power plants, police, fire stations, exposed to flood hazard | 1                                   | 0                                      |
| 1.14 Assessment of environmental impacts of a flood disaster                                                                                                                          | 1                                   | 0                                      |
| <b>Plan includes risk assessment features:</b>                                                                                                                                        |                                     |                                        |
| 1.15 conduct systematic risk assessment, combining probabilities of hazardous events with the likely expected losses from flood events                                                | 1                                   | 0                                      |
| 1.16 Provide loss estimations (number and total value) for public structures                                                                                                          | 1                                   | 0                                      |
| 1.17 Provide loss estimations (number and total value) for private structures                                                                                                         | 1                                   | 0                                      |
| 1.18 Conduct multi-hazard risk assessment                                                                                                                                             | 1                                   | 0                                      |
| 1.19 Emergency shelter demand and capacity data                                                                                                                                       | 1                                   | 0                                      |
| 1.20 Evacuation Clearance Time Data                                                                                                                                                   | 2                                   | 0                                      |
| <b>Data Assessment</b>                                                                                                                                                                |                                     |                                        |
| 1.21 Identification of sources of data                                                                                                                                                | 2                                   | 0                                      |
| 1.22 Assessment of quality of data about flood hazards (reliability, validity, spatial specificity, relevance)                                                                        | 0                                   | 0                                      |
| <b>Sum Score of each indicator</b>                                                                                                                                                    | <b>32</b>                           | <b>7</b>                               |
| <b>Plan Quality Score</b>                                                                                                                                                             | <b>32/44x10 = 7.27</b>              | <b>7/44x10= 1.59</b>                   |
| <b>2.0 Goals and Objectives Principle: 18 items</b>                                                                                                                                   |                                     |                                        |
| Coding Categories                                                                                                                                                                     |                                     |                                        |
| 0 = not included                                                                                                                                                                      |                                     |                                        |
| 1 = included but not detailed                                                                                                                                                         |                                     |                                        |
| 2 = included and detailed                                                                                                                                                             |                                     |                                        |
| <b>Economic Impacts</b>                                                                                                                                                               |                                     |                                        |
| 2.1 Reduce property loss from flood disaster                                                                                                                                          | 1                                   | 2                                      |
| 2.2 Minimize fiscal impacts of flood disasters                                                                                                                                        | 1                                   | 2                                      |
| 2.3 Distribute flood hazard management cost equitably                                                                                                                                 | 1                                   | 2                                      |
| <b>Physical Impacts</b>                                                                                                                                                               |                                     |                                        |
| 2.4 Reduce damage to public property                                                                                                                                                  | 1                                   | 2                                      |
| 2.5 Reduce damage to private property                                                                                                                                                 | 1                                   | 2                                      |
| 2.6 Reduce damage to property in general                                                                                                                                              | 1                                   | 2                                      |
| 2.7 Reduce flood hazard impacts on environment and natural areas                                                                                                                      | 1                                   | 2                                      |
| 2.8 Discourage development in floodplain area                                                                                                                                         | 1                                   | 2                                      |
| 2.9 Minimize impervious surfaces from development                                                                                                                                     | 0                                   | 1                                      |
| 2.10 Encourage open spaces/recreation actions                                                                                                                                         | 2                                   | 2                                      |
| 2.11 Reduce flooding from rainfall events                                                                                                                                             | 1                                   | 1                                      |

| Public Interest                                                                                                     |                     |                       |
|---------------------------------------------------------------------------------------------------------------------|---------------------|-----------------------|
| 2.12 Protect safety of population                                                                                   | 1                   | 2                     |
| 2.13 Promote flood hazard awareness program                                                                         | 1                   | 2                     |
| 2.14 Increase coordination and information availability                                                             | 2                   | 2                     |
| 2.15 Encourage public participation                                                                                 | 2                   | 2                     |
| 2.16 Overarching Vision – increase resilience                                                                       | 1                   | 2                     |
| 2.17 Overarching vision – promote Sustainability                                                                    | 0                   | 2                     |
| 2.18 Presence of measurable objectives                                                                              | 0                   | 2                     |
| <b>Sum Score of each indicator</b>                                                                                  | <b>18</b>           | <b>34</b>             |
| <b>Plan Quality Score</b>                                                                                           | <b>18/36x10 = 5</b> | <b>34/36x10 = 9.4</b> |
| <b>3. Policies, Strategies and Tools Principle (43 Items)</b>                                                       |                     |                       |
| Coding Categories                                                                                                   |                     |                       |
| 0 = policies not mentioned                                                                                          |                     |                       |
| 1 = suggested in plan                                                                                               |                     |                       |
| 2 = fully detailed and mandatory in plan                                                                            |                     |                       |
| <b>A. Development Regulations tools</b>                                                                             |                     |                       |
| 3.1 Permitted Land use (e.g. residential, commercial, industrial, open space. May be tied to zoning code)           | 0                   | 2                     |
| 3.2 Density of land use (e.g. units per acre, may be tied to zoning code)                                           | 0                   | 2                     |
| 3.3 Subdivision regulations (e.g. onsite storm management)                                                          | 0                   | 1                     |
| 3.4 Zoning overlay (restrict permitted land use/density in flood hazard areas / Development away from floodplains)  | 0                   | 1                     |
| 3.5 Setback or buffer zone (e.g. riparian buffer, ocean setback)                                                    | 0                   | 1                     |
| 3.6 Cluster development (e.g. provision requiring clustering of development away from flood hazard areas)           | 0                   | 1                     |
| <b>B. Land Acquisition Program Tool</b>                                                                             |                     |                       |
| 3.7 Acquire land and property (purchase in hazard area)                                                             | 0                   | 2                     |
| 3.8 Dedication of open space for flood hazards/Dedication of conservation easement                                  | 0                   | 2                     |
| <b>C. Density Transfer Provisions Tool</b>                                                                          |                     |                       |
| 3.9 Transfer/purchase of development rights                                                                         | 0                   | 1                     |
| <b>D. Financial Incentives and penalties tool/taxing Tool</b>                                                       |                     |                       |
| 3.10 Density bonuses (allowing development with greater density)                                                    | 0                   | 2                     |
| 3.11 Tax abatement for using flood mitigation (tax breaks offered to property owners)                               | 0                   | 1                     |
| 3.12 Impact/special study /protection fees (for development in flood hazard areas or structural protection fees)    | 0                   | 0                     |
| <b>E. Land use analysis and permitting process Tool</b>                                                             |                     |                       |
| 3.13 Land suitability                                                                                               | 1                   | 2                     |
| 3.14 Site review                                                                                                    | 0                   | 2                     |
| 3.15 Design/construction guidelines/requirements                                                                    | 0                   | 1                     |
| <b>F. Public facilities and Infrastructure Tool</b>                                                                 |                     |                       |
| 3.16 Siting (provision to site public facilities - municipal housing and buildings out of flood hazard areas)       | 1                   | 2                     |
| 3.17 Sizing / capacity (provision limiting capacity of public facilities/buildings, housing, in flood hazard areas) | 1                   | 2                     |
| <b>G. Post Disaster reconstruction decisions Tool</b>                                                               |                     |                       |
| 3.18 Development moratorium                                                                                         | 0                   | 0                     |
| 3.19 Post-disaster land use change                                                                                  | 0                   | 0                     |
| 3.20 Post disaster capital improvements                                                                             | 0                   | 0                     |
| <b>H. Capital Improvements Tool</b>                                                                                 |                     |                       |
| 3.21 Infrastructure hardening or weatherproofing                                                                    | 0                   | 2                     |
| 3.22 Elevating physical structures in flood hazard areas                                                            | 0                   | 1                     |
| 3.23 Drainage improvements/flood control                                                                            | 1                   | 1                     |
| 3.24 Ecosystem enhancement                                                                                          | 0                   | 1                     |
| 3.25 Slope/dune stabilization (to control erosion)                                                                  | 0                   | 2                     |
| <b>I. Structural tool</b>                                                                                           |                     |                       |
| 3.26 Detention ponds/retention/holding                                                                              | 0                   | 1                     |
| 3.27 Levees - Dams                                                                                                  | 0                   | 1                     |
| 3.28 Seawalls                                                                                                       | 0                   | 1                     |
| 3.29 Riprap                                                                                                         | 0                   | 1                     |

|                                                                                                                                                             |                        |                        |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------|------------------------|
| 3.30 Bulkheads                                                                                                                                              | 0                      | 1                      |
| 3.31 Channel maintenance/Channelization                                                                                                                     | 0                      | 1                      |
| 3.32 Slope stabilization                                                                                                                                    | 0                      | 1                      |
| 3.33 Storm water management - Cleaning of debris                                                                                                            | 0                      | 1                      |
| <b>J. Awareness/Educational tool</b>                                                                                                                        |                        |                        |
| 3.34 Education/outreach program                                                                                                                             | 1                      | 2                      |
| 3.35 Training / Technical assistance - Flood forecasting, warning, and response program                                                                     | 1                      | 2                      |
| 3.36 Maps of areas subject to flood hazards                                                                                                                 | 1                      | 1                      |
| 3.37 Post Signs indicating flood hazard areas                                                                                                               | 0                      | 0                      |
| <b>K. Insurance tool</b>                                                                                                                                    |                        |                        |
| 3.38 Participation in flood insurance program (NFIP)                                                                                                        | 2                      | 2                      |
| 3.39 Participation to Community Rating System (CRS)                                                                                                         | 2                      | 2                      |
| <b>L. General Policy</b>                                                                                                                                    |                        |                        |
| 3.40 Discourage development in flood hazard areas                                                                                                           | 2                      | 1                      |
| <b>M. Emergency preparedness</b>                                                                                                                            |                        |                        |
| 3.41 Evacuation                                                                                                                                             | 2                      | 0                      |
| 3.42 Sheltering                                                                                                                                             | 1                      | 0                      |
| 3.43 Require emergency plans                                                                                                                                | 1                      | 0                      |
| <b>Sum Score of each indicator</b>                                                                                                                          | <b>17</b>              | <b>50</b>              |
| <b>Plan Quality Score</b>                                                                                                                                   | <b>17/86x10 = 1.97</b> | <b>50/86x10 = 5.81</b> |
| <b>4.0 Inter-Organizational Coordination and Capabilities (7 items)</b>                                                                                     |                        |                        |
| Coding Categories                                                                                                                                           |                        |                        |
| 0 = not mentioned                                                                                                                                           |                        |                        |
| 1 = mentioned but no detail                                                                                                                                 |                        |                        |
| 2 = mentioned in detail                                                                                                                                     |                        |                        |
| <b>A. Beyond jurisdictional boundary</b>                                                                                                                    |                        |                        |
| 3.1 Other jurisdictions/organizations stakeholders identified                                                                                               | 2                      | 1                      |
| 3.2 Coordination with other jurisdictions/organizations/stakeholders identified                                                                             | 2                      | 1                      |
| 3.3 Coordination with higher levels of governments (state/federal)                                                                                          | 2                      | 1                      |
| 3.4 Coordination with private sectors                                                                                                                       | 2                      | 1                      |
| 3.5 Vertical Integration with other plans/policies in federal, state, and regional parties                                                                  | 2                      | 1                      |
| <b>B. Within jurisdictional boundary</b>                                                                                                                    |                        |                        |
| 3.6 Coordination within jurisdiction / Horizontal coordination with plans or policies of other local parties within or outside local jurisdiction specified | 2                      | 1                      |
| 3.7 Commitment of financial resources                                                                                                                       | 1                      | 0                      |
| <b>Sum Score of each indicator</b>                                                                                                                          | <b>13</b>              | <b>6</b>               |
| <b>Plan Quality Score</b>                                                                                                                                   | <b>13/14x10 = 9.28</b> | <b>6/14x10 = 4.28</b>  |
| <b>Implementation Principle (6 items)</b>                                                                                                                   |                        |                        |
| Coding Categories                                                                                                                                           |                        |                        |
| 0 = not mentioned                                                                                                                                           |                        |                        |
| 1 = suggested in plan                                                                                                                                       |                        |                        |
| 2 = mandatory in plan                                                                                                                                       |                        |                        |
| 5.1 Clear timeline for implementation                                                                                                                       | 0                      | 1                      |
| 5.2 Designation of responsibilities for actions                                                                                                             | 1                      | 0                      |
| 5.3 Identification of financial and technical support                                                                                                       | 1                      | 0                      |
| 5.4 Regular plan updates and assessments                                                                                                                    | 2                      | 1                      |
| 5.5 Monitoring of flood impacts                                                                                                                             | 1                      | 0                      |
| 5.6 Highlighting flood sustainability                                                                                                                       | 1                      | 0                      |
| <b>Sum Score of each indicator</b>                                                                                                                          | <b>6</b>               | <b>2</b>               |
| <b>Plan Quality Score</b>                                                                                                                                   | <b>6/12x10 = 5</b>     | <b>2/12x10 = 1.66</b>  |
| <b>Total Plan Quality Score</b>                                                                                                                             | <b>28.53</b>           | <b>22.74</b>           |

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