Flood Risk Management Strategies for Bridgeport, Connecticut: A Comparative Analysis of Infrastructure Hardening and Managed Retreat

Adejumo Azeez Adewale

Department of Environmental Science, Pace University, Pleasantville, New York, USA

Correspondence: Adejumo Azeez Adewale | Pace University, Pleasantville, NY 10570, USA

ABSTRACT

This study analyzes sea-level rise management options for Bridgeport, Connecticut, comparing infrastructure hardening and managed retreat using a mixed-methods approach that integrates geospatial analysis, policy analysis, and vulnerability assessment. Sea-level rise projections under NOAA scenarios range from 3.3 ft (low emission) to 15.1 ft (extreme) by 2100, with the South End and East End neighborhoods exhibiting the highest composite vulnerability scores. A 30-year cost-benefit analysis demonstrates that while infrastructure hardening provides immediate protection, escalating maintenance costs and the risk of catastrophic failure make it less viable in the long term. Managed retreat offers permanent risk reduction but faces significant social resistance and equity concerns. This study concludes that a hybrid strategy—combining targeted hardening of critical infrastructure with phased managed retreat from the most vulnerable zones—provides the most effective and equitable solution. Equity is identified as a central policy concern, as low-income and minority communities bear a disproportionate share of flood risk. These findings have direct applicability to other coastal cities facing similar challenges, including megacities such as Lagos, Nigeria, where unfettered urban growth has severely compounded flood vulnerability.

Keywords: Coastal Resilience; Flood Risk Management; Managed Retreat; Infrastructure Hardening; Sea-Level Rise; Social Equity; GIS; Bridgeport; Connecticut; Lagos

1. INTRODUCTION

Coastal cities have historically served as economic, agricultural, and strategic centers, drawing populations to waterways for trade, sustenance, and defense [1]. Yet this proximity to water creates inherent vulnerability to flooding, storm surges, and, increasingly, the accelerating effects of climate change. Historical examples—from the ancient Greek city of Helike, destroyed by a tsunami in 373 BCE, to New Orleans during Hurricane Katrina in 2005—demonstrate the catastrophic consequences of inadequate flood management [2].

Bridgeport is the largest city in Connecticut, with a population of 148,654 (2020 Census), situated on Long Island Sound at the mouth of the Pequonnock River [3]. The city has experienced major flood events in 1938, 1954, and 2012 (Hurricane Sandy), and has seen a marked increase in nuisance flooding in recent years. With projected sea-level rise, the frequency and magnitude of these events will intensify, threatening both residents and critical infrastructure [4].

Despite the development of a Hazard Mitigation Plan, Bridgeport lacks a comprehensive, comparative cost-benefit analysis of its primary adaptation options. This study addresses this gap by evaluating the technical, economic, and social feasibility of infrastructure hardening versus managed retreat, and proposes a hybrid approach that prioritizes social equity. The following research questions guide the analysis:

RQ1: What are the present and projected future flood risks in Bridgeport under different sea-level rise scenarios?

RQ2: What are the technical, economic, and social feasibility of infrastructure hardening and managed retreat?

RQ3: What trade-offs exist between the two strategies, and how can a hybrid approach best serve Bridgeport?

2. METHODS AND MATERIALS

2.1 Vulnerability Assessment Framework

For the purposes of this study, *vulnerability* is defined as the predisposition of a community or system to be adversely affected by a hazardous event—a function of physical exposure, socioeconomic sensitivity, and adaptive capacity [6]. This definition follows the IPCC (2022) framework and encompasses three dimensions: (i) social vulnerability, including income, age, and language proficiency [7]; (ii) economic vulnerability, reflecting potential direct and indirect losses [8]; and (iii) environmental vulnerability, relating to the susceptibility of natural coastal systems [9].

2.2 Data Sources

Geospatial data, including high-resolution Digital Elevation Models (DEM) and LiDAR data, were obtained from the U.S. Geological Survey [10]. FEMA Flood Insurance Rate Maps (FIRMs) provided current flood risk designations [11]. Future climate projections were sourced from NOAA's Sea Level Rise Viewer and the Connecticut Institute for Resilience and Climate Adaptation (CIRCA) [4, 12]. Demographic data were derived from the U.S. Census Bureau's 5-year American Community Survey estimates [3], and infrastructure data from the City of Bridgeport's Capital Improvement Plan and GIS Hub.

2.3 Analytical Tools and Approach

ArcGIS Pro was used for spatial analysis and flood inundation modeling. Flood exposure scenarios were modeled at 1-foot (2030–2040), 3-foot (2050–2070), and 6-foot (2100, high emissions) increments above present mean high tide. Excel and R software were employed for statistical analysis and 30-year cost-benefit modeling. Urban Footprint was used to simulate urban growth patterns and their effects on flood risk and community resilience [5].

3. RESULTS

3.1 Sea-Level Rise Projections

NOAA projections indicate that sea levels in Bridgeport could rise between 3.3 ft (Low scenario) and 15.1 ft (Extreme scenario) by 2100. The Intermediate-Low scenario (6.0 ft) is considered most likely under current emission trajectories, while the Intermediate-High scenario (10.0 ft) reflects more dynamic ice sheet behavior [4, 13]. These projections align with global findings on thermal expansion and ice melt contributions to sea-level rise [13].

3.2 Vulnerability Assessment Results

The composite vulnerability analysis revealed significant spatial disparities across Bridgeport's neighborhoods. The South End and East End exhibit the highest vulnerability scores, driven by low median household incomes, aging housing stock, and high proportions of minority residents. These neighborhoods also face the greatest physical flood exposure under all sea-level rise scenarios. The downtown corridor presents high economic vulnerability due to the concentration of critical infrastructure, commercial assets, and the city's seaport.

3.3 Comparative Strategy Assessment

Table 1 presents a comparative evaluation of infrastructure hardening and managed retreat across six key criteria. The 30-year cost-benefit analysis indicates that while hardening provides immediate, high-certainty protection, its long-term costs are substantially higher than managed retreat, particularly under high sea-level rise scenarios. Managed retreat offers permanent risk elimination for relocated areas but carries significant upfront social and political costs.

Table 1. Comparative Assessment of Infrastructure Hardening vs. Managed Retreat

Evaluation Criteria	Infrastructure Hardening	Managed Retreat
Initial Capital Cost	Very High	High
Long-term Maintenance	High (ongoing)	Low (post-buyout)
Flood Risk Reduction	High (to design limit)	Complete (relocated areas)
Environmental Impact	Negative (habitat loss)	Positive (habitat restoration)
Social Acceptance	High	Low to Moderate
Equity Implications	Can exacerbate disparities	High displacement risk if unmanaged

4. DISCUSSION

4.1 The Hybrid Approach

The evidence strongly supports a hybrid strategy that combines targeted hardening with phased managed retreat. This approach divides the city into three strategic zones: (i) **Protection Zones**, where critical infrastructure and high-density economic hubs are hardened; (ii) **Transition Zones**, where accommodation strategies (elevation, floodproofing) are applied; and (iii) **Retreat Zones**, where phased voluntary buyouts are initiated in the most vulnerable low-lying residential areas, with acquired land converted to natural coastal buffers. This "living with water" approach is consistent with emerging literature on hybrid coastal adaptation [14].

4.2 Equity and Policy Implications

A central finding of this research is that flood burdens in Bridgeport are inequitably distributed. Low-income and minority communities—particularly in the South End and East End—face the highest physical exposure while possessing the lowest adaptive capacity. Both hardening and retreat strategies carry significant equity risks if poorly designed. Hardening affluent areas while neglecting poorer neighborhoods can lead to "climate gentrification," while forced retreat can destroy community cohesion and social networks.

Policy Imperative: Effective climate adaptation in Bridgeport requires community-led planning, equitable investment across all neighborhoods, and the provision of safe, affordable relocation options within the city for displaced residents.

Specific policy reforms recommended include: the development of a Climate Resilience Overlay District in the zoning code to restrict new development in high-risk areas; a Community Resilience Trust Fund to finance adaptation measures in low-income neighborhoods; and a Managed Retreat Pilot Program in the three most vulnerable census tracts of the South End, with full community participation and transparent buyout valuations.

5. CONCLUSIONS

This study demonstrates that a hybrid strategy—combining infrastructure hardening with phased managed retreat—provides the most effective and equitable flood risk management solution for Bridgeport, Connecticut. The research makes three primary contributions: (1) a spatially explicit, multi-dimensional vulnerability assessment that identifies the South End and East End as priority areas for intervention; (2) a 30-year cost-benefit analysis demonstrating the long-term economic superiority of managed retreat under high sea-level rise scenarios; and (3) an equity-centered policy framework that places community justice at the center of adaptation planning.

5.1 Broader Implications: Lessons for Lagos, Nigeria

The findings from Bridgeport offer critical lessons for megacities facing similar, but far more severe, challenges. Lagos, Nigeria, with a population exceeding 15 million and projected to be among the world's most populous cities by 2100, faces devastating recurrent flooding exacerbated by unfettered urban growth and extensive informal settlements in flood-prone areas. For Lagos, a hybrid approach is not merely advisable—it is an absolute necessity. Full retreat is demographically and politically unthinkable; full protection is financially and technically impossible. Lagos must adopt a zoned approach, prioritize equity to prevent mass displacement and social unrest, and urgently enforce comprehensive land-use plans to restrict further development in high-risk areas. The Bridgeport case study underscores a universal truth: unchecked urban growth in a changing climate carries terrifying consequences, and only hybrid, equitable, and meticulously planned adaptation strategies offer a viable path forward.

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