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CLIMATE CHANGE IMPACTS ON BRIDGE SCOUR HAZARD IN NEW YORK STATE

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ABSTRACT: Climate change is occurring at unprecedented rates, with significant implications for infrastructure resilience. This study investigates the potential impacts of climate change-induced higher flood risk, due to future precipitation changes, on bridge scour risk in New York State. Bridge scour is the primary cause of bridge failure in the United States. Given the increasing frequency and intensity of extreme weather events, understanding the relationship between climate change and bridge scour is critical for infrastructure management, hazard assessment, and mitigation planning.
This study examines the relationship between future precipitation patterns, flood zones, resulting runoff, and streamflow with bridges vulnerable to scouring. The research employs a GIS-based hazard analysis model, integrating data from the National Bridge Inventory (NBI), climate hazard maps, hydrological datasets, and other geospatial sources. By overlaying future climate projections with existing bridge infrastructure data, this approach enables the identification and mapping of critical scour-vulnerable bridges across New York State.
The study highlights the necessity for adaptive engineering strategies, such as reinforced bridge foundations and enhanced monitoring systems, to mitigate climate-induced scour. The findings emphasize the importance of integrating climate resilience into transportation policy and infrastructure planning. This research supports long-term resilience efforts to safeguard public safety and economic stability against evolving climate hazards.

1. INTRODUCTION

Bridge scour occurs when water flow erodes the soil surrounding bridge foundations, weakening structural integrity and potentially leading to catastrophic failures (Richardson & Davis, 2001). While this process has long been recognized as a critical infrastructure concern, the accelerating impacts of climate change are creating new challenges for bridge safety assessment and management (Melville & Coleman, 2000). Traditional predictive models, such as HYRISK, have served as standard tools for evaluating scour risk, but they frequently overestimate both failure probabilities and economic impacts (Parola et al., 1997). This tendency toward overestimation, combined with changing environmental conditions, necessitates the development of updated frameworks that can more accurately incorporate climate change effects (Hamill, 1999). Recent studies have emphasized the importance of refining HYRISK-based assessments to account for future hydrological extremes and associated uncertainties (Khelifa et al., 2013).

The increasing severity and frequency of extreme weather patterns have made it particularly crucial to assess bridge vulnerabilities through a more comprehensive lens. Factors such as altered precipitation patterns, changes in seasonal runoff, and shifts in stream behavior all contribute to a complex web of variables that affect bridge scour risk (Briaud et al., 2014). As highlighted in recent literature, climate-induced changes pose significant risks to bridge safety and performance, demanding proactive adaptation strategies and improved risk quantification methods (Nasr et al., 2021). Furthermore, post-event assessment and prioritization of mitigation plans play a vital role in minimizing long-term structural risks, especially in storm-prone regions (Gholitabar et al., 2016). The spatial distribution of these risks across regions like New York State requires careful consideration of local geological, hydrological, and infrastructural factors (Lagasse et al., 2012).

To address these challenges, new assessment approaches must move beyond conventional modeling to incorporate multiple data streams and advanced analytical techniques. This study introduces a hazard assessment model that integrates environmental, geospatial, and infrastructure data to enhance the accuracy and reliability of scour risk predictions. By combining these diverse data sources with modern analytical methods such as machine learning and GIS-based analysis, we aim to provide infrastructure managers with more robust tools for evaluating and managing bridge scour risk in an era of climate uncertainty (Lee et al., 2020).

2. METHODOLOGY

This research employs a hazard assessment approach, integrating geospatial analysis and climate change projections to evaluate scour vulnerabilities in bridges.

2.1 Data Integration

Key datasets utilized in this study include:

National Bridge Inventory (NBI): This dataset provides critical information on infrastructure and environmental conditions affecting water levels, channel stability, and sediment transport. It focuses on concrete bridges, analyzing structural stability, protective elements, and waterway adequacy to assess how well bridge openings accommodate flow under varying conditions. Channel protection is evaluated through stream stability assessments, erosion analysis, and the condition of protective measures such as riprap and stream control devices. Additionally, the scour critical classification identifies bridges with unstable abutments or pier foundations due to observed or potential scour, based on hydraulic, geotechnical, and structural evaluations. These factors collectively help determine infrastructure vulnerability and resilience to changing environmental conditions. Through this analysis, 215 bridges from an initial list of 17,574 were identified as being more prone to scour risks.

Climate Change Factors: Variables considered in this study include floodplain extent and precipitation trends, both of which significantly impact bridge scour risk. More frequent and intense storms increase water velocity, accelerating scour erosion. Additionally, heightened rainfall levels elevate water depths and strengthen currents, intensifying scour formation. Alterations in sediment transport further modify riverbed composition, influencing scour depth and structural stability.
For floodplain analysis, this research employed the New York State Freshwater Conservation Blueprint, accessed via GIS Online, to assess floodplain complexes. The study incorporated Active River Area (ARA) data, National Hydrography Dataset Plus (NHDPlus) flowlines, and Northeast Aquatic Habitat Conservation (NEAHC) stream classifications. Key modifications to this GIS-based analysis included the inclusion of small rivers with drainage areas exceeding 38 square miles and consideration of natural cover areas larger than 150 acres adjacent to water bodies.

Additionally, Environmental Protection Agency (EPA) climate indicators were utilized to track changes in flood magnitude and frequency across New York State rivers. This dataset, covering the period from 1965 to 2015, provided insights into long-term trends in flood behavior, essential for assessing evolving scour risks under changing climatic conditions.
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2.2 Analytical Approach

The following methodologies were applied to conduct a detailed scour hazard assessment. A GIS-based spatial mapping approach was implemented using ArcGIS Pro to overlay multiple geospatial datasets. This enabled the identification of high-hazard bridges based on both structural attributes and environmental exposure factors.
The hazard assessment framework integrates the following key components:

Bridge Vulnerability Analysis: Data from the National Bridge Inventory (NBI) was used to identify scour-critical structures, focusing on factors such as foundation type, waterway adequacy, and the condition of protective elements like riprap and stream control devices.

Climate Change Projections: Climate indicators, including projected precipitation patterns and flood frequency trends (e.g., from EPA datasets), were incorporated to evaluate the potential influence of changing hydrologic conditions on scour hazards.

Geospatial Overlays: Spatial maps of scour-critical bridge locations were created and overlaid with floodplain boundaries, precipitation intensity zones, and flood frequency data. This overlay analysis helped identify bridges located in areas with high precipitation, frequent flooding, and vulnerable riverbed conditions.

This multi-faceted approach supports a robust hazard assessment by combining structural and environmental vulnerability analyses with evolving climate conditions. The results of this integration are presented in the form of spatial visualizations that highlight bridges most vulnerable to scour under future climate scenarios.

3. RESULTS AND DISCUSSION

Preliminary findings suggest that climate change significantly impacts scour risk by altering hydrological patterns and increasing the frequency of flooding. The integration of climate hazard maps with bridge inventory data identifies critical regions in New York State that are highly susceptible to scour-related failures. Bridges situated in floodplains and areas with high precipitation face heightened vulnerability. Through geospatial analysis, this study establishes a risk prioritization framework for New York’s bridges, offering valuable insights for infrastructure resilience planning.

The data reveals heightened flood frequency and intensity in two regions: around Catskill Park in Ulster County, as well as Chemung County and near Ithaca (see Figure 1,2 and 3). These areas also record higher precipitation levels. Cross-referencing bridge locations with these high-risk floodplains helped identify the most vulnerable scour-critical bridges, which are listed in Table 1.

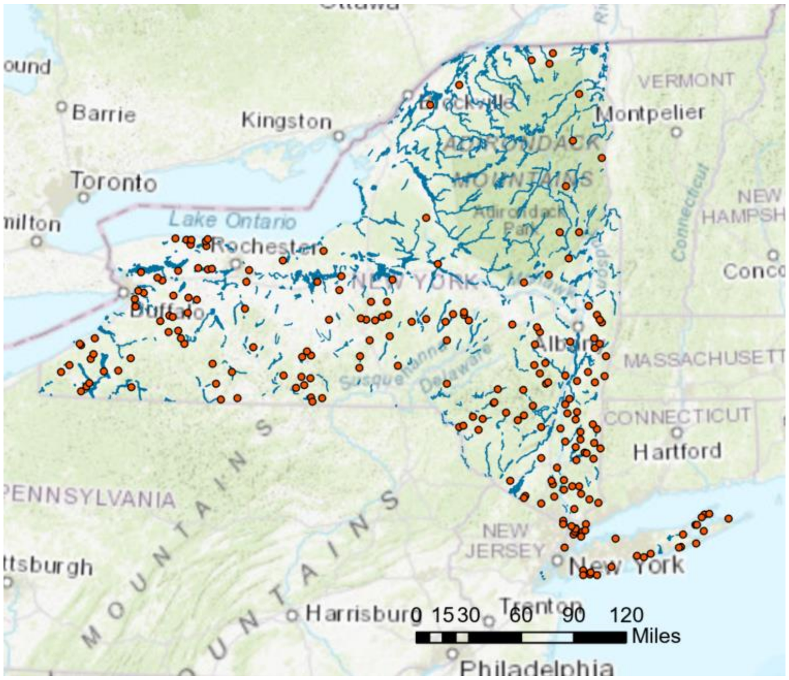

Figure 1: Floodplain zones of active river area (in blue – from GIS online) and Scour-Critical Bridges in NY State (in orange)

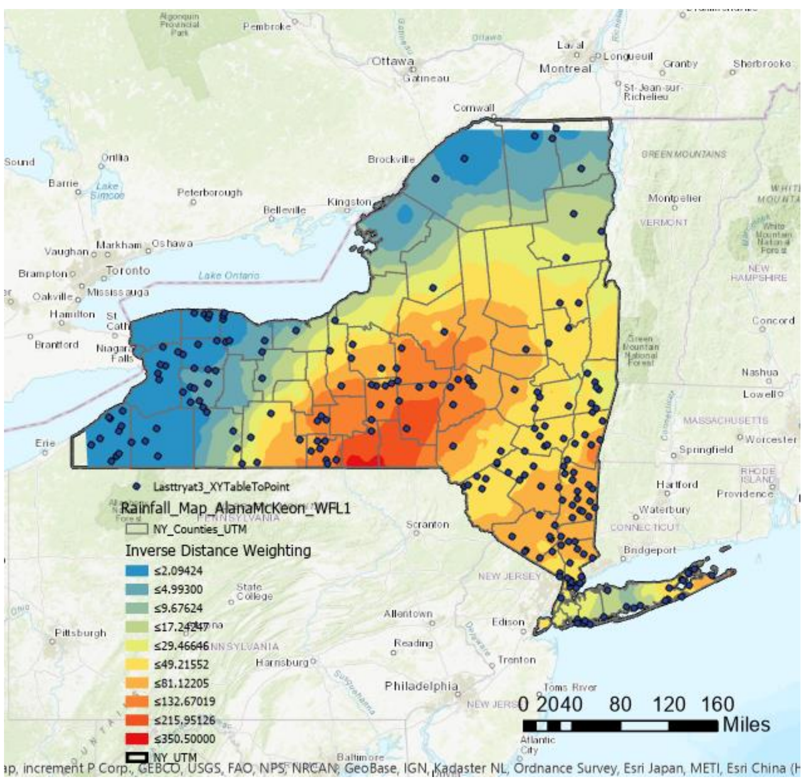

Figure 2: NY state rainfall intensity (from GIS online) and scour critical bridge locations – A visualization showing the correlation between heavy rainfall and scour-prone bridges.

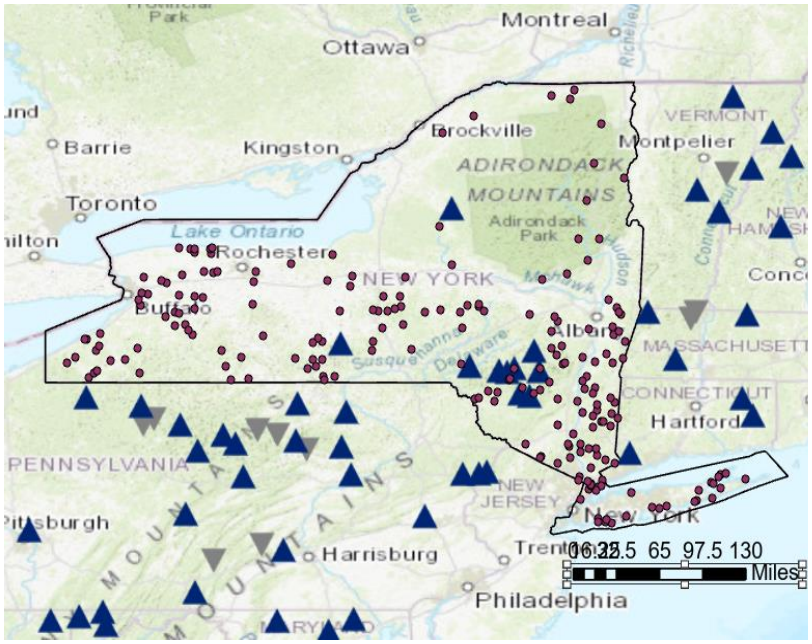

Figure 3: Flood Frequency (dark blue) and scour- prone Bridge Locations in NY state (orange)

Table 1: Scour-Critical Bridges in New York State – Listing the most vulnerable bridges per the climate aspects and floodplains

Item 8 Structural Number The structure number must be unique for each bridge within the State	Item 6A Description of the features intersected by the structure and a critical facility indicator.
Precipitation related	
2226450	Birdsall Brook
3330870	Baldwin Creek
3331420	Baldwin Creek
2309060	Canaseraga Creek
3310800	Nine Mile Creek
Flood frequency related	
2262930	Alder Creek
2270020	Peck Hollow Stream
3353060	E BR Delaware River
2020380	Esopus Creek
3347180	Pigeon Hole Brook
3365180	Alder Creek
3356110	Litt Beaver Kill

4. CONCLUSIONS AND FUTURE WORK

The findings underscore the necessity of integrating climate change projections into bridge scour risk assessments. This research successfully maps scour-critical bridges in New York State, enhancing predictive accuracy through GIS-based analysis. Future work will focus on refining the vulnerability model by incorporating more hydrological and climate change data and expanding risk mitigation strategies. Collaborative efforts among policymakers, engineers, and environmental scientists are essential to safeguarding bridge infrastructure against climate-induced scour threats.

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