TIER 1 UNIVERSITY TRANSPORTATION CENTER

U.S. DEPARTMENT OF TRANSPORTATION

MarTREC

Maritime Transportation Research & Education Center

Financing for Marine Transport: Analyzing the Impact of Resilient Infrastructure Investments for the Inland Waterways (Part II)

Celine Wehbe

Paul Johnson, Ph.D.

Craig Philip, Ph.D.

Hiba Baroud, Ph.D.

September 30, 2025

FINAL RESEARCH REPORT

ACKNOWLEDGMENT

This material is based upon work supported by the U.S. Department of Transportation under Grant Award Number 69A3552348331. The work was conducted through the Maritime Transportation Research and Education Center at the University of Arkansas.

DISCLAIMER

Contents

List of Figures

List of Tables

1 Executive Summary

The U.S. inland waterway system is a critical component of the domestic supply chain, yet its operations are increasingly vulnerable to weather events, particularly flooding. These risks are expected to intensify in the coming years due to the system's aging infrastructure. Despite these challenges, little research has focused on the financial implications of investing in port infrastructure designed to withstand such disruptions. The problem is exacerbated by the limitations of conventional financial valuation methods (e.g., Net Present Value), which are poorly equipped to capture the long-term costs and benefits of resilience investments. As a result, systemic underinvestment in resilient waterborne infrastructure persists.

This report aims to address these gaps by introducing a state-of-the-art, data-driven approach to evaluating strategies for investment in flood-resilient port infrastructure along the inland waterways. The framework combines established work that integrates flood and economic modeling for analyzing disruptions along the inland waterways with recent advancements in financial analysis that allow for more robust and accurate estimates of long-term infrastructure investments. Using this methodology, scenarios are assessed in which investments in resilient waterborne infrastructure provide cost-effective means for mitigating impacts of flood disruptions. In doing so, this project provides a blueprint for researchers being able to quantify the return on investments for long-term, resilient infrastructure projects.

2 Introduction

2.1 Report Overview

The remainder of this report is organized into the following sections. Section 2 presents the motivation and specific objectives of the research. Sections 3 and 4 introduce the novel, integrated risk and financial framework tailored to evaluating costs and benefits of investing in flood-resilient port infrastructure investments along the inland waterways. Section 5 describes a case study on which this framework is applied. Section 6 discusses future work. Section 7 concludes with final observations and implications.

2.2 Background

The U.S. inland waterway system consists of navigable rivers and waterborne infrastructure (e.g., ports and locks-and-dams) that serve as vital components of national supply chains (Johnson et al., 2023; MacKenzie et al., 2012). This system is highly susceptible to weather events, particularly floods, which frequently disrupt operations (Oztanriseven, Nachtmann, and Moradpour, 2022). Extended interruptions caused by such events can generate significant economic impacts at both domestic and global scales (MacKenzie et al., 2012). For example, widespread flooding along the Upper Mississippi River (UMR) in 2019 halted the movement of more than $1.2 billion in agricultural commodities through the region (Fahie, 2019).

Despite the well-documented risks, inland waterway disruptions have received comparatively limited analytical attention relative to other transportation modes (MacKenzie et al., 2012; Oztanriseven, Nachtmann, and Moradpour, 2022). Although, there are a few prominent studies. First, MacKenzie et al. (2012) applied an agent-based model (ABM) to examine how industries responded to closures of the Port of Catoosa and assessed the economic consequences using a multiregional economic model. Later, Oztanriseven and Nachtmann (2017) advanced this line of research by incorporating uncertainty in disruption duration and introducing alternative transport modes into the analysis. Lastly, Johnson et al. (2023) demonstrated how these simulations could be calibrated with historical economic data and applied to a variety of flood scenarios. Together, these systems-level studies form the intellectual foundation for the integrated risk framework developed in this report.

To date, no study has fully integrated a comprehensive risk framework with methods for evaluating investments in flood-resilient port infrastructure. This gap largely reflects the absence of financial tools and methodologies capable of assessing long-term waterway investments under the uncertainty of weather events. Addressing this issue is particularly important given that flood-related risks along the inland waterway system are expected to worsen in the future due to aging infrastructure. In fact, the American Society of Civil Engineer's recent Infrastructure Report Card consistently rated waterway infrastructure among areas in need of the most support (ASCE, 2025).

2.3 Project Goals

In Part I of this project (completed), the research team successfully integrated flood projections with agent-based and economic models. The end result was an effective approach to simulate supply chain disruptions along the inland waterways due to various flood scenarios and estimate resulting economic impacts of businesses' decisions to re-route, or not re-route, shipments in response to these events. This work enabled researchers to robustly quantify economic impacts of disruptions along inland waterway under the uncertainty of different flood scenarios.

In Part II of this project (i.e., this report), the focus shifts to integrating the decoupled net present value (DNPV) financial framework with the aforementioned simulation outcomes. Doing so allows the research team to identify scenarios where investments in resilient, water-borne infrastructure can offer cost-effective means of mitigating impacts of floods. To demonstrate this approach, the methodology is applied to a case study pertaining to the development of The Port of Cates Landing, a flood-resilient port located near the mouth of the Upper Mississippi River. However, this research can be extended to other sections of the waterways, other weather events (e.g., droughts), and even other transportation modes.

This research produces a novel, data-driven solution that combines the recently adopted decoupled net present value (DNPV) financial framework with established integrated risk assessments for analyzing economic disruptions along the waterways. This achievement fills a substantial knowledge gap in the scientific literature and improves the community's understanding of the expected economic impacts of low-water conditions along the Mississippi River and the costs and benefits associated with reducing such impacts via investments in hardened infrastructure. In turn, this approach can help policymakers identify areas where investments in resilient infrastructure can serve as cost-effective opportunities for mitigating future supply chain disruptions.

3 Long Term Economic Returns

Investors often hesitate to pay more for resilient infrastructure because the benefits aren't always visible in the short term. The upfront costs are clear and measurable, while the advantages, such as reduced downtime, lower repair expenses, or avoided losses from weather events, tend to be less tangible until a crisis occurs. To bridge this gap, it is important to examine the long-term economic returns that resilient investments can generate. By quantifying avoided costs, investors can see resilience not just as a form of risk management but as a driver of financial performance.

Understanding the long-term economic returns of resilient port infrastructure requires linking the short-term, localized impacts of floods to the broader financial implications that unfold over decades. Disruptions at inland waterway ports impose immediate costs on firms, industries, and regional economies, as captured by the MRIIM analyses in Section 4.3. However, the value of resilience extends beyond these near-term consequences. The true financial rationale for investing in resilience emerges when these disruptions are projected over the full life of the infrastructure, where recurring closures, repair costs, and lost throughput accumulate into substantial long-term losses.

Traditional Net Present Value (NPV) analysis has been the standard tool for evaluating infrastructure investments, but it often underestimates the benefits of resilience. NPV frameworks tend to obscure risks by embedding them in the discount rate, which makes the costs of flood risks appear abstract and highly sensitive to assumptions about discounting (Espinoza et al., 2020). As a result, resilient projects may look less attractive than they actually are, particularly when compared against lower-cost, non-resilient alternatives.

To address this gap, the analysis incorporates a Decoupled Net Present Value (DNPV) framework (detailed in Section 4.4), which explicitly separates different categories of risks and translates them into quantifiable financial impacts. This approach makes resilience benefits visible in a way that traditional models cannot. DNPV builds directly on the results of the ABM in Section 4.3. Shipment disruptions estimated through the ABM inform how firms respond to closures, and MRIIM uses these results to translate disruptions into regional production losses across sectors. Then, DNPV uses these results as adjustments to port revenues and operating costs.

From an investor perspective, this integration re-frames resilience from being a cost premium to being a value driver. Higher upfront expenditures on resilient design are offset by reduced exposure to flood-related repair costs, lower revenue volatility, and the potential to capture diverted shipments when competitors are disrupted. Ultimately, the benefits of resilience cannot be fully appreciated without considering both regional economic disruptions and project-level financial outcomes.

4 Integrated Risk and Financial Framework

4.1 Background

Ports and inland waterways play a central role in the U.S. freight movement. They carry more than 500 million tons of cargo valued at more than 150 billion dollars annually (Niu et al., 2025). Their cost efficiency and exemplary safety records make them critical components of the national transportation system (Port of Little Rock, 2023). Despite these advantages, ports and waterways remain highly vulnerable to disruptions. Inland waterways are prone to experiencing weather events, leaving ports along them vulnerable to costly repairs and delays in shipment, resulting in lost revenue.

These effects ripple far beyond the immediate site of impact. Because industries are tightly interconnected, a delay in one location can cascade through supply chains and result in production losses throughout the economy. These cascading impacts highlight how strengthening ports today is essential to protect both local operations and the broader economy. Resilient ports and waterways are better able to withstand weather disruptions, minimize structural damage, and avoid prolonged closures. By reducing the need for costly emergency repairs and limiting downtime, resilient infrastructures keeps cargo moving, prevent shipment backlogs, and protect industries from disruptive delays that can ripple across supply chains.

To date, research has examined these challenges through several distinct methodological perspectives. Input–output models have been used to estimate the regional economic effects of major flood events, showing how disruptions propagate through supply chains and reduce output in multiple sectors (Welch et al., 2022). Complementing these economic approaches, engineering research has focused on the physical design of resilient waterway infrastructure, emphasizing technical functionality under adverse conditions (Rezende et al., 2019). Collectively, these contributions provide important but partial insights. What remains underdeveloped is an integrated framework that explicitly quantifies the economic benefits of resilience within the inland waterway systems themselves.

This study aims to quantify the potential economic losses that businesses could face due to floods along inland waterways, and to evaluate the potential benefits of resilience investments. Currently, the financial value of investing in stronger infrastructure is often underestimated. By explicitly assessing both the risks and the expected economic returns, this framework demonstrates the rationale for resilience investments. At the state level, the analysis focuses on economic production losses resulting from disruptions, accounting for the interconnectedness of regions and sectors. This approach identifies which sectors or states are most vulnerable and provides policy makers with guidance on where resilience efforts should be prioritized. At the infrastructure level, the study evaluates the long-term economic returns of resilience investments. By discounting future costs and benefits to present value, it quantifies the potential financial benefits of investing in stronger ports, linking engineering improvements to measurable economic outcomes.

4.2 Flood Analysis

The flood risk in inland waterway ports is estimated using historical river stage data from 25 river gauges along the Upper Mississippi River (UMR), obtained from the U.S. Army Corps of Engineers (USACE), shown in Figure 1. The dataset covers the period from January 1, 2014, to December 31, 2020. Raw discharge data are processed through a data cleanup workflow, which includes interpolation of missing values and imputation, where necessary.

Flood stage thresholds are defined according to the Waterway Action Plan (WAP) Protocol, which specifies water levels at which navigation becomes unsafe, and ports must close. Using the historical river gauge data in conjunction with WAP operating procedures, the number of days per year that each gauge exceeds its corresponding high-water threshold is tabulated.

To model the likelihood of weather events, a Gumbel distribution, Equation 1, is fit to

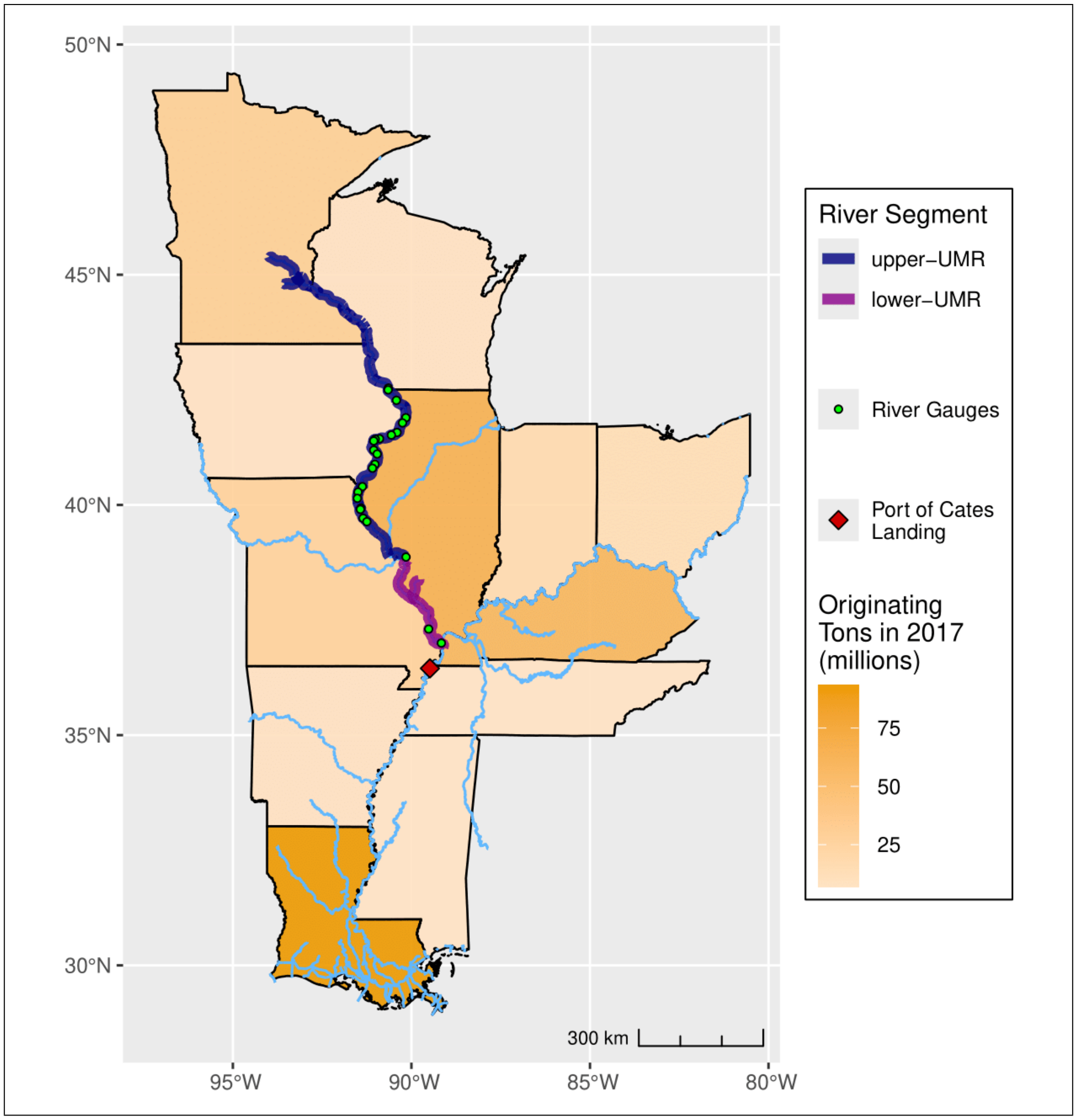

Figure 1: U.S. Inland Waterways Study Area

the annual exceedance counts for each gauge. This enables the prediction of return periods of expected closures due to flood conditions at each location. By fitting Gumbel distributions to the number of days that river gauges exceed high-water thresholds per year, the frequency of flood events at individual gauge locations can be estimated.

$$G(z) = \exp\left[-\exp\left\{-\left(\frac{z-u}{\sigma}\right)\right\}\right], -\infty < z < \infty \tag{1}$$

These results are then aggregated across multiple gauges to generate forecasts for two larger river segments, which represent critical portions of the inland waterway network. Using these segment-level forecasts, the expected number of port closure days associated with specific return periods are determined.

4.3 Regional Economic Losses Framework

To assess the economic impact of flood disruptions on inland waterway ports, production losses incurred by disrupted businesses and regional economies are calculated. this approach integrates flood analysis with economic analysis through a multi-step framework (Figure 2).

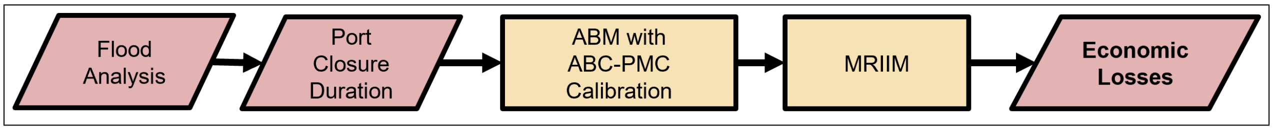

Figure 2: Regional Economic Losses Framework

First, the direct effects of port closures obtained in section 4.2 are translated into shipment disruptions using an agent-based model (ABM). Following the developed framework (MacKenzie et al., 2012), the model represents firm-level decision making under disruption scenarios. Firms decide how to handle cargo during a disruption by choosing among three options: delay shipments by keeping them at the port until it reopens, ship via alternative modes such as rail, or reroute through a resilient port. Each decision is based on a cost-minimization approach, considering cargo weight, shipping distance, and transport rates, and penalties associated with delays (Table 1).

$$C_{port} = (Value_{daily} \times \alpha \times Days_{closed}) + (WaterTonMiles_{daily} \times 0.97) \tag{2}$$

$$C_{rail} = (RailTonMiles_{daily} \times 2.53 + WaterTonMiles_{daily} \times 0.97) \times (1 - \beta) \tag{3}$$

$$C_{cates} = (RailTonMiles_{daily} \times 2.53 + WaterTonMiles_{daily,alt} \times 0.97) \times (1 - \beta) \tag{4}$$

Rail and water transport costs are computed per ton-mile, while rerouted shipments account for combined distances and associated costs. The cost of leaving products at the port, Equation 2, incorporates a penalty α representing fees imposed by the customer for delayed delivery. Conversely, the costs of rerouting shipments, Equations 3 and 4, include the $(1 - \beta)$ adjustment, which represents firms' prioritization of on-time deliveries.

Firms select the least-cost option, and shipments are allocated according to port throughput capacity constraints. Model parameters that influence cost sensitivity and behavioral responses, particularly α and β, are calibrated using an Approximate Bayesian Computation–Population Monte Carlo (ABC-PMC) method (Johnson et al., 2023). Parameters are iteratively adjusted to ensure the simulation outputs align with observed shipment and closure data, providing a realistic representation of industry behavior during flood events.

Table 1: Agent-Based Simulation Parameters

Description	Parameter	Source
Disruption duration (days)	$Days_{closed}$	Flood Scenarios
Cost of shipping by water ($/ton-mile)	0.97	MacKenzie et al., 2012
Cost of shipping by rail ($/ton-mile)	2.53	MacKenzie et al., 2012
Discount factor for on-time delivery	β	Johnson et al., 2022
Penalty cost for late delivery	α	Johnson et al., 2022
Daily cargo value for each company ($)	$Value_{daily}$	USACE, 2017
Ton-miles shipped by water (per day)	$WaterTonMiles_{daily}$	output
Ton-miles shipped by rail (per day)	$RailTonMiles_{daily}$	output

Finally, the outputs from the ABM are used as inputs to a multi-regional inoperability input-output model (MRIIM). This model estimates the cascaded economic effects of disrupted shipments across multiple industry sectors (e.g. manufacturing, agriculture, transportation) across the twelve states that are heavily connected to inland waterway shipments. MRIIMs quantify production losses beyond the immediate vicinity of the affected port (Crowther and Haimes, 2009; Whitman et al., 2019; Magalhaes et al., 2020). The technical definition of the MRIIM is specified by Equation 5.

$$\begin{pmatrix} \tilde{\mathbf{q}}^1 \\ \tilde{\mathbf{q}}^2 \\ \vdots \\ \tilde{\mathbf{q}}^p \end{pmatrix} = \mathbf{T}^* \begin{pmatrix} \mathbf{A}^{*1} & \mathbf{0} & \dots & \mathbf{0} \\ \mathbf{0} & \mathbf{A}^{*2} & \dots & \mathbf{0} \\ \vdots & \vdots & \ddots & \vdots \\ \mathbf{0} & \mathbf{0} & \dots & \mathbf{A}^{*p} \end{pmatrix} \begin{pmatrix} \tilde{\mathbf{q}}^1 \\ \tilde{\mathbf{q}}^2 \\ \vdots \\ \tilde{\mathbf{q}}^p \end{pmatrix} + \mathbf{T}^* \begin{pmatrix} \tilde{\mathbf{c}}^{*1} \\ \tilde{\mathbf{c}}^{*2} \\ \vdots \\ \tilde{\mathbf{c}}^{*p} \end{pmatrix} \tag{5}$$

where

$\tilde{\mathbf{q}}^r$ = an inoperability vector of length n consisting of the difference between normal production levels and disrupted production levels, expressed as a percentage of normal production levels, of the n^{th} industry sector in region r of p total regions;

$\mathbf{T}^* = [\text{diag}(\tilde{\mathbf{x}}^1, \tilde{\mathbf{x}}^2, \dots, \tilde{\mathbf{x}}^p)]^{-1}\mathbf{T}[\text{diag}(\tilde{\mathbf{x}}^1, \tilde{\mathbf{x}}^2, \dots, \tilde{\mathbf{x}}^p)]$;

$\tilde{\mathbf{x}}^r$ = a vector of length n consisting of industry sector production in region r;

$$\mathbf{T} = \begin{pmatrix} \mathbf{T}^{11} & \mathbf{T}^{12} & \dots & \mathbf{T}^{1p} \\ \mathbf{T}^{21} & \mathbf{T}^{22} & \dots & \mathbf{T}^{2p} \\ \vdots & \vdots & \ddots & \vdots \\ \mathbf{T}^{p1} & \mathbf{T}^{p2} & \dots & \mathbf{T}^{pp} \end{pmatrix};$$

$\mathbf{T}^{rs}$ = an $n \times n$ trade interdependency matrix consisting of the proportion of a commodity consumed in region s that is produced in region r;

$\mathbf{A}^{r}$ = an $n \times n$ industry interdependency matrix of region r composed of elements a_{ij}^{r};

$\mathbf{A}^{*r}$ = the inoperability matrix for region r, $[\text{diag}(\tilde{\mathbf{x}}^{r})]^{-1}\mathbf{A}^{r}[\text{diag}(\tilde{\mathbf{x}}^{r})]$;

$$a_{ij}^{r} = \begin{cases} l_i^r a_{ij} & , l_i^r < 1 \\ a_{ij} & , l_i^r \geq 1 \end{cases};$$

a_{ij} = the input of industry sector i to j, expressed as a proportion of the total production inputs to industry sector j;

l_i^r = the location quotient, $\frac{x_i^r/x^r}{x_i/x}$;

x_i^r = industry sector i's production in region r;

x^r = total economic production in region r;

x_i = industry sector i's production across the nation;

x = total national economic production;

$\tilde{\mathbf{c}}^{*r}$ = a demand-side perturbation vector of length n consisting of the difference between normal demand and disrupted demand, expressed as a percentage of normal production levels, of the n^{th} industry sector in region r of p total regions

For example, a closure at a major grain-exporting port may reduce output in agricultural processing, manufacturing, and transport sectors across multiple states. The MRIIM framework ensures that indirect and induced losses, resulting from interdependencies within and between regions, are fully accounted for, allowing the model to capture how disruptions in one state propagate to others and to identify which sectors are most sensitive to port disruptions.

4.4 Decoupled Net Present Value Financial Framework

The DNPV framework is shown in Figure 3.

The financial analysis is built around a project-level cash flow tabulation that captures

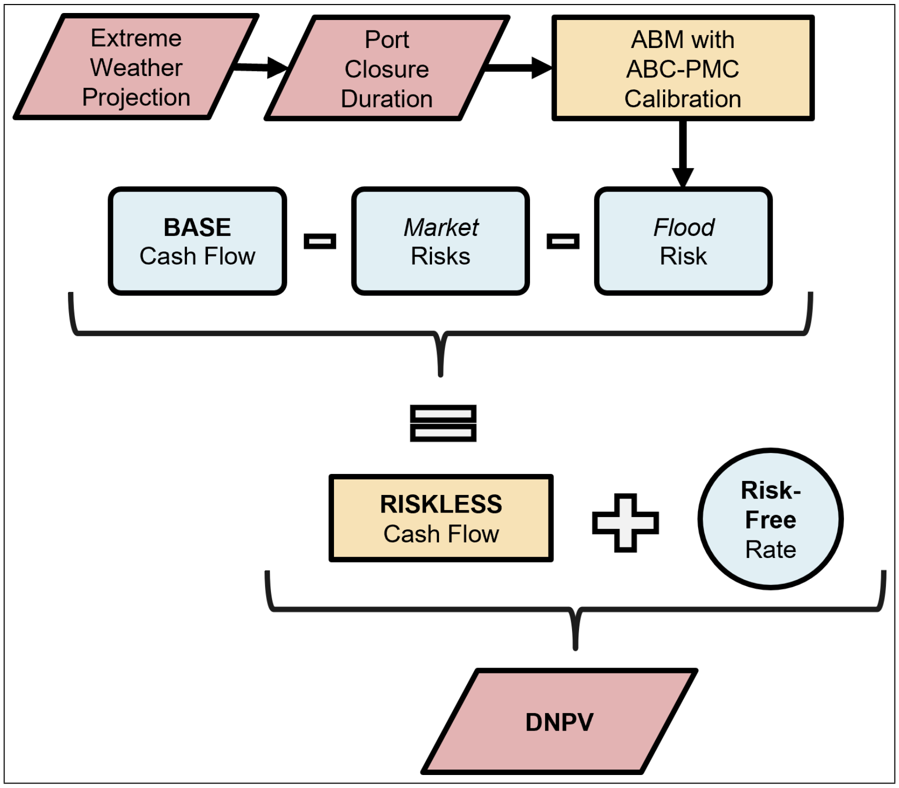

Figure 3: Regional Economic Losses Framework

expected business as usual revenues (tolls, taxes, etc.) and expenses (maintenance, depreciation, etc.). For the base case, an initial investment is assumed in year 0, followed by recurring annual revenues and costs, across a specified time horizon. These values are then subjected to a discount rate to adjust future cash flows to their present value (Equation 6).

$$PV = -I_0 + \sum_{t=1}^{T} \frac{C_t}{(1+r)^t} \tag{6}$$

Traditional Net Present Value (NPV) analysis factors in potential future risks in the discount rate. In NPV:

$$\begin{aligned} C_t &= \text{Revenues}_t - \text{Expenses}_t, \\ r &= \text{Time Value of Money} + \text{Risk}. \end{aligned} \tag{7}$$

However, this approach often leads to debates over which discount rate to apply. Different stakeholders may arrive at widely varying values depending on this assumption. For example, the U.S. Office of Management and Budget (OMB) recommends a rate of 7 percent for federal projects (Office of Management and Budget, 1992). Differences in discount rates can substantially affect the calculated present value of future cash flows and, consequently, the perceived economic viability of resilience investments. Table 2 shows a simplified example of an NPV cash flow sheet.

Table 2: Cash flow example (NPV)

	Year 0	Year 1	Year 2	...	Year 19	Year 50
Cash Flow ($M)	(53)	4	8	...	10	7

NPV = $47.92M, assuming risk-adjusted discount rate of $r = 7\%$

In contrast, the Decoupled Net Present Value (DNPV) approach expresses future risks as a monetary value, and subtracts it from the base cash flow, creating a risk-less cashflow (Espinoza et al., 2020).

$$\begin{aligned} C_t &= \text{Revenues}_t - \text{Expenses}_t - \text{Risk}_t, \\ r &= \text{Time Value}. \end{aligned} \tag{8}$$

In other words, risk-premium adjustments are made to the expected cash-flows (i.e., higher than expected expenses and lower than expected revenues). In turn, these adjustments allow for the use of lower, risk-free discount rates (e.g., the yield on a 20-year Treasury bond) (Savidge, 2022). Additionally, project risks can be separated into distinct categories which provides a clearer assessment of how different risks contribute to overall project uncertainty, as opposed to lumping them all into a single discount rate assumption (Espinoza et al., 2020). Such risk factors often include market-related risks, and resilience-related risks. Tables 3 and 4 show simplified examples DNPV cash flows, for a non-resilient and a resilient port, respectively.

Market variability risks are captured using an option-pricing approach, with the Black–Scholes framework applied to estimate the financial impact of volatility on revenues (Equation 9). The risk depends on the present value of the strike price discounted at the risk-free rate

Table 3: Cash flow example (DNPV) - Not Resilient

	Year 0	Year 1	Year 2	...	Year 49	Year 50
Base Cash Flow ($M)	(53)	4	8	...	10	7
Revenue Risk		1.008	3.001	...	2.003	1.006
Market Variability		1	3	...	2	1
Shipment Variability		0.008	0.001	...	0.003	0.006
Expenditure Risk		0.04	0.04	...	0.04	0.04
Flood Liability		0.04	0.04	...	0.04	0.04
Riskless Cash Flow		2.88	4.96	...	7.95	5.95

DNPV = $105.04 M, assuming risk-free discount rate of $r = 1.3\%$

Table 4: Cash flow example (DNPV) - Resilient

	Year 0	Year 1	Year 2	...	Year 49	Year 50
Base Cash Flow ($M)	(55)	4	8	...	10	7
Revenue Risk		0.98	2.98	...	1.98	0.98
Market Variability		1	3	...	2	1
Shipment Variability		-0.02	-0.02	...	-0.02	-0.02
Expenditure Risk		0	0	...	0	0
Flood Liability		0	0	...	0	0
Riskless Cash Flow		3.04	5.04	...	8.04	6.04

DNPV = $107.33 M, assuming risk-free discount rate of $r = 1.3\%$

and adjusted by the probability terms. S_0 represents the current value of the asset (here, projected total revenues). The strike price K is also set as the projected revenues. The terms Φ_1 and Φ_2 capture the relationship between the total revenue, asset life T, volatility σ, and the risk-free rate r. Together, these components allow the model to account for both the time value of money and the uncertainty associated with fluctuations in the underlying asset when determining the option's fair value.

$$P = Ke^{-rT}\Phi(-d_2) - S_0\Phi(-d_1) \tag{9}$$

with

$$d_1 = \frac{\ln\left(\frac{S_0}{K}\right) + \left(r + \frac{1}{2}\sigma^2\right)T}{\sigma\sqrt{T}}, \qquad d_2 = d_1 - \sigma\sqrt{T}$$

Resilience-specific factors are integrated into the analysis in two ways. First, shipment variability risks are modeled as probabilistic reductions (or in some cases increases) in annual revenues driven by port closures. For non-resilient ports, revenue declines are proportional to the number of closure days projected from flood modeling, while resilient ports may absorb diverted shipments from closed competitors and thus realize revenue gains. These diverted shipments are obtained from the ABM results discussed in section 4.3. Second, flood liability risks are treated differently for resilient versus non-resilient facilities: non-resilient ports incur repair and recovery costs that scale with the severity of each flood event, whereas resilient ports are assumed to experience negligible repair costs. The implications of these resilience-specific differences can be seen by comparing the example cash flows in Tables 3 and 4. Although the resilient port requires a slightly higher upfront investment (–$55M vs. –$53M), its lifetime value as measured by DNPV is higher ($107.33M vs. $105.04M). This difference arises because resilience reduces long-term flood liability costs and allows for revenue gains from diverted shipments, which together outweigh the higher initial capital cost.

5 Case Study

5.1 Port of Cates Landing

The Port of Cates Landing, located in Tiptonville in northwest Tennessee, is a modern public port facility strategically positioned along the Mississippi River. The port was constructed on naturally elevated ground above the 500-year floodplain. Uniquely situated between the upper and lower Mississippi, the port benefits from its location, as the upper Mississippi floods much more frequently than the lower, allowing shipments from upstream to be efficiently rerouted through Cates to the lower river. Built at a cost of $43 million, with an additional $12 million invested to connect it to the rail system, the facility is designed to support multi-modal transportation needs, and has a throughput of 1.6 million tons (Davis, 2018). The port offers the capability to load and unload barges and trucks, complemented by a 37,500-square-foot warehouse located adjacent to the barge dock for efficient storage and handling of goods. In addition, the port is equipped with truck scales featuring radiation detection, underscoring its preparedness for both safety and compliance in cargo handling (Inland Rivers Ports and Terminals).

Flood risks are modeled probabilistically across the entire 50-year analysis horizon. Each year, there is a probability that one of several flood return-period events occur (e.g., a 25-year, 50-year, 100-year, or 500-year flood, or that no significant flood occurs that year). This structure allows multiple floods to occur within the lifespan of the port, rather than assuming a single catastrophic event. Each event's financial consequences are reflected in closure days, lost or diverted shipments, and repair costs where applicable.

As described in Section 4.4, the financial analysis is done using a cash flow sheet, similar to the one shown in Table 5. An infrastructure lifetime of 50 years is assumed. The initial investment is determined by the port's resilience level, with higher resilience requiring greater investment. These investments vary from $50 million to $55 million (Davis, 2018). Revenues and expenses are estimated using financial statements from comparable ports, ensuring that the port's economic performance is compared to realistic industry standards. In NPV, cash flows are discounted using a risk-adjusted rate of 7%, while DNPV uses a risk-free rate of 1.3%. The risk determination is explained in Section 4.4. A volatility of 25% is assumed for the Black Scholes formula in the market variability risk. For shipment variability risk, closure durations are obtained from flood modeling in section 4.2, ranging from roughly one month for a 25-year flood to about two months for a 500-year flood. The shipping revenue assumption of 5$ per ton is used to estimate the revenue for the port from rerouted shipments. For flood liability risk, repair costs increase with flood intensity, from approximately $15 million for a 25-year event to $20 million for a 500-year event (Port City Daily, 2024).

Table 5: Cash Flow Sheet for Cates Landing

	Year 0	Year 1	Year 2	...	Year 49	Year 50
Initial Investment	51.50	0.00	0.00	...	0.00	0.00
Revenues	0.00	33.00	8.29	...	5.06	9.58
Fees	0.00	0.65	0.26	...	0.56	1.18
Rentals	0.00	3.70	0.89	...	2.30	2.36
Interest Income	0.00	0.46	0.55	...	0.35	0.18
Grants	0.00	27.97	6.54	...	1.82	5.71
Misc.	0.00	0.22	0.04	...	0.03	0.15
Expenses	0.00	5.54	3.79	...	3.25	3.49
Administrative	0.00	0.68	0.68	...	0.21	0.39
Depreciation	0.00	1.41	0.49	...	0.02	0.57
Insurance	0.00	0.01	0.13	...	0.07	0.06
Maintenance	0.00	0.05	0.08	...	0.11	0.24
Wages	0.00	3.00	2.35	...	2.23	1.31
Utilities	0.00	0.40	0.06	...	0.62	0.91
Base Cash Flow	-51.50	27.46	4.50	...	1.80	6.09
Revenue Risk	0.00	3.09	1.05	...	1.32	2.48
Market Variability	0.00	3.05	1.04	...	1.31	2.48
Shipment Variability	0.00	0.03	0.01	...	0.00	0.01
Expenditure Risk	0.00	0.18	0.18	...	0.18	0.18
Flood Liability	0.00	0.18	0.18	...	0.18	0.18
Riskless Cash Flow	-51.50	24.19	3.27	...	0.30	3.43

5.2 Results

Figure 4 illustrates how shipments are distributed after disruptions occur: as resilience increases, a growing proportion of shipments are successfully rerouted through Cates Landing, while a smaller share remain at the original port. This highlights Cates Landing's increasing importance in handling redirected shipments.

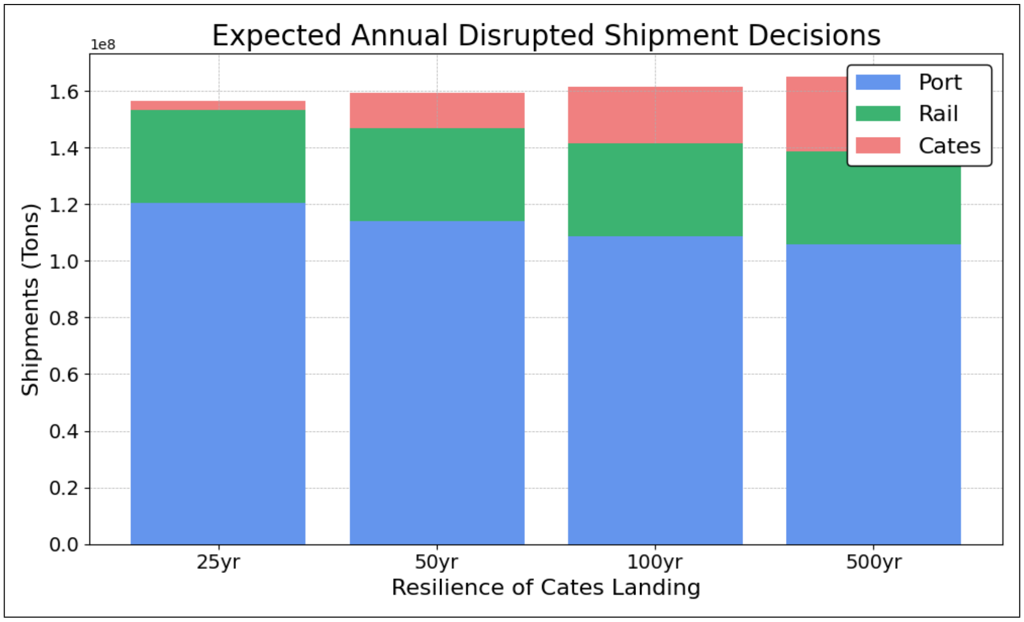

Figure 4: Disrupted Shipments by ABM Decision Under Different Resilience Scenarios

Figure 5 demonstrates that greater resilience reduces production losses. Specifically, as the port becomes more capable of handling and rerouting shipments during disruptions, the likelihood of supply chain interruptions decreases, which in turn lowers the expected annual losses experienced by regional producers.

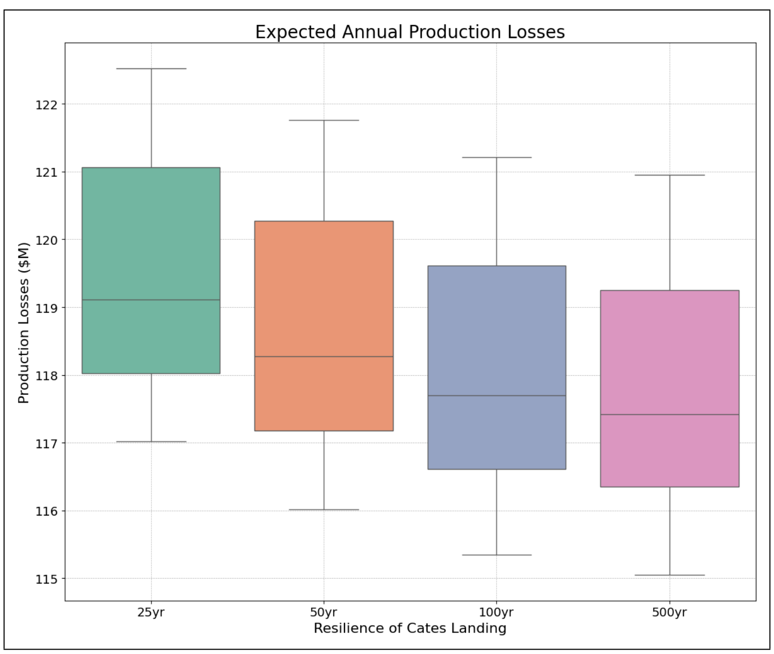

Figure 5: Expected Annual Production Losses Under Different Resilience Scenarios

Figure 6 further emphasizes this relationship by showing the corresponding increase in production savings as resilience increases. Notably, chemical, agriculture and petroleum & coal commodities demonstrate the largest absolute gains across resilience scenarios, highlighting their vulnerability to disruptions and their potential for economic recovery through resilience investments. In contrast, metal commodities show relatively minor improvements, indicating either lower exposure or more localized resilience effects. From a regional standpoint, Illinois stands out as a consistently significant contributor across nearly all commodity categories and resilience scenarios. This suggests that strengthening resilience there would lead to widespread economic benefits, not just locally but across interconnected industries. On the other hand, states such as Iowa and Louisiana shows concentrated savings primarily within specific sectors, meaning that targeted investments in their key industries could yield high returns. This shows the economic value of investing in resilience: it protects regional supply chains and reduces the economic impact of weather disruptions on businesses. These quantified savings can then guide decision-makers on where resilience investments are most effective. Resilience investments are not uniformly beneficial but instead depend on each region's economic composition and exposure profile.

Investors often hesitate to pay more for resilient infrastructure because the benefits aren't always obvious. To make these benefits clearer, NPV and DNPV metrics are compared across different flood return periods and port resilience. In Figure 7, traditional NPV changes monotonically and indicates that paying more for a higher resilience leads to lower returns. However, DNPV quantifies the financial benefits of investing in more resilient infrastructure, demonstrating where these investments yield positive returns. DNPV provides a clear case to investors that spending more today on flood-resilient ports can lead to better returns in the future. Figure 8 shows that with the economic conditions and port variables used, the optimal investment resilience is a 100-year resilient port.

The NPV breakdown, Figure 9 illustrates the role of risk in the valuation. The total bar height shows the present value under a risk-free discount rate, while the solid portion

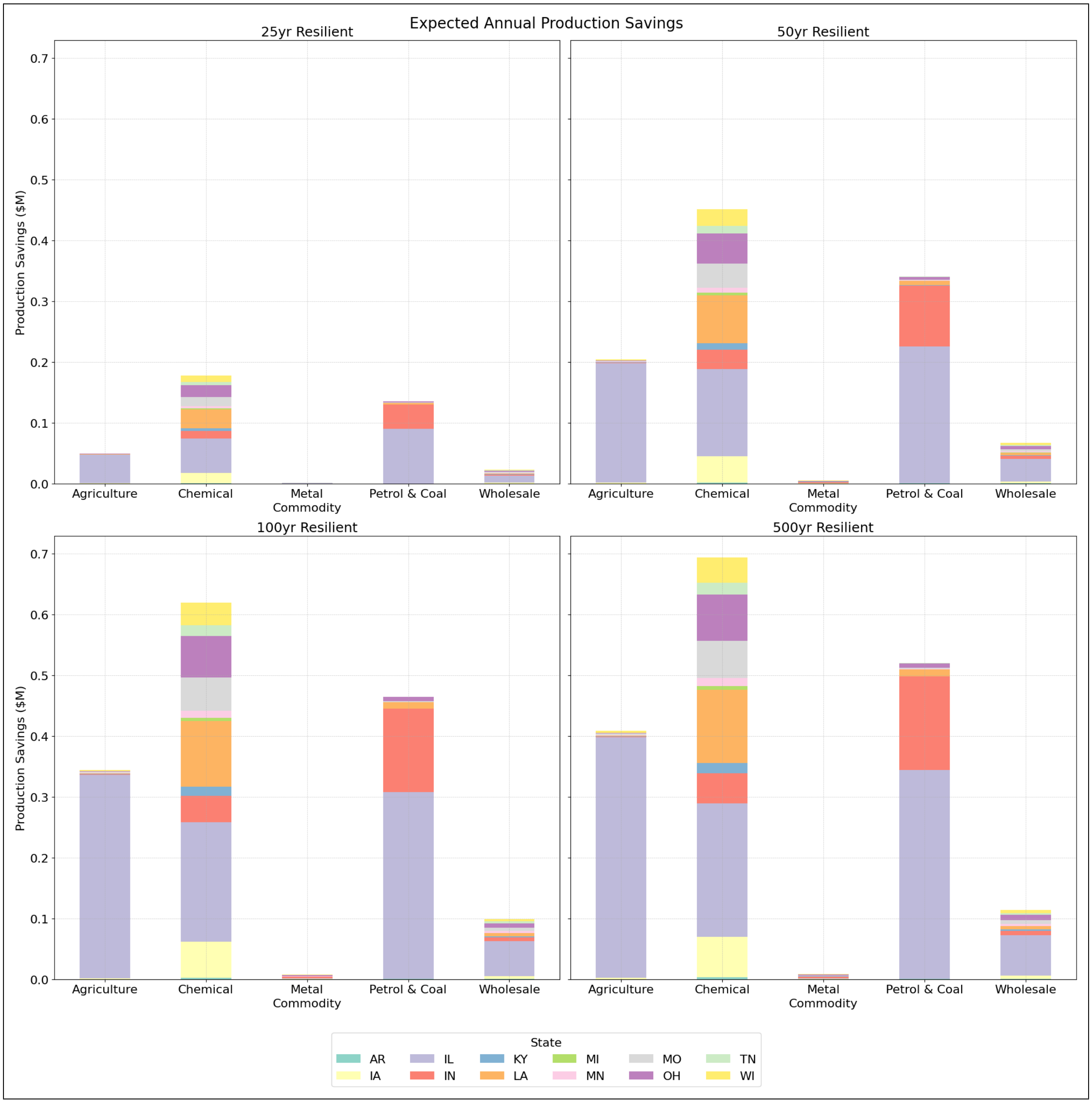

Figure 6: Expected Annual Production Savings Under Different Resilience Scenarios by State and Commodity

represents the risk-adjusted value, effectively capturing the extent of risk included in the calculation. The DNPV breakdown, Figure 10 similarly distinguishes the role of risk in the valuation. By explicitly separating revenue risk and expense risk, DNPV incorporates less risk into the discounting, which results in a higher present value.

Finally, the return on investment (ROI) across different return periods and levels of

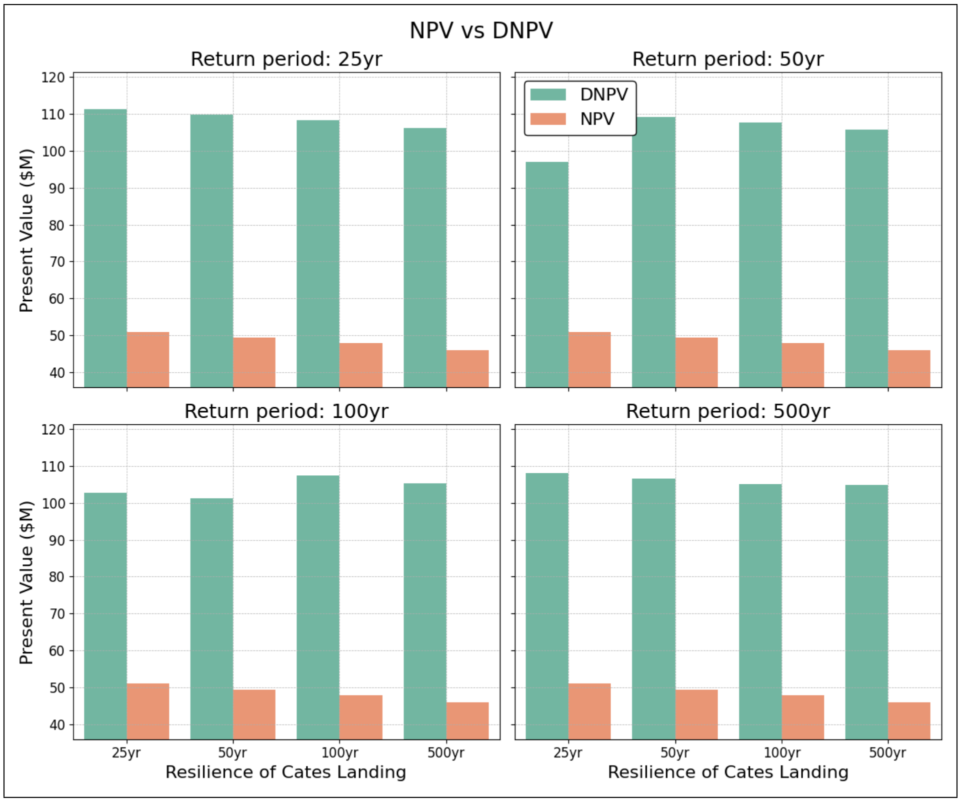

Figure 7: Comparison of NPV and DNPV Across Different Return Periods and Resilience Scenarios

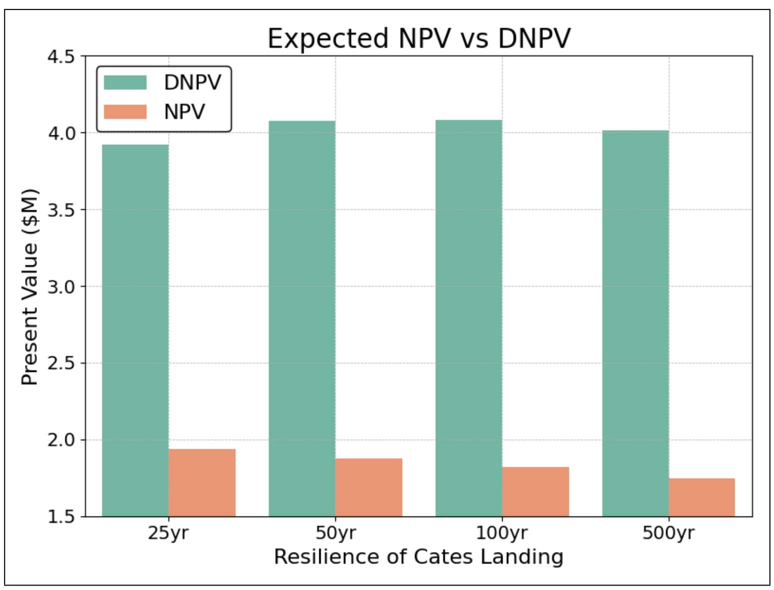

Figure 8: Comparison of Aggregated NPV and DNPV Across Different Resilience Scenarios

resilience is assessed. Across all return periods, the riskless scenario consistently outperforms the base case, with values roughly twice those of the base scenario, showing that the DNPV

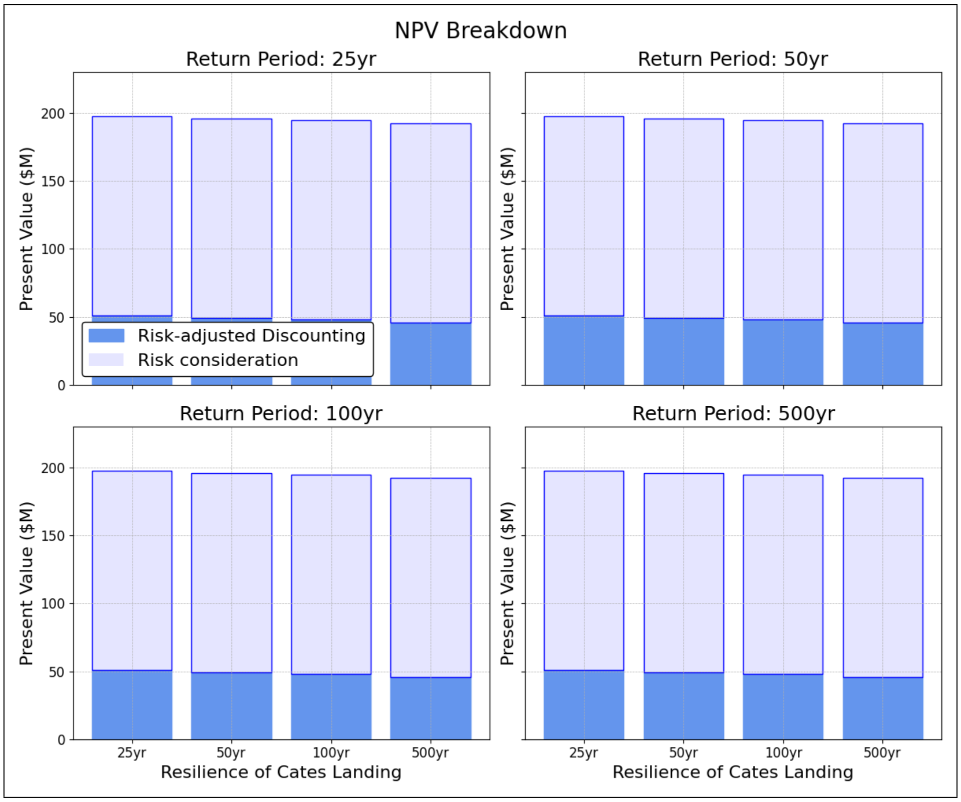

Figure 9: NPV Breakdown

analysis is more likely to attract investor confidence. ROI under the base case decreases steadily as the resilience level increases, indicating that higher resilience requirements lead to diminishing returns when risks are not explicitly addressed. On the other hand, the riskless scenario shows a more variable ROI response across resilience levels, highlighting which resilience investments provide the highest returns when combined with risk mitigation. While NPV is unaffected by the flood intensity due to the lack of inclusion of flood-related losses in the analysis, DNPV shows the impact of the return period on the returns. Overall these results emphasize the benefits of DNPV in identifying the best resilience for optimal returns, which are robust even under intense conditions.

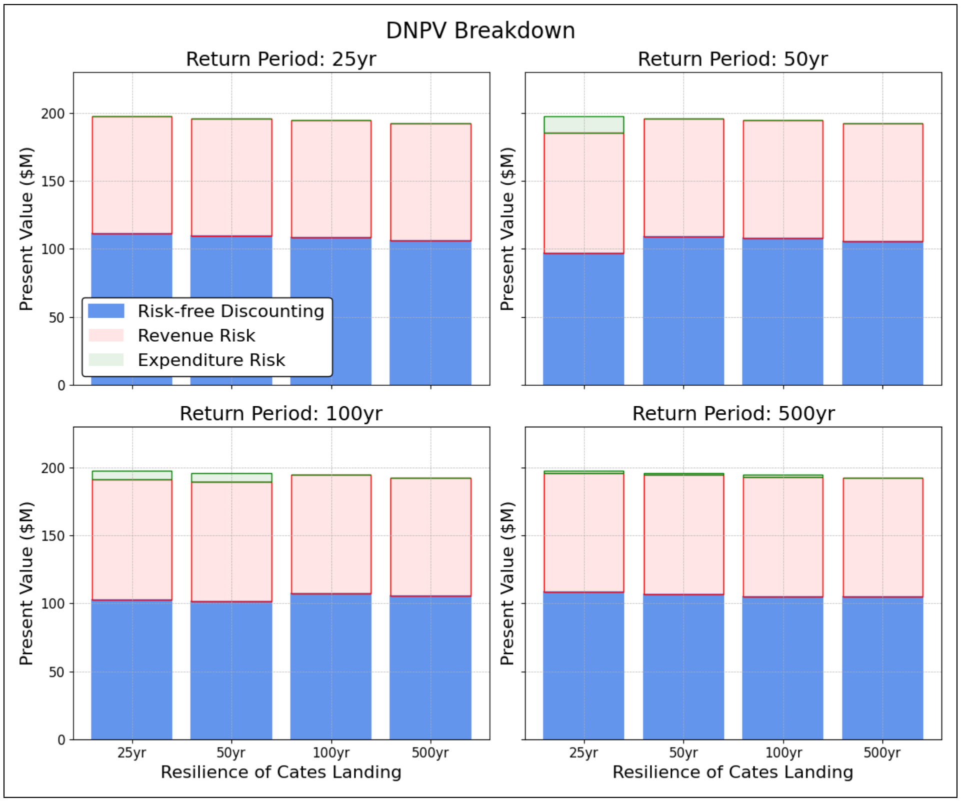

Figure 10: DNPV Breakdown

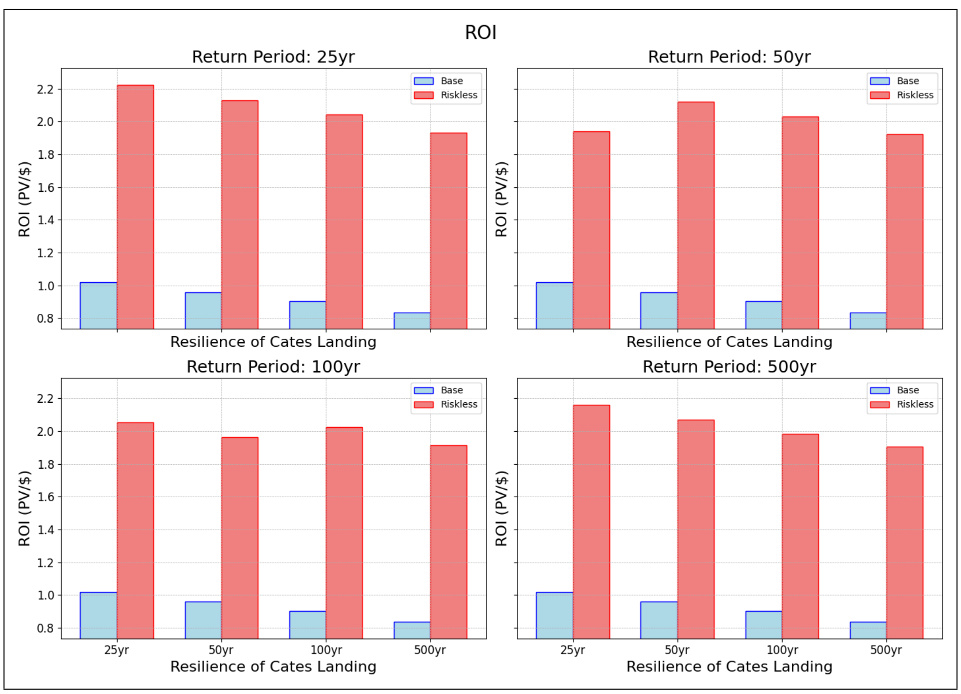

Figure 11: Return on Investment Across Different Return Periods and Resilience Scenarios

6 Future Work

While this study establishes a framework for evaluating the economic and financial benefits of resilient inland waterway ports, several extensions could enhance its applicability and robustness.

First, the analysis should incorporate phased or staged investment strategies rather than assuming a full upfront investment. This would better reflect real-world planning and allow assessment of the timing and sequencing of resilience measures.

Second, future work could expand the scope of disruptions considered. In addition to flooding, droughts, port equipment failures, and other operational disruptions could be included to provide a more comprehensive understanding of risk exposure along inland waterways.

Third, alternative financial and risk assessment metrics could complement the DNPV approach. Approaches such as real options analysis, internal rate of return, or risk-adjusted cost-benefit ratios may offer additional insights into investment decision-making under uncertainty.

Finally, the modeling framework could be applied to more complex network structures, capturing interactions among different transportation corridors, and regional supply chains.

7 Conclusion

This study demonstrates that resilient inland waterway ports can substantially reduce economic losses by mitigating supply chain disruptions during flood events. By integrating flood risk analysis with economic modeling and the decoupled net present value (DNPV) approach, the framework quantifies both the direct and cascading benefits of resilience investments, making the financial advantages clearer for investors.

The results indicate that there is an optimal level of investment for each flood scenario, balancing upfront capital costs with anticipated long-term economic returns. Resilient ports can maintain operations during flood events, reroute shipments, and absorb additional cargo from affected ports, preventing widespread production losses across interconnected supply chains. Non-resilient ports, in contrast, experience longer closures, higher repair costs, and greater disruption to regional economies.

This study provides a practical and adaptable framework for evaluating inland port resilience. By explicitly linking infrastructure improvements to measurable economic outcomes, the study supports data-driven decision-making for investors, policymakers, and port authorities. Ultimately, the findings underscore the value of proactive resilience planning as a cost-effective strategy to enhance the reliability and efficiency of inland waterway transportation. Overall, the analysis underscores that resilience is not just a cost but an investment that protects supply chains, supports regional economies, and strengthens the financial case for inland waterway infrastructure.

References

ASCE (2025). *A Comprehensive Assessment of America's Infrastructure*. American Society of Civil Engineers.

Crowther, Kenneth G. and Yacov Y. Haimes (2009). "Development of the multiregional inoperability input-output model (MRIIM) for spatial explicitness in preparedness of interdependent regions". In: *Systems Engineering*.

Davis, R. Chad (2018). *The Port of Cates Landing: Yesterday, Today and Tomorrow*. Tech. rep. University of Tennessee / CIS (Capstone Project).

Espinoza, David, Javier Rojo, and Jeremy W. F. Morris (2020). "DNPV: a valuation methodology for infrastructure and capital investments consistent with prospect theory". In: *Construction Management and Economics* 38.3, pp. 259–274.

Fahie, Monique (2019). *Impacts of the 2019 Upper Mississippi River Flooding on Barge Movements in the Upper Midwest Region*.

Inland Rivers Ports and Terminals (n.d.). *Port of Cates Landing*. `https://www.irpt.net/map-location/port-of-cates-landing/?mpfy_map=399&mpfy-pin=716`.

Johnson, Paul et al. (2023). "An integrated approach to evaluating inland waterway disruptions using economic interdependence, agent-based, and Bayesian models". In: *The Engineering Economist* 68.1, pp. 2–19.

MacKenzie, Cameron A., Kash Barker, and F. Hank Grant (2012). "Evaluating the Consequences of an Inland Waterway Port Closure With a Dynamic Multiregional Interdependence Model". In: *IEEE Transactions on Systems, Man, and Cybernetics - Part A: Systems and Humans* 42.2.

Magalhaes, Mauricio Rodrigues de et al. (2020). "Disaster Waste Management Using Systems Dynamics: A Case Study in Southern Brazil". In: *Operations Management for Social Good*. Springer International Publishing, pp. 251–261.

Niu, Tianlin et al. (2025). *Toward greener freight: Overview of inland waterway transportation in the United States*. Tech. rep. Research Brief.

Office of Management and Budget (1992). *Circular A-94: Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs*. United States Government Printing Office. Circular A-94.

Oztanriseven, Furkan and Heather Nachtmann (2017). "Economic impact analysis of inland waterway disruption response". In: *The Engineering Economist* 62.1. Publisher: Taylor & Francis _eprint: https://doi.org/10.1080/0013791X.2016.1163627, pp. 73–89. ISSN: 0013-791X. DOI: 10.1080/0013791X.2016.1163627.

Oztanriseven, Furkan, Heather Nachtmann, and Samareh Moradpour (2022). "Economic Impact of Investment Scenarios in the McClellan-Kerr Arkansas River Navigation System". In: *Journal of Marine Science and Engineering* 10.7, p. 923. ISSN: 2077-1312. DOI: 10.3390/jmse10070923.

Port City Daily (2024). *With $10M in Storm Damage, CB Earmarks $800K for Stormwater Pump Repairs & Debris Cleanup.*

Port of Little Rock (2023). *The Benefits of River Transportation.*

Rezende, Osvaldo Moura et al. (2019). "A framework to introduce urban flood resilience into the design of flood control alternatives". In: *Journal of Hydrology* 576, pp. 478–493.

Savidge, Thomas (2022). *What's in a Discount Rate?*

Welch, Katherine et al. (2022). "Flood-induced disruption of an inland waterway transportation system and regional economic impacts". In: *Water* 14.5, p. 753.

Whitman, Mackenzie, Hiba Baroud, and Kash Barker (2019). "Multicriteria risk analysis of commodity-specific dock investments at an inland waterway port". In: *The Engineering Economist* 64.4.