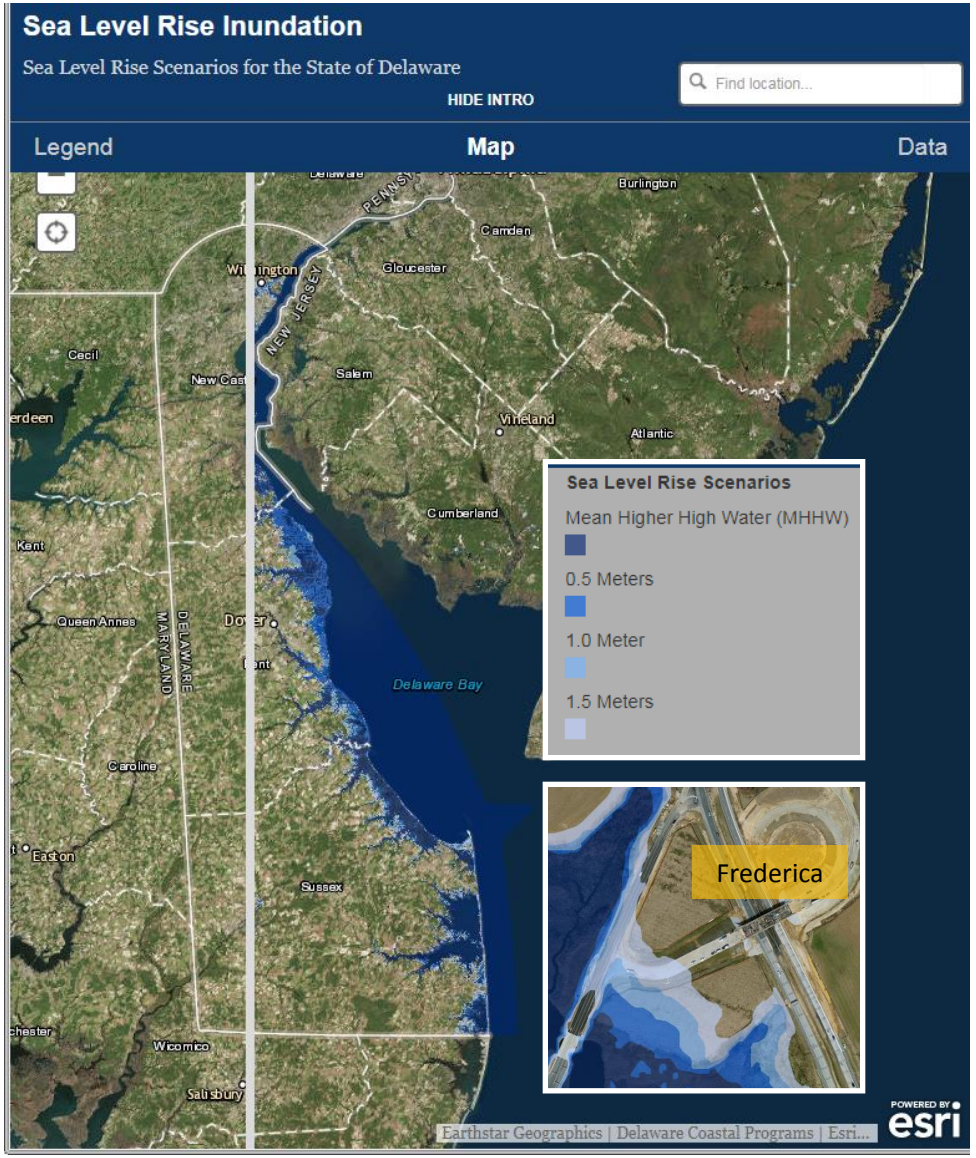
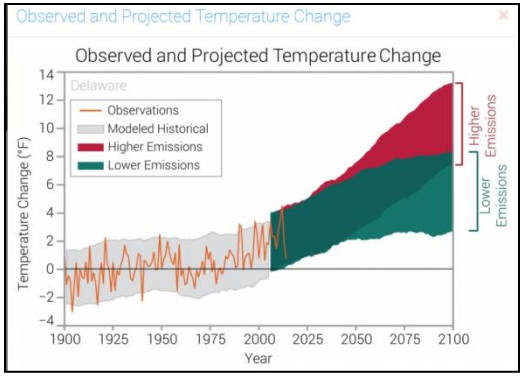
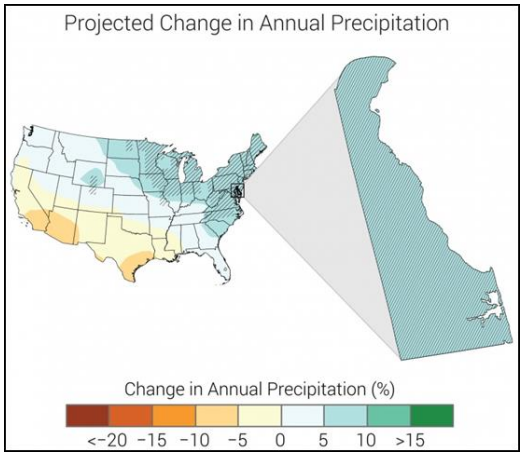
DELDOT RISK AND RESILIENCE MANAGEMENT FRAMEWORK

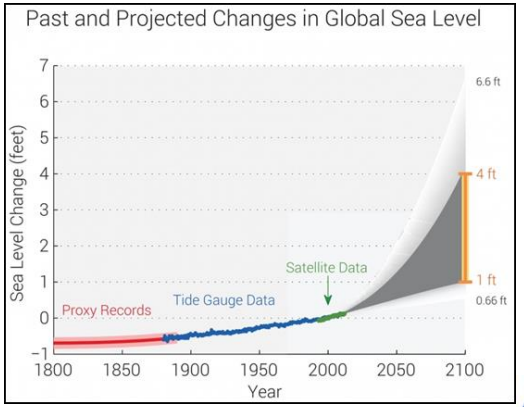
Seminar 1: The Delaware Floodplain Impacts of Severe Storms on Infrastructure in a Low Lying State



http://firstmap.gis.delaware.gov/inundation/
https://statesummaries.ncics.org/de



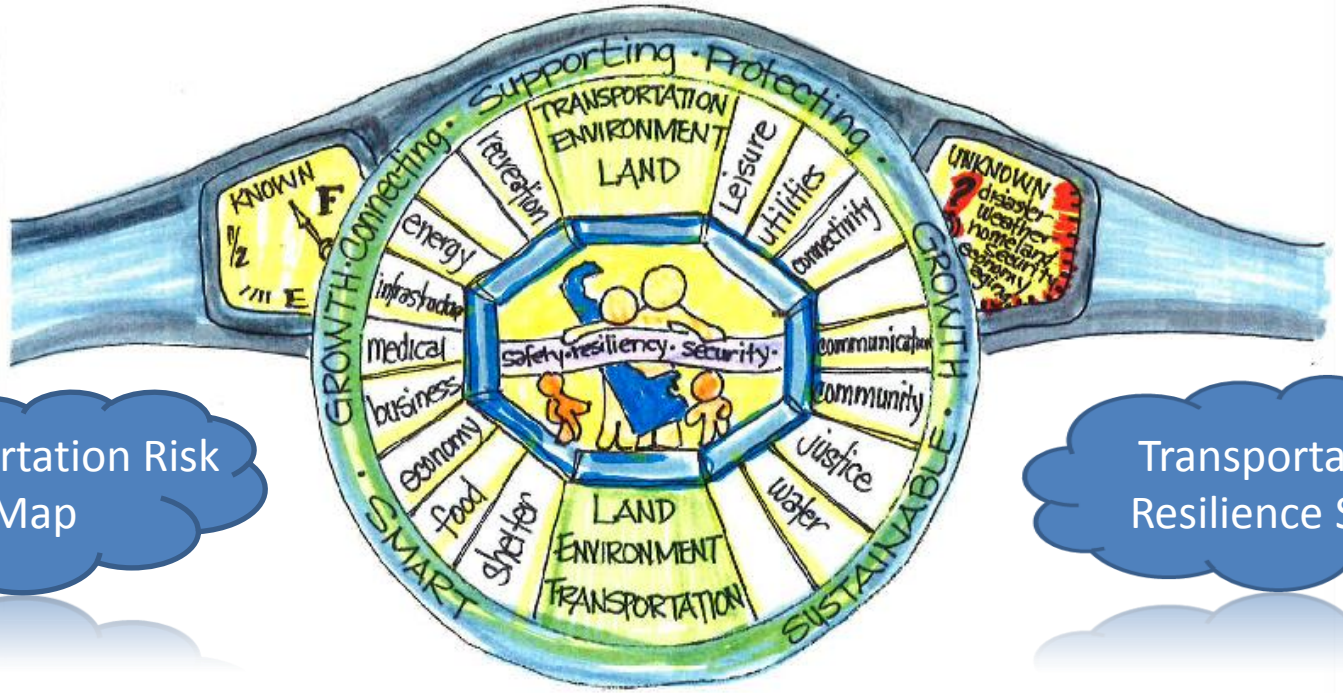




Questions

1. What components of DelDOT's infrastructure are at risk from storm surge
2. What information about transportation exposure is necessary to quantify the risk
3. What types of output can we produce using catastrophe risk models, and how should they be interpreted
4. What order of magnitude of loss (in economic or damage terms) should DelDOT expect to experience each year on average
5. What is the range of loss that DelDOT might experience from a storm surge event
    a. What are the probability of such losses
    b. What are the surge footprints of these events
6. Are there areas that are impacted more frequently and more severely than others (a risk map of damage and loss)
7. What is the relative risk between different sections of road, or between road and bridges
    a. Are there 'weak links' in the network
8. If DelDOT were to spend a dollar on increasing resilience, where does it have most value in risk reduction

Enterprise Resilience Management Strategy



Transportation Risk Map

Transportation Resilience Suite

2 Flood

8 Hurricane

1 Coastal Storm

5 Snow

1 Drought

4 Severe Storm

21 Natural Disasters since 1953

https://www.fema.gov/data-visualization-disaster-declarations-states-and-counties

DelDOT's Mission and Goals

Reading Statement

" … is to ensure that every trip taken on its transportation network is safe, reliable, and convenient for the people and commercial entities that use it – delivering a nationally recognized, financially and environmentally sustainable transportation system that can maximize the prosperity of the region, and benefit communities and economies alike over the long term."

Delaware Department of Transportation

AECOM

RMS

Delaware Department of Transportation vision: Every Trip | Every Mode | Every Dollar | Everyone

" Any potential hazardous impacts should be assessed and benchmarked against DelDOT's safety, service level, financial and environmental tolerances."

Align with

- DelDOT's Climate Change Strategic Implementation Plan
- Enterprise Resilience Management Strategy

Delaware Department of Transportation

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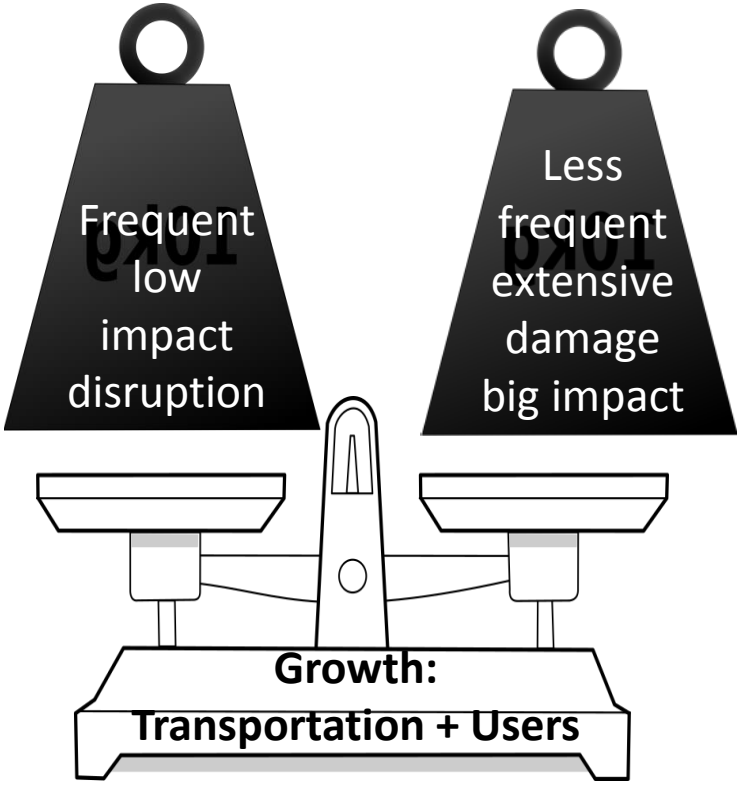
Risk & Resilience Management Framework:
A cycle-based approach to decision-making



Source: Risk Management Solutions (RMS)

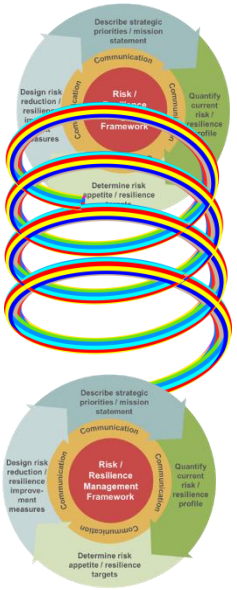
DelDOT Resilience Strategy

Maintain business as usual during an event

&

Restore timely, decreasing disruption through effective investments

Inclusive of uncertainty: occurrence of an event and forecasted amount of loss



Reassess, address shifting and residual risk, evolve

Risk & Resilience Management Framework: *A cycle-based approach to decision-making*

Step 1: Strategic priorities & organizational mission (details)

a. **Safety and security**
b. **Performance**
c. **Environmental sustainability**
d. **Financial stability**

a. Measured enhanced safe & secure travel
b. High level of service + ADA, multi-decadal changing conditions, continuous movement
c. Maintain, develop, protect the infrastructure network in an environmental sustainable way across time
d. Ensure defined level of financial strength to meet safety, security, performance and sustainability goals

Step-1: SR-9 R&R Management Framework

- Scope: SR-9 near to Old Corbitt Road
- Hazard: flooding
- Question:
  - What is an effective strategy for managing the storm surge to State Route 9?

Risk & Resilience Management Framework:
A cycle-based approach to decision-making

Step 2: Risk Quantification

a. Peril identification
b. Data acquisition and assessment
c. Qualitative and quantitative risk assessment
a. Identification of high risk areas

a. Concerning shocks and stresses to transportation
b. Data and models to assess relevant perils
c. Relative and absolute severity to assets/networks based on relevant data, models and expertise
d. Assessment informed high risk assets per location and strategy identification - benefits from improvement in resilience or efforts in risk management

e.g. DHS RRAP, THIRA …

TEAM DelDOT
Transparent Efficient Accountable Measured

Step-2: SR-9 R&R Management Framework

1. Defining and analyzing the exposure
2. Selecting the hazard
3. Quantifying the risk (exposed asset to hazard)

Question	Example
1a. What type of assets form SR9?	• Road
	• Bridges
1b. What are the physical characteristics of the assets?	• Construction type
	• Year Built
2. Where are the assets?	• Coordinates (for point assets)
	• Shapefiles (for linear assets)[3]
3. What are the asset values?	• Rebuild Cost
	• Insured Value
	• Value at risk from interruption of service

TABLE 1 EXPOSURE ANALYSIS QUESTIONS

Step-2: Hazard Selection

- Analysis: flooding due to storm surge
- RMS North America storm surge model
  - associated probability of occurrence (frequency)
  - Frequency + severity= risk to exposure

Risk Analysis Type	Illustrative Analytical Output
Probabilistic (stochastic method)	The probability of exceeding 5 ft. of storm surge at latitude x, longitude y is 0.05%.
Deterministic (scenario based method)	If a defined storm surge event occurs (historical or simulated), the storm surge height at latitude x, longitude y is 5 ft.

TABLE 2 ILLUSTRATION OF MODELLING METHODS

Step-2: Risk Quantification

- *How likely is the exposure to experience different levels of storm surge?*
- *What is the expected damage or, better, loss to the exposure from that likely experience of storm surge…*
  - On an annual average basis?
  - *For severe catastrophes?*
  - Across the full range of severity and frequency?

- *What are the critical assets, and how do they contribute to the total risk?*
- What is the best way to communicate the risk to inform decision making?
- *Where should investments in resilience be prioritized and what risk-adjusted return might reasonably be expected?*

Step-2: Exposure

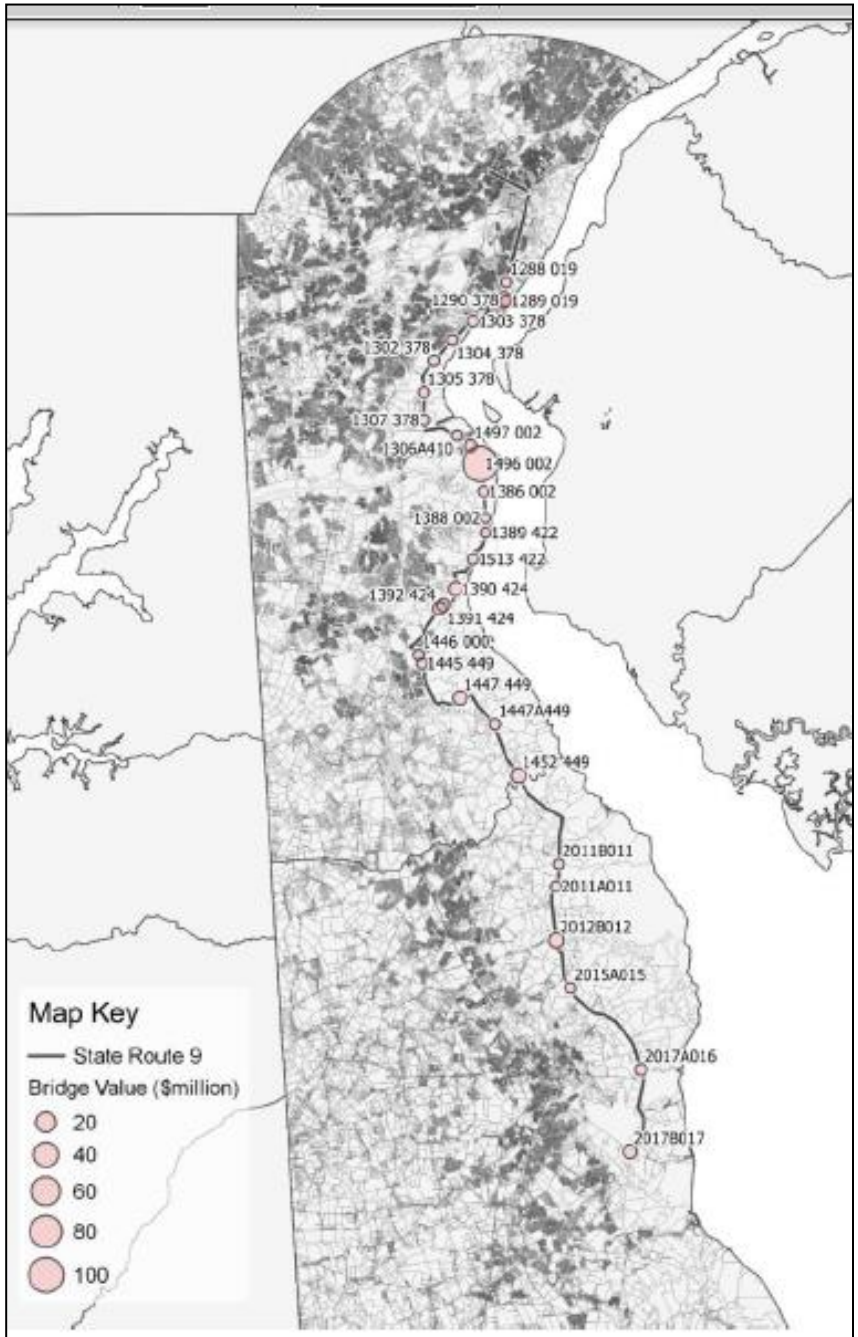


FIGURE 1 STATE ROUTE 9: EXPOSURE DATA

- SR-9: exposed highway (length)
- SR-9: exposed 29 bridges (rebuild cost - $300/square foot + bridged deck)
- Roadway rebuild cost: $20 M per mile (gross assumption)
- Reedy Point bridge: 72% exposure

FIGURE 2 1496 002: REEDY POINT BRIDGE (LEFT), 1290 378: WEST 6TH STREET BRIDGE (RIGHT). THE SATELLITE IMAGES SHOW THAT THE LOCATION DATA FOR THE EXPOSURE IS ACCURATE

Step-2 Risk Analysis

- Bridges and Roadways
- Non-economic analysis
- Example of question it answers:
  - *How frequently is a particular portion of road expected to be impacted by 2 ft. of storm surge?*
  - (Good to develop resilience strategies, prioritize and design resilience measures)

1. *What is the risk of damage and loss to the bridge assets in the Old Corbitt Road area from storm surge?*
2. *What is the risk of impact to the road network in the Old Corbitt Road area from storm surge?*

Step-2: Overview of Risk to Bridges

- Occurrence Exceedance Probability (OEP) to bridges:

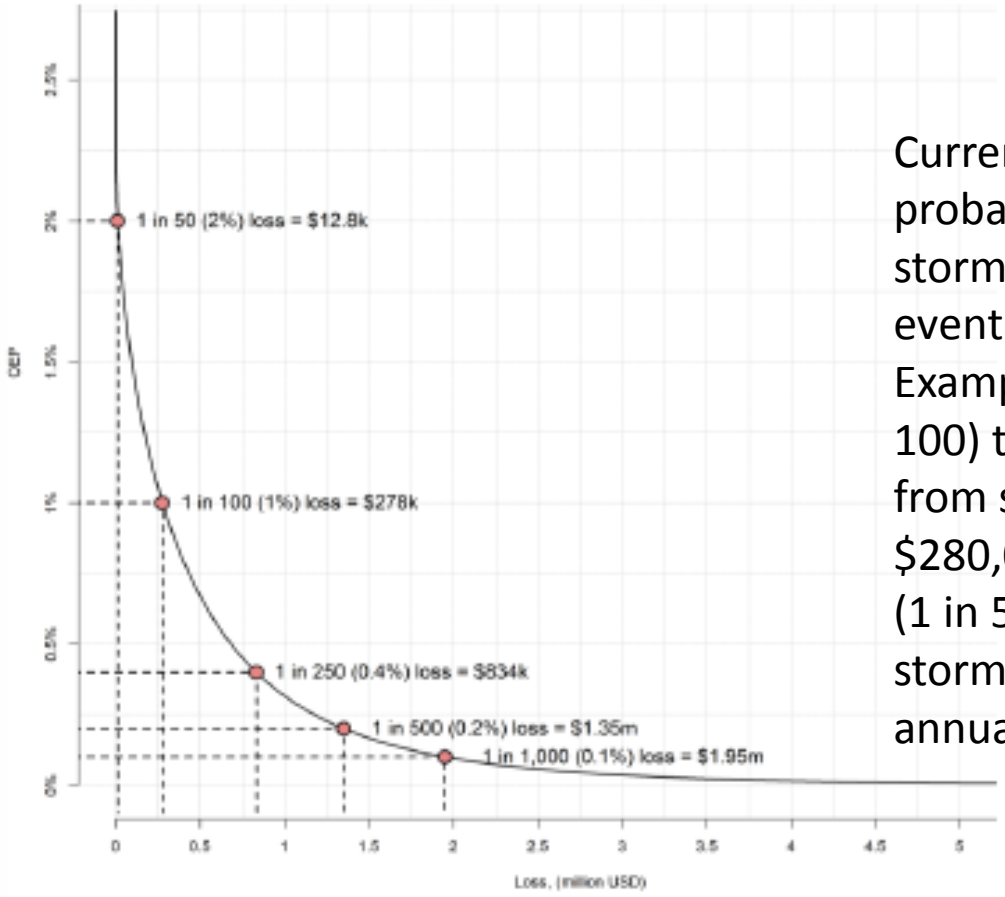


FIGURE 4 BRIDGE OEP

Current (29 bridges) range of probability of losses to bridges from storm surge annually from a single event.
Example, there is a 1% chance (1 in 100) that the annual loss to bridges from storm surge will exceed $280,000, while there is a 0.2% chance (1 in 500) that the loss to bridges from storm surge will exceed $1,350,000 annually.

Step-2: Prioritization of Bridges

Bridge Number	Value[12]		AAL		100-year RP		250-year RP		500-year RP	
	Rank	(%)[13]	Rank	(%)	Rank	(%)	Rank	(%)	Rank	(%)
1496 002	1	72.3%	1	63.4%	1	73.6%	1	67.2%	1	65.7%
1290 378	2	5.7%	5	1.8%	6	0.5%	6	0.8%	5	1.2%
1452 449	3	3.6%	7	1.0%	-	-	8	0.1%	7	0.5%
2012B012	4	3.1%	9	0.3%	-	-	-	-	10	<0.1%
1447 449	5	2.8%	2	13.9%	3	8.3%	2	13.7%	2	15.3%
2017B017	6	2.5%	-	-	-	-	-	-	-	-
1390 424	7	2.4%	4	8.0%	2	9.9%	4	6.7%	4	4.6%
1391 424	8	1.5%	3	9.4%	4	6.6%	3	9.8%	3	10.5%
1392 424	9	1.5%	-	-	-	-	-	-	-	-
1497 002	10	0.7%	10	0.2%	8	0.1%	9	0.1%	9	0.1%
2017A016	11	0.7%	8	0.4%	7	0.2%	7	0.2%	8	0.4%
1386 002	17	0.2%	6	1.0%	5	0.7%	5	1.1%	6	1.2%
Other[14]	-	3.1%	-	-	-	-	-	-	-	-

TABLE 4 CONTRIBUTION TO RISK BY BRIDGE (TOP 3 RANKED BRIDGES BY PERSPECTIVE HIGHLIGHTED IN BLUE)

Finding	Explanation	Implication
Overall economic risk from storm surge to the SR9 bridges is low.	Bridge design typically considers the possibility of flooding and storm surge events.	Perhaps with a few exceptions, bridges should not be the focus of DelDOT's resilience investments along SR9.
Risk is driven by a small number of bridges, with only four contributing together 95% of the overall AAL (Figure 5).	Proximity to the coast or other water sources, along with the value of the bridge, drives the risk.	These four bridges should be targeted by DelDOT for both more accurate valuation data and potential resilience measures. The other bridges do not merit as much focus.
The drivers of risk are spatially very concentrated, specifically along a 20-mile section of SR9 to the south of Delaware City.	This is the portion of the SR9 which runs closest to the coast.	The road between these bridges is also likely to experience greater losses. This area merits further, more detailed analysis.
The Reedy Point Bridge is the main driver of risk.	Assets with higher value cause a greater financial loss if damaged. This bridge is also relatively close to open water.	DelDOT should prioritize Reedy Point Bridge above all when planning resilience measures for the SR9 bridges.

TABLE 5 RISK ANALYSIS INSIGHTS FOR BRIDGES

TEAM DelDOT
Transparent Efficient Accountable Measured

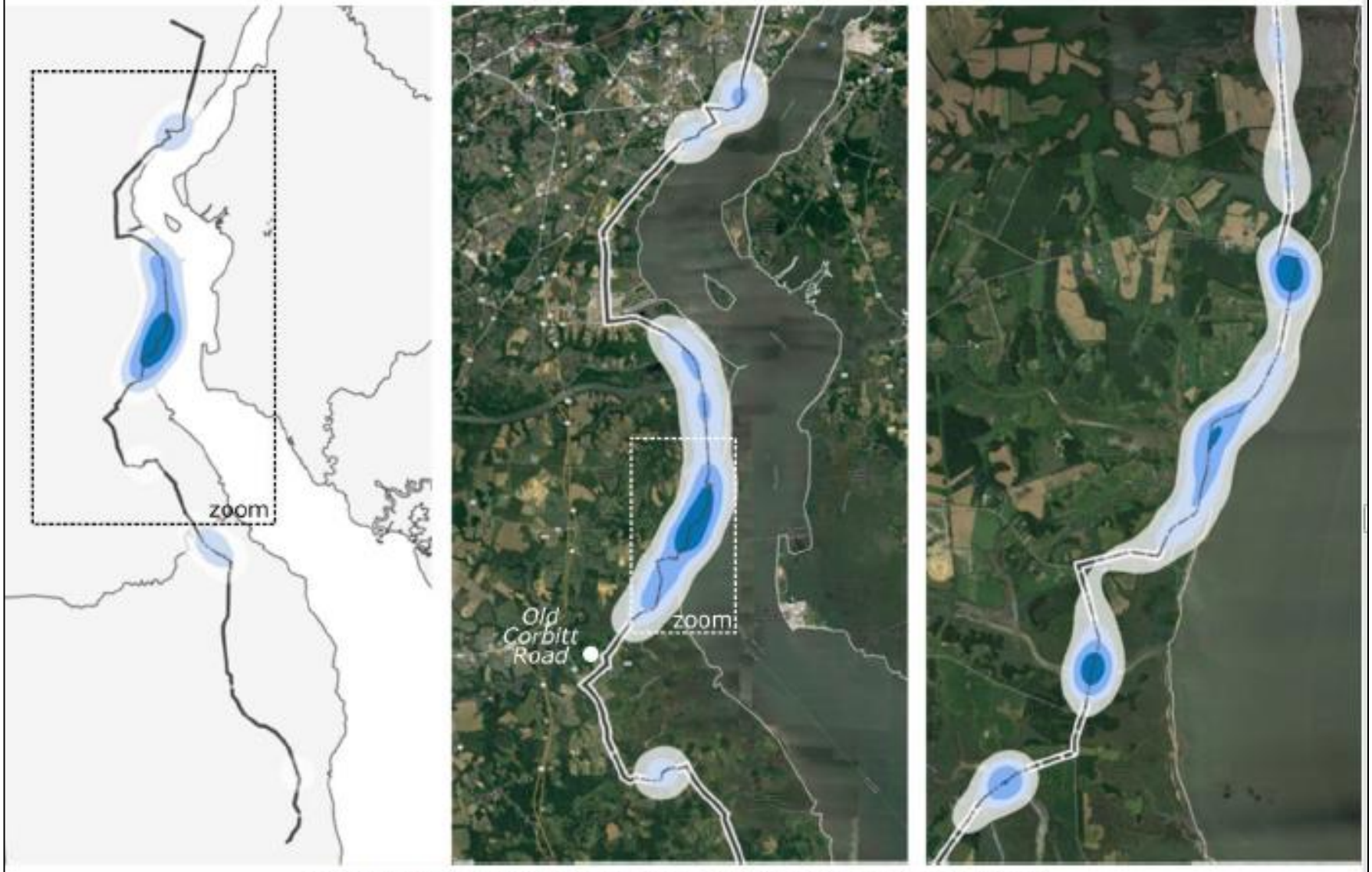


FIGURE 7 RELATIVE STORM SURGE AAL TO SR9 ROAD NETWORK: THREE PROGRESSIVE ZOOMS

Left: overall perspective on the storm surge risk. Middle and right shows progressive levels of zoom on the road network portion that contributes most to the overall risk

Step-2: Quantification of Risk to Road And Non-Financial Impact

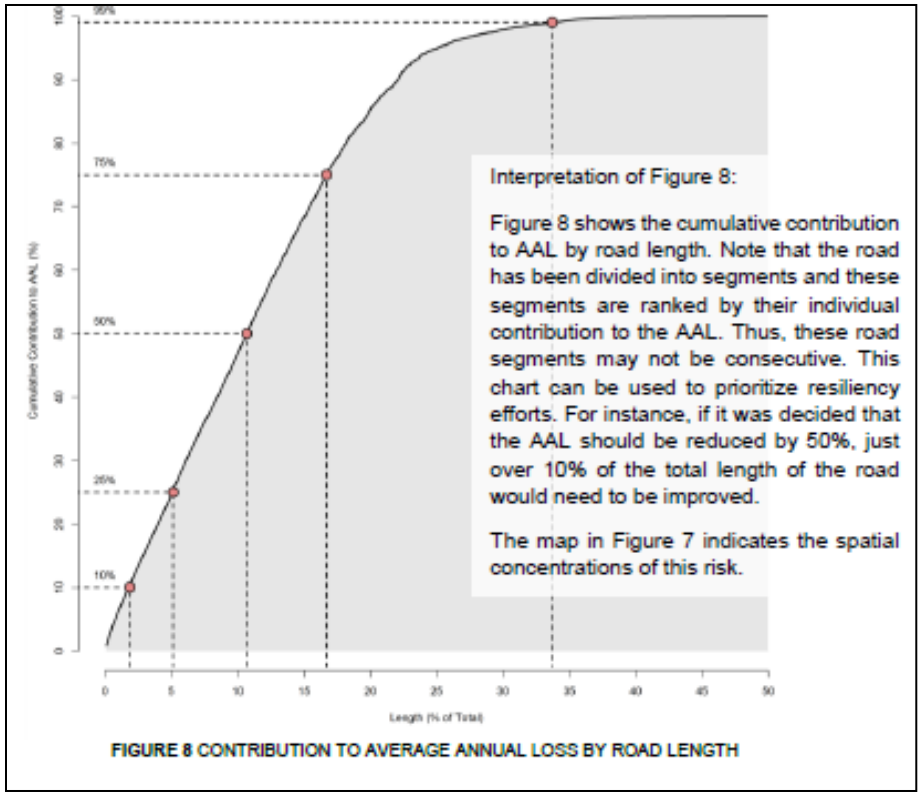


FIGURE 8 CONTRIBUTION TO AVERAGE ANNUAL LOSS BY ROAD LENGTH

Majority of the road exposure (over 65%) does not contribute materially to the modelled loss

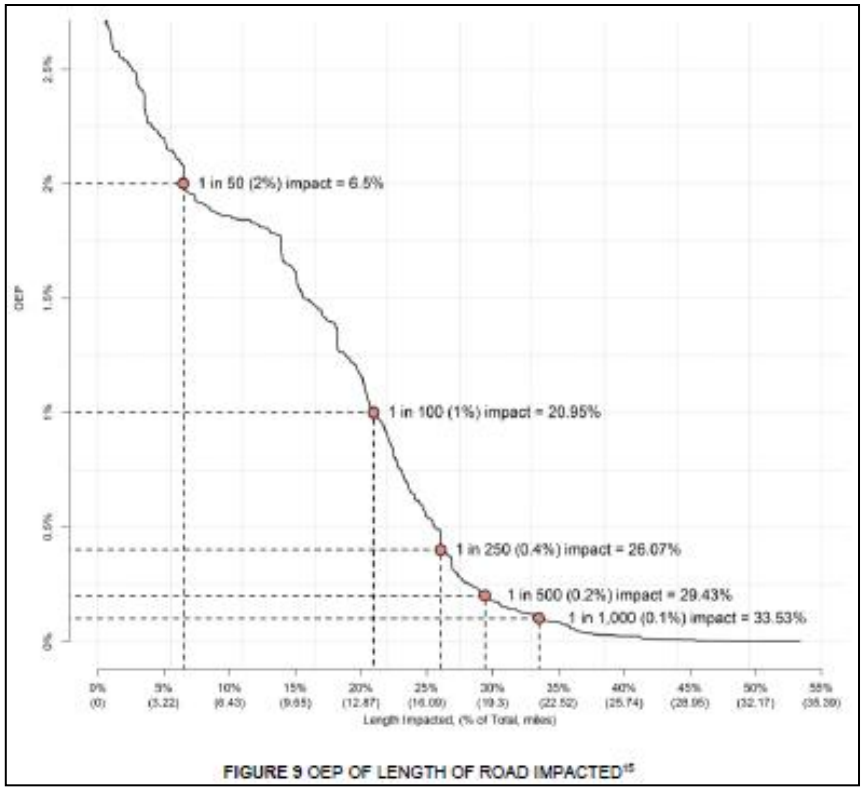


FIGURE 9 OEP OF LENGTH OF ROAD IMPACTED[15]

2% probability (1 in 50) that at least 6.5% of the total length of SR9 will be impacted by a single storm surge event. 1% probability (1 in 100) of impacting at least 20.95% of the road.

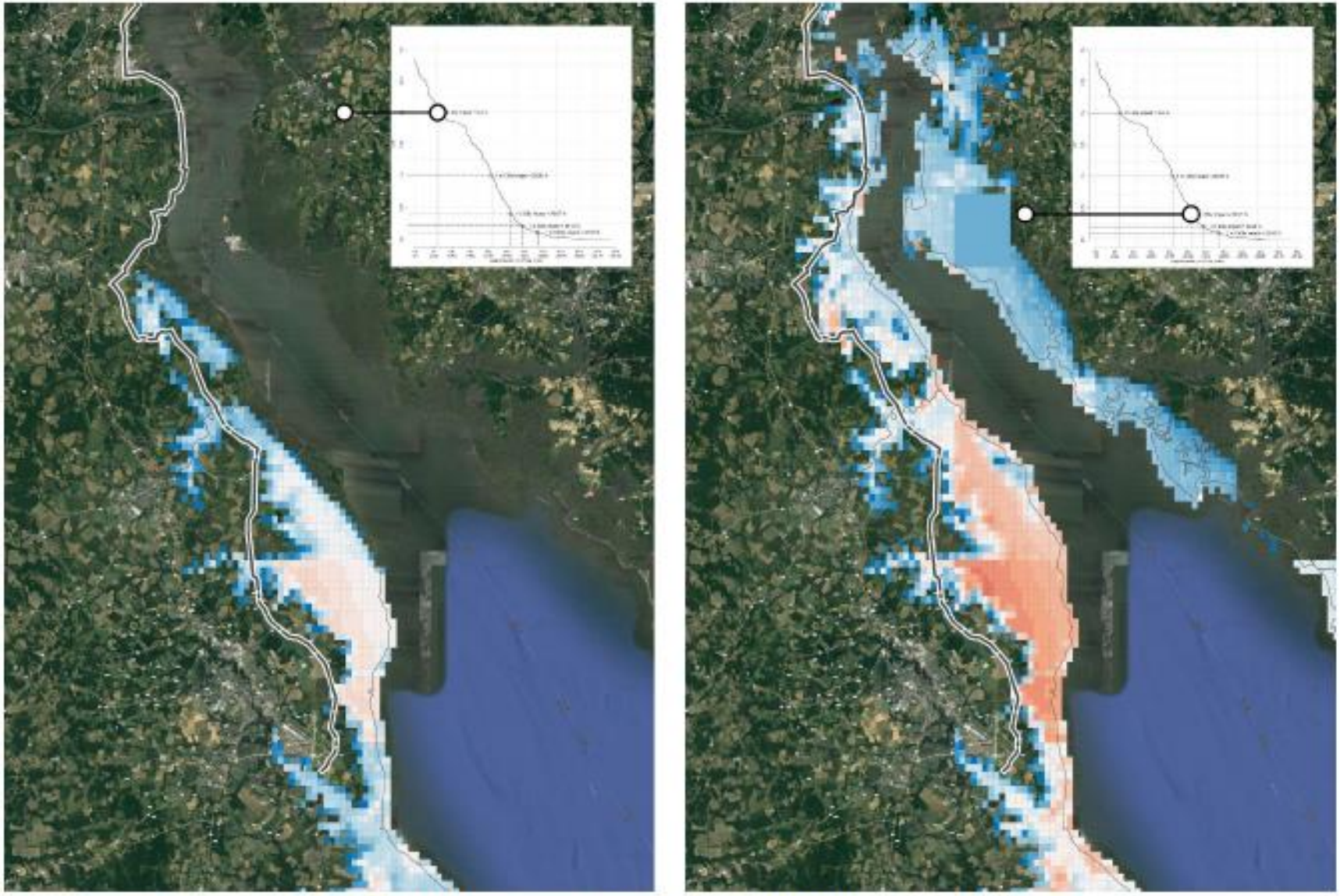


FIGURE 10 STORM SURGE FOOTPRINTS FOR SELECT STOCHASTIC EVENTS[16]

Findings	Explanations	Implications
The road network is more vulnerable than the bridges, with an MDR of 0.036% compared to 0.007% for the bridges.	Unlike bridges, roads are not built to withstand storm surge events.	Resilience measures would be better targeted at the road network than the bridges.
The EP curve for the road network is less smooth than for the bridges, with the largest inflection at the 2% probability mark.	Storm surge events can produce jumps in losses to linear assets, where a small increase in surge height causes a large increase in loss.	Risk tolerance levels could be determined to protect against expected jumps in losses and risk reduction measures (whether physical or financial) could be designed around these jumps.
Portions of the SR9 closes to the coast or rivers drive the total loss from storm surge.	Flood is the most localized of all natural perils, as a water source is needed to initiate losses. Proximity to water is therefore of heightened importance in analysing storm surge risk.	Exposures on the coast should be prioritised over those inland and attention should be paid to which exact areas along the coast are most at risk when considering future network developments.
The overall risk is driven by only a small portion of the road's length, with 99% of AAL stemming from 34% of road length and over 65% not contributing at all to losses.	There is a large difference between potential losses to the most vulnerable portions of road near the coast and those inland.	DelDOT can focus its resilience investments on certain sections of the road rather the whole length.
Accounting for almost 55% of the total risk to the entire SR9, a 16-mile section at St Augustine Road is the riskiest by far.	This is the portion of road closest to the coast.	Resilience measures targeted at St. Augustine Road will deliver the greater risk-adjusted return on investment.
Increasing resilience makes more difference at lower return periods.	The EP curve is not linear. At the beginning of the curve, reducing the exceedance probability greatly increasing the loss threshold. Further along the curve, less likely events have lower potential to increase losses.	After a certain point, resilience measures become less cost effective, so the flattening of the EP curve should be considered when setting resilience targets.

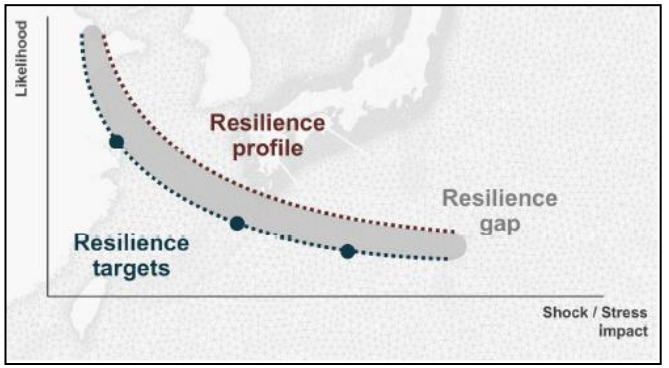
TABLE 6 RISK ANALYSIS INSIGHTS FOR ROAD NETWORK

Risk & Resilience Management Framework:
A cycle-based approach to decision-making

Step 3: Assess Risk Tolerance & Resilience Targets

Risk
- **Safety and security**
- **Performance**
- **Financial stability**

Targets
- **Simple**
- **Progressive**
- **Aligned**
- **Realistic**
- **Quantifiable**



TBD
- Do nothing?
- Risk greater than current agency's capability? (mitigate, transfer…)

Risk & Resilience Management Framework:
A cycle-based approach to decision-making

Step 4: Adopt Risk Reduction and Resilience Measures with Defined Targets

- **Risk Retention**
- **Monitoring & Early Warning Systems**
- **Risk Adaption**
- **Risk Transfer**
- **Federal Backstop**

TBD

General Outcomes

- 99% of the losses to the road network stem from less than 35% of the road
  - DelDOT can focus its resilience efforts with confidence on very specific sections of SR9: St Augustine Road (contributes approximately 50% of the road network's total AAL)
  - the area around Old Corbitt Road requires attention
- One bridge asset (Reedy Point Bridge, US Army Corps of Engineers jurisdiction), contributes 64% to the risk of the bridge portfolio on average and 74% at the lower return periods such as the 1-in100
  - This asset is within 10 miles of Old Corbitt Road
  - This is one of the most vulnerable areas of SR9

Future Work

1. *Determine internally if the assets are appropriately protected (financially, or structurally)*
2. *Further validate the asset values*
3. *Develop a bespoke component based vulnerability model to calibrate the modeled losses (using engineering studies and site studies)*
4. *Investigate the potential for wider spread disruption upon damage to certain parts of the network*
5. *Assess whether the existing resilience measures are suitable (e.g. scour protection)*
6. *Estimate the cost-benefit of increasing the physical protection*
7. *Extend the analysis to include all of DelDOT's assets*
8. *Consider more scenario events to prepare for a variety of potential losses*
9. *Compare the risk profile of different areas with the potential for land development*

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Thank you!

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