TRB TRANSPORTATION RESEARCH BOARD OF THE NATIONAL ACADEMIES

# Improving Transportation Infrastructure System Resilience Using Federal Tools and Customized Models

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Workshop 171: Risk Assessment, Part 2: Loss Estimation Models and Tools

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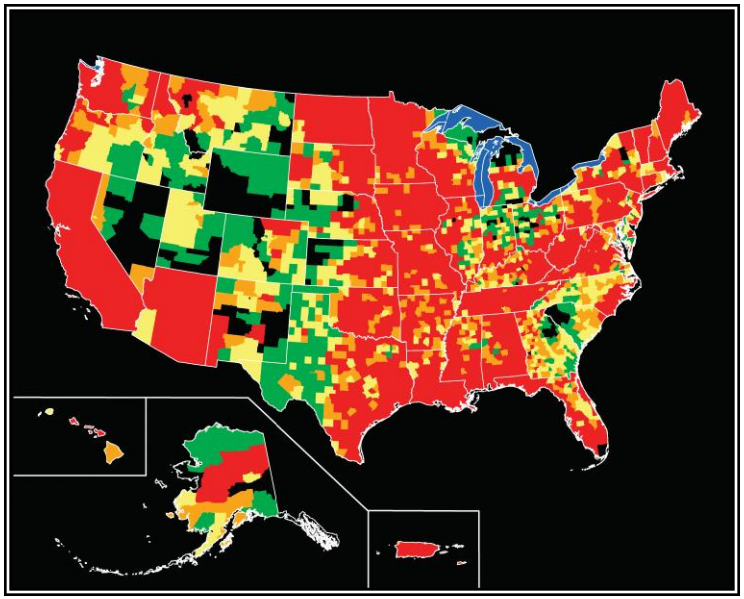
# Discussion topics

- Ph.D. research: Managing Critical Infrastructure Systems for Disaster Resilience: a Challenge
- An approach to resilience
- The need for Decision Support Models and Tools to promote critical transportation infrastructure protection
- Loss estimation models and tools
- Conclusion

# Managing Critical Infrastructure Systems for Disaster Resilience: a Challenge - I



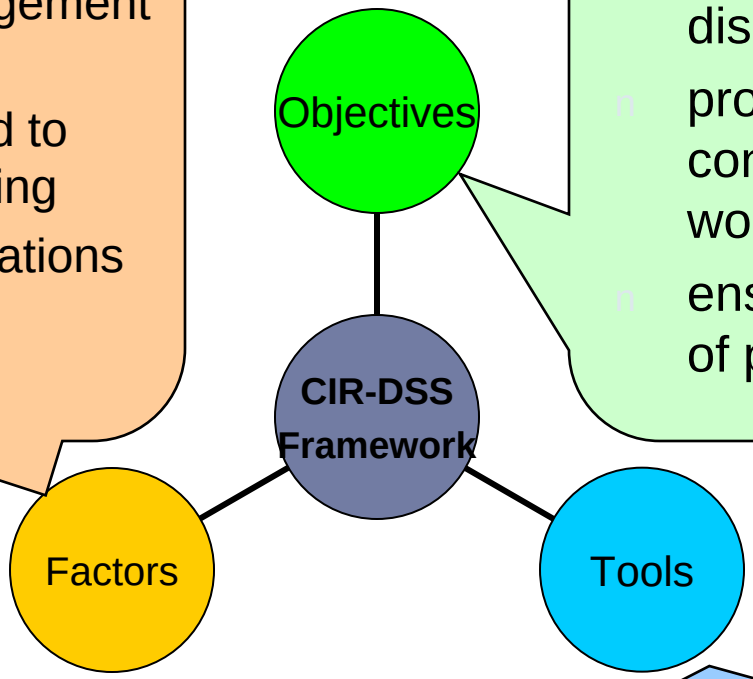
USGS, presidential disaster declarations, flooding 1965 to 2003.

http://www.autoblog.com/2009/11/11/report-more-than-25-of-us-bridges-are-structurally-deficient/

Disruption of essential services

# Managing Critical Infrastructure Systems for Disaster Resilience: a Challenge - II

- operations and management nature
- data and tools needed to support decision making
- failure/degraded operations and performance consequences

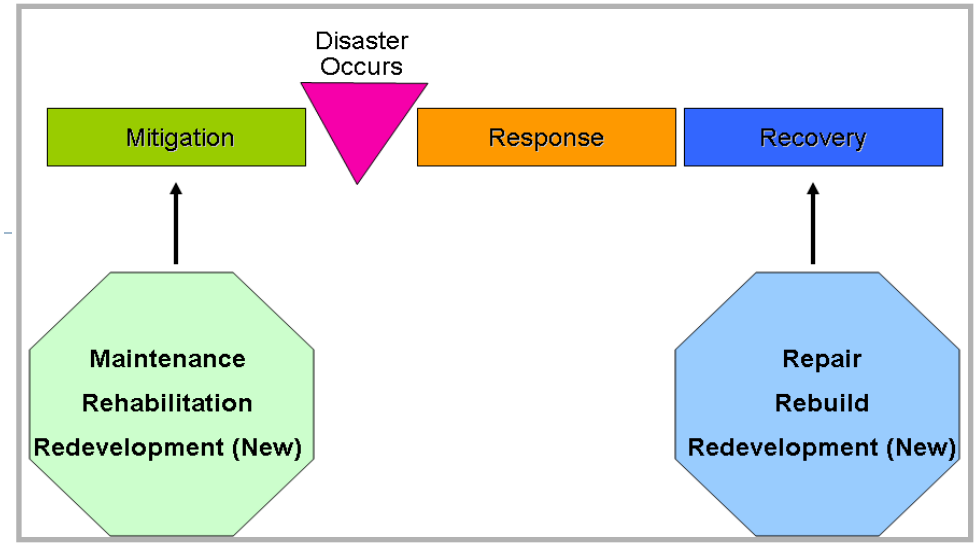


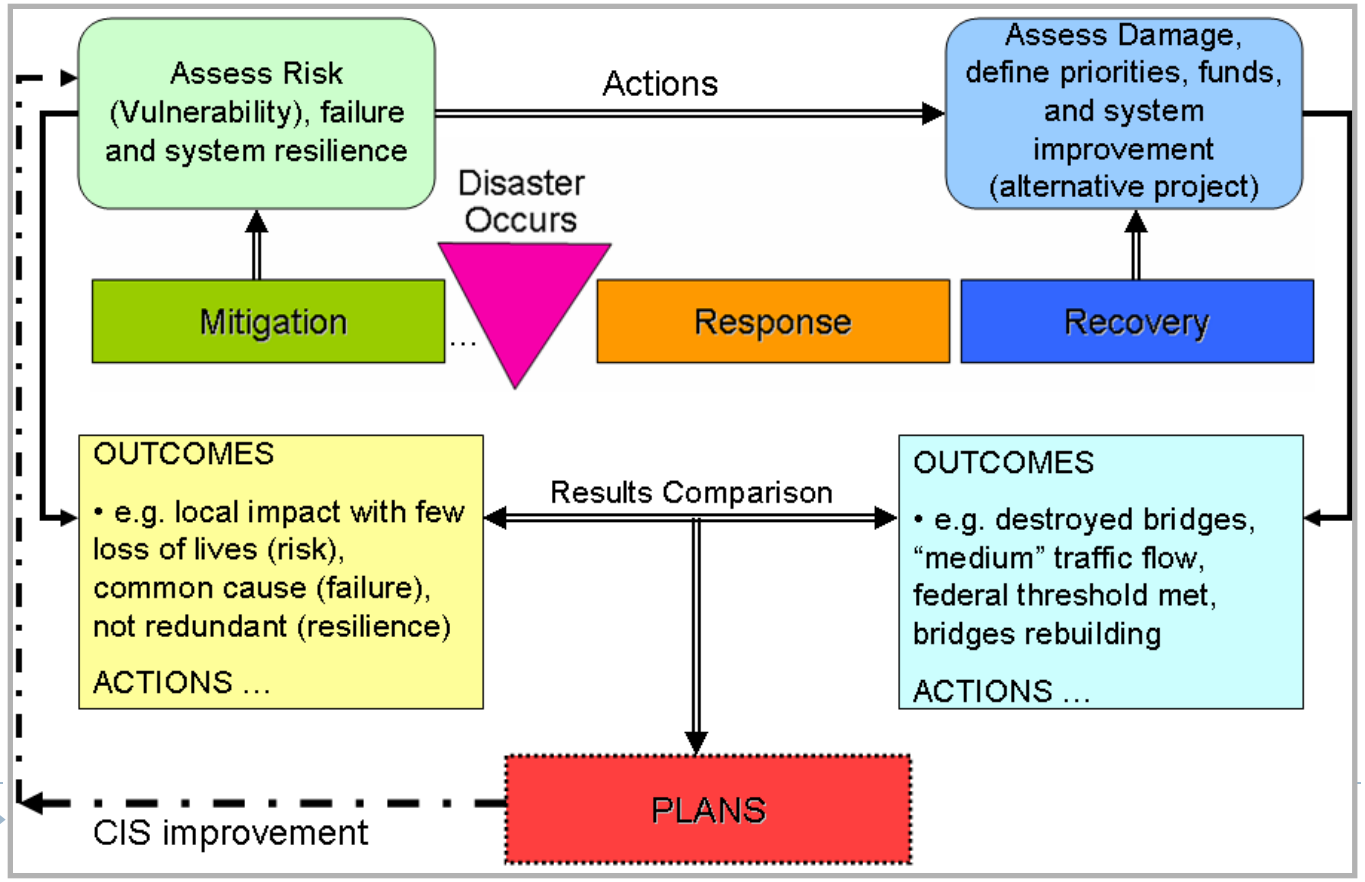

- mitigate CIS failure, disruption, and damage
- promote better physical conditions for systems to work
- ensure continuity of flow of people and goods

- geographical context,
- civil infrastructure systems analysis (asset management systems),
- vulnerability and impact assessment


Disaster Cycle

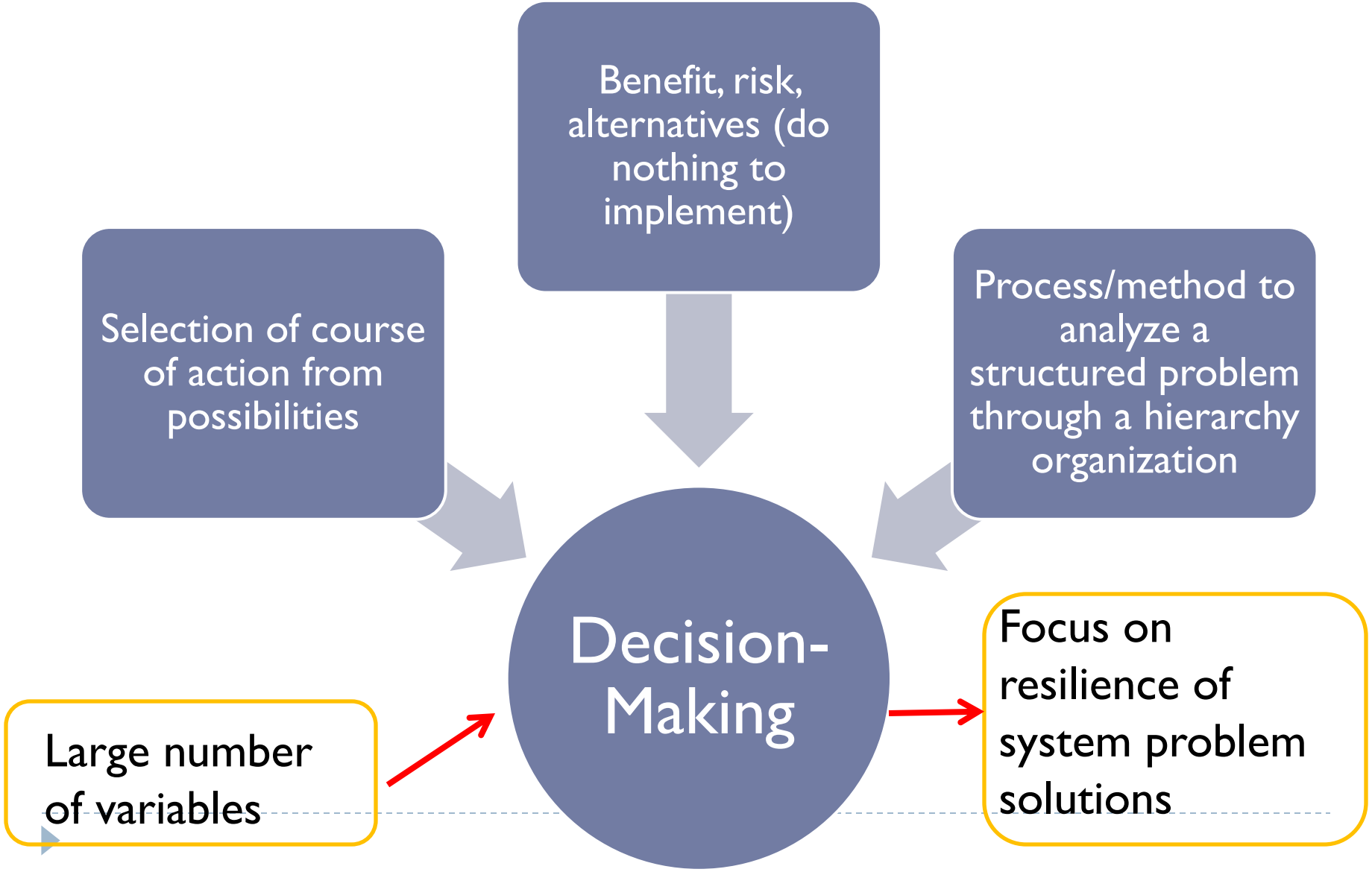
Disaster Timeline for CIR-DSS



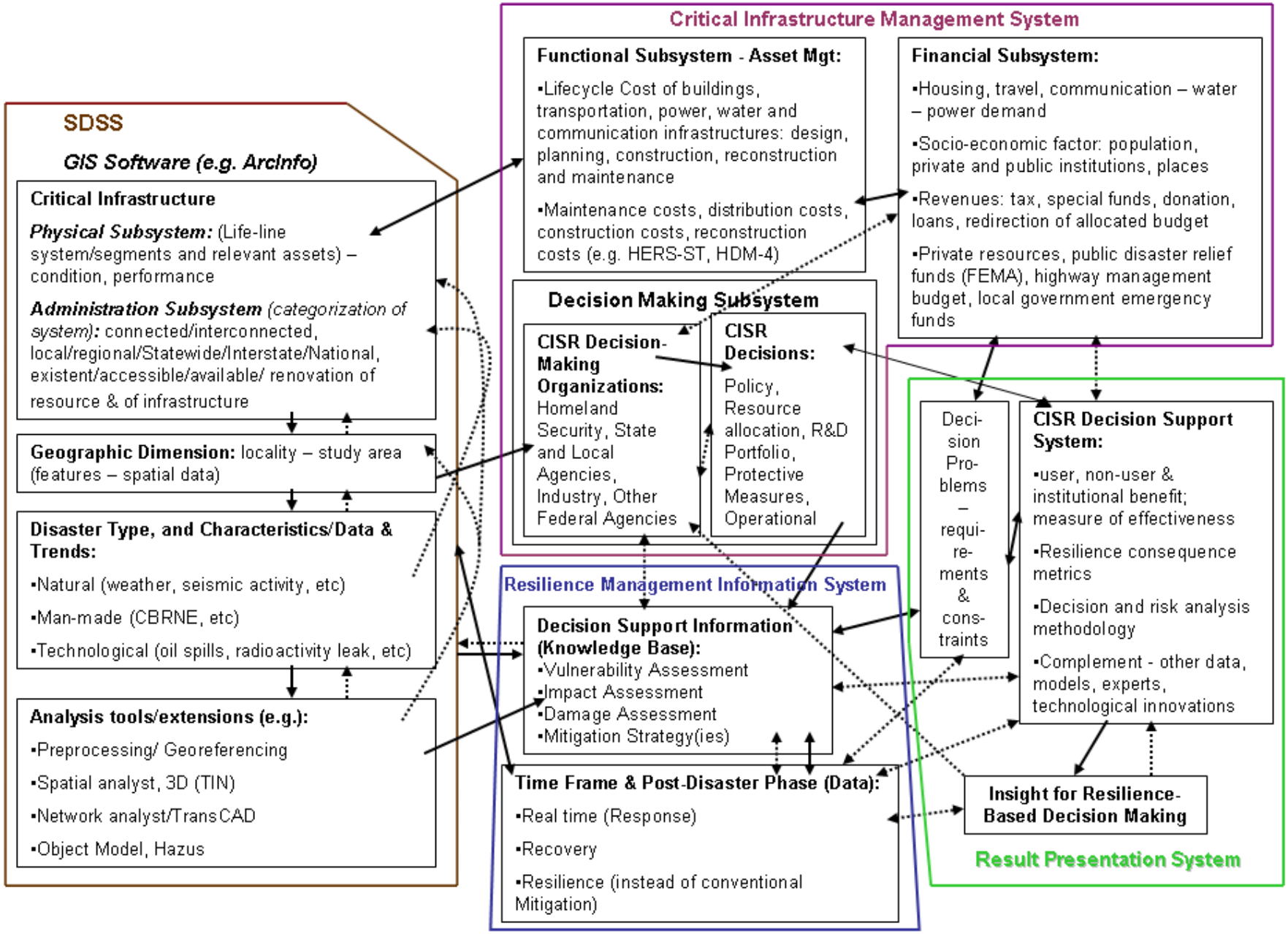




CIR-DSS Framework What-if scenario

# Decision-Making – CIR-DSS Macro Environment



# System Dynamics Diagram of Decision Support System for Critical Infrastructure System Resilience (CISR)



# Managing Critical Infrastructure Systems for Disaster Resilience: a Challenge - III

- Manage infrastructure and ensure transportation functionality by
  - Evaluating component or system failures & vulnerabilities
  - Changing vulnerability of networked systems evaluation
  - Changing cause of failure – use exceeding capacity or negative interactions

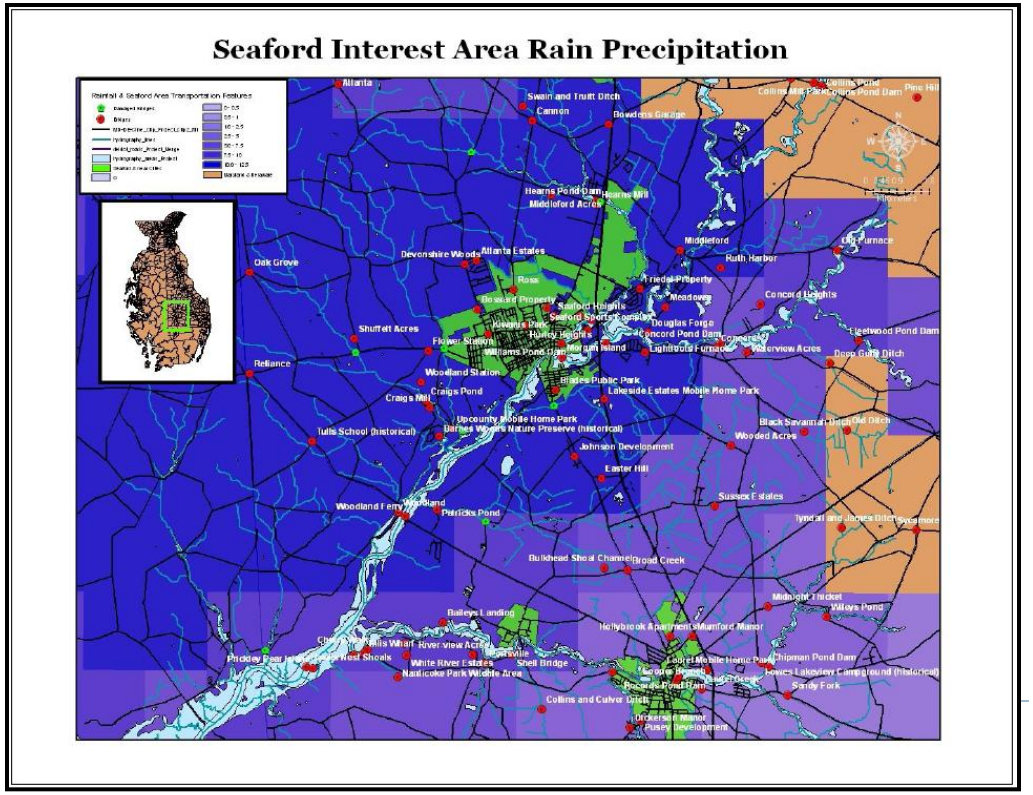
Improving Resilience of System

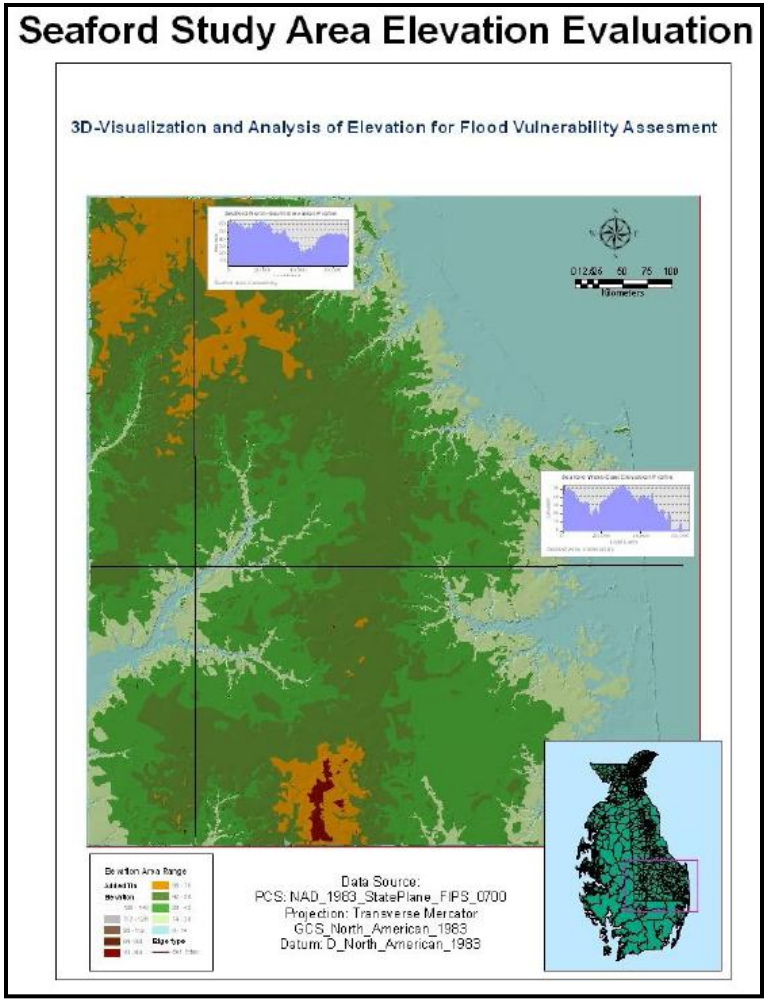
# Resilience (network)

- System's ability to provide and maintain an acceptable level of service when facing faults and challenges to its normal operation
- System's ability to recover/restore itself to former conditions or, adaptive capacity
- Resilience metrics
  - performance indicators,
  - safety measures, and/or
  - rating systems capturing systems behavior

# Loss Estimation Approach - GIS

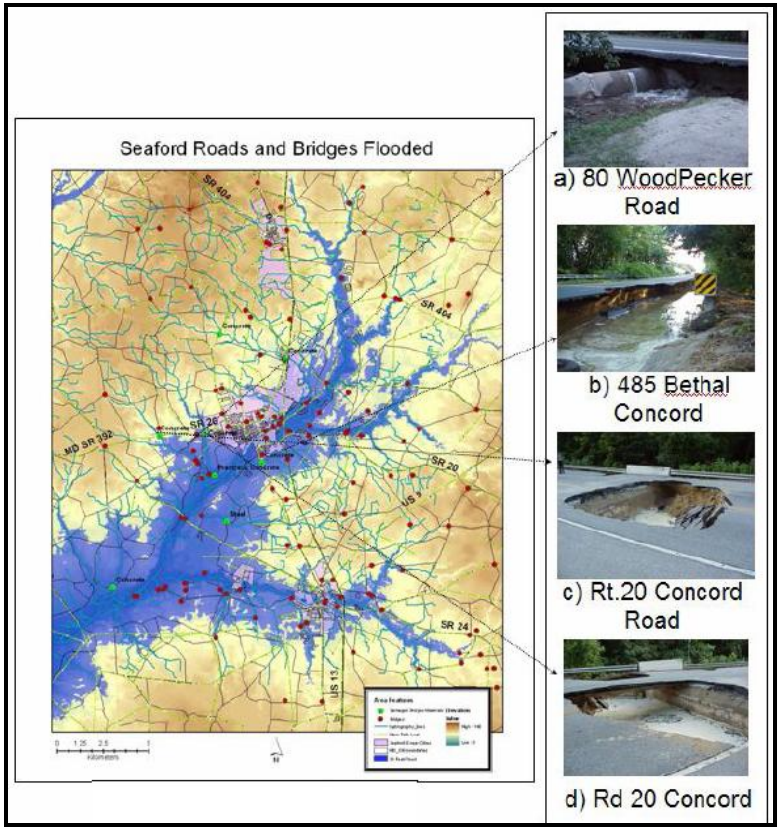
- **Vulnerability** - measure of susceptibility to suffer loss or damage.
  - Human product of physical exposure to a disaster resulting in some degree of loss, considering human capacity to withstand, prepare for, and recover from disasters.



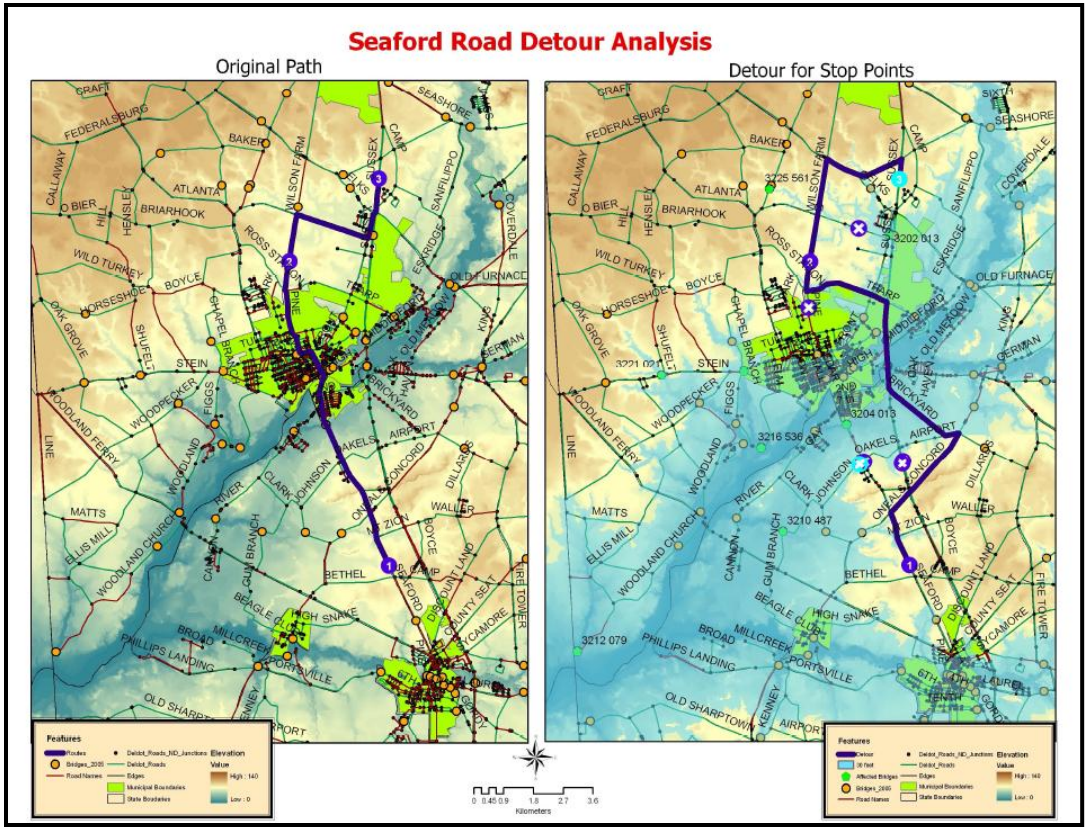




Seaford, Sussex County, DE

# Loss Estimation - GIS for Assessing Resilience




Location of Damaged Infrastructure in the Seaford Flooded Area



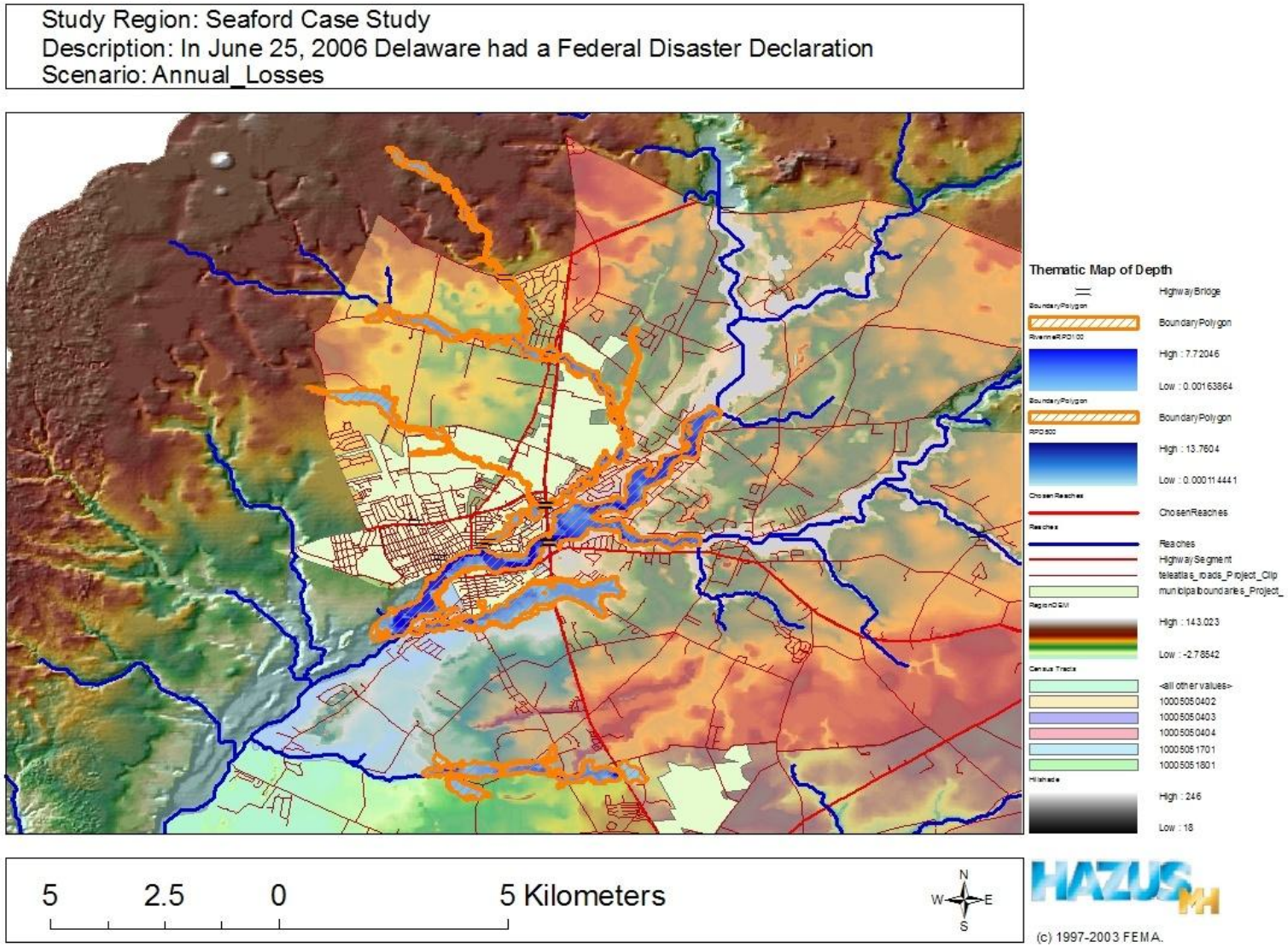

Seaford Road Network and Detours Analysis

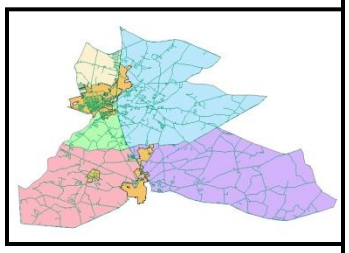
# Loss Estimation and Impact Assessment - HAZUS-MH


- Federal Official standardized software for loss estimation and impact assessment
- Provides organizing principle and an analytical capabilities
  - Qualitative and Quantitative
- Uses official organizations for collecting data, building basic inventory and mathematical functions
- Works with 3 Levels for Analysis
- Is constantly being updated and building more in depth analysis capability

# HAZUS-MH for CIR-DSS

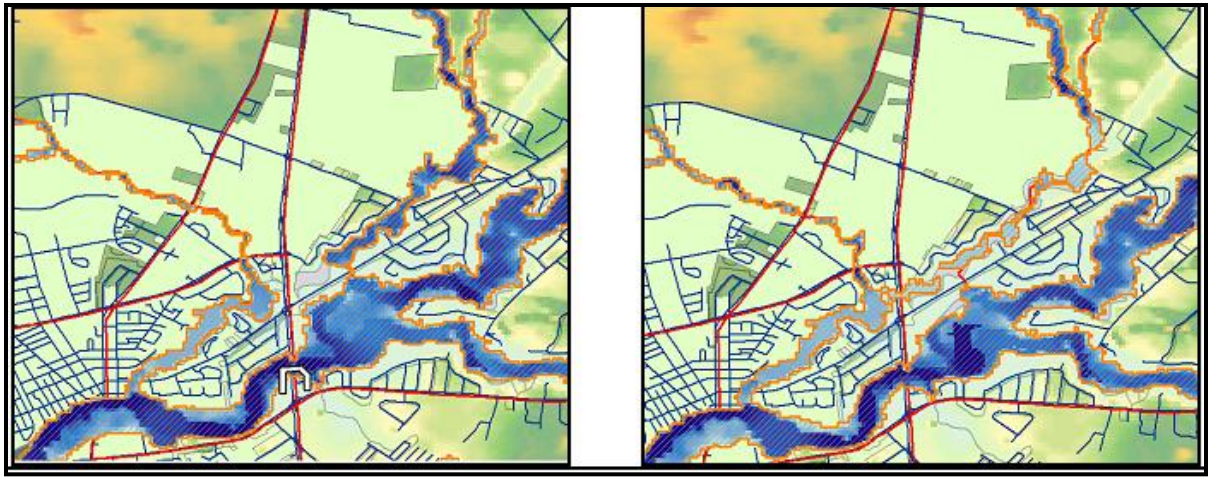
Seaford Area Annual Losses Map of Depth



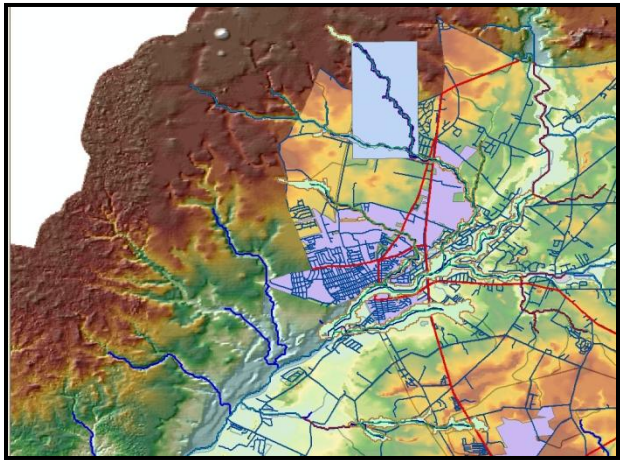



Base Map

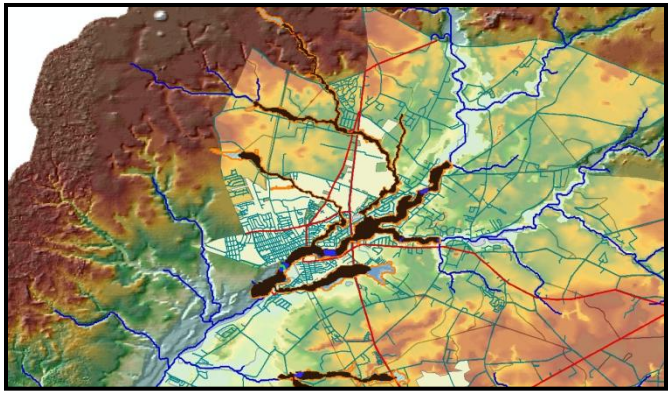
# HAZUS-MH Analyses for CIR-DSS



"What if" Levee Protection Scenario



"What if" Flow Regulation Scenario



Floodwater Velocity Estimation Scenario

Damage related to US13 in Sussex County

## Transportation System Dollar Exposure

*October 27, 2008*

*All values are in thousands of dollars*

| | Highway | Railway | Light Rail | Bus Facility | Ports | Ferries | Airport | Total |
|---|---|---|---|---|---|---|---|---|
| **Delaware** | | | | | | | | |
| **Sussex** | | | | | | | | |
| Segments | 205,419.68 | 31,130.00 | 0.00 | 0.00 | 0.00 | 0.00 | 67,754.40 | 304,304.08 |
| Bridges | 14,754.85 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 14,754.85 |
| Tunnels | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Facilities | 0.00 | 0.00 | 0.00 | 1,188.10 | 0.00 | 0.00 | 5,940.50 | 7,128.60 |
| **Total** | **220,174.53** | **31,130.00** | **0.00** | **1,188.10** | **0.00** | **0.00** | **73,694.90** | **326,187.53** |
| **Total** | **220,174.53** | **31,130.00** | **0.00** | **1,188.10** | **0.00** | **0.00** | **73,694.90** | **326,187.53** |
| **Study Region Total** | **220,174.53** | **31130.00** | **0.00** | **1,188.10** | **0.00** | **0.00** | **73,694.90** | **326,187.53** |

## Debris Summary Report

*October 27, 2008*

*All values are in tons.*

| | Finishes | Structures | Foundations | Total |
|---|---|---|---|---|
| **Delaware** | | | | |
| Sussex | 1,709 | 323 | 765 | 2,797 |
| **Total** | **1,709** | **323** | **765** | **2,797** |
| **Scenario Total** | **1,709** | **323** | **765** | **2,797** |

# HAZUS-MH Assessment Summary

- Enables comparison of some mitigation alternatives

| Building Exposure by Occupancy Type for the Scenario | | |
|---|---|---|
| Occupancy | Exposure ($1000) | Percent of Total |
| Residential | 307,736 | 72.7% |
| Commercial | 89,543 | 21.1% |
| Industrial | 12,150 | 2.9% |
| Agricultural | 1,515 | 0.4% |
| Religion | 7,296 | 1.7% |
| Government | 3,098 | 0.7% |
| Education | 2,248 | 0.5% |
| **Total** | **423,586** | **100.00%** |

Global Summary for Annual Loss

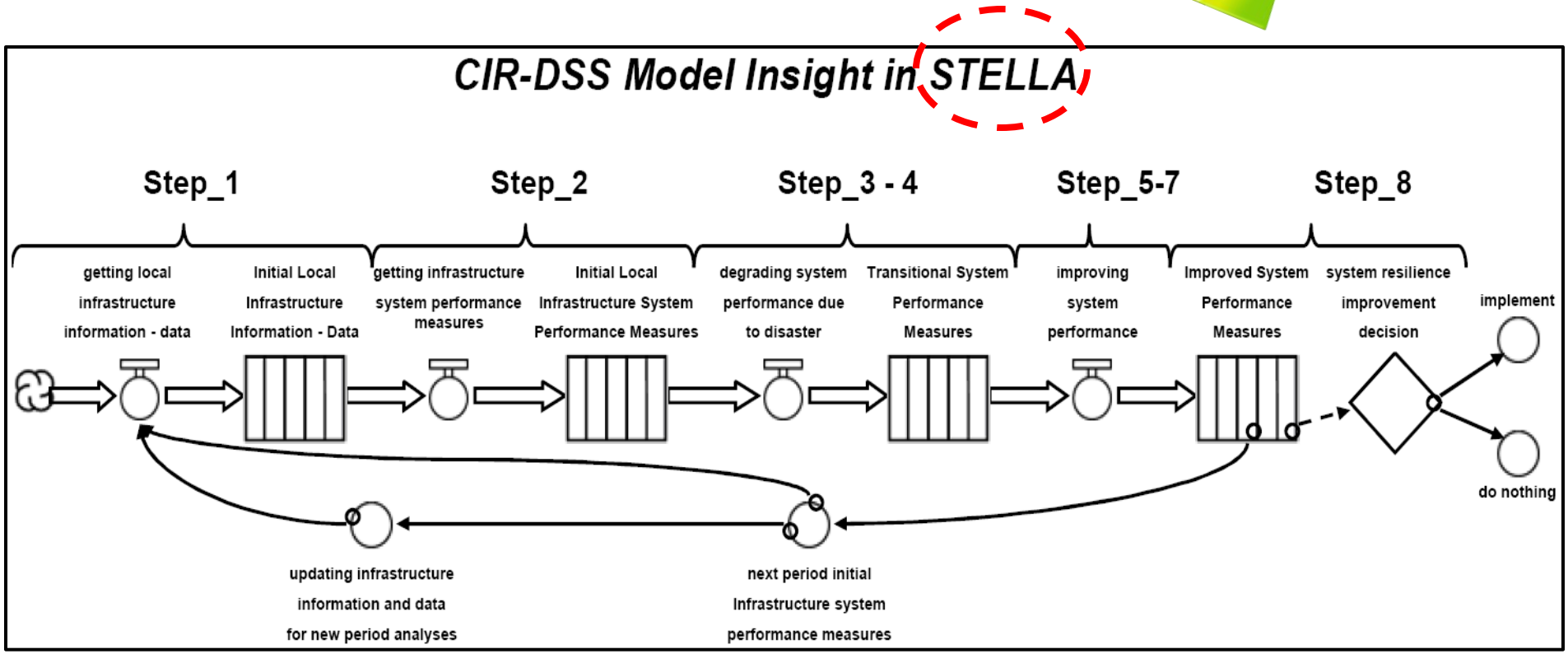
| Building Exposure by Occupancy Type for the Scenario | | |
|---|---|---|
| Occupancy | Exposure ($1000) | Percent of Total |
| Residential | 319,933 | 74.2% |
| Commercial | 85,604 | 19.9% |
| Industrial | 12,221 | 2.8% |
| Agricultural | 1,645 | 0.4% |
| Religion | 7,213 | 1.7% |
| Government | 2,286 | 0.5% |
| Education | 2,248 | 0.5% |
| **Total** | **431,150** | **100.00%** |

Global Summary for Single Return Period - Levee

# CIR-DSS Model Framework

Stella – system dynamics software

GIS + HAZUS-MH



# STELLA Analyses Step Example

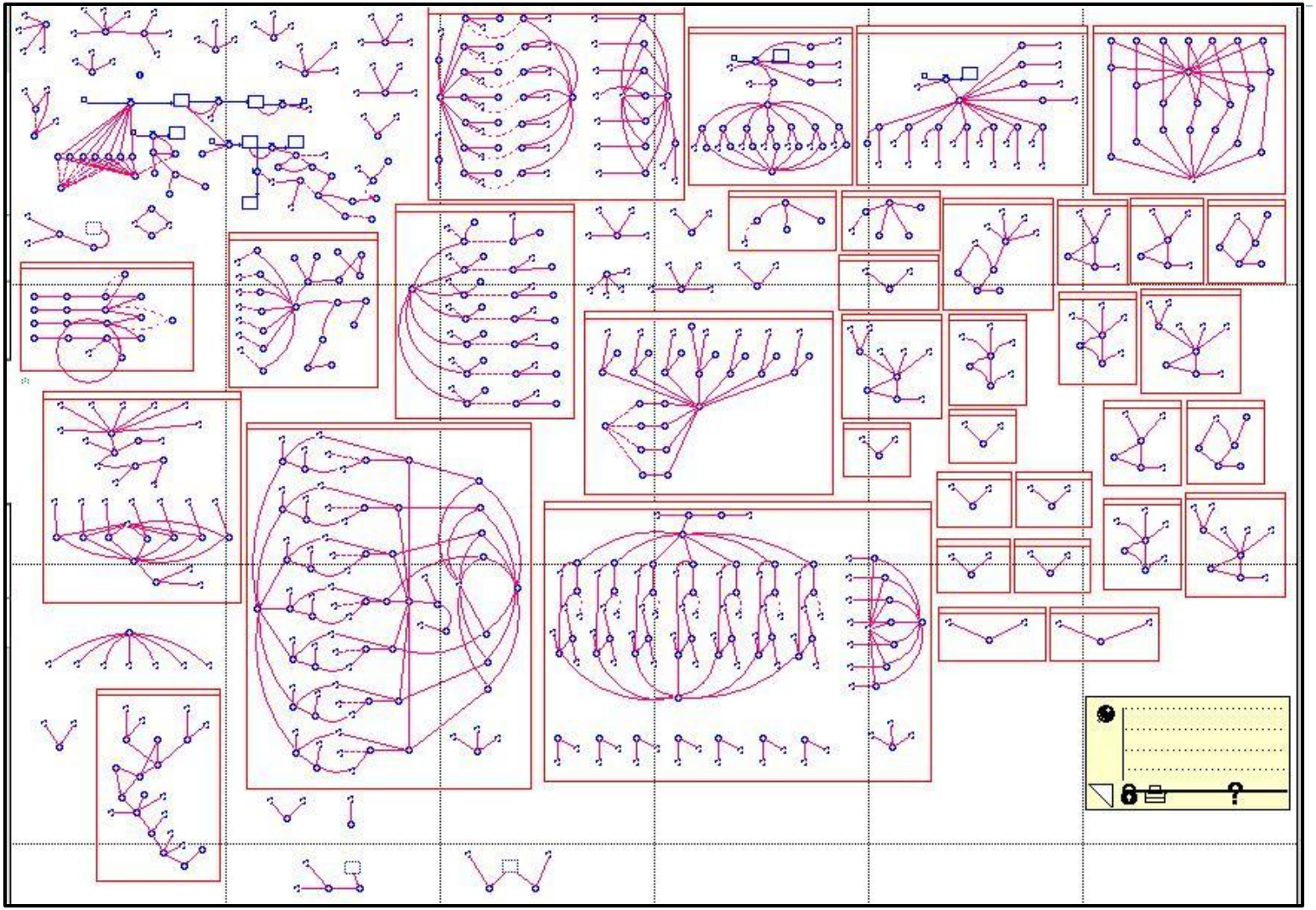
- US13 assessment values assumption:
  - Percentage based on totals from the highway network cost / US13 cost (34,60%)

| | | | |
|---|---|---|---|
| Highway Cost<br>205,419,000.69 | Vulner. Asses.<br>220,174,000.53 | Impact Asses.<br>3,000,000.00 | Damage Asses.<br>341,888.00 |
| US13 Cost<br>71,079,000.02 | Vulner. Asses.<br>76,180,387.38 | Impact Asses.<br>1,038,000.00 | Damage Asses.<br>118,293.25 |

| OBJECTID | ID | Name | Length | Traffic | Cost | NumLanes | Pavement | Capacity |
|---|---|---|---|---|---|---|---|---|
| 4 | DE000060 | Sussex Hwy | 10.83 | 0 | $32,206.20 | 4 | 0.7 | 9600 |
| 5 | DE000066 | Sussex Hwy | 0.88 | 0 | $2,628.59 | 4 | 0.7 | 9600 |
| 6 | DE000068 | Sussex Hwy | 2.54 | 0 | $7,543.82 | 4 | 0.7 | 9600 |
| 7 | DE000069 | Sussex Hwy | 0.33 | 0 | $987.21 | 4 | 0.7 | 9600 |
| 8 | DE000085 | United States Highway | 3.62 | 0 | $21,534.23 | 4 | 0.7 | 9600 |
| 21 | DE000509 | United States Highway | 0.77 | 0 | $4,555.43 | 4 | 0.7 | 9600 |
| 22 | DE000511 | United States Highway | 0.27 | 0 | $1,623.54 | 4 | 0.7 | 9600 |

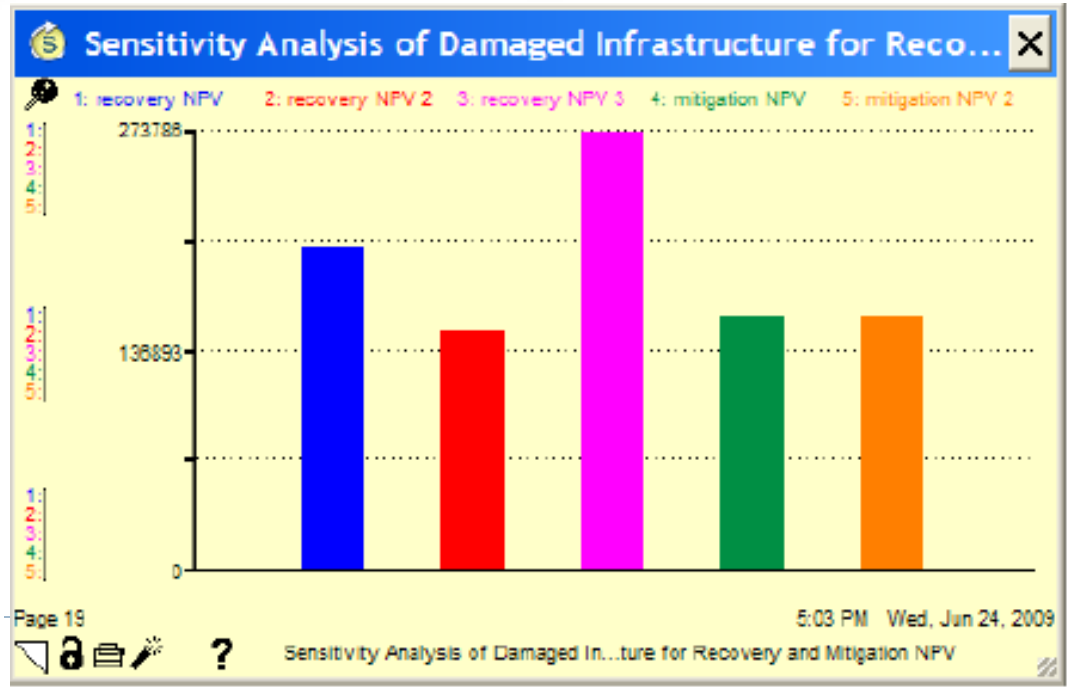
Study Area US13 Infrastructure (US$ in Thousands)

# CIR-DSS Model



- Model Map in 25% Zoom Scale with All 8 Steps

| Probability of a 100-year storm event in the case study area | Result of (Recovery projects - Mitigation projects) |
|---|---|
| 1% | -9809 recovery cost less than mitigation |
| 4% | 44065 recovery cost more than mitigation |
| 8% | 115896 recovery cost more than mitigation |




↑ frequency of the 100-year storm event

↑ worthwhile investments in mitigation projects

# Conclusion

- Complex system modeling required  many assumptions and models to capture changes over time
- Data from many sources were used as input into the model
- Comprehensive development offers insights into tradeoffs and opportunities to capture damage and costs in the context of resiliency
- Framework and model can be scalable
- Model can benefit from refinements to operationalize this approach

# Aknowledgements


- DelDOT
- Dr. Sue McNeil
- FEMA – Hazus Program and Risk Analysts Officials