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HAZUS User Group Topic Specific Call
02/15/2011

INTEGRATING HAZUS-MH DATA AND OUTPUTS TO A DECISION SUPPORT SYSTEM

BUILDING BLOCKS

- A complex problem to research
- Critical Infrastructure Resilience Decision Support System (CIR-DSS)
- Spatial Decision Support System (SDSS)
  - The Case Study
  - SDSS: GIS + HAZUS-MH analyses
  - SDSS Benefits and Limitations
- HAZUS-MH Data and Analyses Integration to CIR-DSS
  - Inventory and analyses results from HAZUS
  - Summary of processes integrating HAZUS data and analyses results
  - Case Study results summary
- Future Work with HAZUS-MH and Expected Benefits

A COMPLEX PROBLEM TO RESEARCH

- Limited Resources for Infrastructure Improvement/Repair/Replacement
  - Aging Infrastructure
  - M, R & R challenges
- Increasing Awareness of Catastrophic Failure
  - Katrina 2005
  - DelDOT/TMC – Seaford/DE 2006
- Evidence of increasing threats, e.g.
  - Terrorists (9/11/2001)
  - Storms due to climate change

CIR-DSS FRAMEWORK

- What if scenario (e.g.)

Assess Risk (Vulnerability), failure and system resilience

Actions

Assess Damage, define priorities, funds, and system improvement (alternative project)

Disaster Occurs

Mitigation

…

Response

Recovery

OUTCOMES

• e.g. local impact with few loss of lives (risk), common cause (failure), not redundant (resilience)

ACTIONS …

Results Comparison

OUTCOMES

• e.g. destroyed bridges, "medium" traffic flow, federal threshold met, bridges rebuilding

ACTIONS …

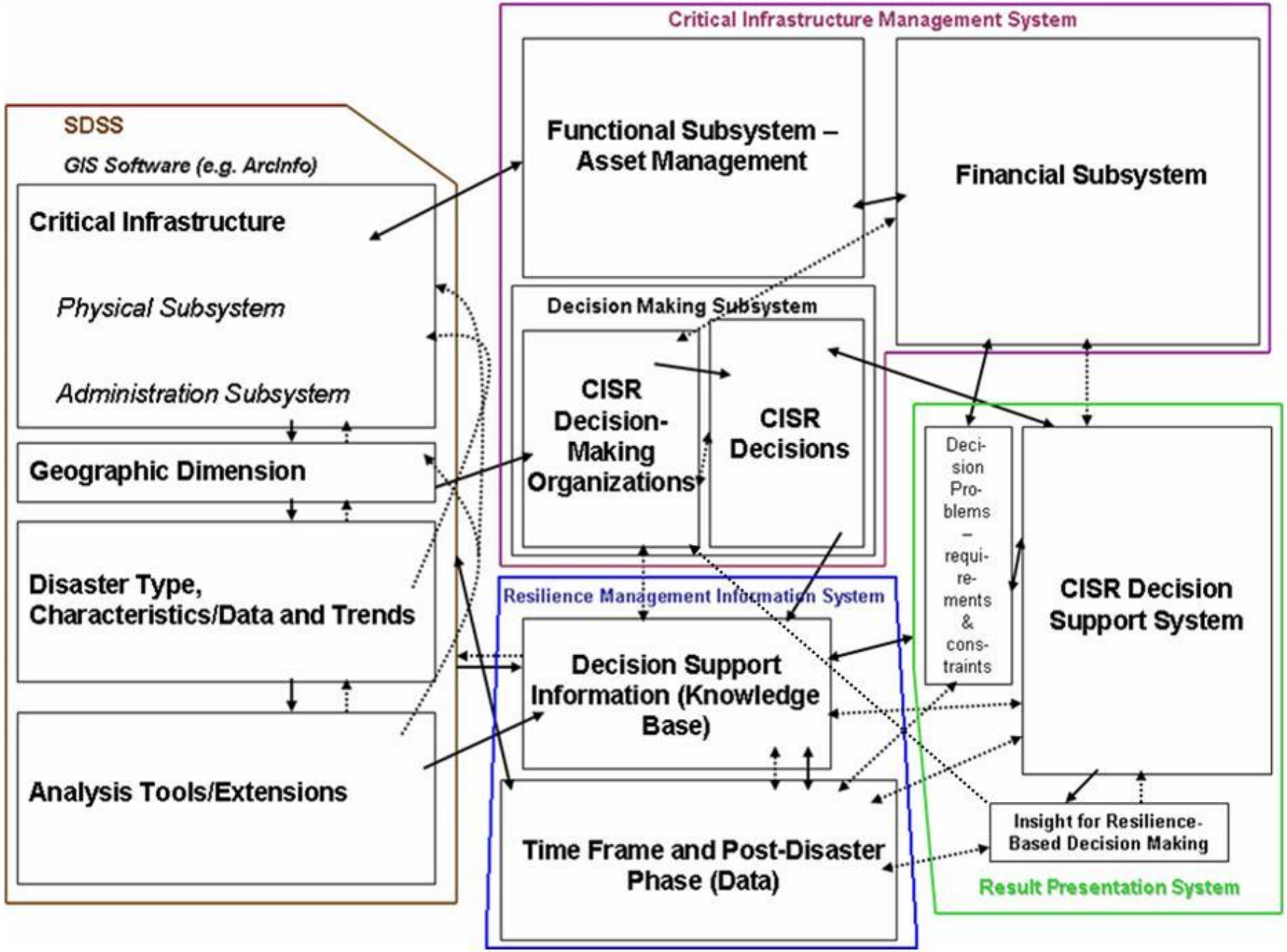
PLANS

CIS improvement

CRITICAL INFRASTRUCTURE DECISION SUPPORT SYSTEM (CIR-DSS)

- Objective: *To improve the resilience of critical infrastructure systems*
  - Decision variables – To undertake mitigation
  - Other variables
- Resilience metrics: capacity, pavement condition, level of service
- Net present value of costs and costs avoided
  - Recovery and/versus Mitigation

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



DATA AND ANALYSIS FOR DECISION MAKING

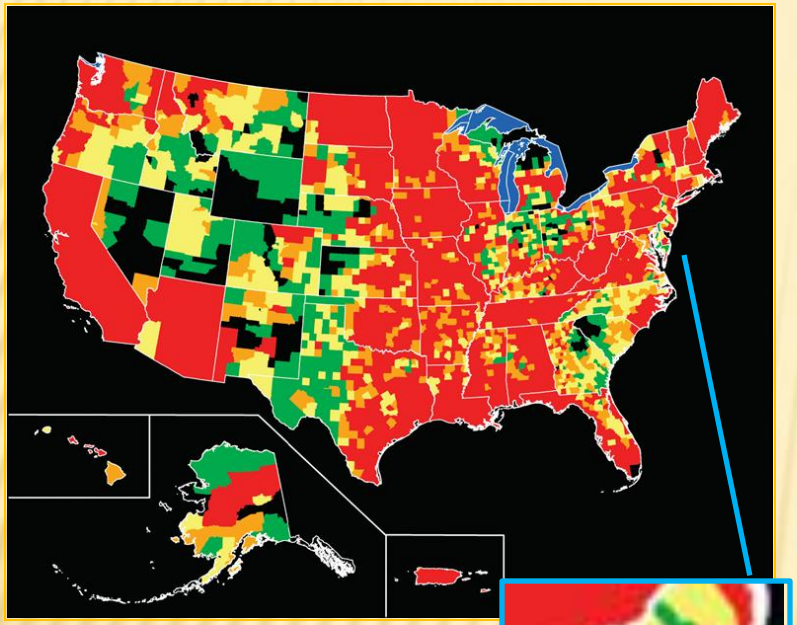
DATA NEEDS (LOCAL)

- Geographic: hydrology, elevation
- Hazard: weather, disaster history records and trends
- Infrastructure: roads, bridges
- Financial: cost of infrastructure
- Institutional/cultural: decision-makers, policies and funding
- Infrastructure life-cycle
- Expected infrastructure life-cycle with mitigation

ANALYSES/ASSESSMENTS

- Vulnerability, Risk/Impact and Damage Analysis
- Pre-, During and Post-Event Assessment – infrastructure condition and performance
- Mitigation Strategies (definition)
- Pre-, During and Post-Event Resilience Assessment
- Cost-Benefit Analysis
- Recovery and Mitigation Strategies Comparison
- Scenarios Test/Evaluation

CASE STUDY: DELAWARE FLOODING – JUNE 2006



(USGS) Federal Disaster Declarations 1965-2003: Sussex County – DE

- 1 FDD
- 2 FDD
- 3 FDD
- 4 or more FDD

DATA SOURCES AND TOOLS

MAIN DATA SOURCES

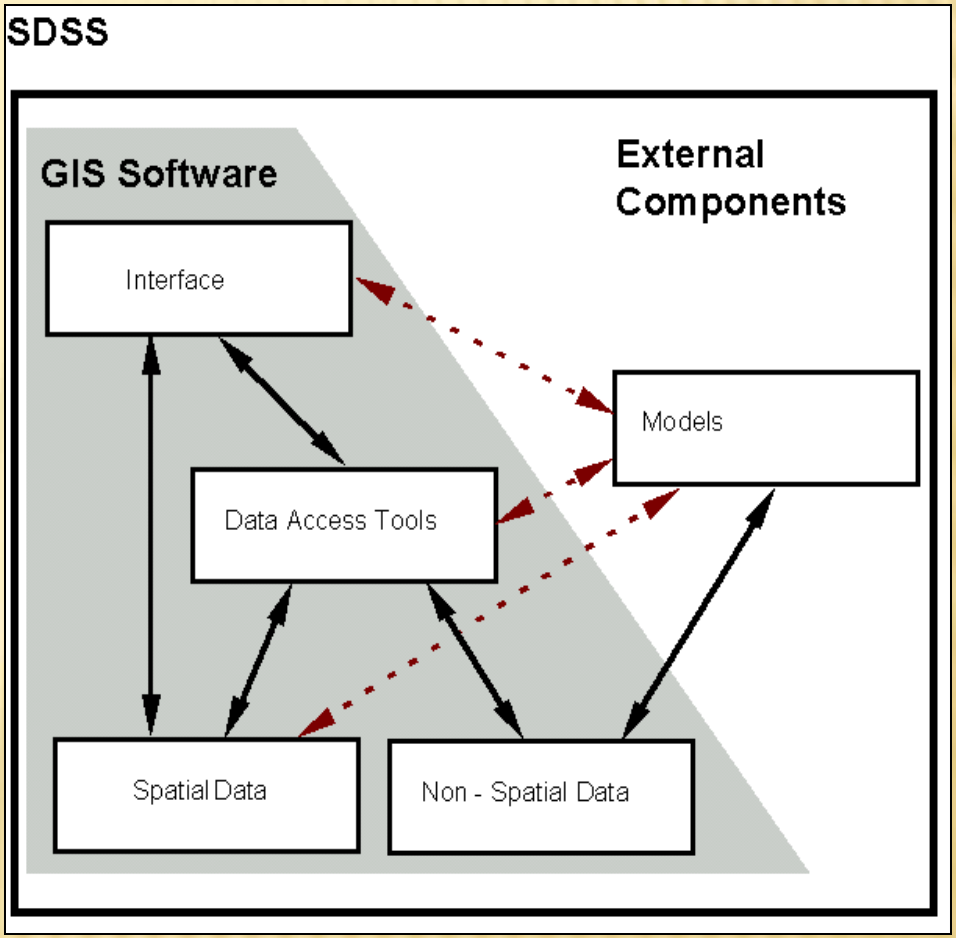
- DelDOT Transportation Management Center: pictures, traffic and detours reports (DelDOT Officials)
- DelDOT Bridge Management: bridge data (GIS), reports of local damaged bridges, digital maps (pdf) (DelDOT Officials)
- DelDOT (others): roads , State boundaries
- Spat Lab (U.D.): Elevation Data
- DataMIL: roads, rivers, hydrology, municipal boundaries
- Delaware Environmental Observing System (DEOS): radar derived rainfall
- HAZUS-MH MR3 inventory
- Literature

TOOLS

- GIS ArcInfo and extensions
  - Spatial Analyst
  - Network Analyst
- Excel
- HAZUS-MH MR3
  - Flood Model
  - Analysis Level 1
- STELLA®

SPATIAL DECISION SUPPORT SYSTEM

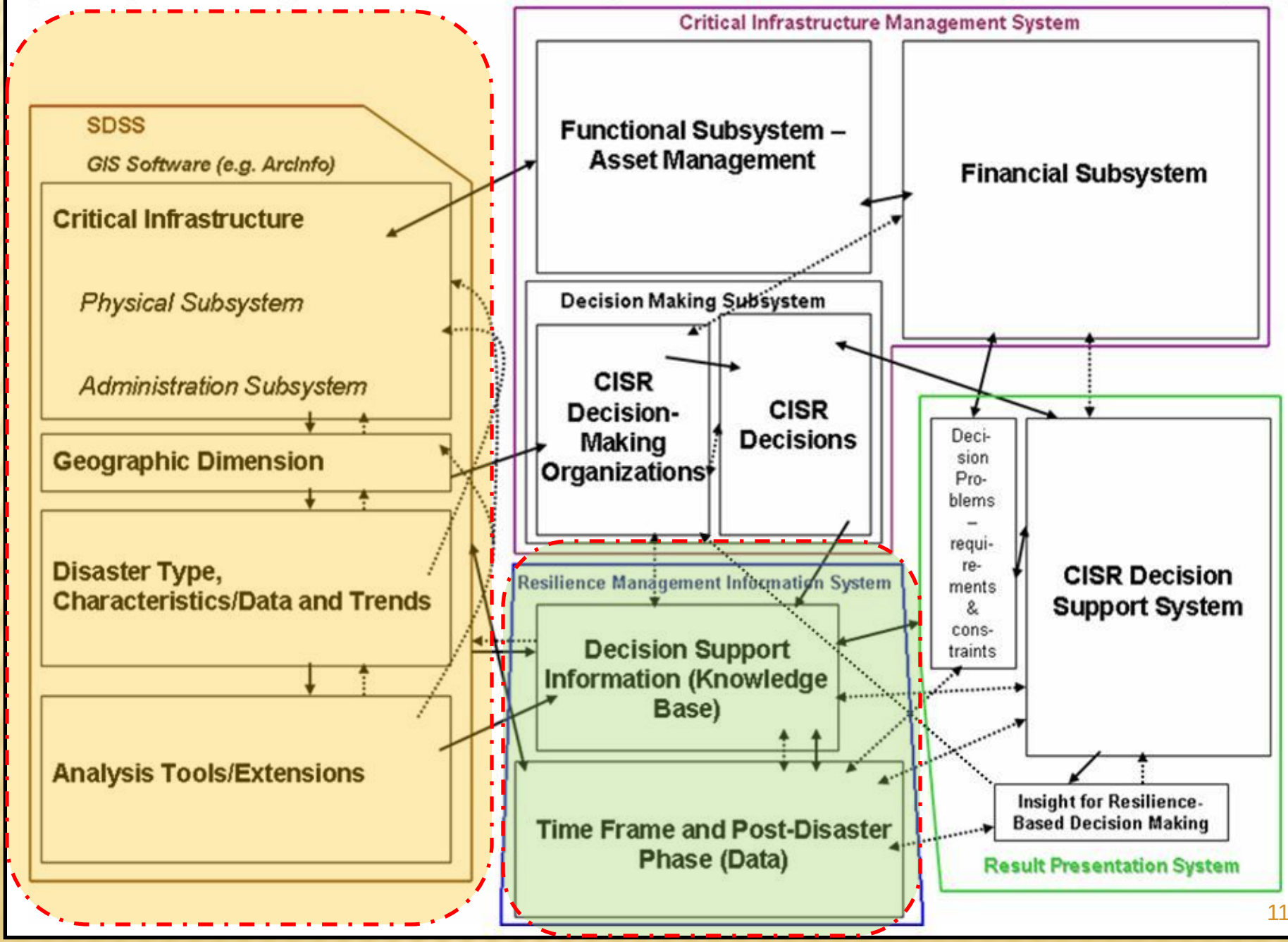
- Specific locations issues – spatial data and local infrastructure
- Complex problems structuring to support decision-making processes
- Does not replace users' decision-making
- Easiest data and information sharing/integration (further analyses)
- Analysis outputs help support decisions for infrastructure repair, improvement and mitigation



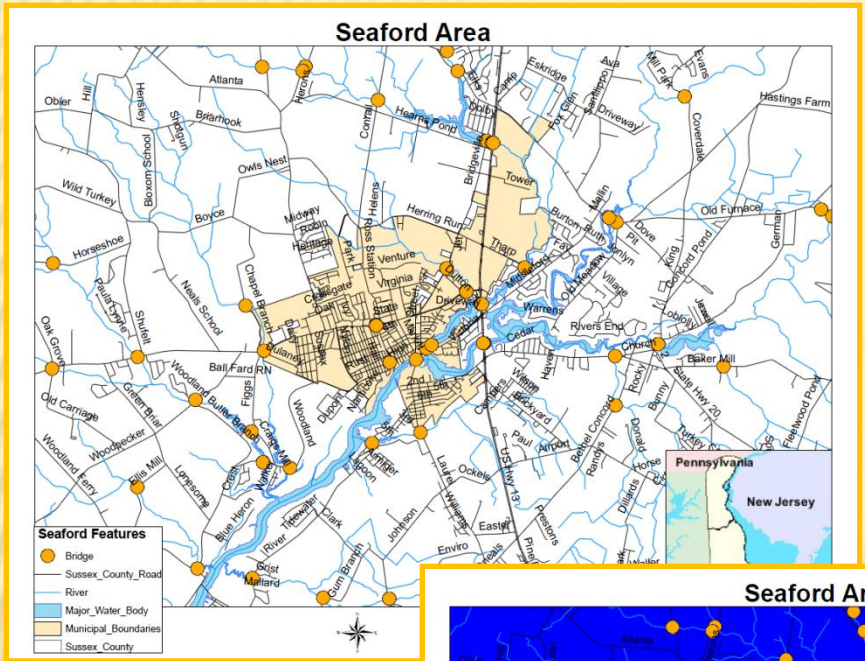
GIS (generator) & Transportation

P. Keenan (2004)

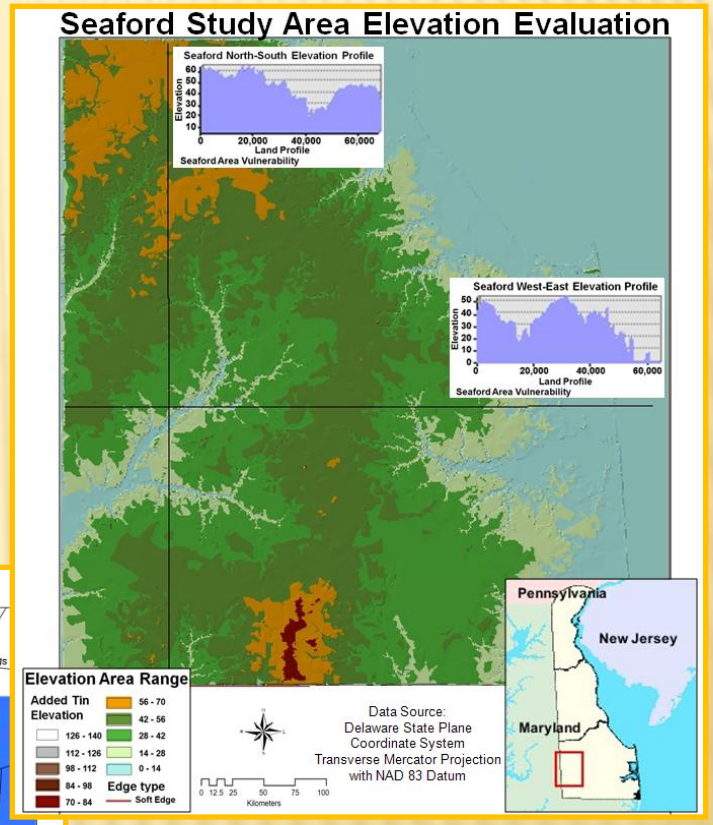
System Dynamics Diagram of Decision Support System for Critical Infrastructure System Resilience (CISR)



GIS ANALYSES FOR CIR-DSS

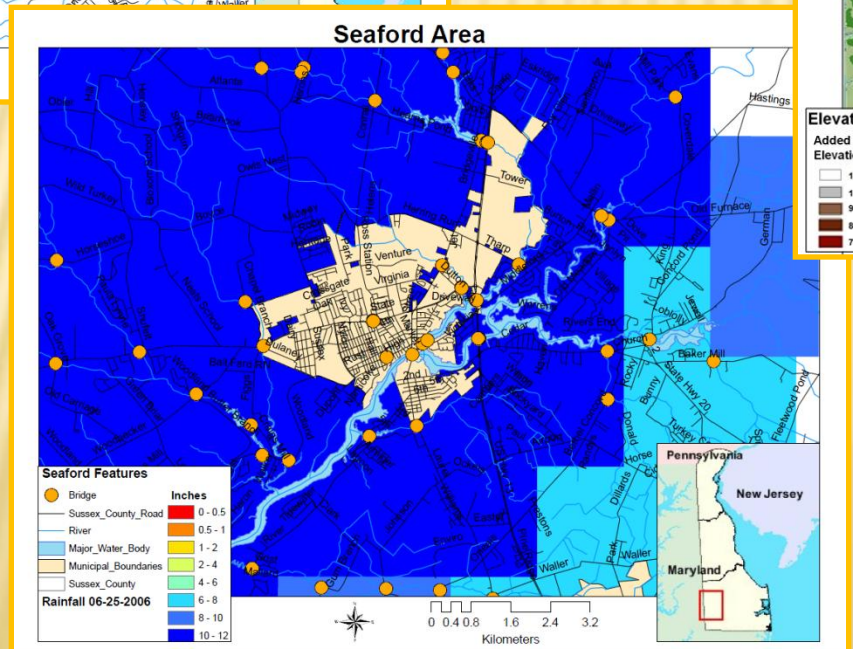


Study Area



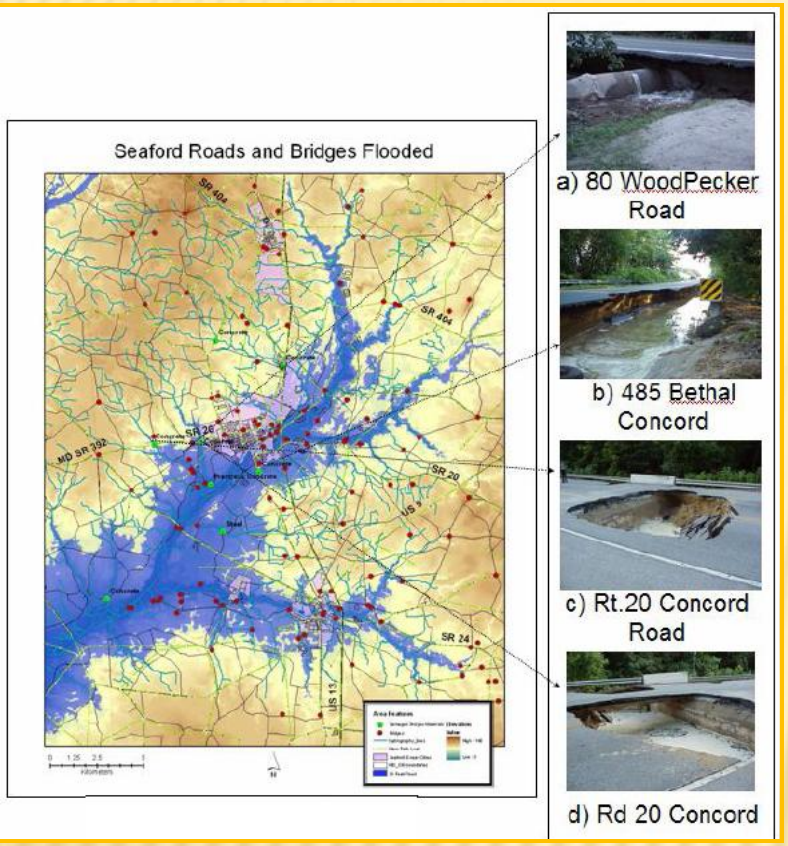
Elevation

Rain Fall
06/25/2010

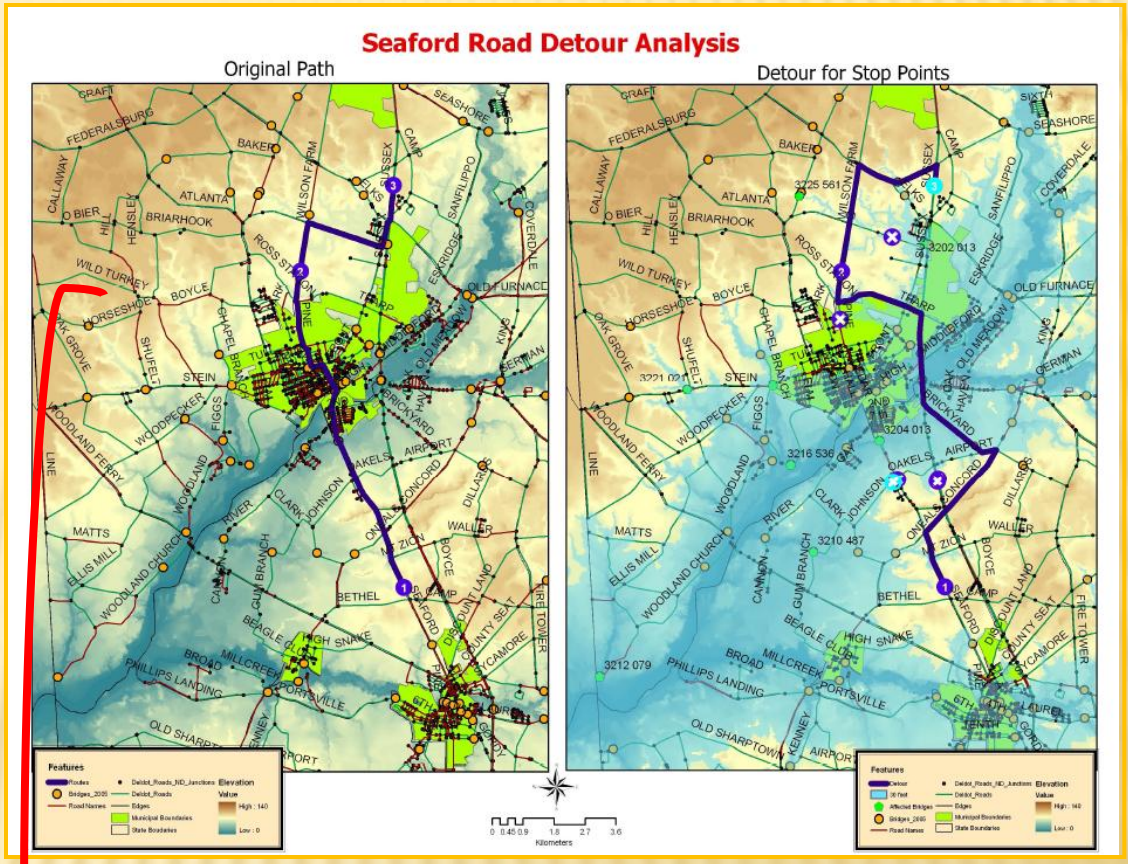


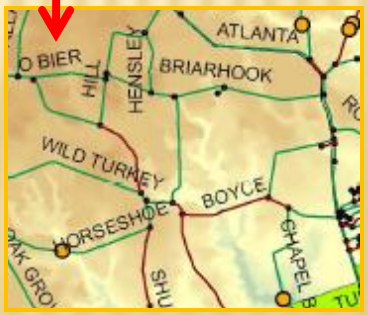
Vulnerability:
exposure
↓
loss/damage

GIS ANALYSES FOR CIR-DSS



Location of Damaged Infrastructure in the Seaford Flooded Area





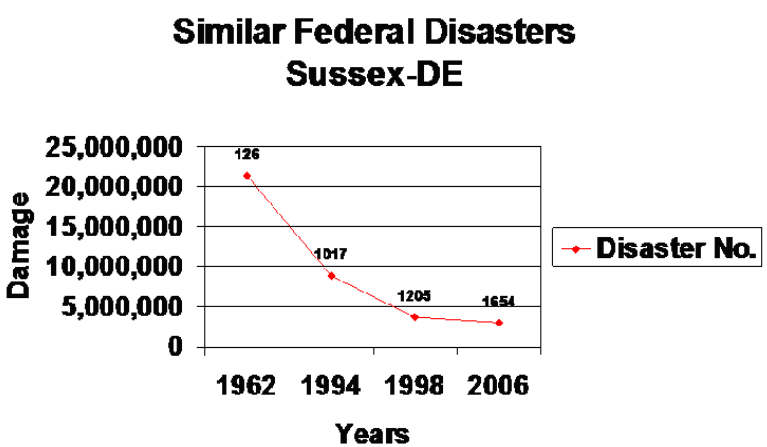
Seaford Road Network and Detours Analysis (2006)

HAZUS-MH ANALYSES FOR CIR-DSS

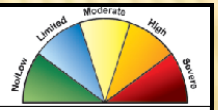
Organizing principle

Potential Hazard	Hazard of Interest	Description	Source of Information
Riverine Flood	Riverine Flood	On 6/25/06 there was flood (100-year) due to a huge amount of rainfall (12 inches in some areas) which caused serious damage and destruction to roads and bridges infrastructures (49 road network points in Sussex County). the 49 identified points consisted on: 28 roads (segments) with high water, 6 road closures, 2 washed out bridges, 12 road failures, 1 sink hole. Later inspections showed 9 bridges with main problems (i.e. replace structures, flow-in fill to restore stream bed under the bridge). Bridges minor problems: repairs of erosion embankments, and fill and riprap replacement. It flooded to an elevation of 30 feet high. State of Emergency declared at 2:30 PM – 6/26/2006. Seaford is located at 38°38?41? N, 75°36?58? W (38.644654, -75.616107).	DelDOT – TMC and other Sectors, DEOS, DataMil, SpatLab

Events	Event Number	Year	Damage (US$ Million)
1	126	1962	21,391,487
2	1017	1994	8,907,958
3	1205	1998	3,721,100
4	1654	2006	3,000,000



HAZARD: Flood – Seaford-DE



Summary of Risk Factors	
Rank of factors for local profile	Period of occurrence: June 25, 2006
Severity score: high	Probability of event:1% (100-year flood)
History: (similar events) 40	Warning time: 1 to 2 days very certain, 10 days trends.
Vulnerability: (Guessing) 75 Maximum Threat: 80	Major contributor(s): Low elevation, East coast State, Major river Risk of injury? Yes, and risk of death
Probability: 80	Potential for facilities shutdown? Yes. Major roads for 30 days or more
Total score: 275	Percent of affected properties that may be destroyed or suffer major damage: guessing 15% of local road network

FLOOD (HAZARD) PROFILE (DATA)

Background and Local Conditions

Delaware has moderate risk for snowfall, has more than just a few but not frequent risk for thunderstorms, has moderate to low risk for wind, and some risk for hurricanes. The overall composite risk is moderate. Sussex County in Delaware stands together the other U.S. areas with the most number of disaster declarations given. Seaford, in particular, is located at 38°38?41? N, 75°36?58? W (38.644654, -75.616107), Southwest of Delaware. This area has low elevation, prone to flooding. Seaford's weather has a mild subtropical climate consisting of hot, humid summers and mild winters, moderated by the Atlantic Ocean. Common to have flooding event occurring also in the Maryland neighboring area, having to share solutions for traffic. Local transportation infrastructure usually in good and fair conditions, propitiating the traffic Level of Service A to C. Area prone to be heavily impacted as the ice on the Poles melts because of Climate Change – Global Warming.

Historic Frequency and Probability of Occurrence

Flooding is the most common disaster type in the U.S. and for Sussex County. Considering similar events since the 1960's registered as a Federal Disaster Declaration, the number of events are 4. Earlier events lack easy source for getting the information. Table 5 shows the events and their related damages. Figure 5 shows the related graph considering the time trend among Federal Disaster Declarations (p.s. other different and minor events took place in other years).

Severity

Considering other the U.S. areas, Delaware is considered a moderate risk area. However, Sussex in Delaware is the area that most suffers disasters, which matches with other areas that received about the same amount of Federal Disaster Declarations (USGS). In this sense the risk for Flooding can be considered high. According to the flooded area map developed in ArcGIS and studies about global warming, events like the 100-year storm and other more rare events (i.e. 500-year storm) can increase in frequency and strength.

Historic Losses and Impacts

Great damage has occurred to transportation infrastructure, crops, buildings, and some loss of lives (NOAA). The 2006 flood impacts list for Seaford area includes:

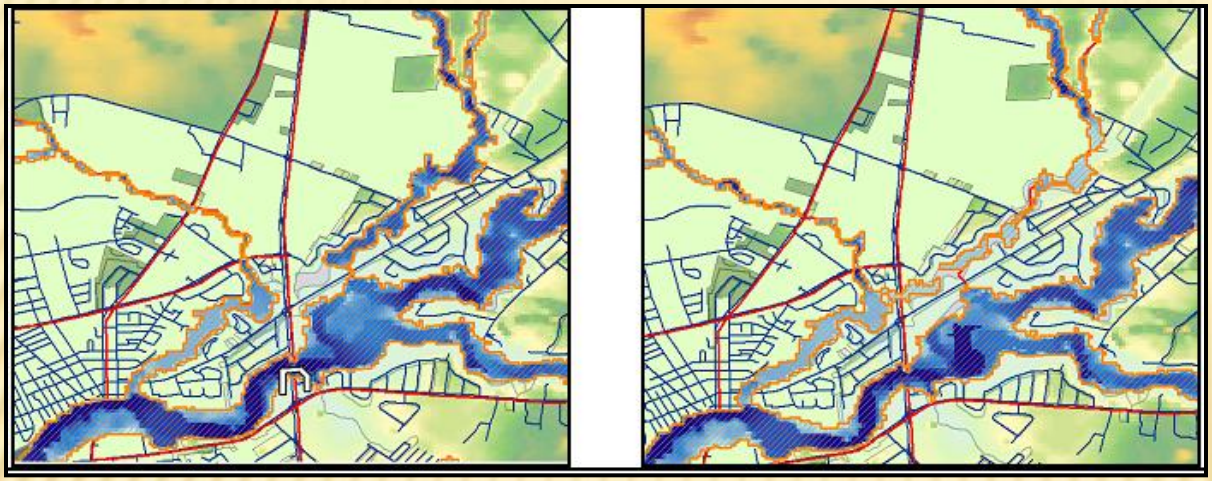
- damage to the police department situated in the city of Seaford, and the Seaford School District parking lot,
- barricades and high water signs emergency repairs and placement in the Town of Georgetown, totalizing $1,905,
- traffic control and other security measures of the Delaware State Police, totalizing $9,822,
- road and bridge repair under the responsibility of the Delaware Department of Transportation, totalizing $341,888, and
- road repair work at the Delaware Technical and Community College, totalizing $13,340.

Designated Hazard Areas

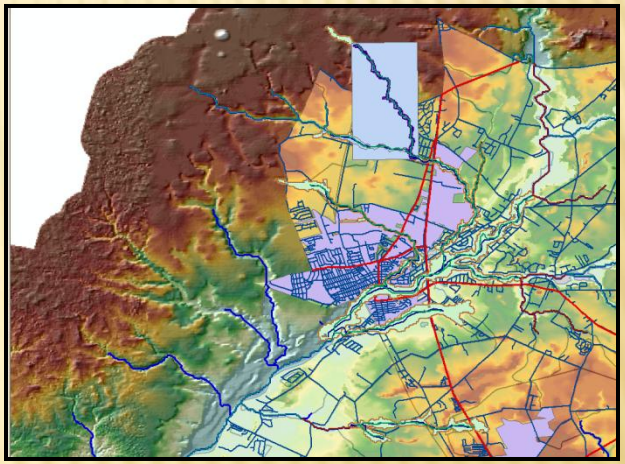
The elevation profile map and the flooded area map developed earlier using ArcInfo show the areas most prone to flooding. They were built prior to the base map developed in HAZUS-MH. The use of HAZUS-MH software is to do a deeper analysis of the problem.

HAZUS-MH ANALYSES FOR CIR-DSS

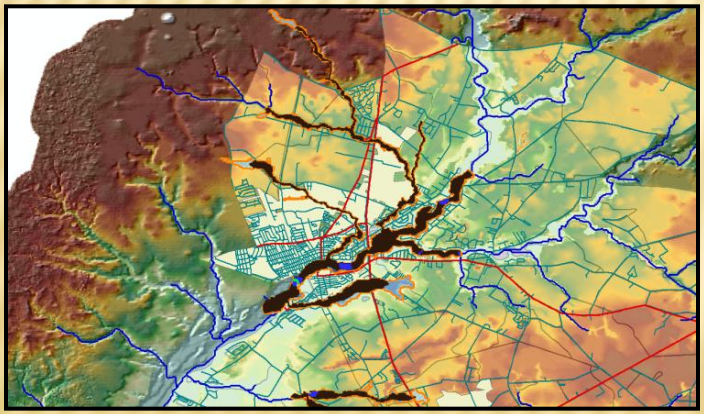
Analytical capability



"What if" Levee Protection Scenario



"What if" Flow Regulation Scenario



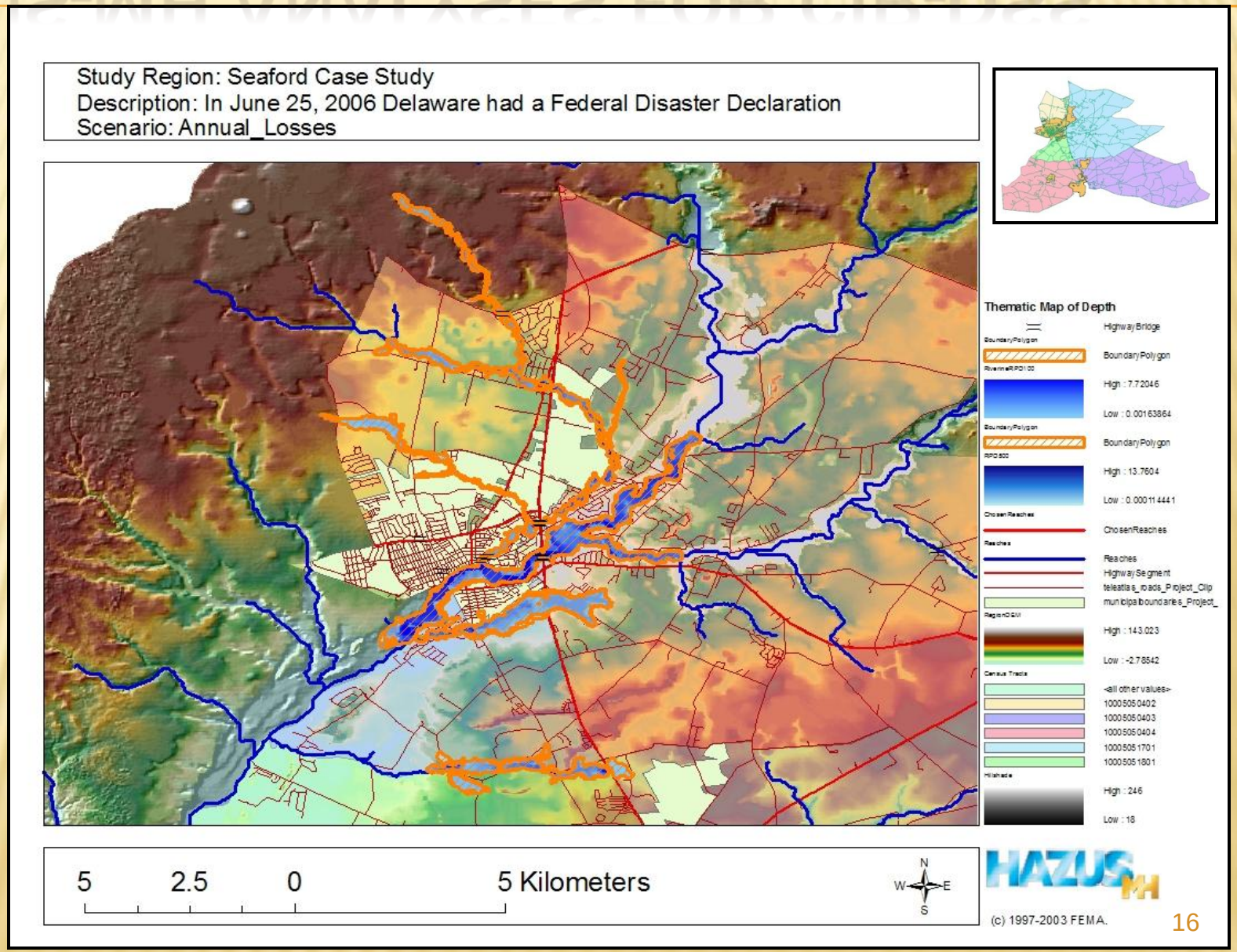
Floodwater Velocity Estimation Scenario

Damage related to US13 in Sussex County

HAZUS-MH ANALYSES FOR CIR-DSS

Seaford Area Annual Losses Map of Depth

10-year-flood-map



SDSS BENEFITS AND LIMITATIONS

BENEFITS

PROBLEM DIAGNOSIS:

GIS + HAZUS-MH

REPLICATION OF FIELD ACTIVITIES

E.g. detours

HAZUS-MH MITIGATION ALTERNATIVES WITH COSTS

warning system, levee, policy, "what if scenarios" (e.g. river reaches and water speed), flooded area

LIMITATIONS (HAZUS-MH)

ANALYSIS FOCUSES ON LIMITED AREA

LIMITED TOOLS TO ANALYZE TRANSPORTATION INFRASTRUCTURE (T.I.)

- Road segmentation not official
- Vehicle exposure does not consider flow, just Census
- Exposure same as vulnerability ?
- No dynamic modeling – T.I. resilience changes
- No financial trade-off tools for solutions evaluation

WHAT HAVE WE LEARNED ?

- Many rich data sources to support decision making
- Tools

HAZUS-MH MR3

- Useful
- Limited
- Non-trivial
- Complementary

GIS

- Helps communication
- Provides insight

<u>Analyses results/data integration with Management Information System</u>

- transportation inventory (roads – segments values)
- transportation exposure/vulnerability value
- warning system value (10%)
- connectivity mitigation insight

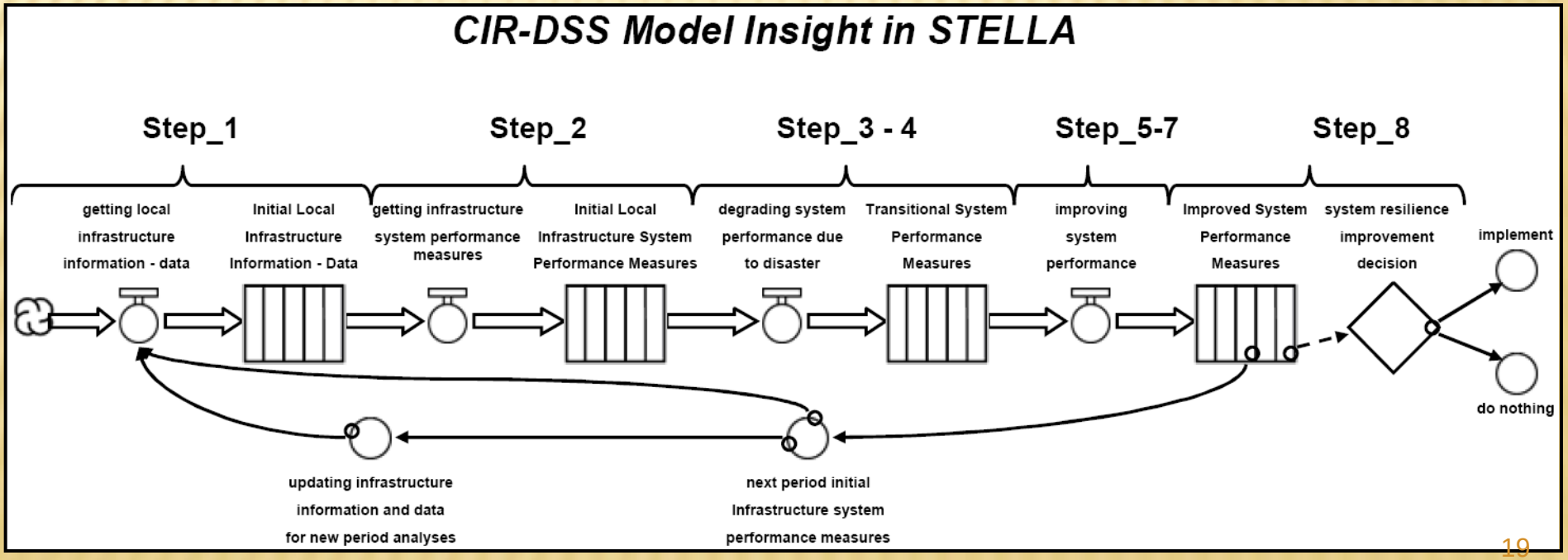
CIR-DSS MODEL FRAMEWORK

GIS

+

HAZUS-MH

Resilience Metrics: Key Performance Indicators



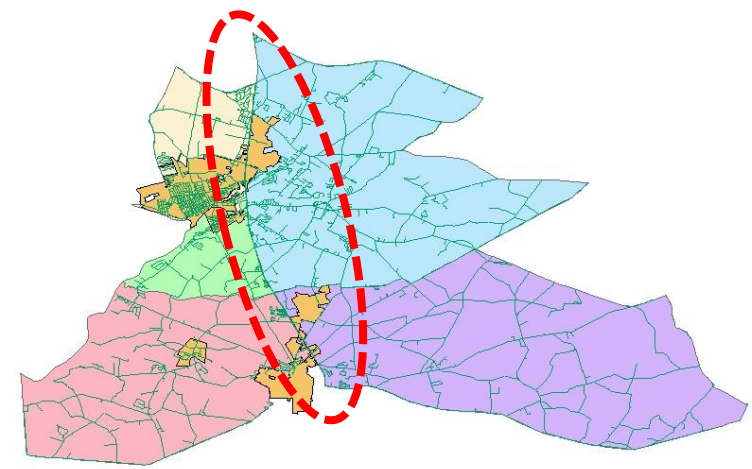
HAZUS-MH INVENTORY

Highway | Railway | Light Rail | Bus | Port | Ferry | Airport

Table Type:

Highway Segments

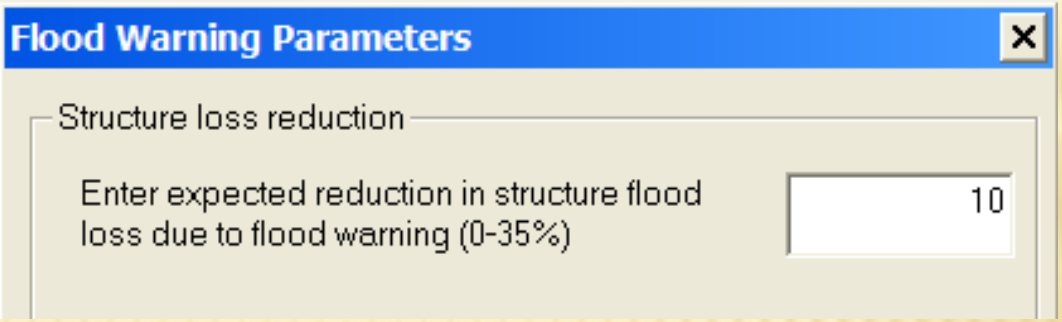
???



Highway

	ID	Name	Owner	SegmentClass	Description	Length	Traffic	Cost
1	DE000043	Front St		HDFLT	Default Road	1.31	0	$3,883.4
2	DE000045	Georgetown Rd		HDFLT	Default Road	0.98	0	$2,925.9
3	DE000046	Georgetown Rd		HDFLT	Default Road	0.37	0	$1,109.1
4	DE000060	Sussex Hwy		HDFLT	Default Road	10.83	0	$32,206.2
5	DE000066	Sussex Hwy		HDFLT	Default Road	0.88	0	$2,628.5
6	DE000068	Sussex Hwy		HDFLT	Default Road	2.54	0	$7,543.8
7	DE000069	Sussex Hwy		HDFLT	Default Road	0.33	0	$987.2
8	DE000085	United States Highwa		HDFLT	Default Road	3.62	0	$21,534.2
9	DE000138	Bowdens Garage Rc		HDFLT	Default Road	2.88	0	$8,572.6
10	DE000139	Bowdens Garage Rc		HDFLT	Default Road	1.04	0	$3,095.4
11	DE000144	Bridgeville Hwy		HDFLT	Default Road	3.66	0	$10,877.1
12	DE000212	Concord Rd		HDFLT	Default Road	10.98	0	$32,643.3
13	DE000215	County Seat Hwy		HDFLT	Default Road	4.74	0	$14,103.4
14	DE000217	County Seat Hwy		HDFLT	Default Road	0.55	0	$1,635.4
15	DE000255	High St		HDFLT	Default Road	0.94	0	$2,780.2
16	DE000355	Market St		HDFLT	Default Road	0.13	0	$377.6
17	DE000378	Norman Eskridge Hw		HDFLT	Default Road	1.33	0	$3,960.7
18	DE000389	Old Bridgeville Hwy		HDFLT	Default Road	0.91	0	$2,691.0
19	DE000399	Poplar St		HDFLT	Default Road	0.59	0	$1,751.4
20	DE000444	Seashore Hwy		HDFLT	Default Road	0.91	0	$2,702.9
21	DE000509	United States Highwa		HDFLT	Default Road	0.77	0	$4,555.4
22	DE000511	United States Highwa		HDFLT	Default Road	0.27	0	$1,623.5
23	DE000515	United States Highwa		HDFLT	Default Road	0.19	0	$1,153.7
24	DE000516	United States Highwa		HDFLT	Default Road	0.37	0	$2,200.4
25	DE000520	United States Highwa		HDFLT	Default Road	1.99	0	$11,852.4

HAZUS-MH ELEMENTS



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**

Table 18 Summarized Mitigation Measures based on HAZUS-MH and History for Transportation Infrastructure - Roads

Mitigation Activities	Output	Completed Items
Preliminary options	Regulatory measures: • reinforcement of construction codes (i.e., elevate degree of protection for rehabilitation, elevate-road design to flood level, engineering design improvement, site access points, roadway/pedestrian paths) • incentives for mitigation measures implementation, flow regulation • education measures (public awareness) • natural resource protection measure (preserve and restore natural systems) Rehabilitation measures (cost, importance, vulnerability?): • structural and non-structural modifications of road segments (i.e. increase structural resistance – impact load, retrofit roadways, enlarge road shoulders) • improve highways lights and signs • remove, relocate, and/or to elevate roads/road segments to meet new performance objectives Protective and control measures • floodwalls, levee, warning system (i.e., based on weather forecast) • protective vegetation belts • review and build connections	HAZUS-MH mitigation insights √
Review of options	Regulatory measures: • reinforcement of construction codes (i.e., elevate degree of protection for rehabilitation, elevate-road design to flood level, engineering design improvement, site access points, roadway/pedestrian paths) Rehabilitation measures (cost, importance, vulnerability?): • structural and non-structural modifications of road segments (i.e. increase structural resistance – impact load, retrofit roadways, enlarge road shoulders), • improve highways lights and signs • remove, relocate, and/or to elevate roads/road segments to meet new performance objectives Protective and control measures • floodwalls, warning system (i.e., based on weather forecast) • review and build connections	STAPLEE √
Final list of options	"Impossible with current HAZUS-MH functions, for exception for the adoption of warning system already included in current results." Although the listed mitigation options could all be analyzed for US13, these options are later carefully reviewed to reach an improved resilience of transportation system goal. HAZUS-MH does not discuss resilience.	To be further explored in STELLA
Verification of options	No conflicting measures to mitigate hazard impact.	√

CRITERIA FOR EVALUATING MITIGATION MEASURES

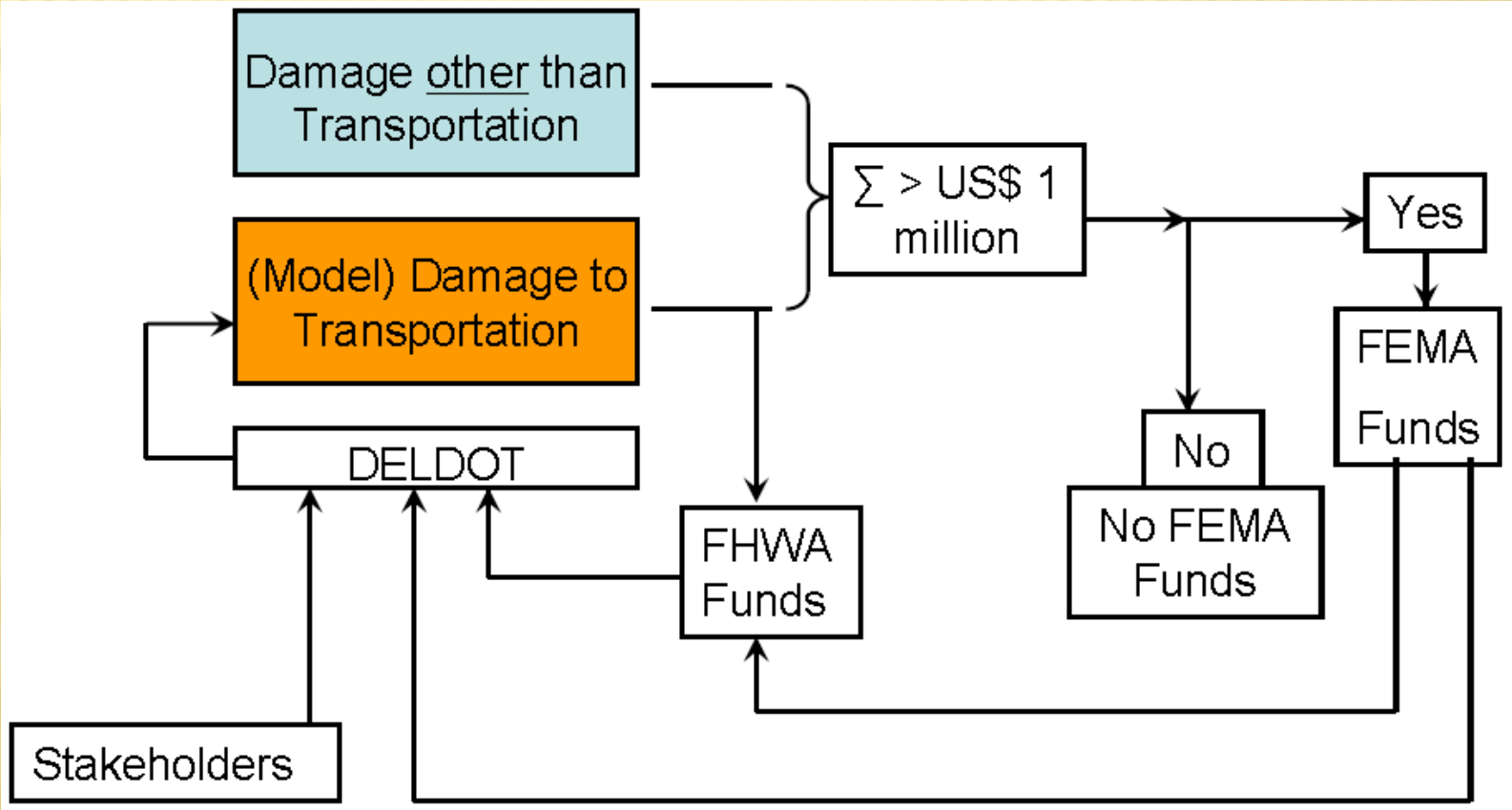
STAPLEE Criteria	S Social		T Technical			A Administrative			P Political			L Legal			E Economic				E Environment				
Considerations → For Alternative Actions ↓	Community Acceptance	Effect on Population Segment	Technical Feasibility	Long-term Solution	Secondary Impacts	Staffing	Funding Allocated	Maintenance/Operations	Political Support	Local Champion	Public Support	State Authority	Existing Local Authority	Potential Legal Challenge	Benefit of Action	Cost of Action	Contributes to Economic Goals	Outside Funding Required	Effect on Land/Water	Effect on Endangered Species	Effect on HAZMAT Sites	Consistent w/ Community Environmental Goals	Consistent w/ Federal Laws

Comments:

Source: (Rock Island County 2008)

INTEGRATING HAZUS-MH DATA

- Building the Model - beginning
  - Variables not used in GIS or HAZUS-MH for resilience, functional and financial analysis
    - infrastructure system inventory, condition and performance measures, decision makers and decisions



MAIN ASSESSMENTS

Damage* and Vulnerability Assessments

US$ 1 million threshold policy

Impact/Risk Assessment

Depends on Infrastructure overall performance
Note: 1 element in HAZUS risk assess.

Resilience Assessment

Decision makers/ Decisions (construction projects)

- Policies recovery/ mitigation
- More resilient system or not

Framework Application		Diagram Color and Information Flow Arrow	Case Study Components (Examples)
Steps	Description		
1	a) Choose a CIS b) Choose Place and Event c) Identify Decision Organizations		Roads and Bridges; Seaford-DE, Hazard-flood; DEMA, DelDOT
2	a) Problem Diagnosis b) (HAZUS-MH) c) Initial mitigation insights focusing in system resilience		Infrastructure condition before event and hazard; infrast. cond. after event (with/without mitigation); HAZUS assessm.: vulnerability, impact, damage
3	Pre/post-event comparison		Performance, Administrative Structure, LCC
4	Financial		Resources required to support normal operations
5	Impact and Resource		Impact plus resource assessment needed to recover and mitigate damaged CTI
6	Identify Institutional Constraints – decision makers and factors to restore CIS		Other constraints – consider CTIS and enhanced system (resilience)
7	Evaluation, review, and adjustment of analysis (making more resilient systems)		Evaluate/iterate analysis (inputs required by decision makers – step number six)
8	Evaluation/communication of results		Report result – benefits, effectiveness, consequence, methodology, complementary data, options considered, alterations, strategy options (improve CTIS resilience)

DATA ADJUSTMENTS

OBJECTID	ID	Name	Length	Traffic	Cost	NumLanes	Pavement	Capacity
4	DE000060	Sussex Hwy	10.83	0	$32,206.20	4	0.7	7600
5	DE000066	Sussex Hwy	0.88	0	$2,628.59	4	0.7	7600
6	DE000068	Sussex Hwy	2.54	0	$7,543.82	4	0.7	7600
7	DE000069	Sussex Hwy	0.33	0	$987.21	4	0.7	7600
8	DE000085	United States Highway	3.62	0	$21,534.23	4	0.7	7600
21	DE000509	United States Highway	0.77	0	$4,555.43	4	0.7	7600
22	DE000511	United States Highway	0.27	0	$1,623.54	4	0.7	7600

- US13 - 4 lanes x 1,900 passenger cars per lane per hour = 7,600
- Carrying/service capacity classification - good (5,070 - 7,600), fair (2,530 – 5,070), poor (1 – 2,530), or none (0)
- “Pavement Condition Index” (PCI) - good prior the disaster = 0.7 (scale 0 to 100)
- Length decimal degrees converted to feet (used projection tool in GIS)

ASSUMPTIONS AND APPROACHES

- Transportation mitigation projects: 100% effective (FEMA specifies 80%)
- Frequency of similar events – which/when recovery or mitigation strategies should be adopted
- "Functional Downtime" for roads/bridges closures determine direct economic impacts
  - Number of days for repair and reopening for traffic
  - Average delay/ detour time for motorist (loss of time)
  - FEMA's standard value for loss of time = US$32.23
    - benefits of projects in terms of avoided delay
- Hazard mitigation projects for roads/bridges include average daily vehicle count.

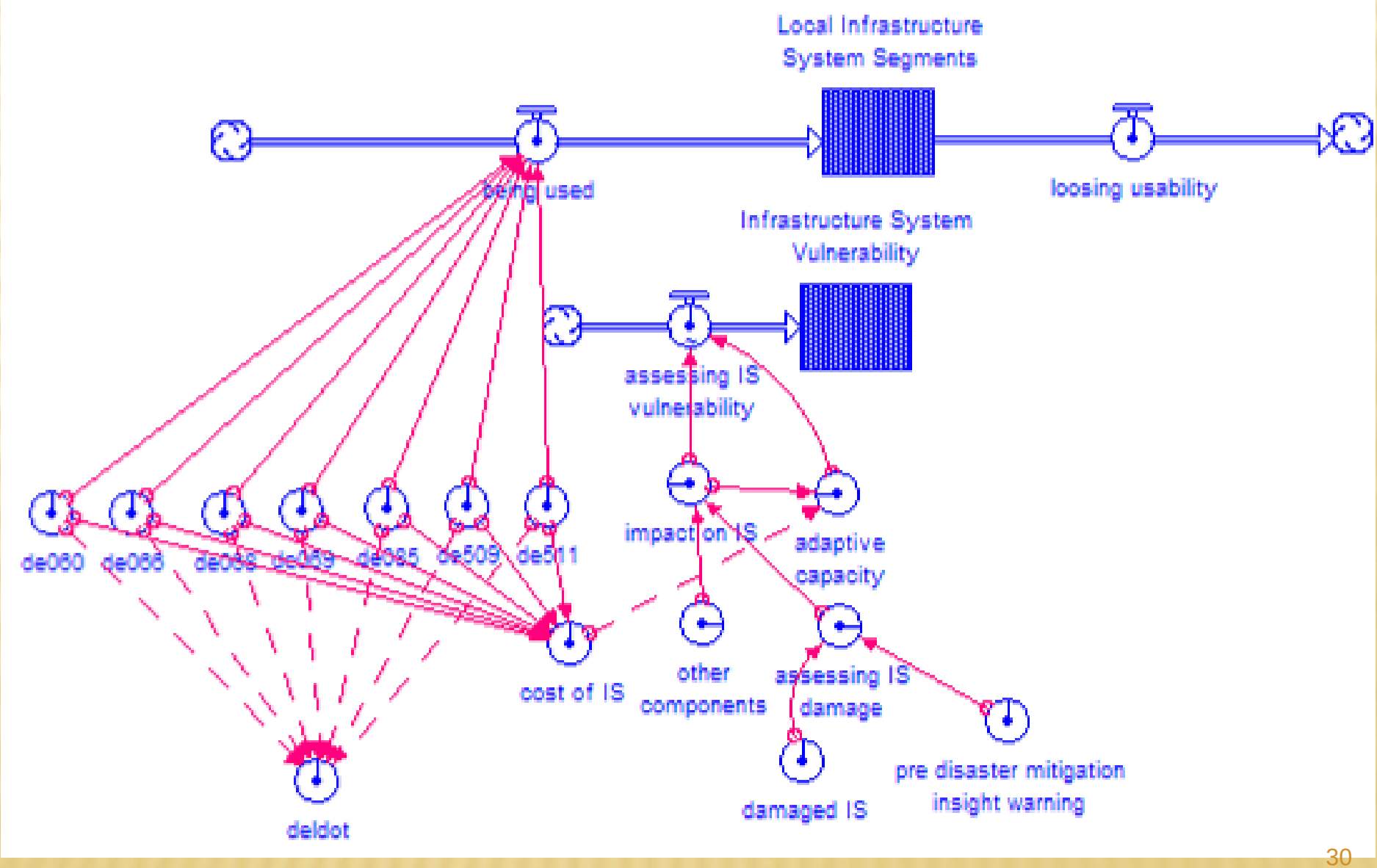
FEMA BCA - BCR

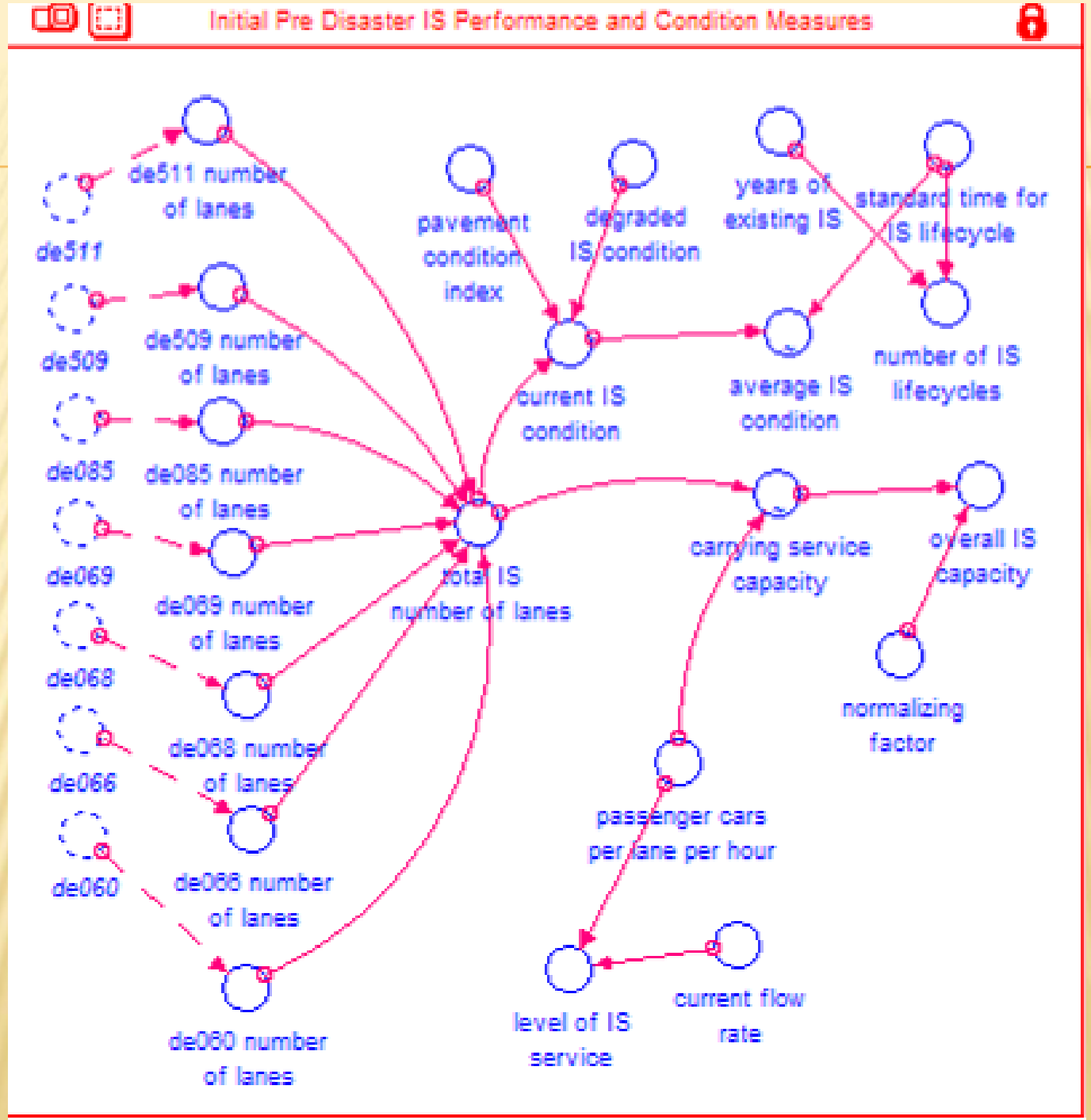
Projects BCR determine project effectiveness (requested format from FEMA)

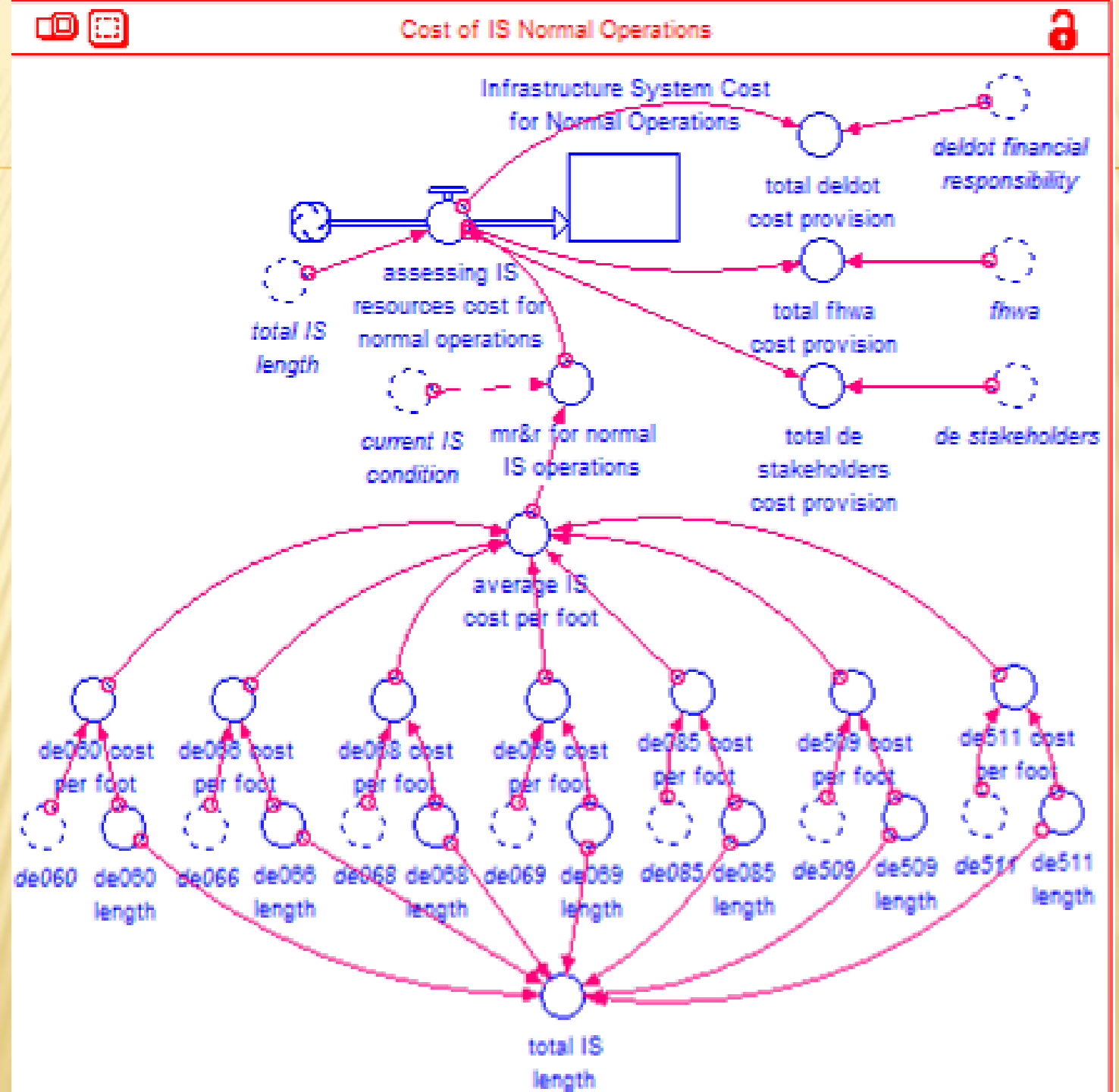
Mitigation Projects Categories of Benefits for Roads and Bridges

	Categories of Damages/Benefits	Notes for Mitigation Projects
1	Physical Damages	Consider vulnerability according to flooding.
2a	Loss-of-Function Impacts (e.g. displacement costs)	Not applicable (road and bridge cannot be displaced to temporary other locations).
2b	Loss-of-Function Impacts Other (e.g. loss of service - economic impact)	Road/bridge closures - generally the largest category of benefits.
3	Casualties	Generally not significant for flood
4	Emergency Management Costs	"Generally not considered; road/bridge mitigation projects neglects impact on a communities overall emergency management costs."

EXAMPLES OF HAZUS DATA IN MODEL




Initial Pre Disaster IS Performance and Condition Measures
de511 number of lanes
de511
de509 number of lanes
de509
de085
de085 number of lanes
de069
de069 number of lanes
de068
de068 number of lanes
de066
de066 number of lanes
de060
de060 number of lanes
pavement condition index
degraded IS condition
years of existing IS
standard time for IS lifecycle
current IS condition
average IS condition
number of IS lifecycles
total IS number of lanes
carrying service capacity
overall IS capacity
normalizing factor
passenger cars per lane per hour
level of IS service
current flow rate


Cost of IS Normal Operations
Infrastructure System Cost for Normal Operations
deldot financial responsibility
total deldot cost provision
assessing IS resources cost for normal operations
total IS length
total fhwa cost provision
fhwa
current IS condition
mr&r for normal IS operations
total de stakeholders cost provision
de stakeholders
average IS cost per foot
de060 cost per foot
de066 cost per foot
de068 cost per foot
de069 cost per foot
de085 cost per foot
de509 cost per foot
de511 cost per foot
de060
de060 length
de066
de066 length
de068
de068 length
de069
de069 length
de085
de085 length
de509
de509 length
de511
de511 length
total IS length

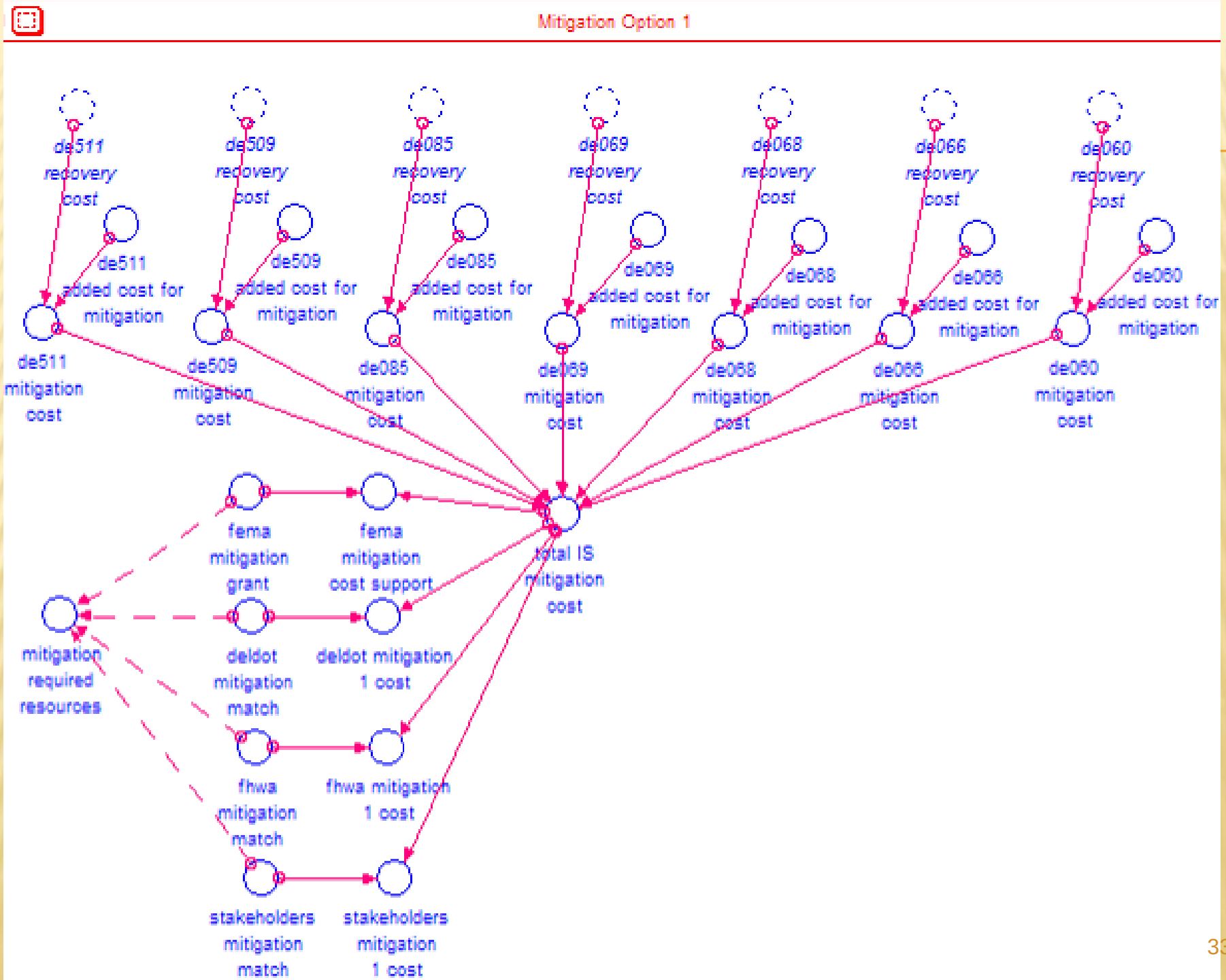

Mitigation Option 1
de511 recovery cost
de509 recovery cost
de085 recovery cost
de069 recovery cost
de068 recovery cost
de066 recovery cost
de060 recovery cost
de511 added cost for mitigation
de509 added cost for mitigation
de085 added cost for mitigation
de069 added cost for mitigation
de068 added cost for mitigation
de066 added cost for mitigation
de060 added cost for mitigation
de511 mitigation cost
de509 mitigation cost
de085 mitigation cost
de069 mitigation cost
de068 mitigation cost
de066 mitigation cost
de060 mitigation cost
fema mitigation grant
fema mitigation cost support
total IS mitigation cost
mitigation required resources
deldot mitigation match
deldot mitigation 1 cost
fhwa mitigation match
fhwa mitigation 1 cost
stakeholders mitigation match
stakeholders mitigation 1 cost

Table 49 Variables Values and Assumptions for Calculating the BCA of Mitigation Projects

Segments	Damaged lanes	Road Issue	Mitigation Strategy	Mitigation Cost (assumption)	Recovery Cost ($)	Associated % per damaged segment value	Related disaster value (thousands)
de060	2	Road failure	Reinforce (+ resistance)	Recovery cost + 20% 89,242	*74,360* *de060 recovery cost*	57.15	67,604.59
de066	0	None	None	0	*0*	0	0
de068	0	None	None	0	*0*	0	0
de069	2	High water	Elevate	Recovery cost + 50% 3,419	*2,280* *de069 recovery cost*	1.75	2,070.13
de085	1	Sink hole	Reinforce (+ resistance)	Recovery cost + 20% 59,671	*49,725* *de085 recovery cost*	38.22	45,211.68
de509	0	None	None	0	*0*	0	0
de511	1	Road closed	Build containing wall with drainage ducts	Recovery cost + 30% 4,874	*3,749* *de511 recovery cost*	2.88	3,406.85
Total	--------	---------	----------	**~157,206** *total IS mitigation cost*	**~130,123** *total lanes recovery cost*	**100**	**118,293.25**

Table 58 Summary of Benefits for Mitigation Projects

Net Present Value of Future Benefits • No damage to mitigated infrastructure (assuming small part of road segment mitigation is possible instead of the whole segment length) • No Loss of Function - services value not being provided due to damage (total disaster delay cost) *Total:*	$118,293.25 $601,006.00 *$719,299.25*
Mitigation Project Costs	$157,206
Benefit-Cost Ratio (Net Present Value of Future Benefits ÷ Project Costs)	**4.6**

Table 60 Summary of Benefits for Recovery Projects

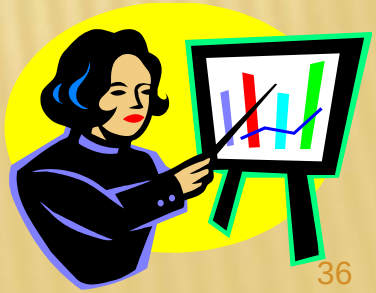
Net Present Value of Future Benefits • Possible repetition of damage to mitigated infrastructure (no certainty of extent of damage possible to be bigger and/or smaller, despite physical conditions improvement) • Possible repetition of Loss of Function - services value not being provided due to damage (total disaster delay cost) • Improved road condition (1% - average IS recovered condition) *Total:*	($118,293.25) ($601,006.00) 1% x(118,293.25 + 601,006.00) *($23,042.00)*
Recovery Project Costs (total lanes recovery cost)	$130,123.00
Benefit-Cost Ratio (Net Present Value of Future Benefits ÷ Project Costs)	**-0.18**

Scenarios Explored

Eight scenarios assessing impacts (costs) uses:

- Infrastructure Projects
  - Recovery only
  - Recovery and Mitigation
- Probability of a 100-year storm event in the case study area

  1% 4% 8%
- Time required for disaster response
  - 2 days
  - 4 days

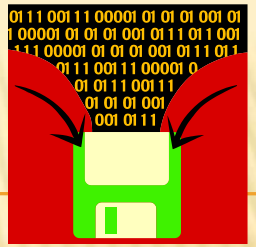


ILLUSTRATIVE RESULTS

- 1% probability of 100-year storm (study area)

Variables	2 days Disaster Response	4 days Disaster Response
Recovery NPV	148,081	512,958
Mitigation NPV	157,890	600,629
Result from mitigation investment	-9,809	-87,671
Loss of function for recovery (benefit)	-1,463	-2,479
Loss of function for mitigation (benefit)	719,299	1,218,060

CONCLUSION



- Complex system modeling required many assumptions and models to capture changes over time
- SDSS plays major role in setting the stage for problem analysis, diagnosis, mitigation insights (many sources of data)
  - SDSS results are important inputs into the model
  - SDSS can be better customized to include better analysis tools for infrastructure
  - **HAZUS-MH inventory enables further analyses, integration and shows the potential to add/improve analyses for infrastructure**
- Comprehensive development offers insights into trade-offs and opportunities to capture damage and costs in the context of resiliency
- Refinements are needed

FUTURE WORK WITH HAZUS AND EXPECTED BENEFITS

- Include FEMA BCA tool kit in HAZUS-MH expand insights of mitigation strategies and projects towards making HAZUS better help support decision making.
- Level 2 analysis customizing transportation infrastructure inventory and include calculation of roads/bridges debris in the cost for recovery and mitigation.

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