INTEGRATING SOCIAL VULNERABILITY AND FLOOD SAFETY MODELING

HURRICANE IKE AND GALVESTON, TEXAS: A CASE STUDY

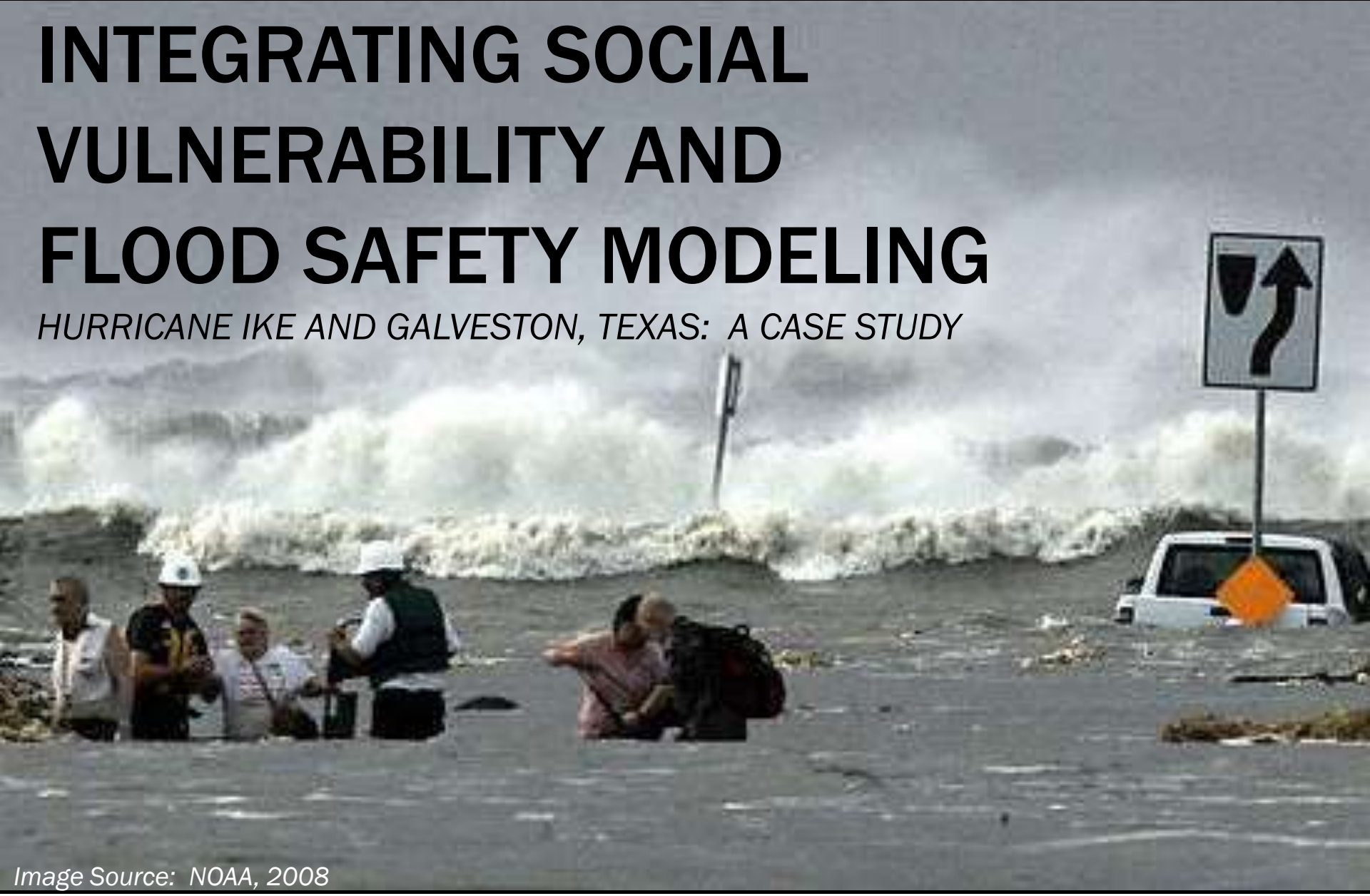

Image Source: NOAA, 2008

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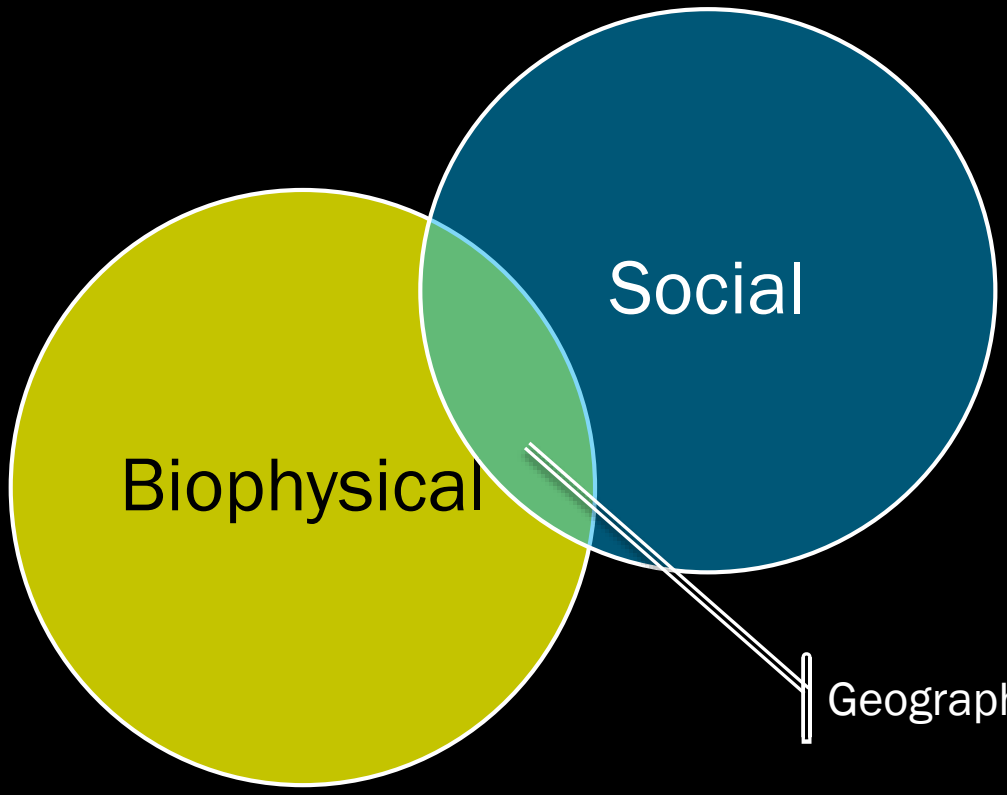
Overview

- Background
- Disaster Modeling Framework
- Hurricane Ike and the Galveston experience
- Integrating Social Vulnerability
- Findings and Next Steps

Risk Factor Nexus: A Recipe for Disaster

Hazard Amplifiers:

- **Climate Change**
- **Aging Infrastructure**



Consequence Amplifiers:

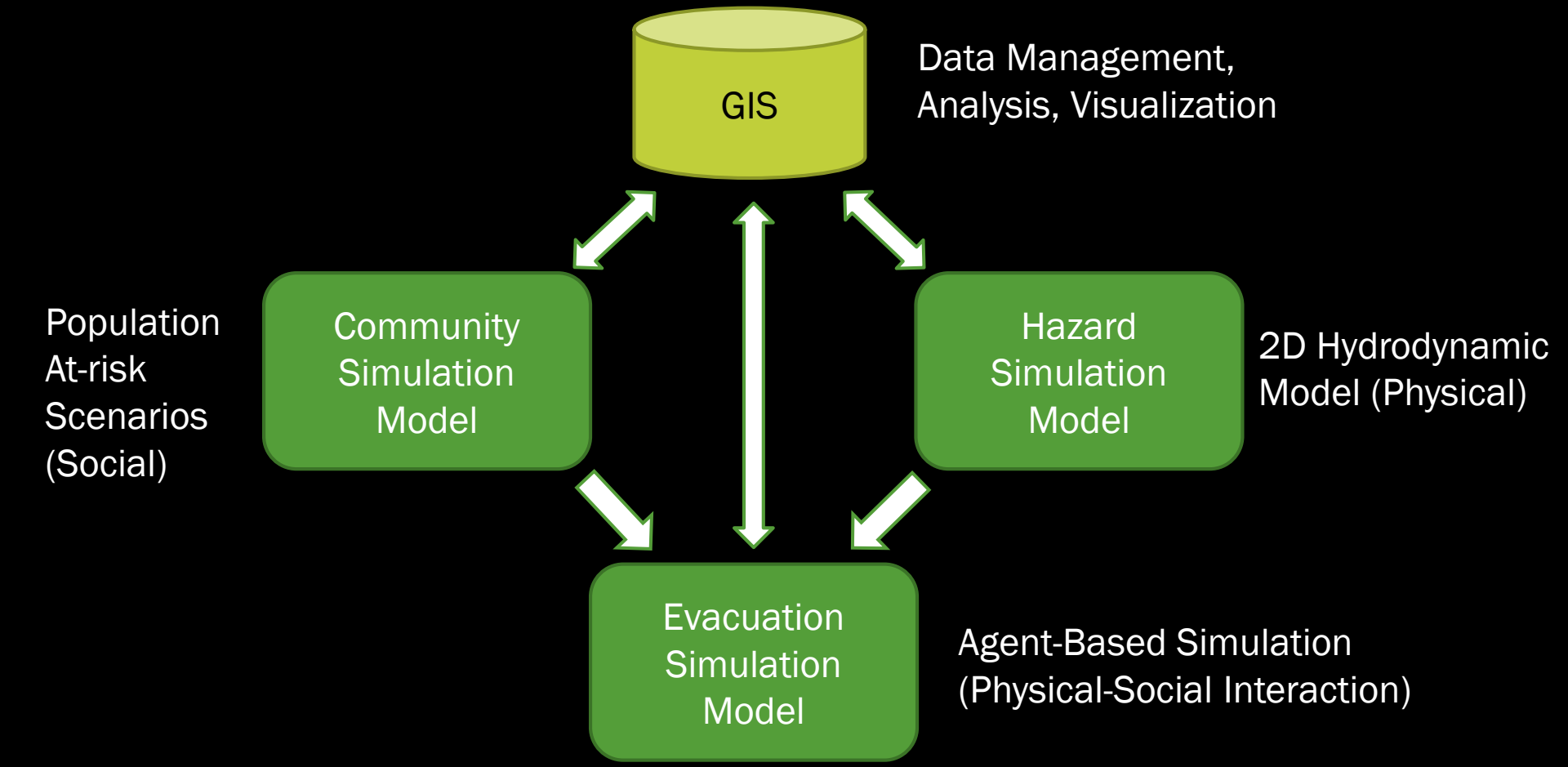
- **Social**
- **Cultural**
- **Institutional**

Social Vulnerability:

"susceptibility of social groups to the impacts of hazards, as well as their resiliency, or ability to adequately recover from them" – Cutter & Emrich, 2006.

National Guard trucks haul residents through floodwaters to the Superdome after Hurricane Katrina hit in New Orleans, Tuesday, August 30, 2005. (Image Source: The Washington Times, 2014)

Disaster Modeling Framework[1]



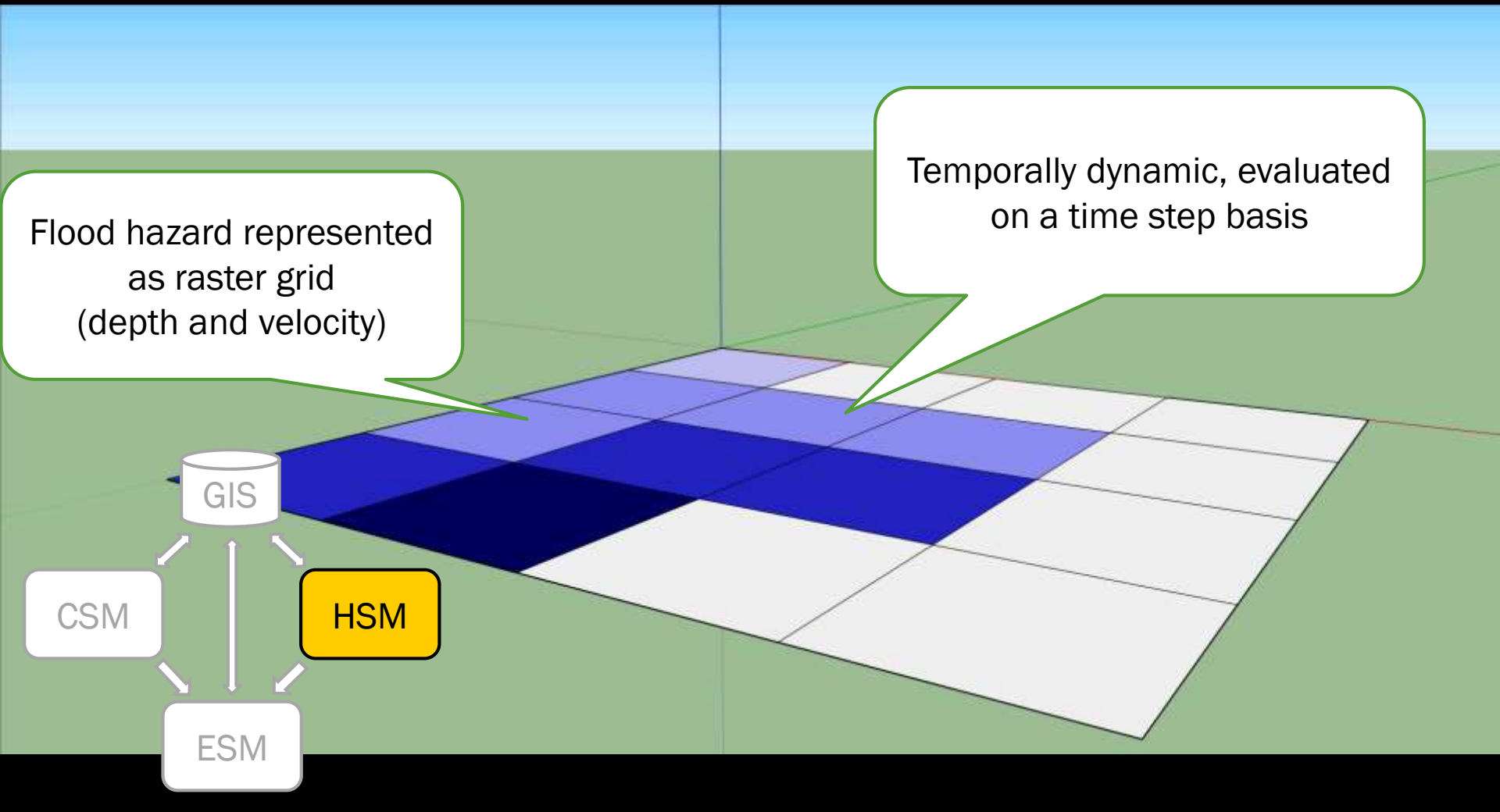
[1]*Adapted from Assaf, 2011.*

Definition: Agent-based Model

- Use of autonomous agents (people, vehicles, animals) to simulate complex adaptive systems
- Identify macro phenomena emerging from micro level behavior

Source: Janssen, 2005.

Objects within the model framework



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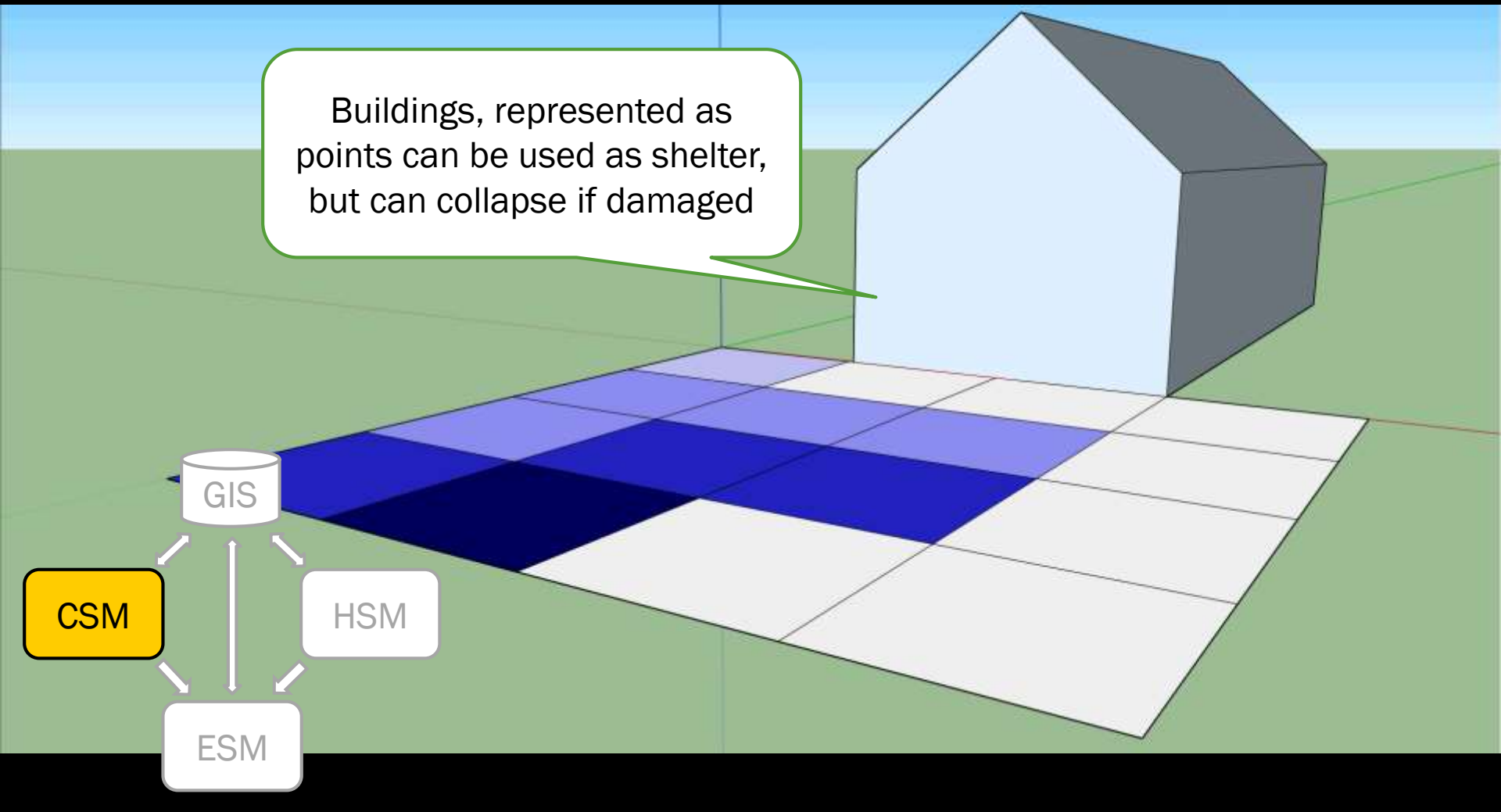

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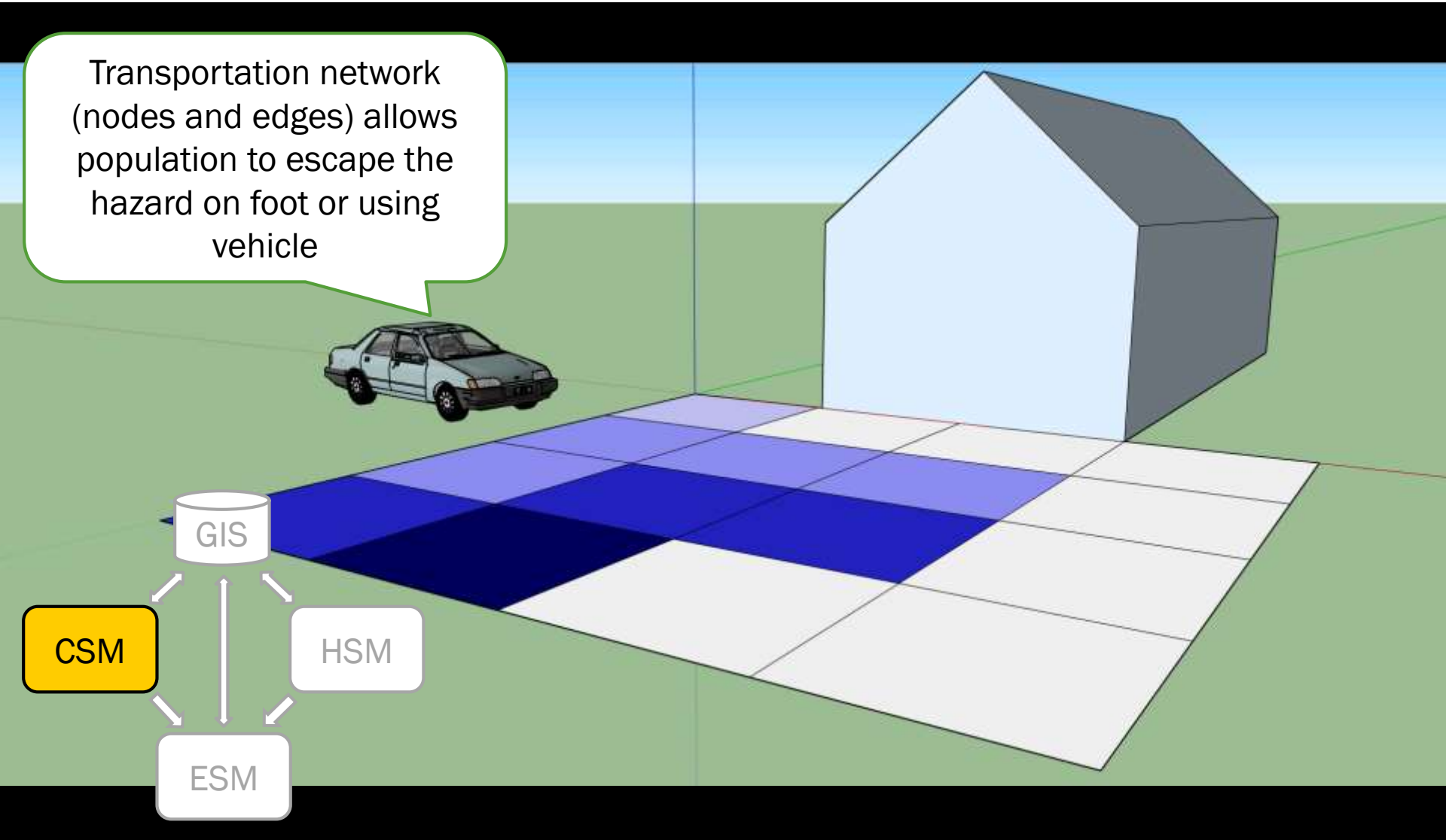

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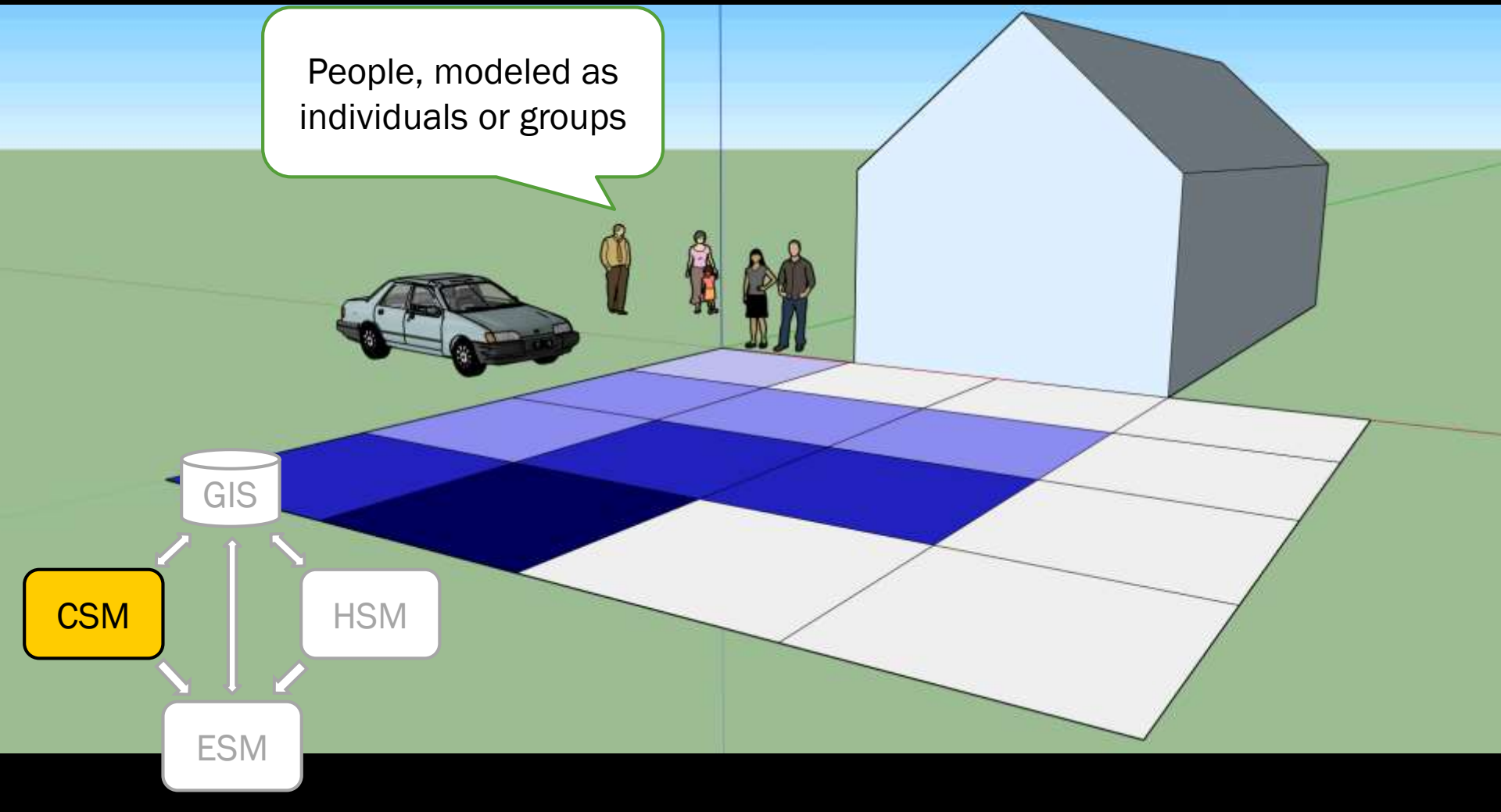

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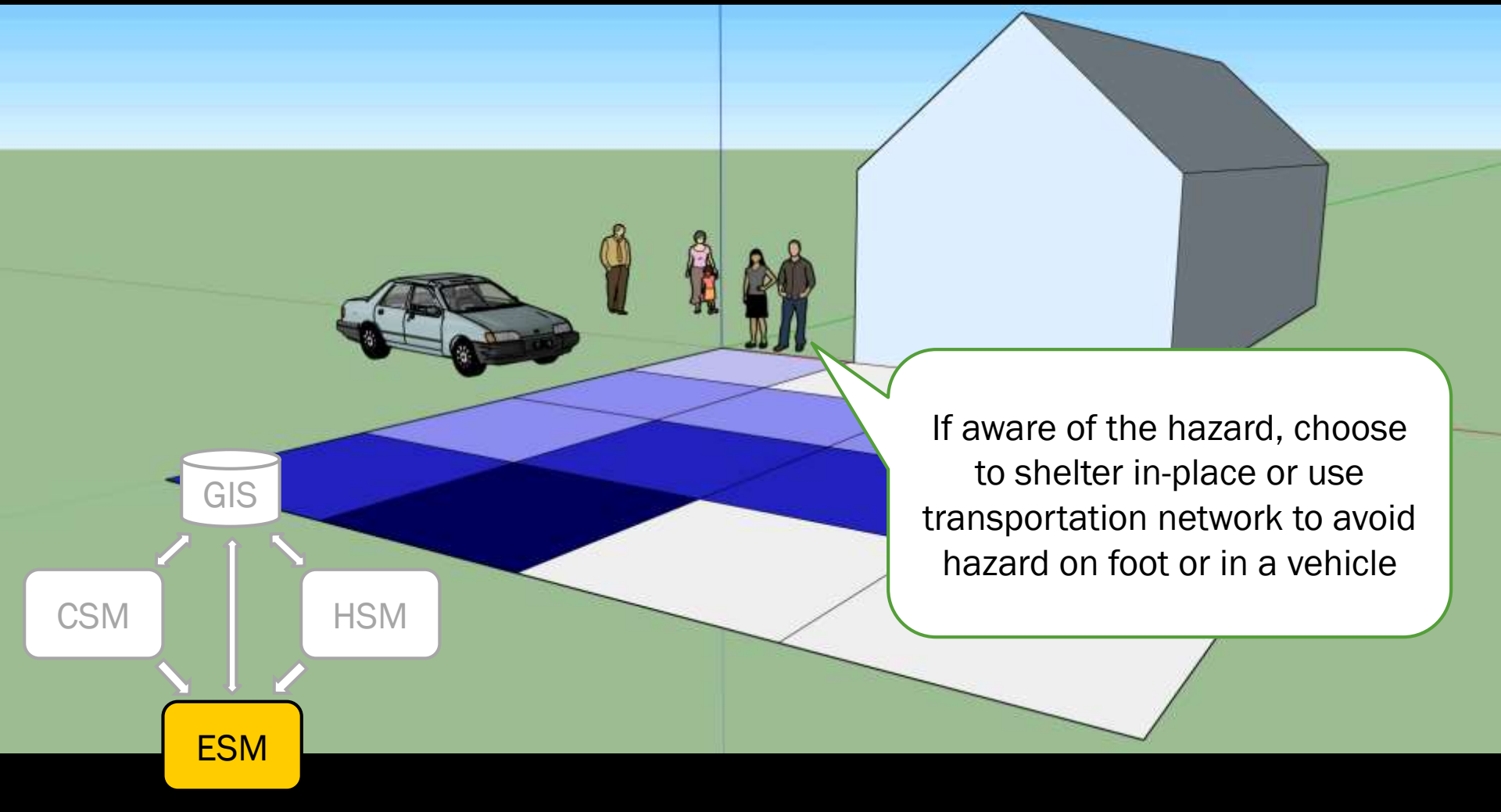
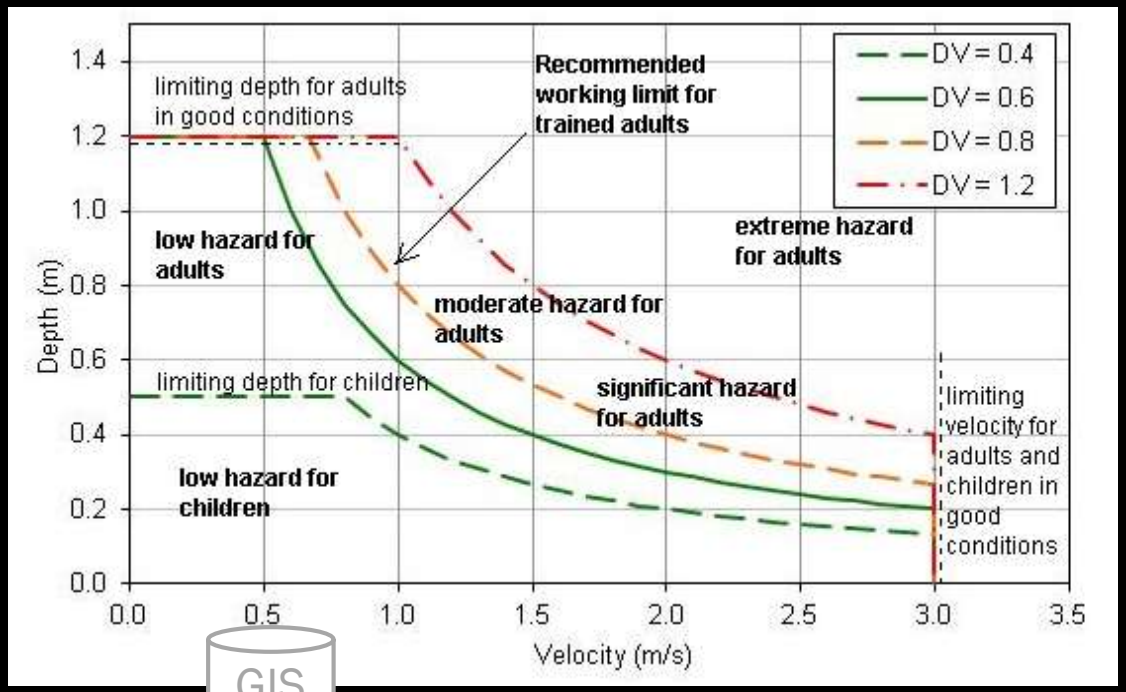
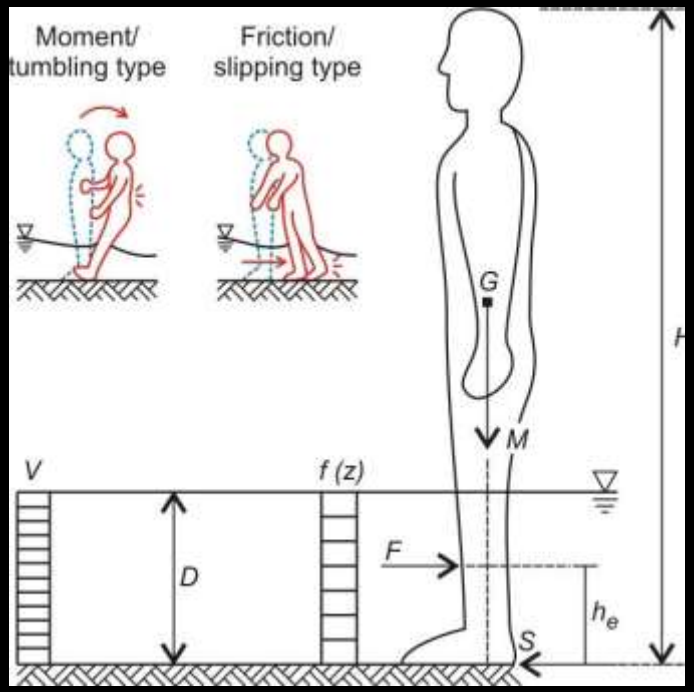
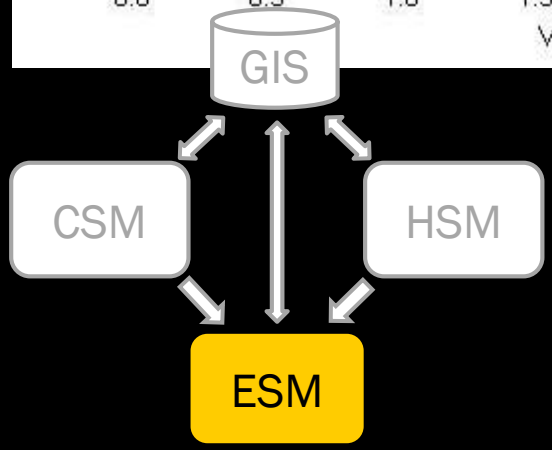


Fate of objects in the evacuation simulation are determined at each time step

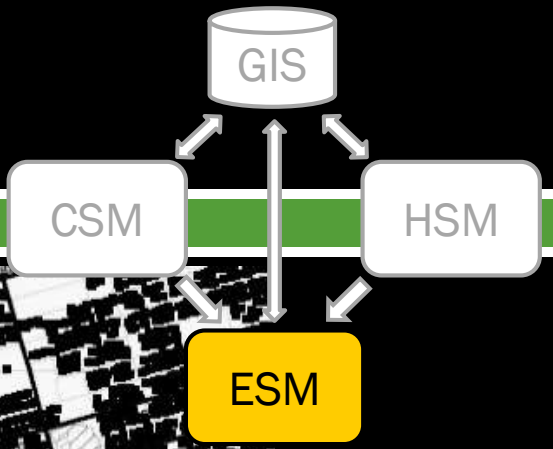




Safety Criteria for People in Variable Flow Conditions and Typical Modes of Instability in Floods (Source: Cox et al, 2010)



Visualizing the model results



(Source: Map tiles by Stamen Design, 2017)

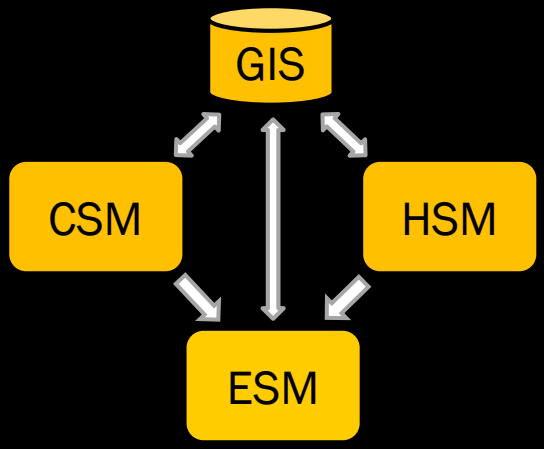
Modeling the system as a whole allows us to ask new questions about a place

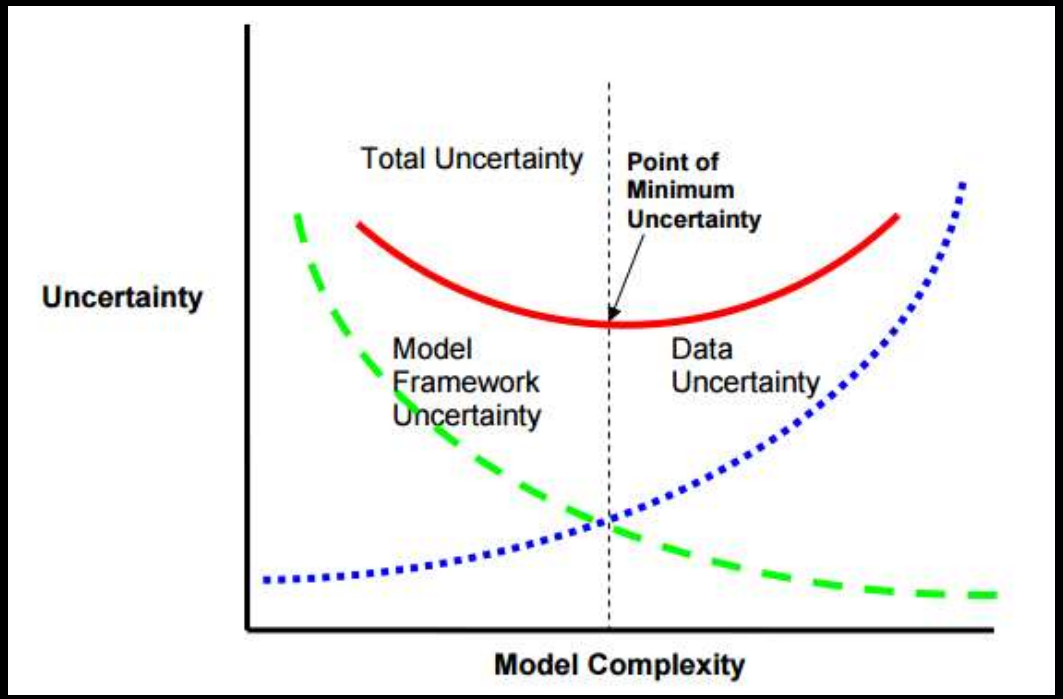
- Evacuation Planning
  - Is the evacuation plan effective?
  - How significant is traffic congestion?
  - Is risk affected by time of day or year?
  - Are some groups at greater risk of harm?
- Scenario-based
  - Test efficacy of mitigation actions
  - Training (“what if…?”)
  - Communication with managers and public

However, there is a catch…

"inherent complexity and uncertainty in such modeling means that being within ± 100% of the actual result can be considered a 'good' outcome."

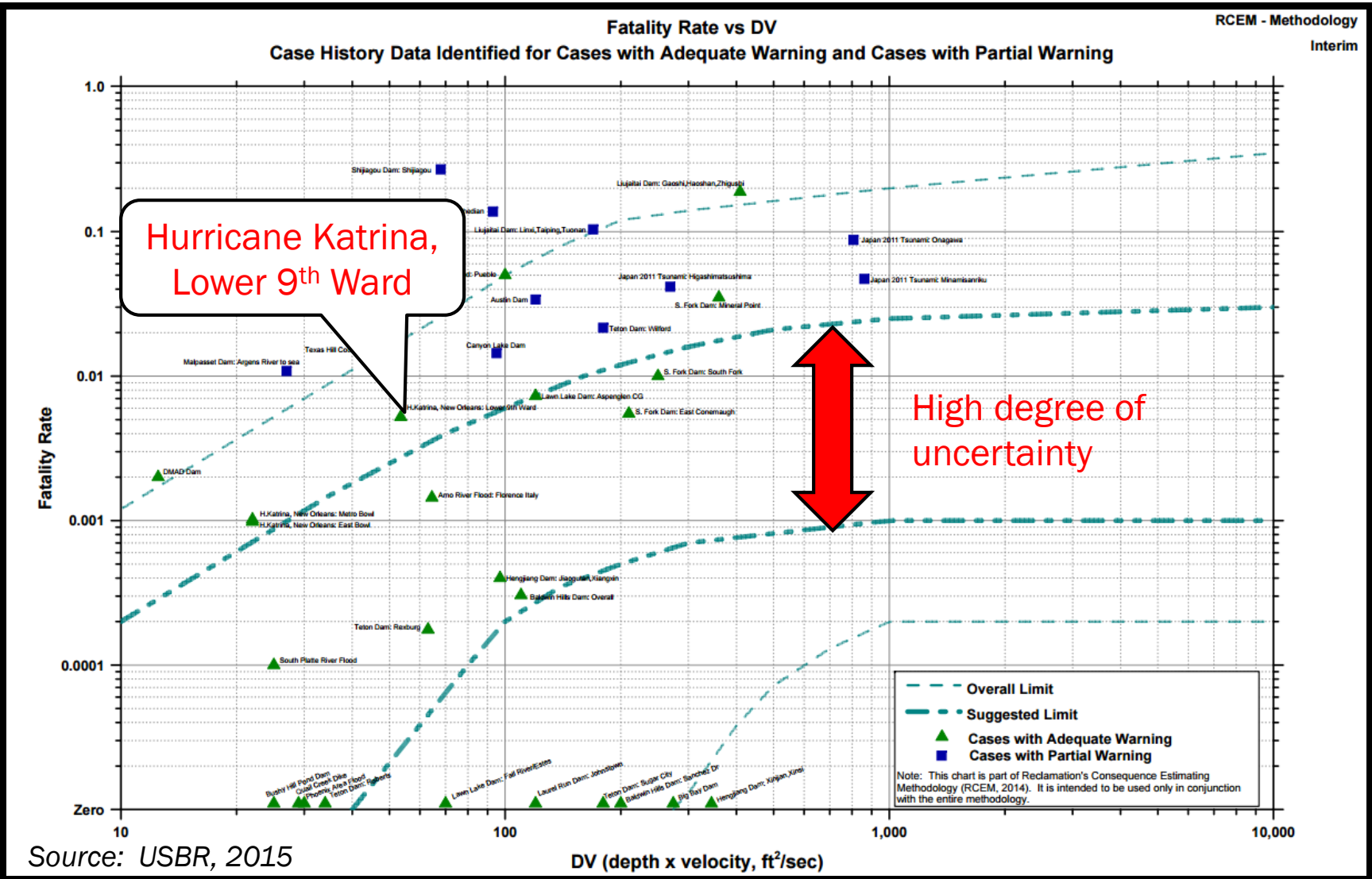
(Lumbroso and Davison, 2016)





Relationship between model uncertainty and complexity (Image Source: EPA, 2009).

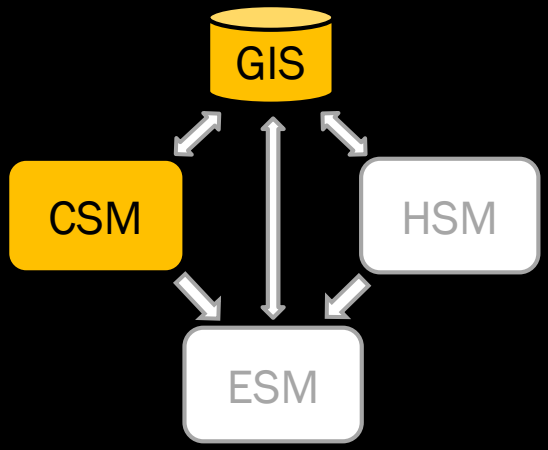
Compared to empirical methods…



Source: USBR, 2015

Research Question: Can the Disaster Simulation Model be refined using Social Vulnerability Data?

- In the U.S., history tells us that roughly a third of the population will not evacuate prior to a hurricane (Weller et al., 2016)
  - Who stays behind?
  - Why do they stay behind?
  - More importantly, where are they located?

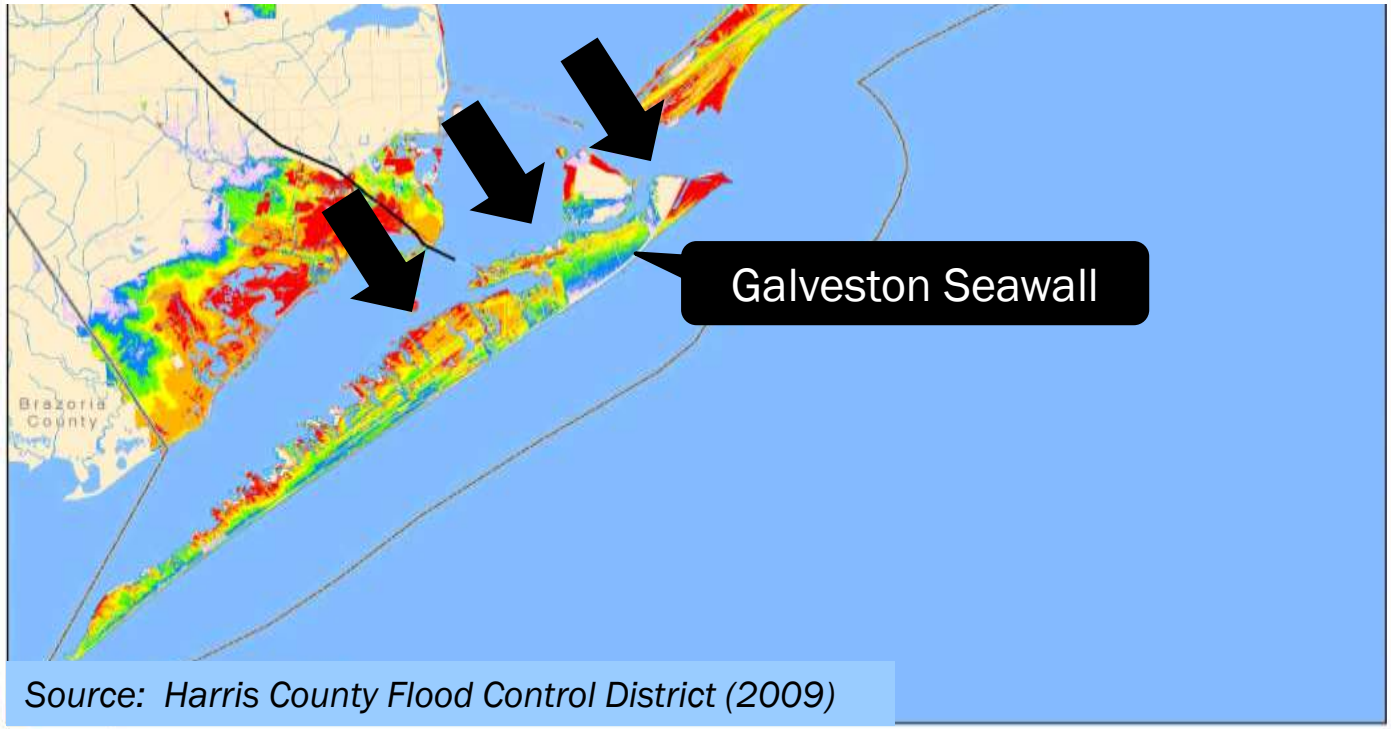


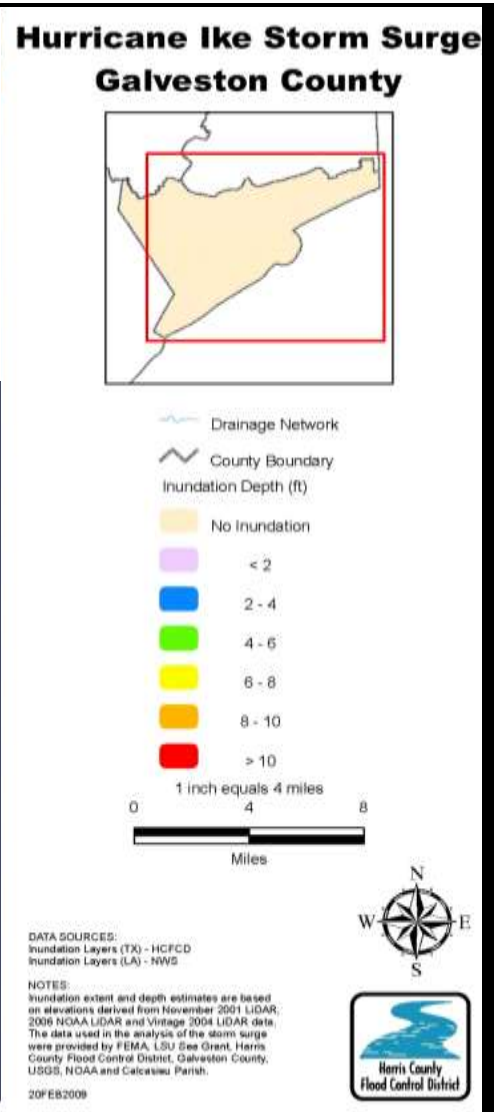
Why Galveston?

- History of flooding
- Physically constrained
- Primary data required is publicly availability

What happened in Galveston during Hurricane Ike in 2008?

- Category 2 wind speeds
- Category 4 storm surge
- Large wind field – storm surge arrived early
- Storm surge came from the backside of the Island, outflanking the Galveston Seawall.





Source: Harris County Flood Control District (2009)

Comparing the Hurricane of 1900 with Hurricane Ike (2008)

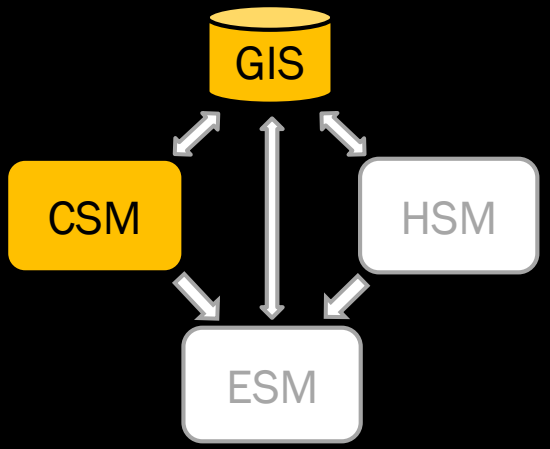
	Hurricane of 1900 (Roth, 2010; and USACE, 1981)	Hurricane Ike (City of Galveston, 2011)
Casualties	6,000	16
Damages	$25 million (unadjusted)	$200 million+
Population on Galveston Island	30,000	57,000
% Evacuated (Approx.)	66%	60-75%
Fatality Rate of Residual Population at Risk	60%	0.14%

Galveston, Texas following Hurricane of 1900 (Image source: Roth, 2010)

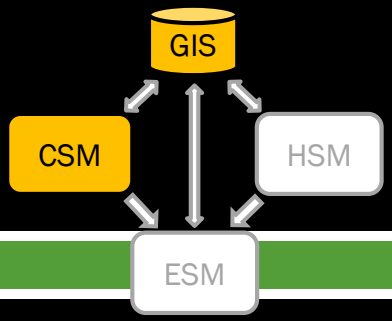
Galveston, Texas following Hurricane Ike (Image source: USAF, 2008)

Preparing the Community Simulation Model: who stayed behind, and where were they?

- Data Uncertainties:
  - Census data is aggregated at block group level, for privacy reasons a one-to-one match with actual population isn't possible
  - Data from post-disaster surveys is largely qualitative, difficult to integrate into a GIS framework
  - Estimates of evacuation compliance vary



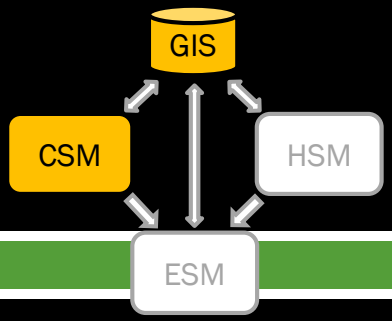
Data Uncertainty: Spatial Distribution of Synthetic Population



- ICLUS 90-meter grid resolution is too course to map population to individual parcels

(Sources: RTI, 2014 and Esri World Imagery service layer, 2017)

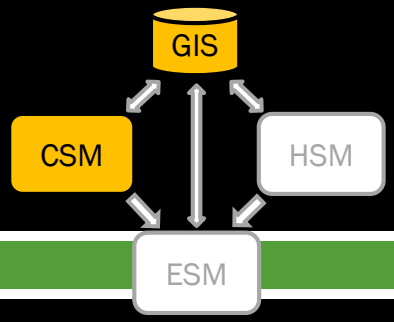
Data Uncertainty: Spatial Distribution of Synthetic Population



- Result: households moved to residential parcel centroids

(Sources: Galveston County Central Appraisal District, 2016 and Esri World Imagery service layer, 2017)

Data Uncertainty: Who Stayed Behind?

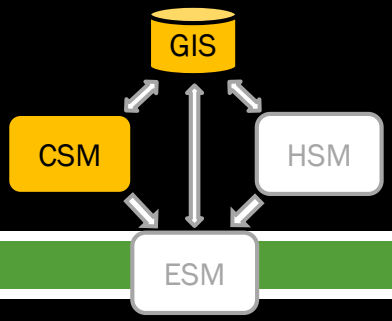


- Actual spatial distribution of unevacuated PAR cannot truly be known, but Monte Carlo simulation can be used to create an envelope of outcomes
  - Null hypothesis: select unevacuated population at random
  - Alternative hypothesis: stratified sampling based on presence of children in the household will reduce sampling error and improve model predictions
  - Based on sensitivity analysis, assume that 40% of households remain behind (approx. 23,000 people).

Definition: Stratified Sampling

- Random sampling may not be representative of the actual population.
- Stratified sampling methods separate the data into classes and selecting random samples from each.
- Requires understanding of variables that might be relevant and their influence on the sample distribution.

Stratified Sampling: Who Stayed Behind?

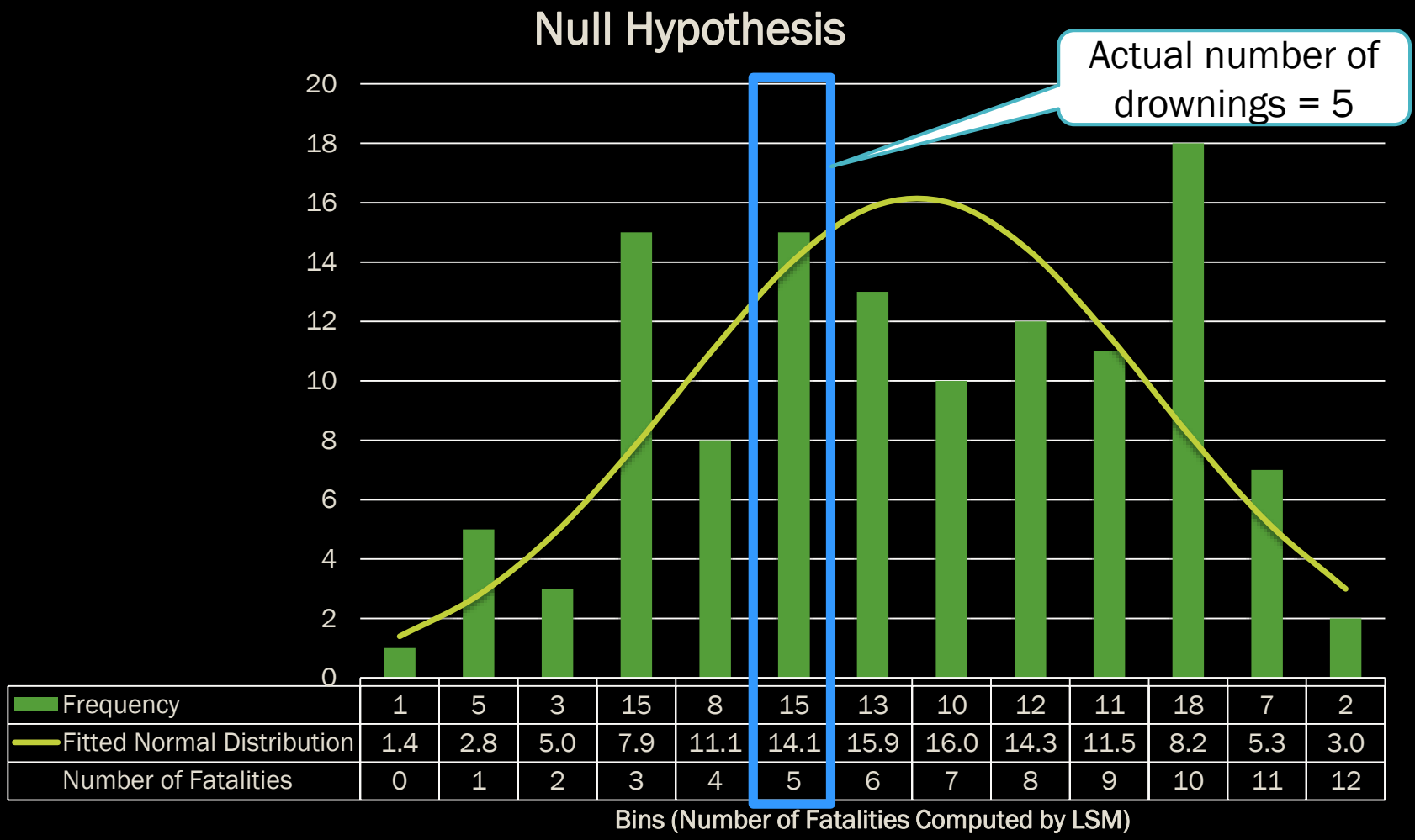


Sample Description (Weller et al, 2016)

Variable	Evacuated (n = 16)	Stayed (n = 16)
Educational Level (years)	15.3	14.5
Age	44.7 (33-63)	48.3 (21 -64)
Length Residency (years)	28.6 (5.5 -61)	26.1 (4-64)
Own home (%)	80	75
Windstorm insurance (%)	77	71
Flood insurance (%)	57	60
Ethnicity (%)		
White	31.3	62.5
Hispanic	43.8	18.8
African-American	18.8	12.5
Nat. American/Pac Islander	6.3	6.3
Gender (female) (%)	38.8	43.8
Have Children	56.3	18.8
Storm damage	8% no damage	33% no damage
	38% minimal damage	8% minimal damage
	54% major damage	58% major damage

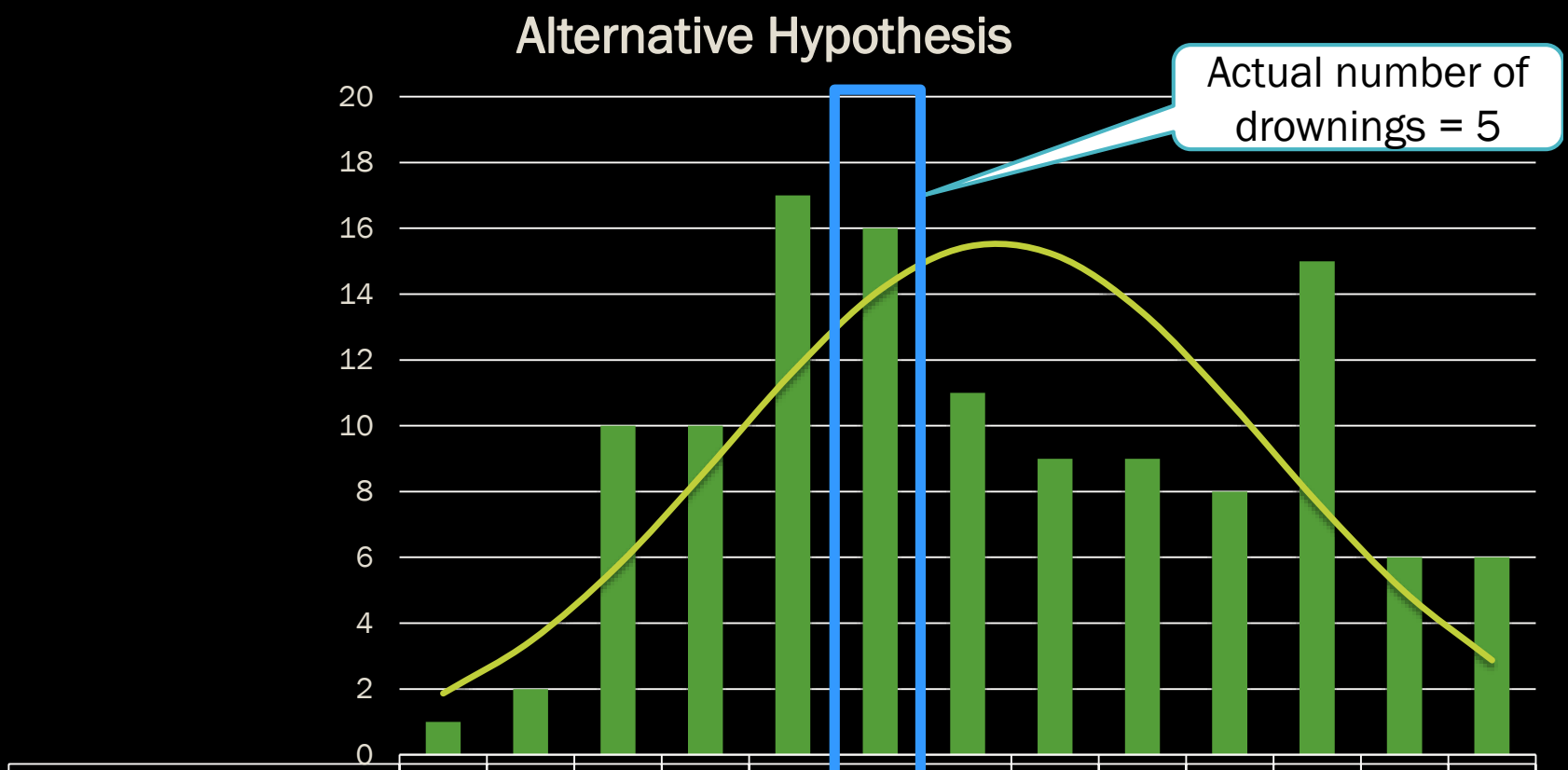
"...importance of family safety and the evacuation of vulnerable family members (children, elderly, handicapped, and infirm) to a safer place." (Weller et al., 2016)

Simulation Results



Frequency	1	5	3	15	8	15	13	10	12	11	18	7	2
Fitted Normal Distribution	1.4	2.8	5.0	7.9	11.1	14.1	15.9	16.0	14.3	11.5	8.2	5.3	3.0
Number of Fatalities	0	1	2	3	4	5	6	7	8	9	10	11	12

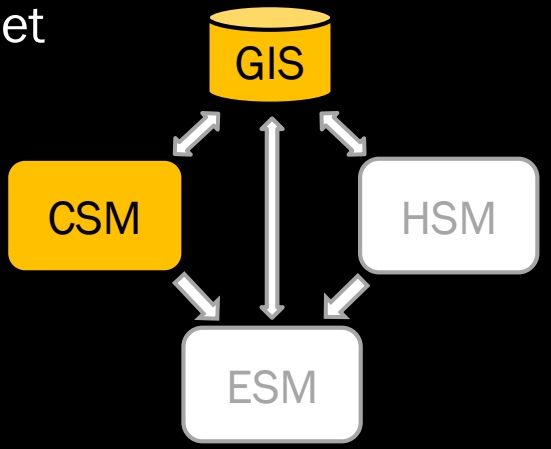
Simulation Results



Frequency	1	2	10	10	17	16	11	9	9	8	15	6	6
Fitted Normal Distribution	1.9	3.5	5.8	8.6	11.6	14.1	15.4	15.2	13.4	10.7	7.7	5.0	2.9
Number of Fatalities	0	1	2	3	4	5	6	7	8	9	10	11	12

Conclusion and Next Steps

- Social vulnerability indicators ***can*** be integrated within the CSM framework
- Additional simulations required before drawing conclusions
- Improving the CSM in the future
  - Harmonize census data with disaster timeline
  - Add SV attributes to Synthetic Population dataset
  - Integrate institutional populations
  - Purpose-specific post-disaster surveys
  - Refine cadastral / building inventories



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- BMT WBM, Pty., Ltd.
- Wood Rodgers, Inc.

Questions and Discussion

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