Risk Assessment of Interconnected Infrastructure Systems

Applications to Coastal and Delta regions

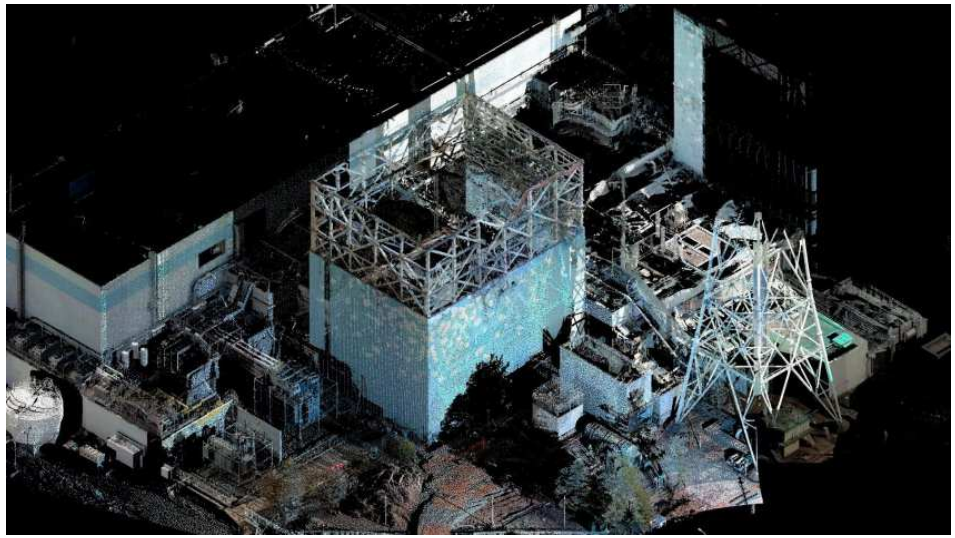
Prof. dr. ir. Bas Jonkman
Professor of Hydraulic Engineering, Delft University

Background

- (Infrastructure) Systems in modern societies are highly interconnected
- Effects of flood disasters may cascade:
  - From one system to the other
  - Outside the direcly affected area
- Many existing design guidelines and risk assessments do not take into account these interconnections
- "single-systems" and / or "single-hazards"
- Objective: develop and demonstrate approaches for risk assessment for ICIS threatened by multiple hazards

Examples: NY, Fukushima & New Orleans

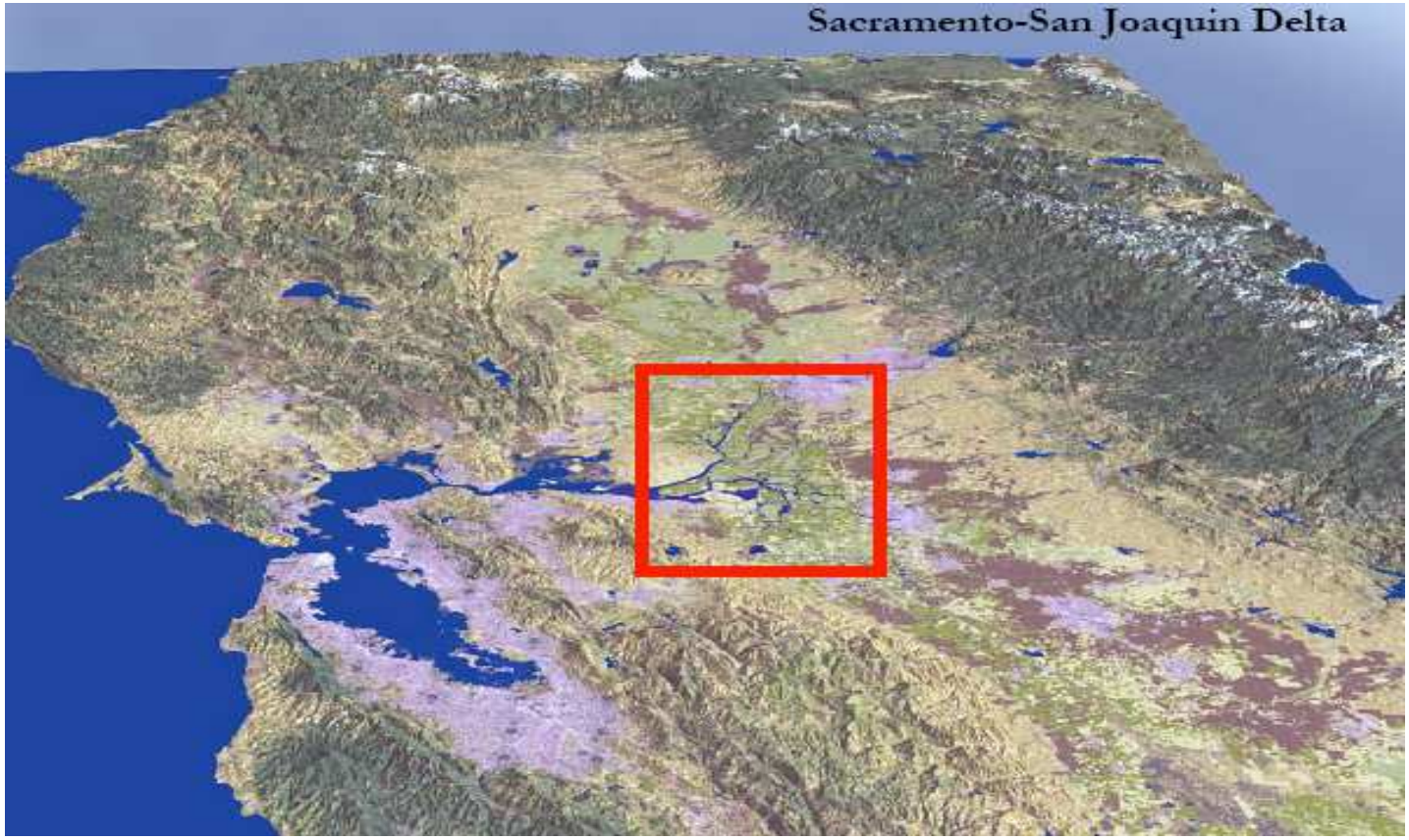
Japan, 2011



New Orleans, 2005

New York, 2012

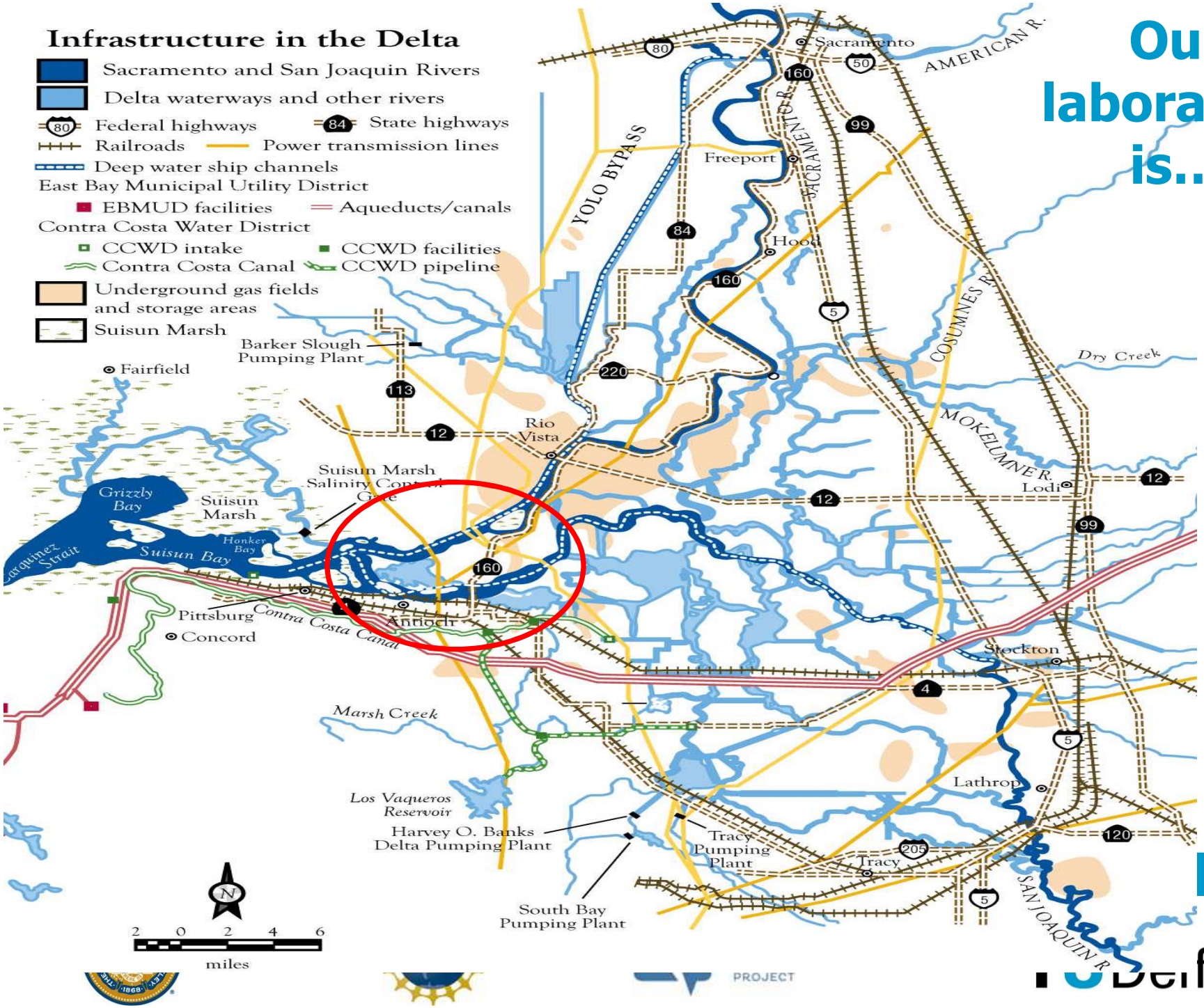
RESIN Resilient and Sustainable Infrastructure Networks



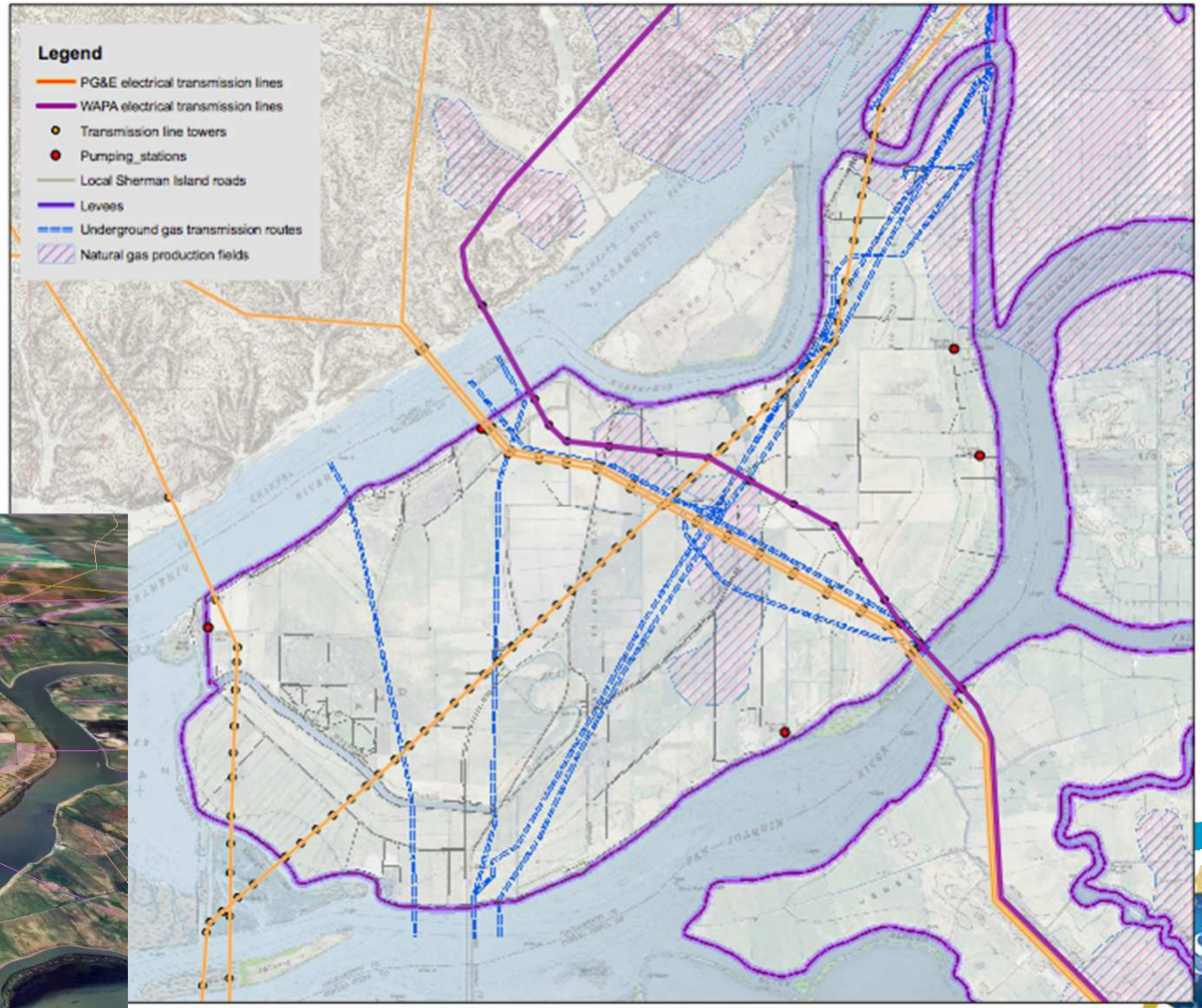
THE AIM OF RESIN IS…

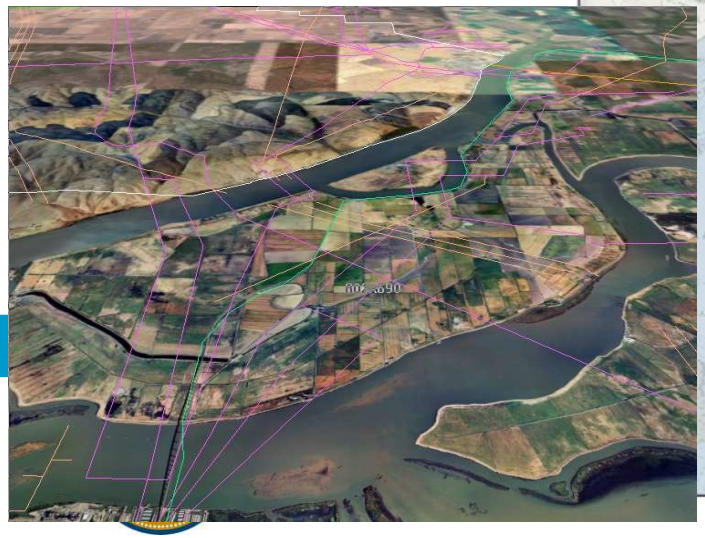
To create, validate, & apply improved Risk Assessment & Management (RAM) approaches for the high reliability management of resilient & sustainable interconnected critical infrastructure systems (ICIS).

Our laboratory is…



Sherman Island infrastructures - levees, electric power & gas, transportation





Levee - Power & Gas - Transportation - Ecological 'Interactions'

Power & Gas Transmission (PG&E)

power for pumps

supports of towers

support of pipelines

Water Security - Levees (DWR)

support of roadways

Road Transportation (CalTrans)

flood fighting access

induction of salt water

protection of levees

Ecological Infrastructure (CalF&G)

Interactions associated with storms, levee breaching & flooding

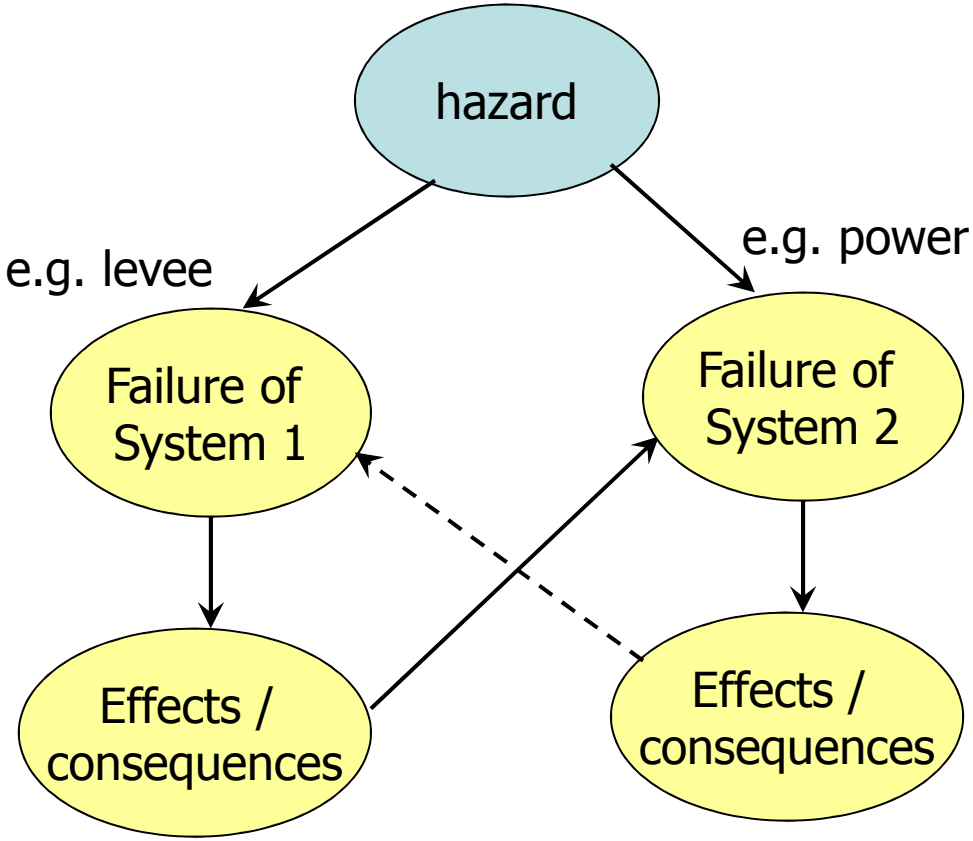
Sherman Island 1998

source: RD341

Sherman Island 2006

source: RD341

Concepts: Interconnections



Hazard Dependence

Cascade

Interdependence

Methods and risk metrics

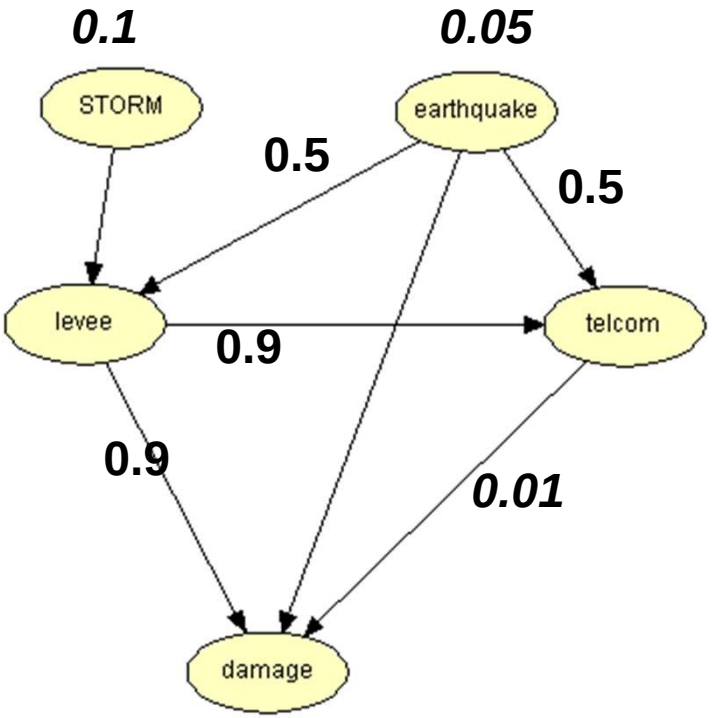
•Methods: Influence diagram and Bayesian networks

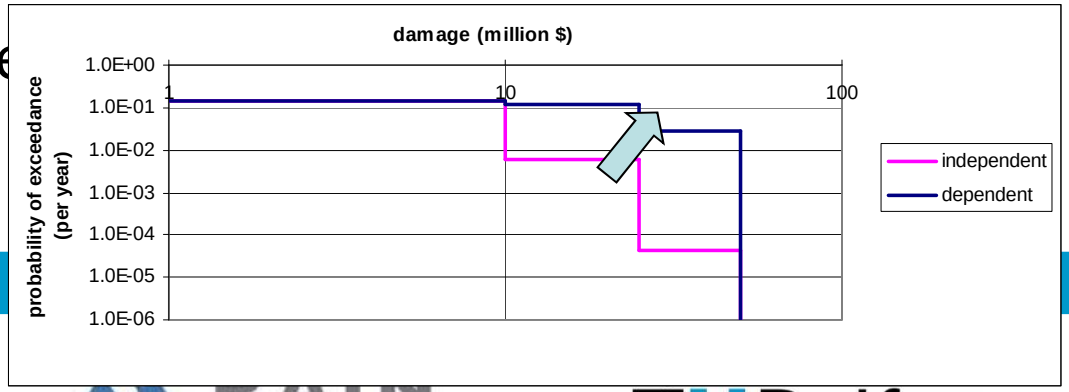
Systems characerization:

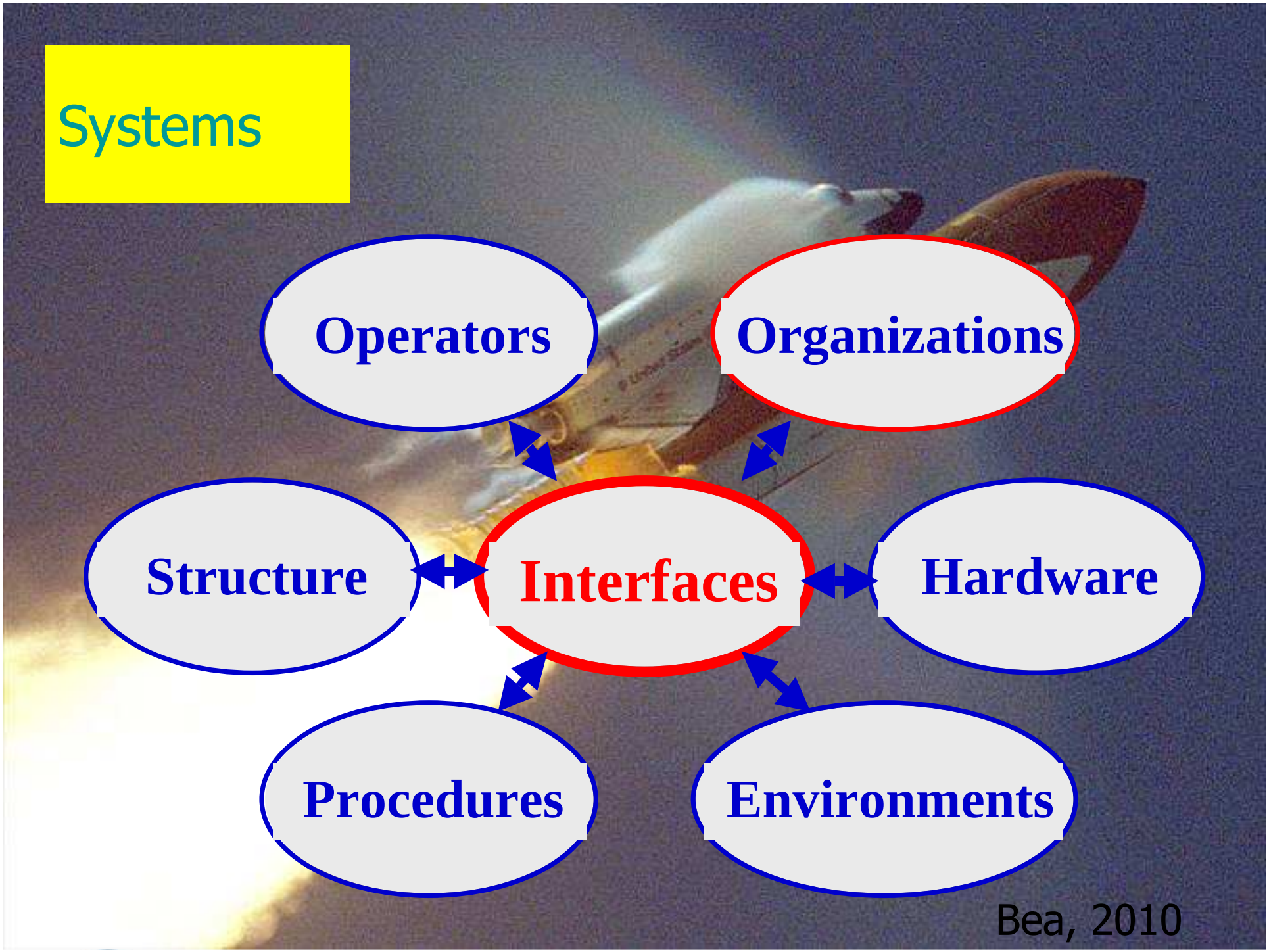
- •Structures
- •Operations and organizations
- •Environment and hazards

•Risk metrics: Risk, Resilience

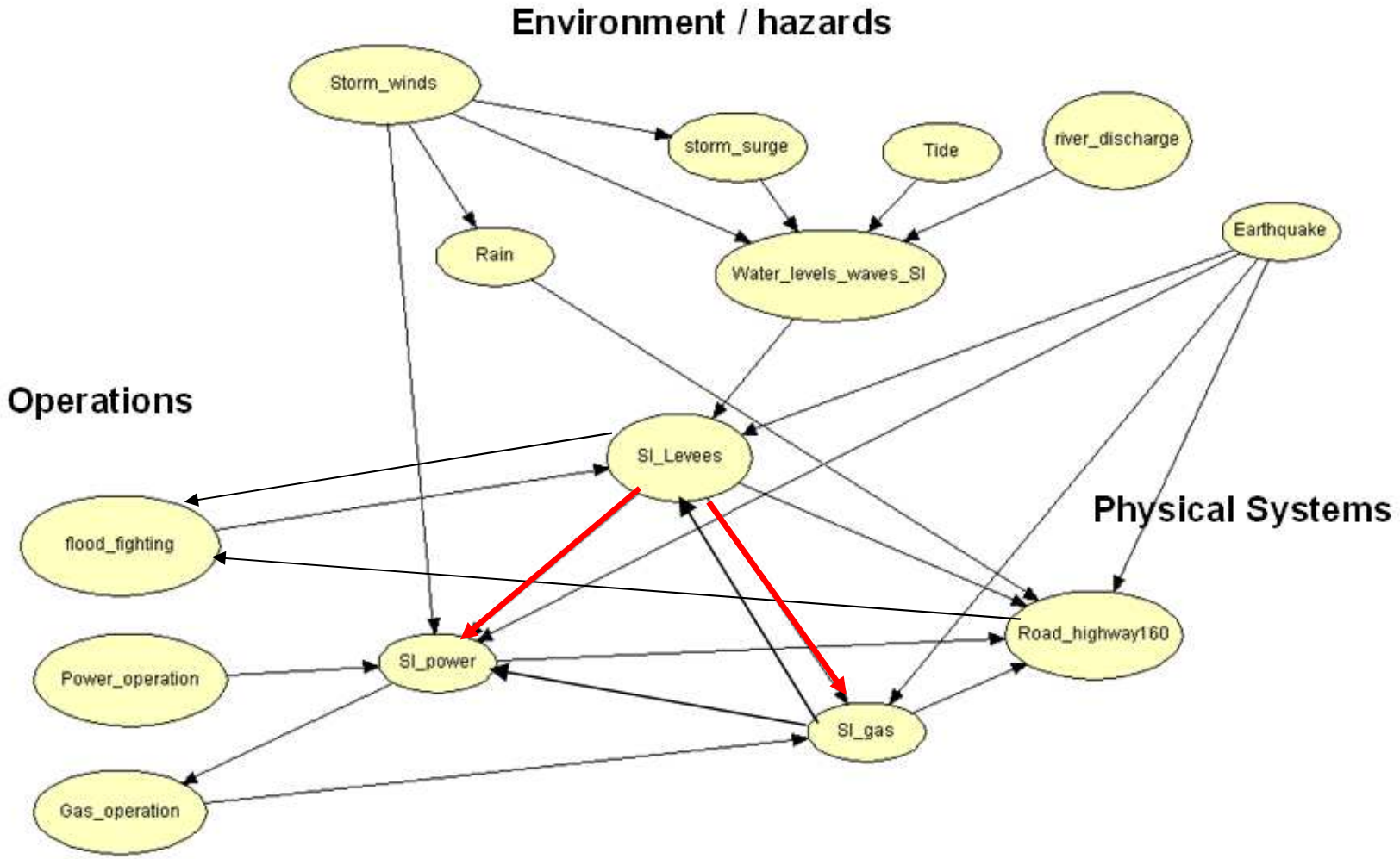
•Dependence of events and cascading damage will increase risk (Pf, Cf)

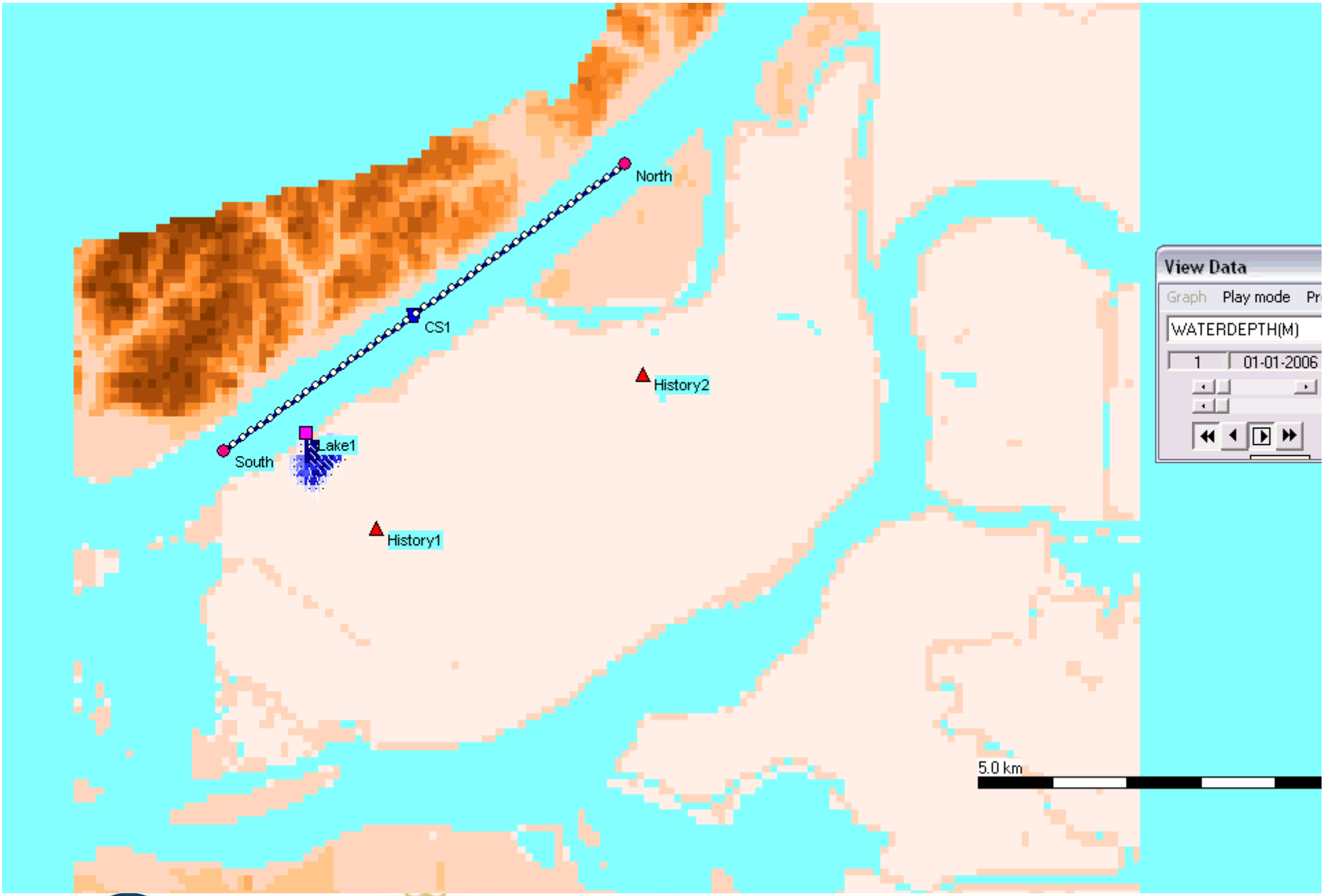





Systems
Operators
Organizations
Structure
Interfaces
Hardware
Procedures
Environments
Bea, 2010

Sherman Island Case Study




North
CS1
South
Lake1
History2
History1
View Data
Graph
Play mode
WATERDEPTH(M)
1
01-01-2006
5.0 km

Power and Gas transmission lines

- Failure due to erosion of supports in breach zones?

Sherman Island Results (prelim.)

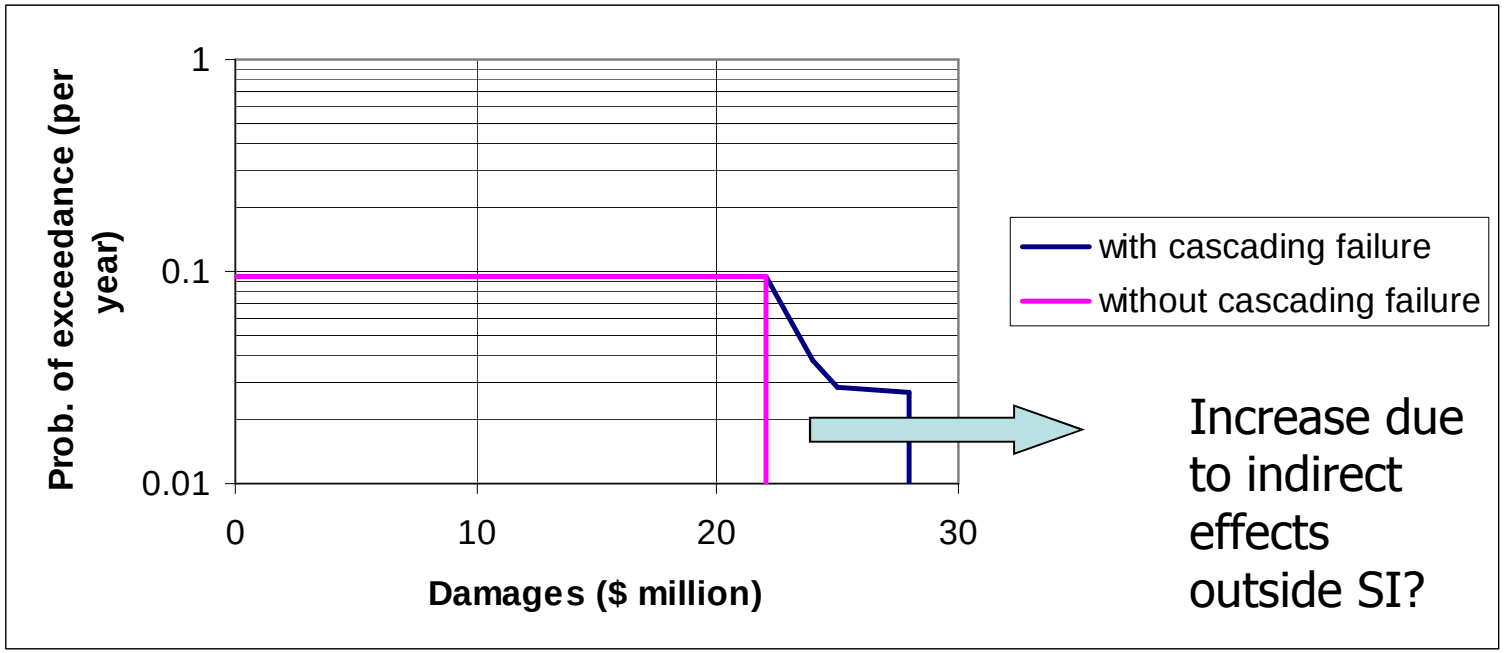
	Storm	Earthquake
Nr. of levee breaches	2	10
Probability of levee failure p.a. DRMS study (URS, 2009)	0.058	0.037
Conditional probabilities		
Road flooding	1	1
Powerline damaged	0.094	0.63
Gasline damaged	0.15	0.75
Power AND Gasline	0.068	0.62

prevention

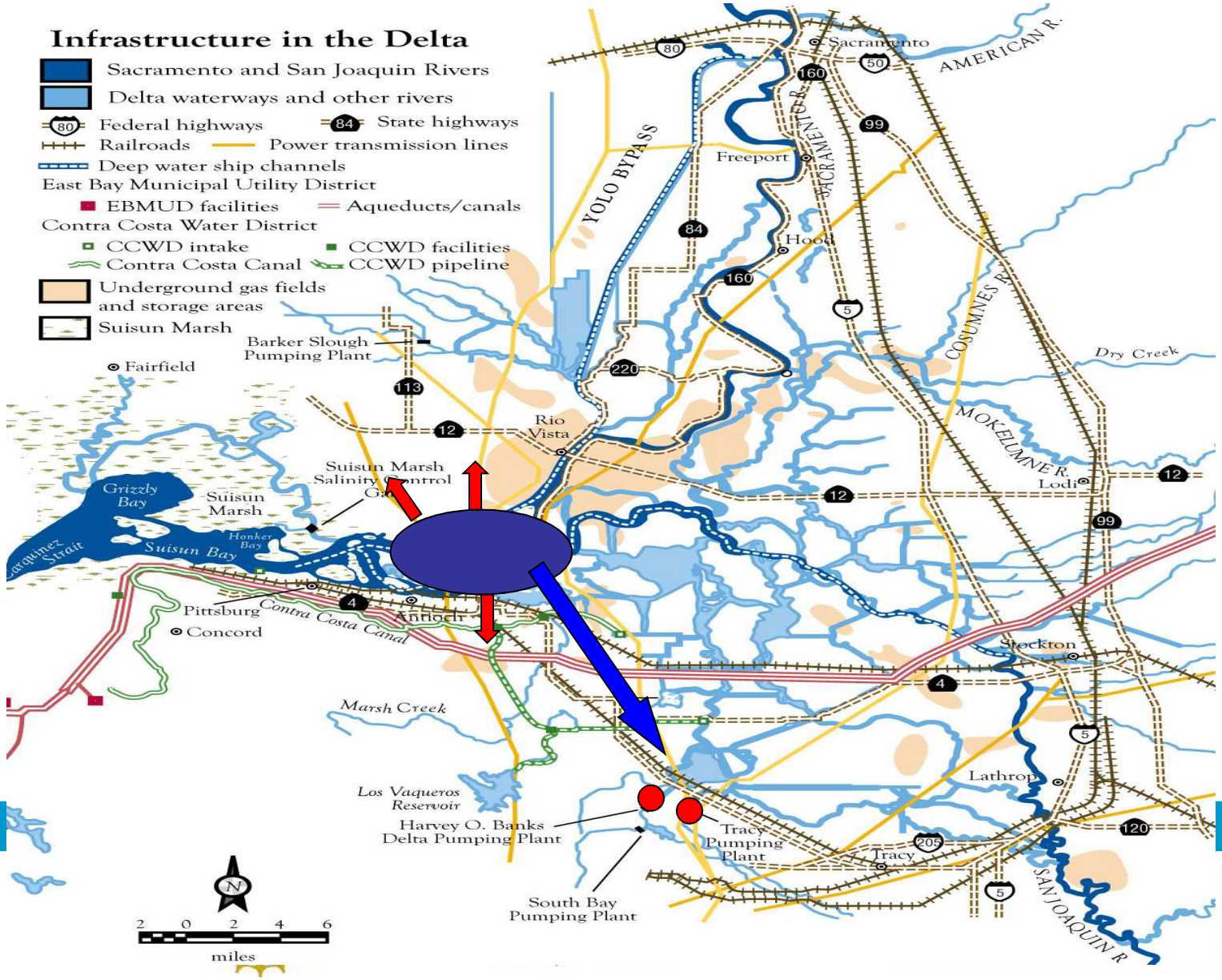
Flood proofing / resilience

Sherman Island results

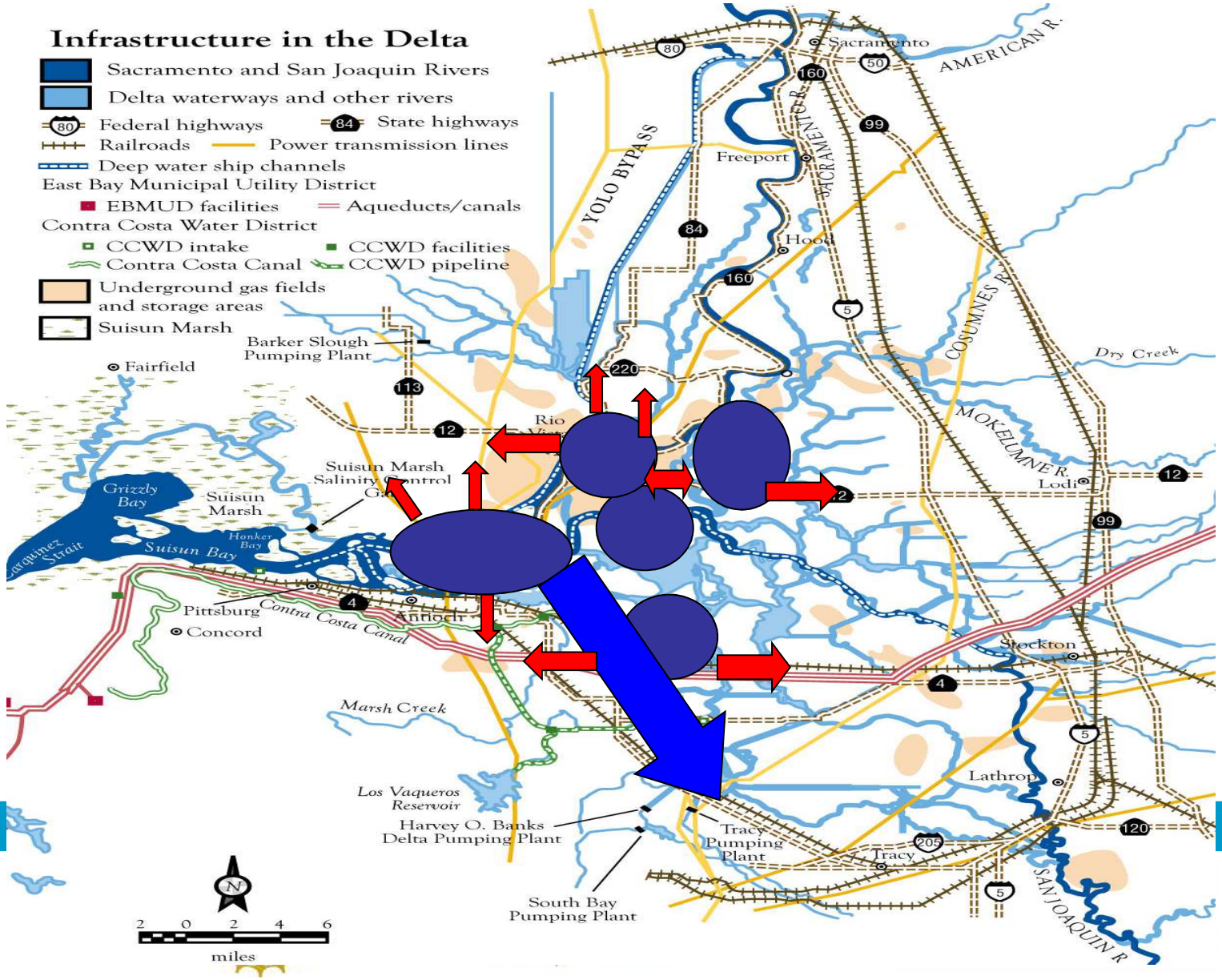
- Levee failure "adds" significant Pf to power and gas transmission systems.
- E.g. gas transmission line:
  - "normal" failure rate S.I.: 10^{-5} per year
  - Due to flooding ~10^{-2} per year
- Co-location of power and gas transmisison and number of breaches important for risk



Sherman Island: delta interactions

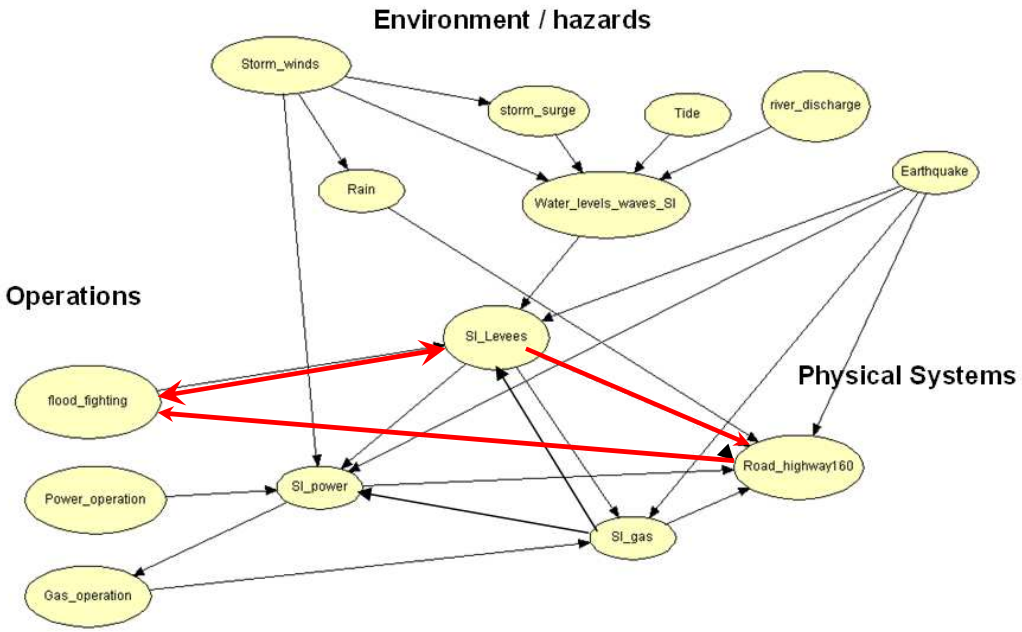


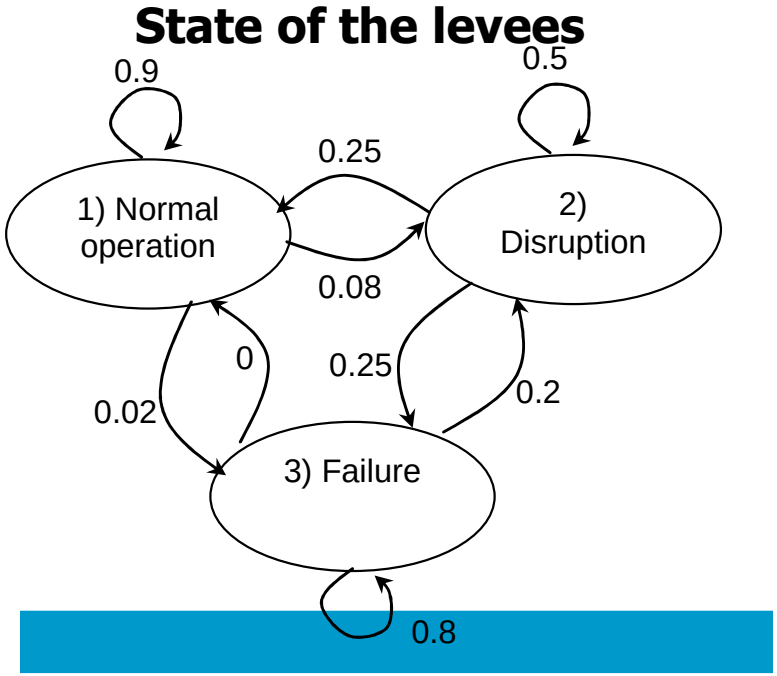
Delta scale: multiple islands flood



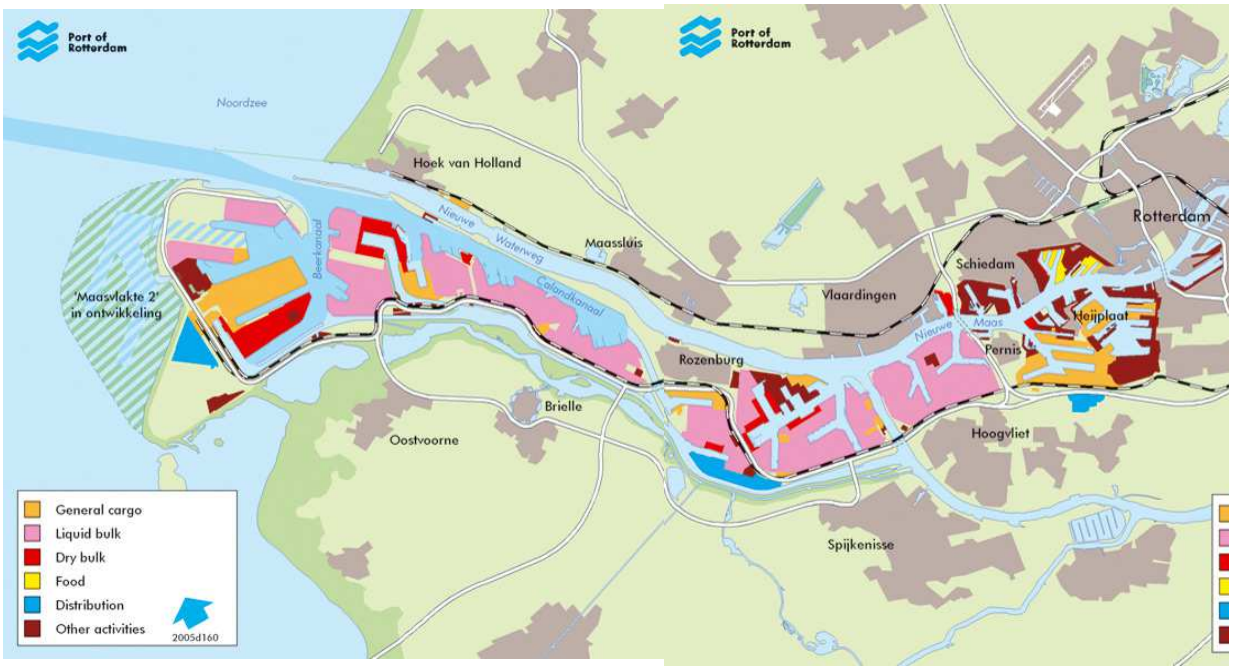
Interdepencies

- Interactions difficult to take into account in static risk assessment
- Attempt to explore Markov chains for flood fighting

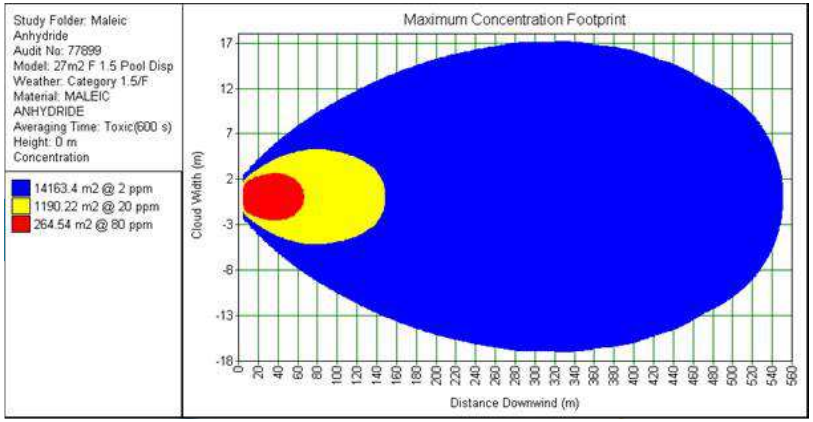


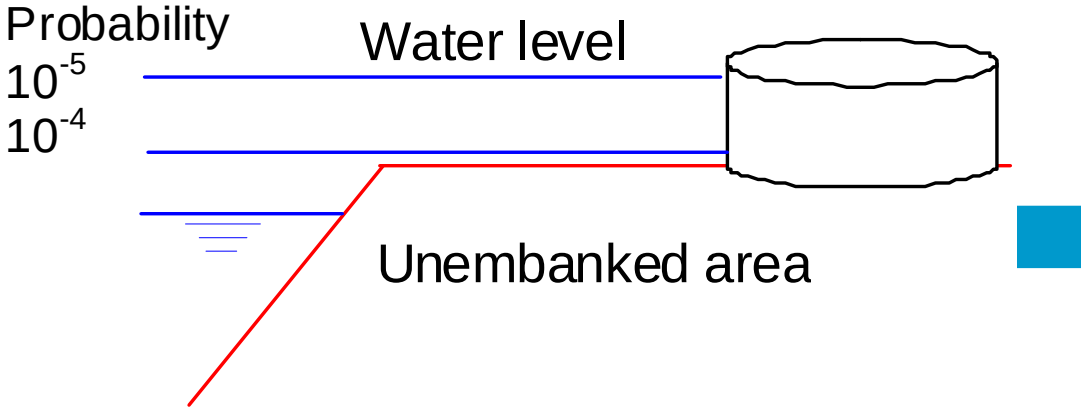


Case: Port of Rotterdam



- Analysis of vulnerability and criticality of functions
- Cascading effects of flooding
- concerns for "liquid bulk"





Concluding remarks

- Analysis of risks of interconnected systems is challenging, but important
- It is necessary to include multiple hazards and interconnections in design and management of high-reliability systems
- Cases, Levee failure leads to important risk "add-on"
  - In the CA delta
  - Critical facilities in the Netherlands
- ICIS Risk analysis requires a mix of disciplines and approaches / tools (risk analysis, phyiscal models, human organizational factors)