# Modeling Dynamic Resilience to Climate Change Caused Natural Disasters

Slobodan P. Simonović
Department of Civil and Environmental Engineering
Western University

## 2 | CONCLUSIONS

- There are practical links between disaster risk management, climate change adaptation and sustainable development
- Reduction of disaster risk and building resilience – a new development paradigm
- The greatest improvement –incorporation of land use, urban and spatial planning in disaster risk management
- Understanding of local context of vulnerability and exposure is fundamental for reducing risk

Western
UNIVERSITY · CANADA

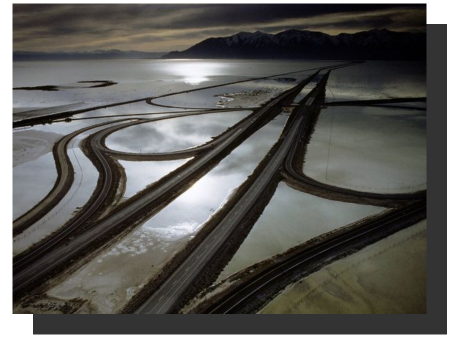
# PRESENTATION
## Outline

- Introduction
- Resilience modeling effort
  - System approach
  - Resilience measure
  - System dynamics modelling
  - City model
- Coastal Cities at Risk (CCaR) project – a snapshot
- Conclusions

Western University · Canada

# 4 | INTRODUCTION
## Needs

- Hazards from natural disasters
  - No procedures to quantify resilience
  - No procedures for comparison of communities in terms of resilience
- Resilience framework
  - Not only assessment of direct and indirect losses
  - Broader framework
- Need to move beyond qualitative conceptualizations to more quantitative measures
  - To better understand factors contributing to resilience
  - To provide for more systematic assessment of various measures to increase resilience



Western
UNIVERSITY · CANADA

# 5 | MODELING RESILIENCE
## Basics

- Definitions
  - General
    - …the ability to recover quickly from illness, change or misfortune…
    - …buoyancy…
    - …the property of material to assume its original shape after deformation…
    - …elasticity…
  - Ecology – based (Holing, 2001)
    - …the ability of a system to withstand stresses of 'environmental loading'…
  - Hazard – based
    - …capacity for collective action in response to extreme events…
    - …the capacity of a system, community, or society potentially exposed to hazards to adapt, by resisting or changing, in order to reach and maintain an acceptable level of functioning and structure…
    - …the capacity to absorb shocks while maintaining function…
    - …the capacity to adapt existing resources and skills to new situations and operating conditions…

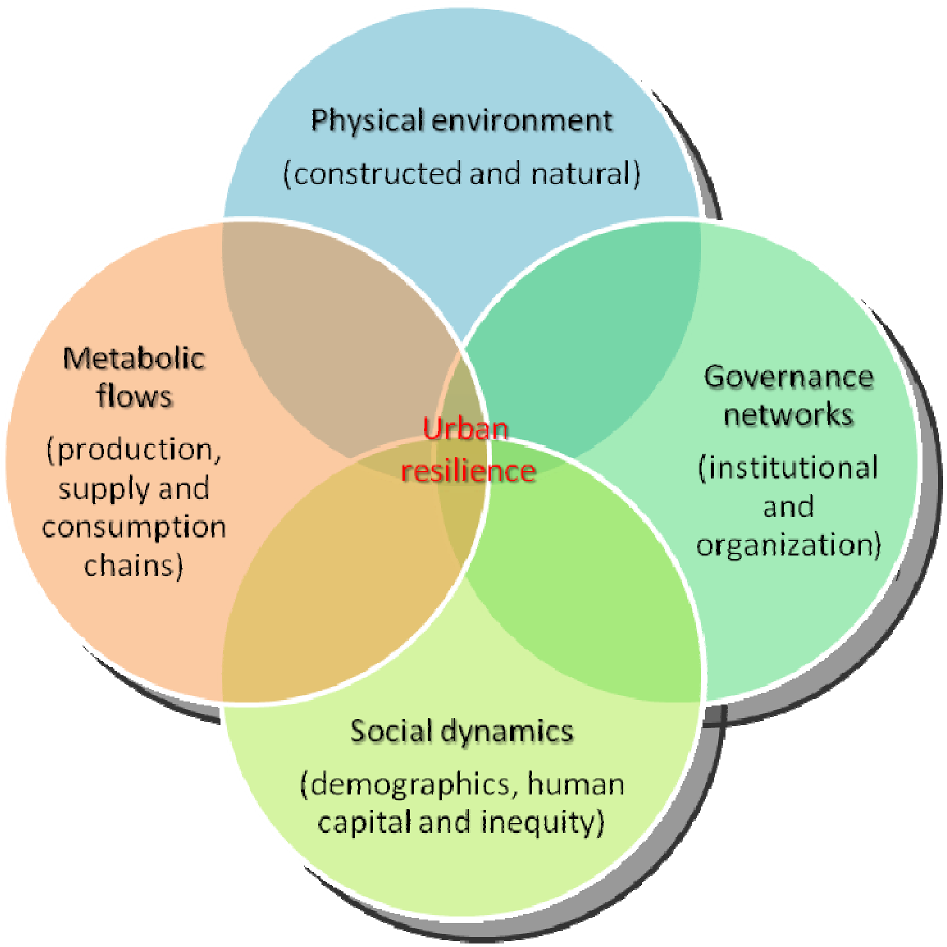
# 6 | MODELING RESILIENCE
## Basics

- Commonalities
  - …the ability to adjust to 'normal' or anticipated levels of stress
  - …the ability to adapt to shocks and extraordinary demands
  - …spanning pre-event measures and post-event strategies

- Community resilience
  - In a resilient system, change has the potential to create opportunity for development, novelty and innovation.
  - A resilient city is a sustainable network of physical (constructed and natural environment) systems and human communities (social and institutional) .

Western
UNIVERSITY · CANADA

# 7 | MODELING RESILIENCE
## Basics

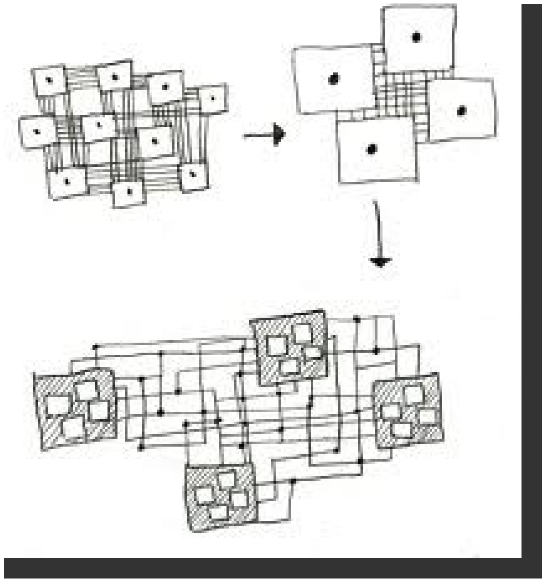



*Modified after Resilience Alliance, 2012 (www.resalliance.org)*

Western UNIVERSITY · CANADA

# 8 | MODELING RESILIENCE
## Basics

- City/Community/Urban environment – system of systems
  - Use of systems thinking to understand the behaviour of complex city systems!
  - Can we couple existing models of various aspects of the urban system to better understand resilience?
- Essential sub-systems
  - Water lifelines
  - Power lifelines
  - Acute-care hospitals
  - Emergency management organizations (firefighters, police,…)
  - Transportation lines



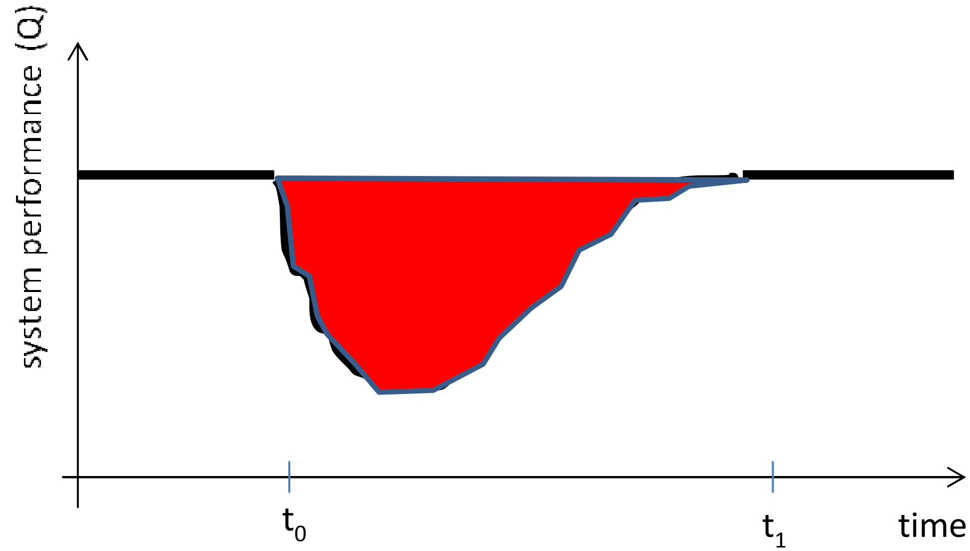
# 9 | MODELING RESILIENCE
## Measure of resilience

- Quantifying the concept of resilience
  - Performance of any system can be measured as a point in a multidimensional space of performance measures
  - The performance of a system over time can be characterized as a path through the multidimensional space of performance measures
- Broader concept of resilience
  - The ability of the system to reduce the chance of shock, to absorb a shock if it occurs and to recover quickly after a shock
  - Resilient system is one that:
    - Reduces failure probability
    - Reduces consequences from failures in terms of live lost, damage, and negative economic and social consequences
    - Reduces time to recovery (restoration of a specific system or set of systems to their 'normal' level of performance)

Western
UNIVERSITY · CANADA

# MODELING RESILIENCE

## Measure of resilience




$$R = \int_{t_0}^{t_1} [100 - Q(t)]\, dt$$

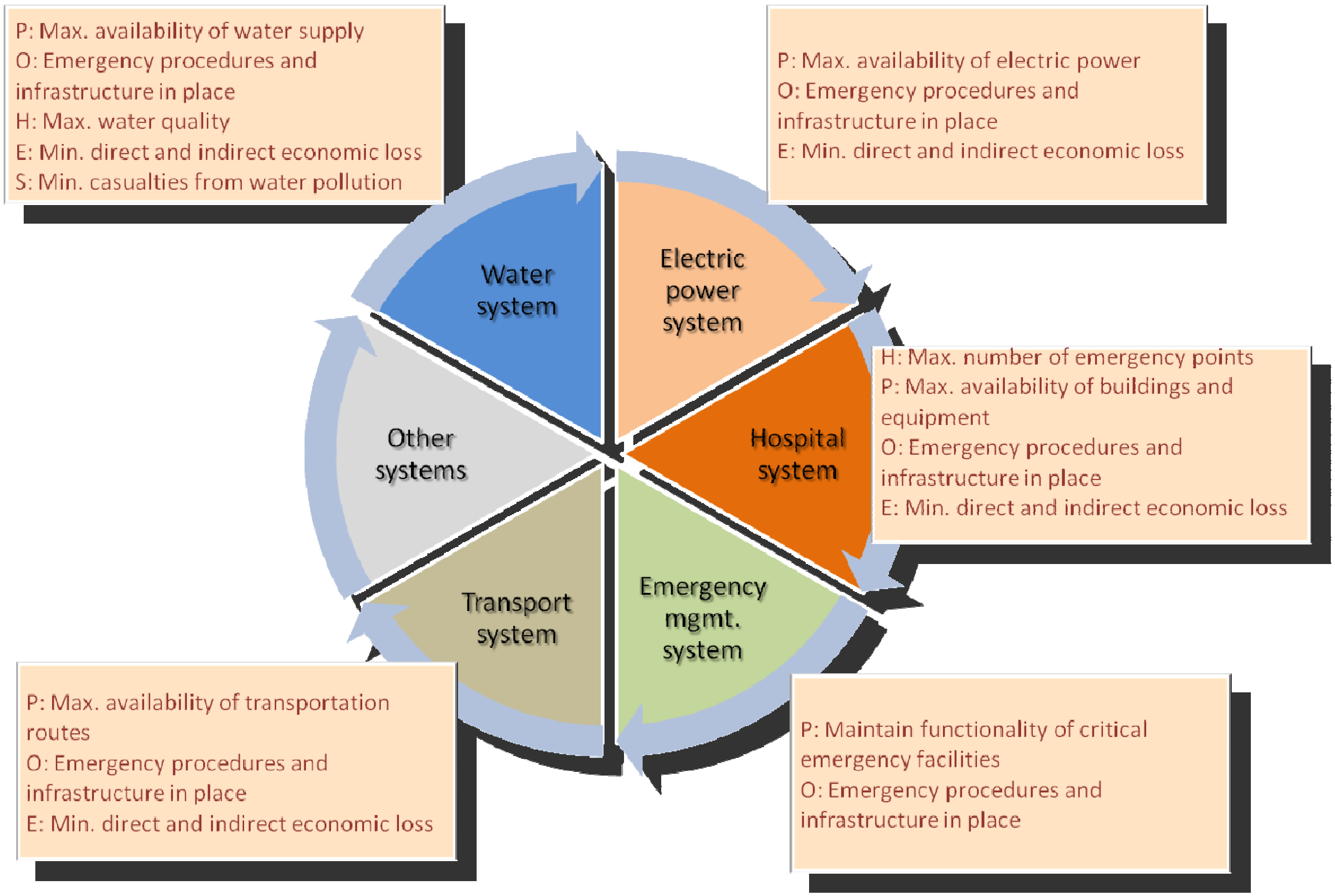
Resilience - the ability of physical and social systems to withstand disaster impacts through situation assessment, rapid response, and effective recovery strategies (measured in terms of reduced failure probabilities, reduces consequences, and reduced time to recovery)

# 11 | MODELING RESILIENCE
## Measure of resilience

- Dimensions of resilience (t, s)
  - Time
  - Space
- Properties of resilience (physical and social systems) – AC
  - Robustness
  - Redundancy
  - Resourcefulness
  - Rapidity
- Units of community resilience analysis - PHEOS
  - Physical
  - Health
  - Economic
  - Organizational
  - Social

# MODELING RESILIENCE

## Measure of resilience



# MODELING RESILIENCE

## Measure of resilience

General definition

$$R = \int_{t_0}^{t_1} [100 - Q(t)]\, dt$$

Representation of dimensions and properties

$$R(t,s) = f(E(t,s), V(t,s), AC(t,s))$$

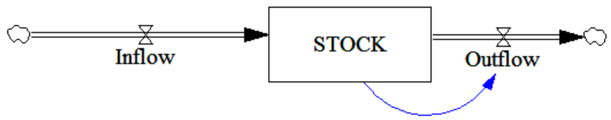
Integration of resiliency units (PHEOS)

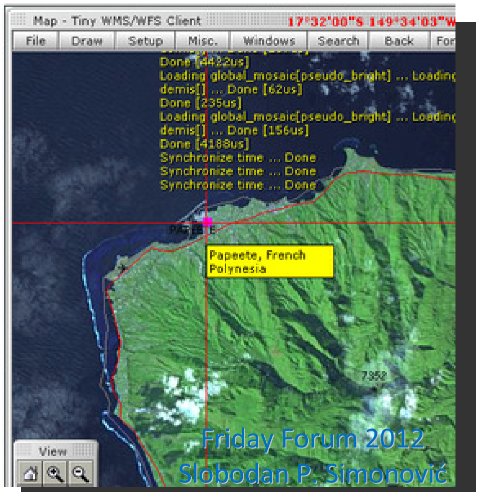
$$R\,(t,s) = \Big(\prod_{i=1}^{M} \gamma^{i}(t,s)\Big)^{\frac{1}{M}}$$

Western UNIVERSITY · CANADA

# MODELING RESILIENCE
## Implementation

- Implementation
  - Temporal dynamics – System dynamics simulation
  - Spatial dynamics - GIS
- System dynamic simulation
  - A rigorous method of system description, which facilitates feedback analysis via a simulation model of the effects of alternative system structure and control policies on system behavior
- GIS
  - An information system that integrates, stores, edits, analyzes, shares, and displays spatial information for informing decision making.

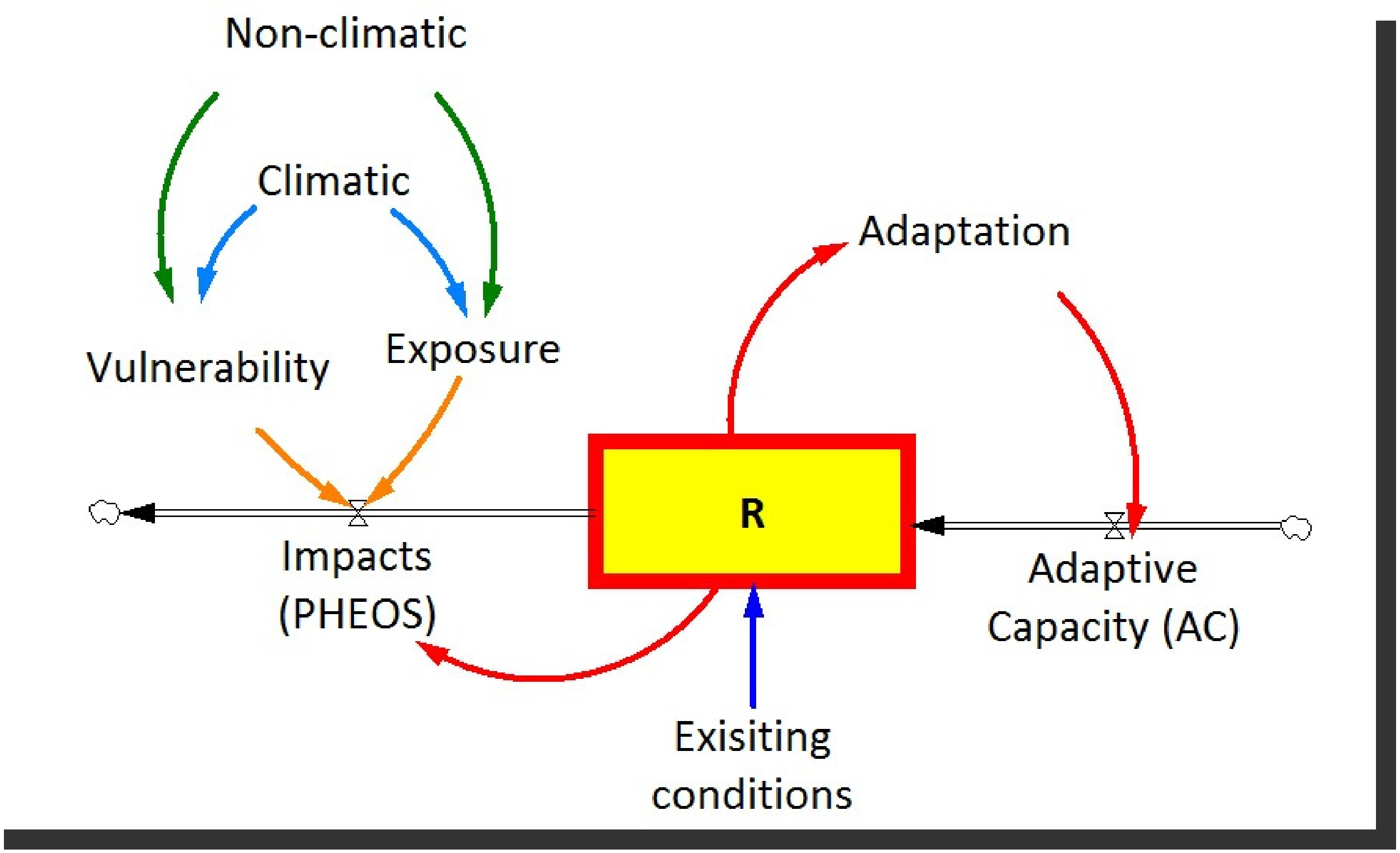



Western
UNIVERSITY · CANADA

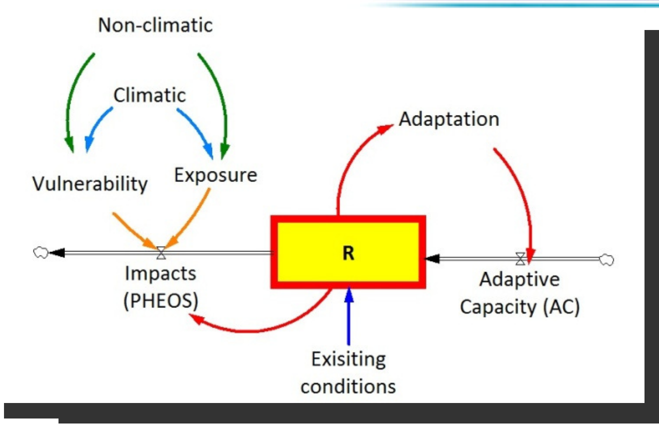
# 15 | MODELING RESILIENCE

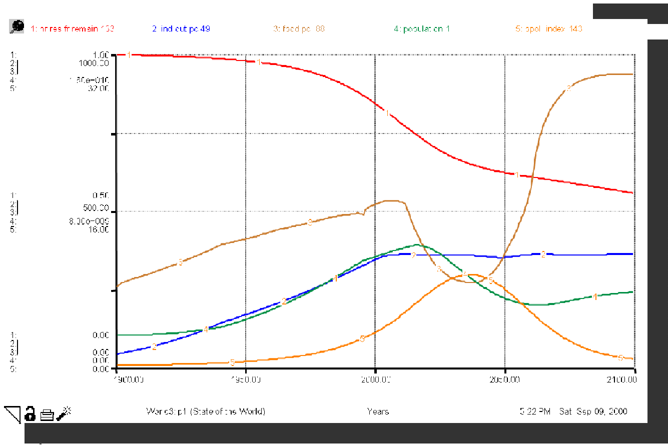
## City resilience simulator



# MODELING RESILIENCE

## City resilience simulator



Temporal dynamics

SD ⟺ GIS

dynamic data exchange

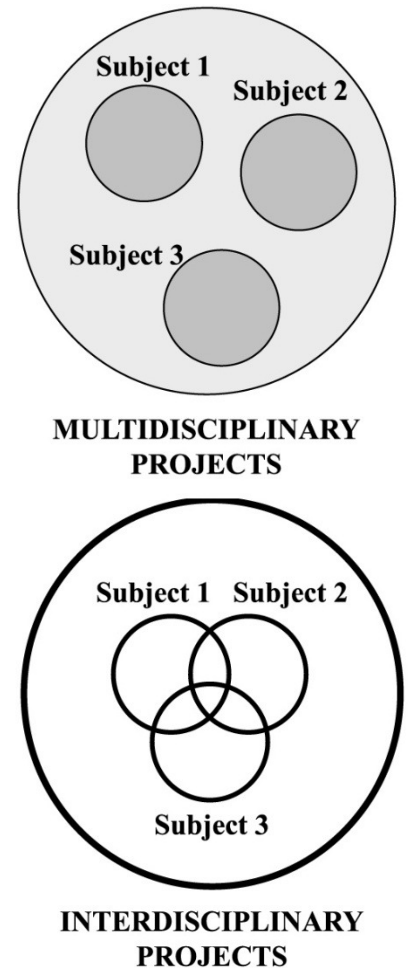
Spatial dynamics

Western
UNIVERSITY · CANADA

- Project: Coastal Cities at Risk (CCaR) - Building Adaptive Capacity for Managing Climate Change in Coastal Megacities
- Coastal megacities under stress
  - Population growth
  - Economic development
  - Social problems
  - Health issues
  - Cultural difficulties
- Climate change and coastal megacities
  - Seal level rise
  - Storm surges
  - Flooding
  - High disaster risk
  - Increase in social, health and economic vulnerability

# 18 | CCaR Project

- Project objectives
  - Knowledge base development
  - Enhancement of adaptive and copping capacity
- Interdisciplinary approach
  - Natural sciences
  - Engineering
  - Social sciences
  - Health sciences
- Methodology
  1. Characterization of vulnerability and risk
  2. Characterization of hazards
  3. Understanding decision making
  4. Development of SD resilience simulator
  5. Development of response strategies
  6. Knowledge transfer and capacity building




Western
UNIVERSITY · CANADA

# MODELING RESILIENCE

## Following steps

- Completed work
  - Development of resilience framework
  - Development of resilience measure
  - Training of international partners
- Current work
- Model development
- Integration of SD and GIS
- Future work
- Vancouver City Model
- Transfer of generic City model
- Assistance in development of Bangkok City Model, Manila City Model and Lagos City Model
- Adaptation scenarios
- Model simulations
- Model results analyses

# 20 | Bangkok
October 25, 2011

- Floods of 2011
  - The largest in half a century
  - 550 $m^3$ million/day
  - Chao Phraya basin under water
  - In the city up to 1.5 m of flooding (including airport)
- Close to 600 dead, over 120,000 in shelters, and close to 800,000 in need of medical attention
- Damage US$40 billion
- 7 industrial estates and 1250 factories flooded
- 2.5% drop in national GDP

*Courtesy of Dr. Wijitbusaba Marome*

# 21 | LAGOS
July 10, 2011

- Storm of 2011
  - Over 16 hr of un-interrupted rain (named “rain of terror”)
  - 233.3 mm
  - Unusually high tide
  - Channels blocked
- 25 lives lost
- Many properties lost or damaged (largest insured flood damage in history of Nigeria)
- Estimated loss US$200 million
  - Roads of the megalopolis under 1 – 1.5 m of water
  - Airport flooded
  - Social and economic activities disrupted for many days

*Courtesy of Dr. Ibidun Adelekan*

Western UNIVERSITY · CANADA

# 22 | MANILA
Sep 27, 2011

- Manila Nesat typhoon of 2011
  - Rain from 650 km cloud band
  - Winds up to 194 km/h
  - Physical and human caused flooding (subsidence, sedimentation, aging and insufficient infrastructure,…)
  - 1m deep water throughout the city
- 55 people killed
- More than 100,000 affected (1M without electricity)
- 43,000 homes destroyed
- Over US$300 million damage
- Six-lane highway a huge brown river
- Neck-deep waters on the ground floor of the Manila Hospital
- ...” It's flooded everywhere. We don't have a place to go for shelter”...
- ...and one week later typhoon Nalgae

*Courtesy of Dr. Antonia Yulo Loyzaga*

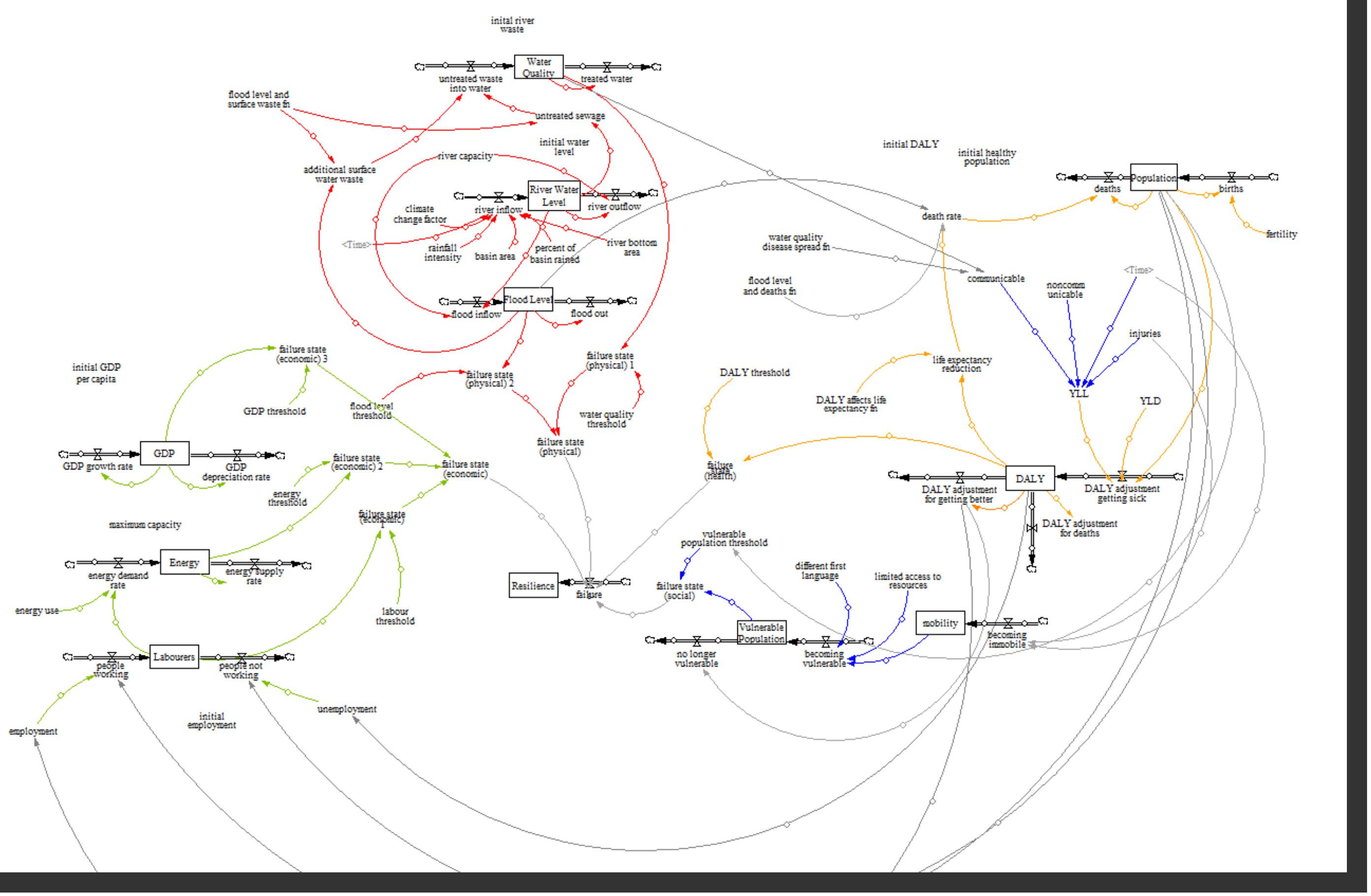
Western
UNIVERSITY · CANADA

# Vancouver
November 27, 2011

- Storm of 2011
  - 150 mm of rain over the weekend
  - Wind up to 110 km/hr
- Flood advisory and storm warnings issued
- Cancellations of BC Ferries sailings
- The Corporation of Delta – emergency operations
- BC Hydro – outages and service interruptions

# 24 | MODELING RESILIENCE

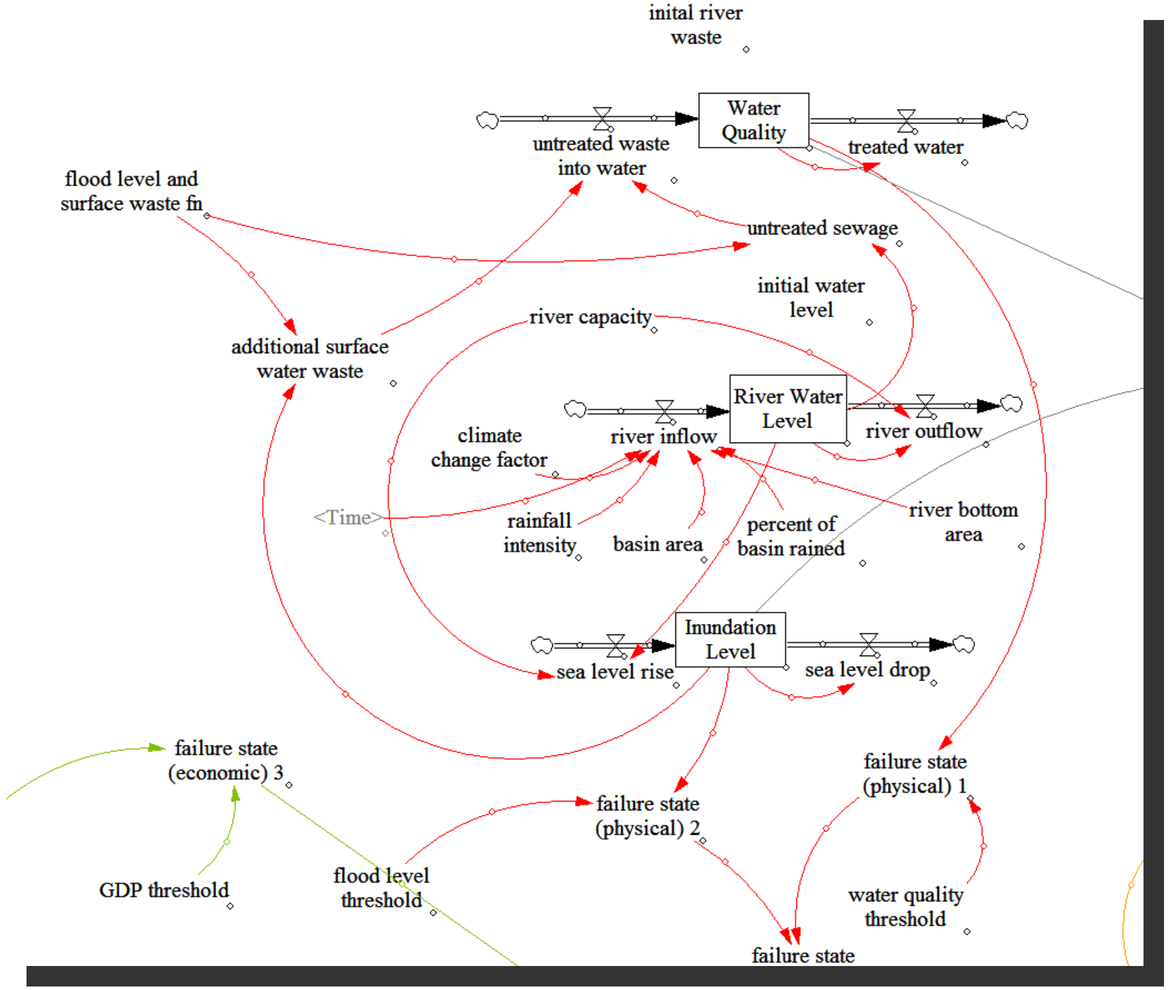
## City resilience simulator – ver 1




Western
UNIVERSITY · CANADA

# MODELING RESILIENCE

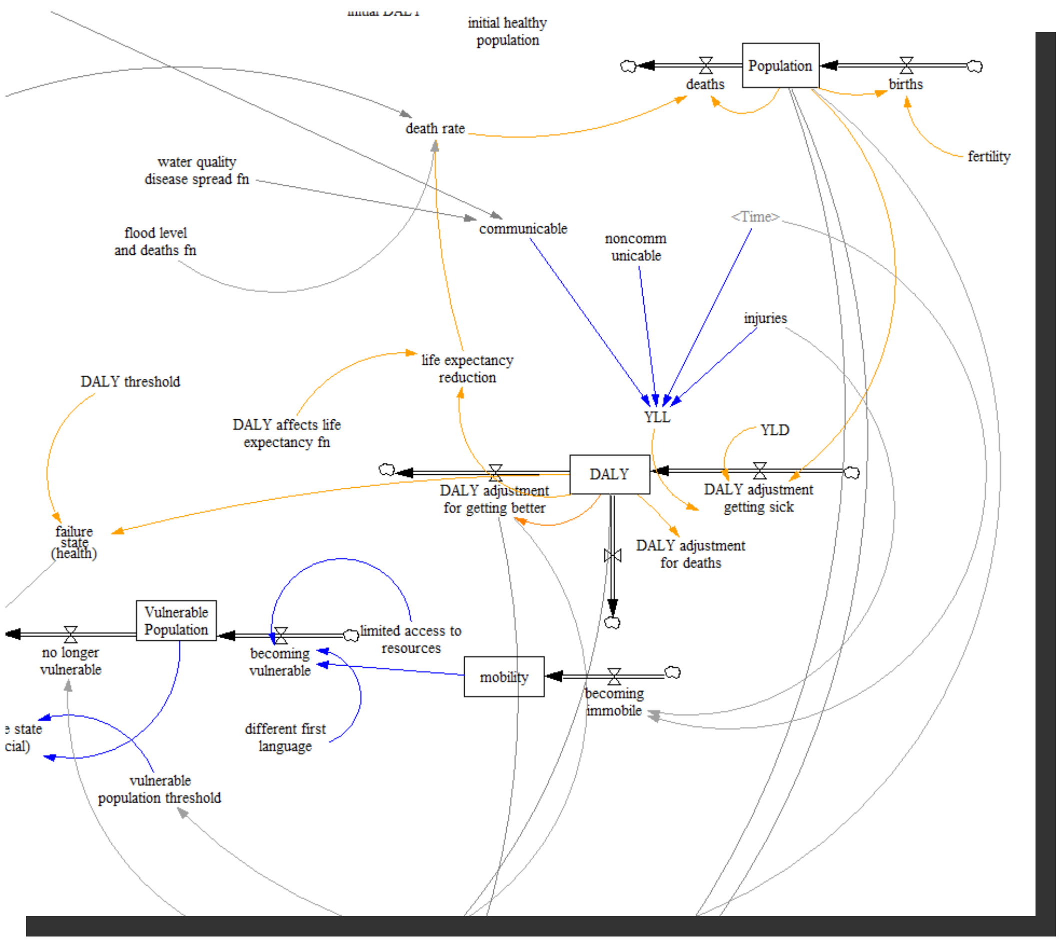
## City resilience simulator – ver 1




Friday Forum 2012
Slobodan P. Simonović

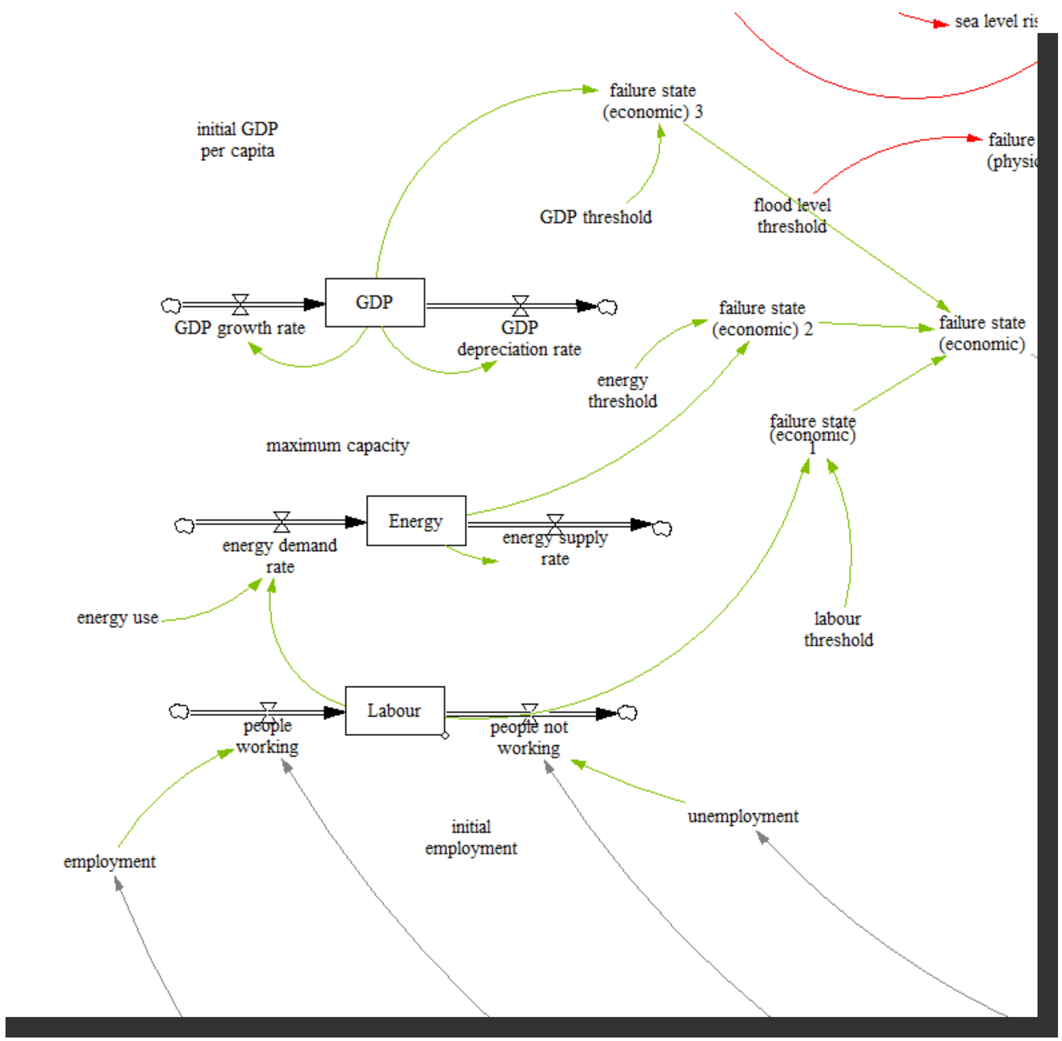
# 26 | MODELING RESILIENCE

## City resilience simulator – ver 1



# MODELING RESILIENCE

## City resilience simulator – ver 1



# MODELING RESILIENCE

## Model data needs

- Data needs – time series

*Other*

Details related to water infrastructure, coastal infrastructure types, properties and maintenance

Disaster response plans and emergency management provisions

Details pertaining to expected disaster aid

*Physical*

Local climate patterns

Hazard data (historical and predicted)

Damage data

*Economic*

City-wide economic data including: imports and exports of goods, provision of services, production

Gross Domestic Product (GDP)

Work and labour data – employment statistics; jobs data

Energy production, consumption and distribution data

*Social*

Population statistics

Behavioural data (culture, religion, etc) related to disaster preparedness, response, recovery and adaptation

*Health*

Local disease data and statistics

DALY values

Mobility data (impact of local diseases on mobility)

Infection data (onset time, rate , duration of infection

Vaccination availability for communicable diseases

Model data needs

- Data needs – spatial information

*Other*

Digital Elevation Models (DEMs)

Digital boundary files; define geographic area of interest

Water features (rivers, lakes, oceans, ponds etc.)

Land cover data (trees, grass, sand, etc.)

Land use data (agricultural, industrial, commercial, residential, etc.)

Hydrological surveys of coast and rivers

*Physical*

Spatial distribution of hazards (area affected)

*Economic*

Fine resolution economic data (focus on locations)

Distribution of wealth

Energy distribution system

*Social*

Population characteristics;

  Age (population under 19; population aged 65 and over; etc)

Gender (female population; ethnicity, etc)

Social status (average dwelling value; household income; incidence of low income; population who rent; etc)

  Education (population with high school education; population with university education; etc)

  Household arrangement (single-parent families; female-headed single-parent families; etc)

  First language

# CONCLUSIONS

- There are practical links between disaster risk management, climate change adaptation and sustainable development
- Reduction of disaster risk and re-enforcing resilience as a new development paradigm
- The greatest improvement – disaster risk management incorporation in land use, urban and spatial planning
- Understanding of local context of vulnerability and exposure is fundamental for reducing risk

# RESOURCES

www.slobodansimonovic.com

Research -> FIDS -> Research projects