# RESILIENCE
# A New Metric for the Assessment of Measures for Adaptation to Global Change

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# 2 | CONCLUSIONS

- There are practical links between adaptation to global change and sustainable development leading to:
  - re-enforcing resilience as a new development paradigm
- The main goal of Regional Resilience Assessment Program in Canada and US is to identify and analyze the resilience and interdependencies of water sectors using an all-hazards approach
- Systems approach to quantification of resilience allows:
  - capturing temporal and spatial dynamics of water resources management
  - better understanding of factors contributing to resilience
  - more systematic assessment of various measures to increase resilience

# 3 | PRESENTATION OUTLINE

- Introductory remarks
- From risk to resilience
    - Limitations of risk management
    - Definition of resilience
    - Quantification of resilience
    - Implementation of quantitative resilience measure
        - Systems approach (simulation, time and space)
- Examples
    - Climate change caused urban flooding
    - Multi purpose reservoir operation
    - Urban infrastructure network system
- Conclusions

# 4 | INTRODUCTION
Research support

*Principal investigator*

- Systems Engineering Approach to the Reliability of Complex Hydropower Infrastructure
  - NSERC CRD with BC Hydro: 2014-2018 **$673,334**
- Linking Hazard, Exposure and Risk Across Multiple Hazards
  - NSERC CRD with Chaucer Synd.: 2015-2019 **$1,375,600**

*Co-investigator*

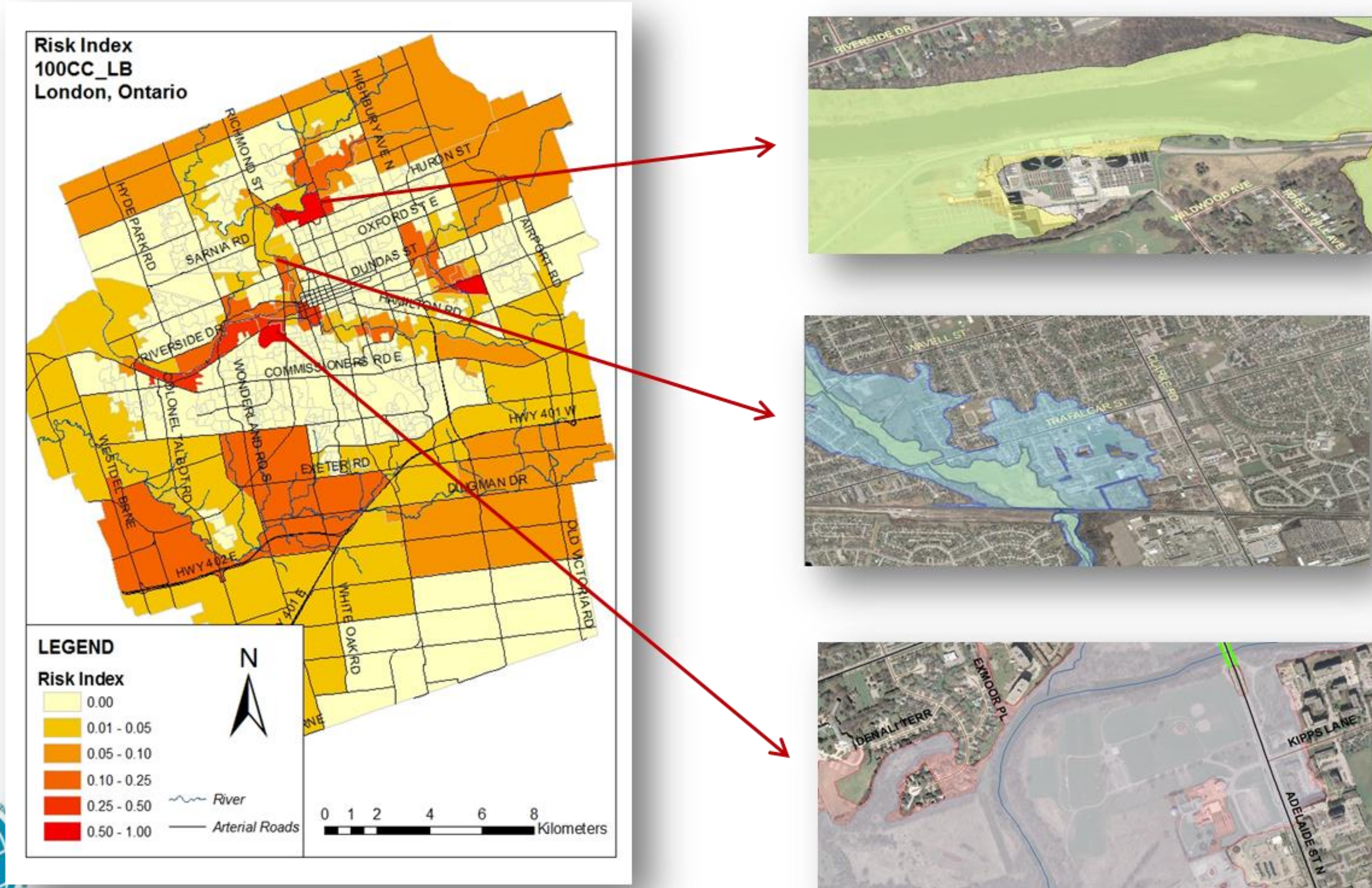
- Coastal Cities at Risk (CCaR): Building Adaptive Capacity for Managing Climate Change in Coastal Megacities
  - IDRC - International Research Initiative on adaptation to Climate Change: 2011 – 2016 $2,500,000
- Advanced Disaster, Emergency and Rapid Response Simulation
  - NSERC CREATE: 2015-2021 $1,650,00

# INTRODUCTION
## Global change

- Global change
  - Population growth
  - Land use change
  - Climate change
  - Complexity and uncertainty
- Infrastructure systems (hard)
  - Water
  - Energy
  - Transport
  - Communications
- Infrastructure (soft)
  - Institutional
  - Social
  - Cultural

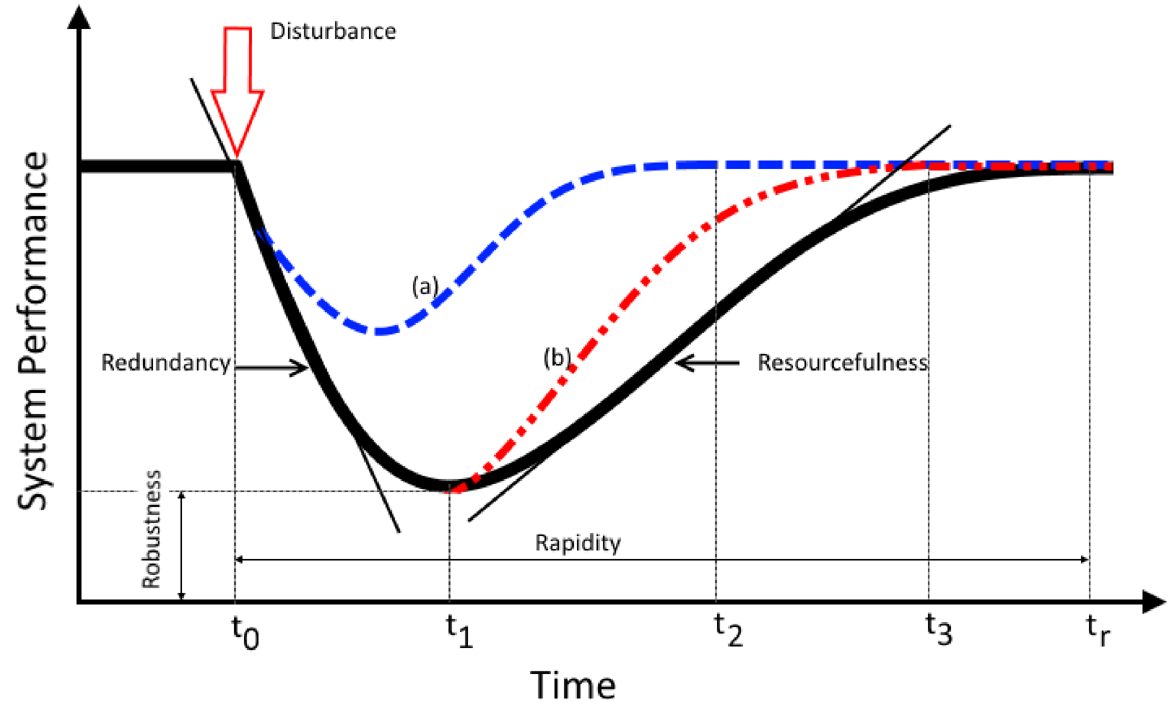
# 6| RISK TO RESILIENCE

## Need for paradigm change



# RISK TO RESILIENCE

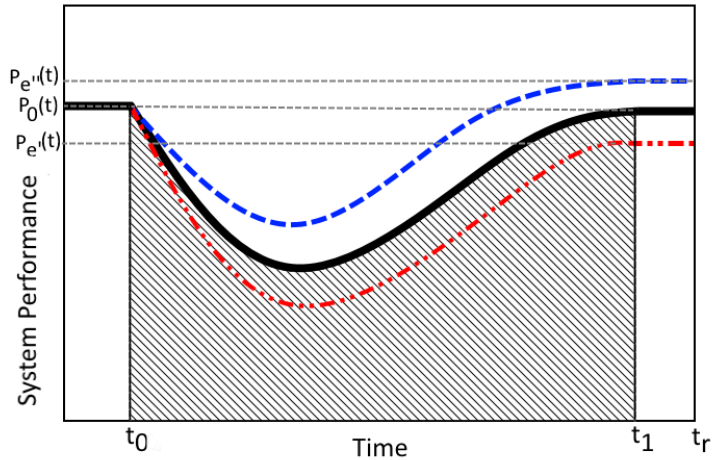
## Need for paradigm change

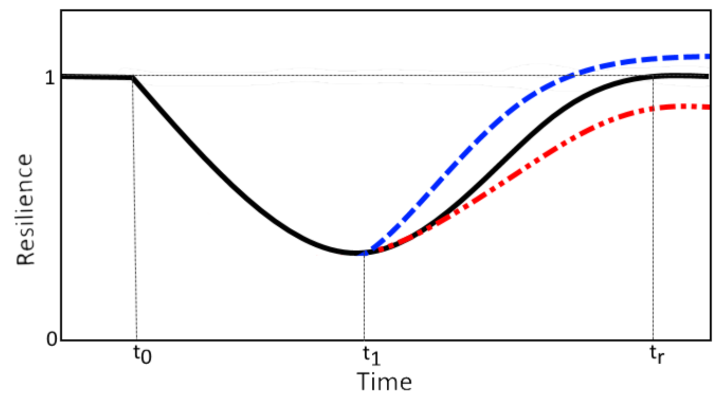


# RESILIENCE
## Definitions

- Latin origin *resilire, resilio* – bounce
- Mechanics – strength and ductility of steel beams (Rankin, 1867)
- Systems theory - ecology (Von Bertalanffy, 1950; Holling, 1973)
    - …measure of he persistence of systems and their ability to absorb change and disturbance and still maintain the same relationships between populations or state variable…
- Hazard – based
    - …capacity for collective action in response to extreme events…
    - …the capacity to absorb shocks while maintaining function…
    - …the capacity to adapt existing resources and skills to new situations and operating conditions…
- Used in this research –after UNISDR (2009)
    - …the ability of an infrastructure system and its component parts to absorb, accommodate or recover from the effects of a system disruption in a timely and efficient manner, including through the preservation, restoration or improvement of its essential basic structures and functions…
    - System performance and system adaptive capacity

# 9| RESILIENCE
Quantification




- System performance and system adaptive capacity
- Transformation of system performance into resilience

# RESILIENCE
## Quantification

$$\rho^i(t,s) = \int_{t_0}^{t} [P_0^i - P^i(\tau,s)]d\tau$$

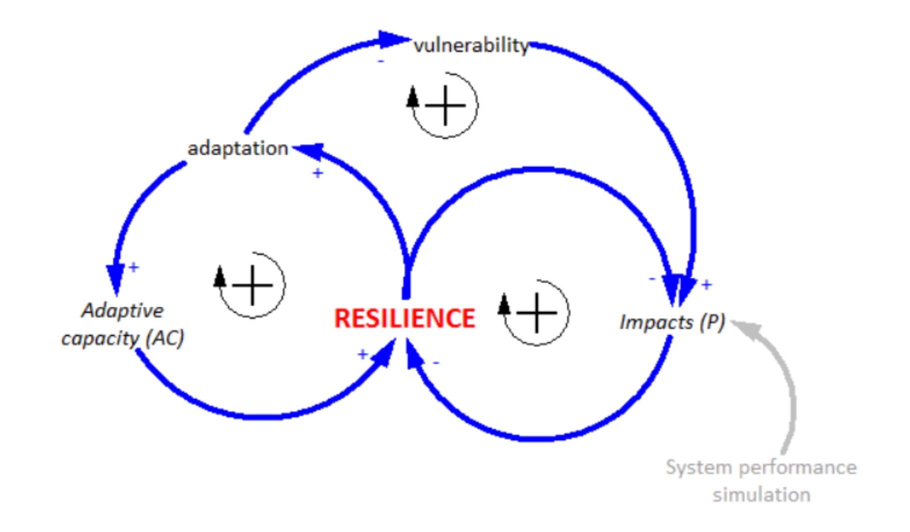
$$r^i(t,s) = 1 - \left(\frac{\rho^i(t,s)}{P_o^i \times (t - t_o)}\right)$$

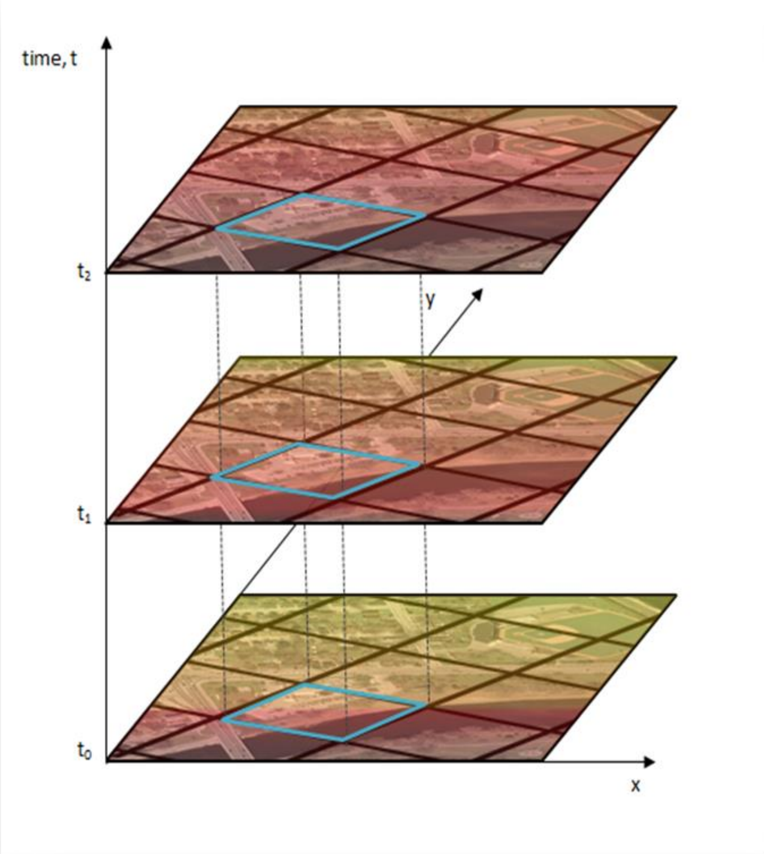
$$R(t,s) = \{\prod_{i=1}^{M} r^i(t,s)\}^{\frac{1}{M}}$$

$$\frac{\partial R(t,s)}{\partial t} = \prod_{i} [AC^i(t,s) - P^i(t,s)]$$

$$where\ t \in [t_0, t_r]$$

# 11 | RESILIENCE
## Implementation – temporal and spatial dynamics

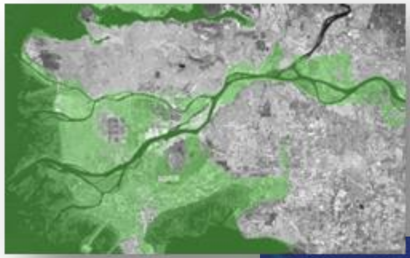


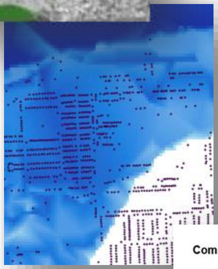



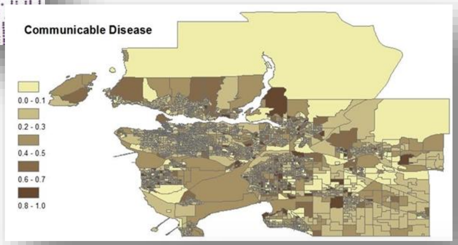
# EXAMPLE 1

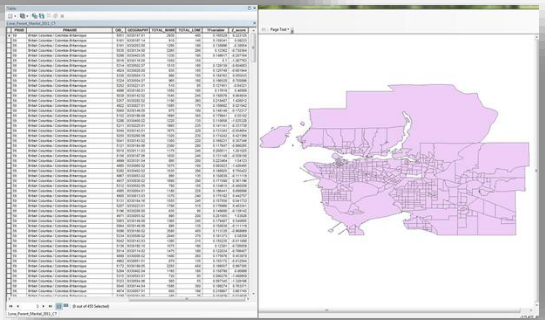
## Climate change caused urban flooding

- Vancouver
  - Sea level rise
  - Riverine flooding
  - Set of climate scenarios
- Impacts (*i*)
  - Physical
  - Social
  - Health
  - Economic

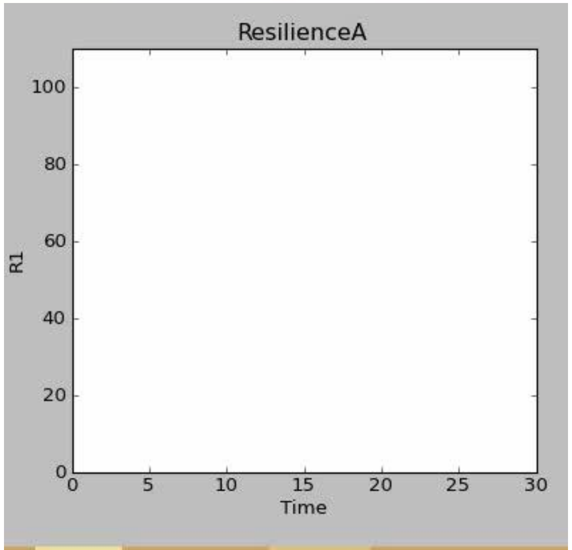


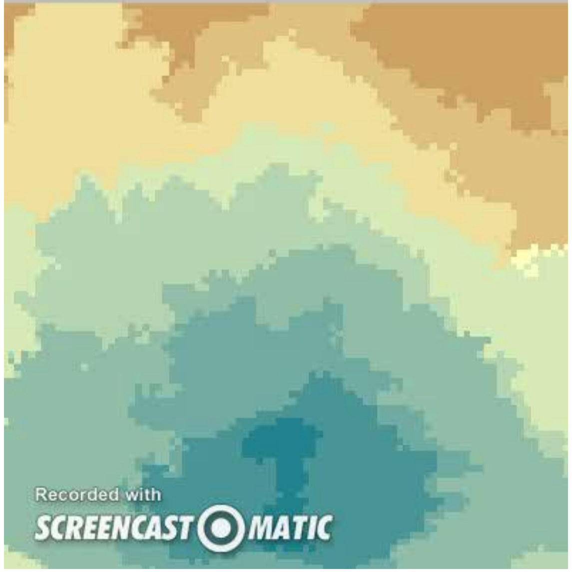




# EXAMPLE 1
Climate change caused urban flooding



# 14 | EXAMPLE 2

## Multi purpose reservoir operation

- Reservoir (BC Hydro)
  - Hydropower production
  - Water supply
- Continuity

$$S_t = S_{t-1} + I_t - TR_t - O_t - SP_t$$

- Power production

$$P_t = \gamma * PR_t * \eta * (E_t - E_{TL})$$

- System performance

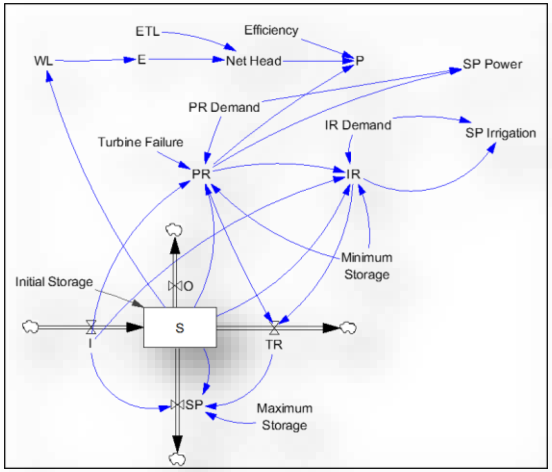
$$SP_{p,t} = \frac{PR_t}{PR_t^{demand}} \quad SP_{i,t} = \frac{WS_t}{WS_t^{demand}}$$

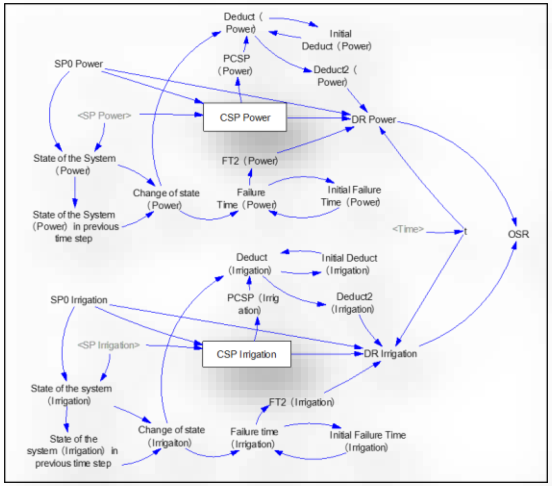
- Resilience

$$CSP_{i,t} = \int_{t0}^{t} [SP_{i,0} - SP_{i,t}]\, dt$$

$$DR_{i,t} = 1 - \left(\frac{CSP_{i,t}}{SP_{i,0} \times (t - t_0)}\right)$$

$$SR_t = \left[\prod_{i=1}^{I} DR_{i,t}\right]^{\frac{1}{I}}$$

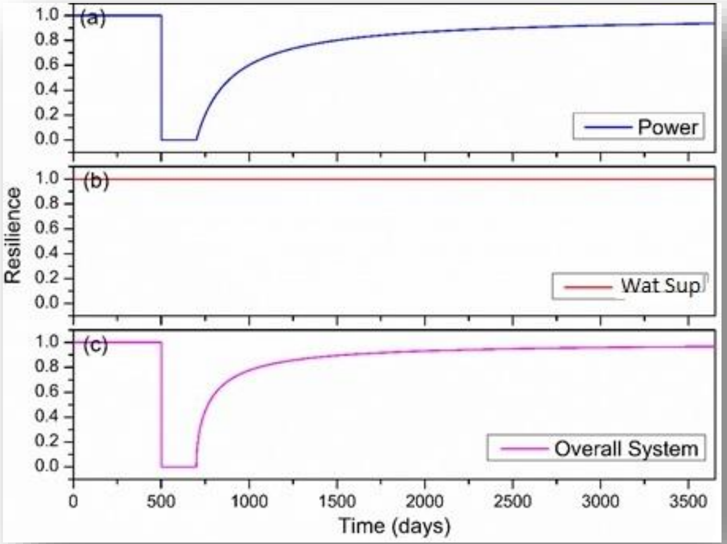


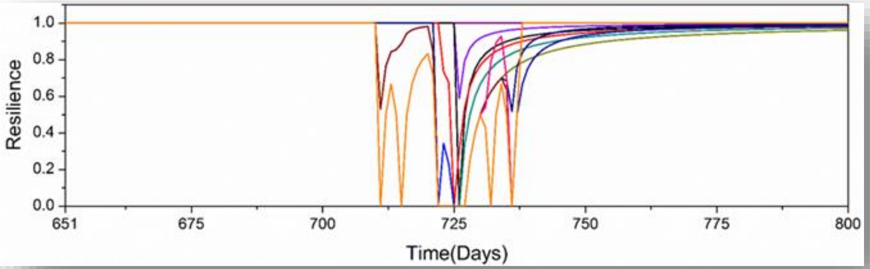



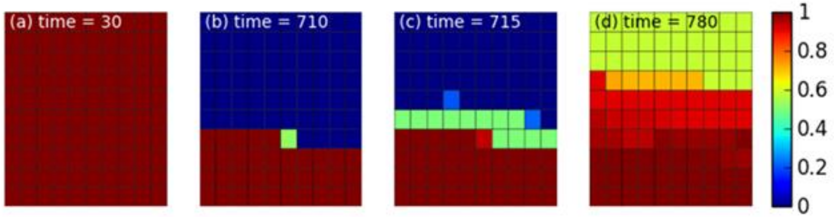
# EXAMPLE 2

Multi purpose reservoir operation

- Turbine failure
  - Single event
  - Temporal variability
  - No spatial variability
- Water scarcity
  - Water supply
  - Temporal and spatial variability

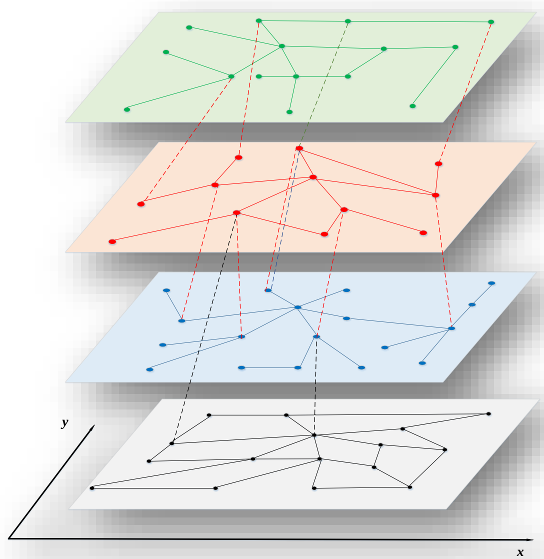


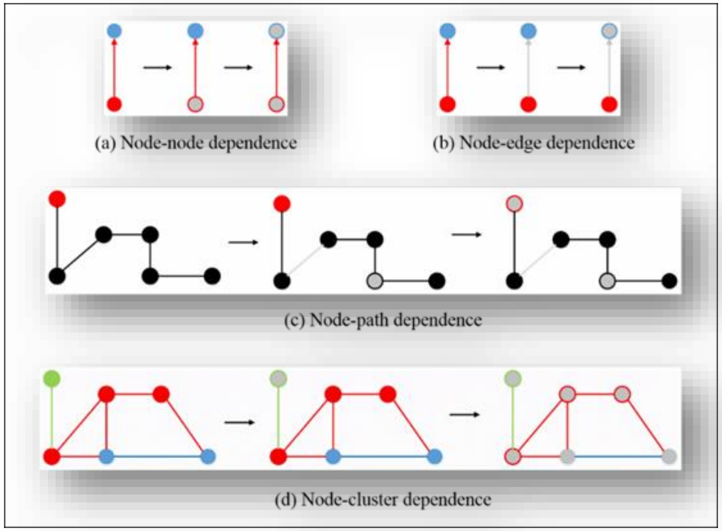



# EXAMPLE 3

## Urban infrastructure network system



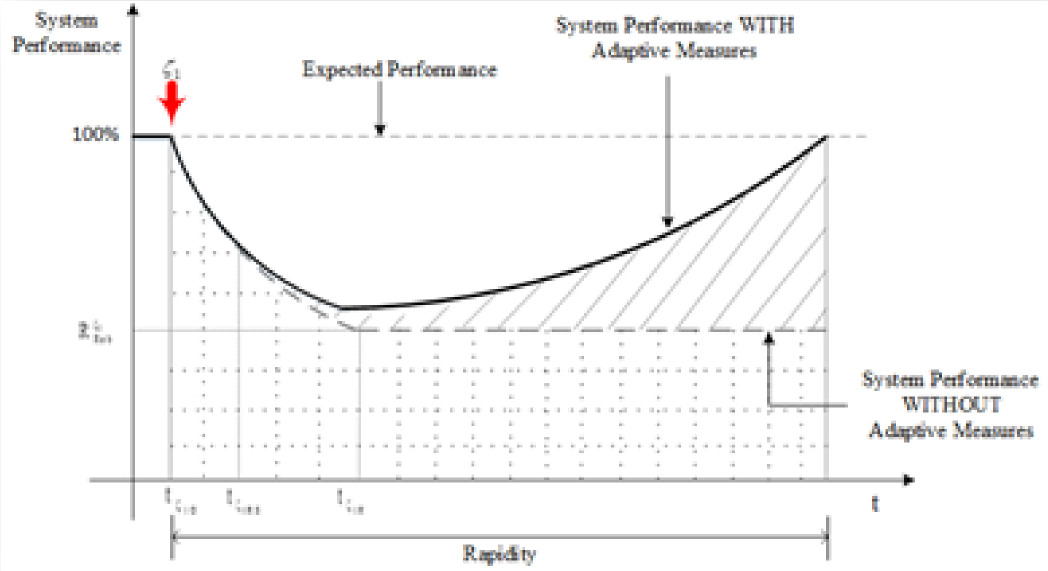




- Four layers:
  - **Streets**
  - **Water supply**
  - **Energy supply**
  - **Information**
- Nodes and edges (two states)
- Intra and interconnections
- Single and multiple disasters

- Five recovery strategies
  - First repair first failures
  - First repair last failures
  - First repair important components independently
  - First repair the obvious dependent elements
  - First repair the hidden dependent elements

# 17 | EXAMPLE 3

## Urban infrastructure network system




$$R^{\zeta_1}_{Rob}(t_{\zeta_{1RM}}) = \frac{\sum_{\phi}\left(n^{\phi}_{o}(t_{\zeta_{1RM}}) + e^{\phi}_{o}(t_{\zeta_{1RM}})\right)}{\sum_{\phi}(N^{\phi} + E^{\phi})}$$

$$R^{\zeta_1}_{Res}(t) = \int_{\phi} f\left(RS^{\phi,\zeta_1}(t)\right)$$

$$R^{\zeta_1}_{Rap} = \max\left\{R^{\phi,\zeta_1}_{Rap}(t)\right\}$$

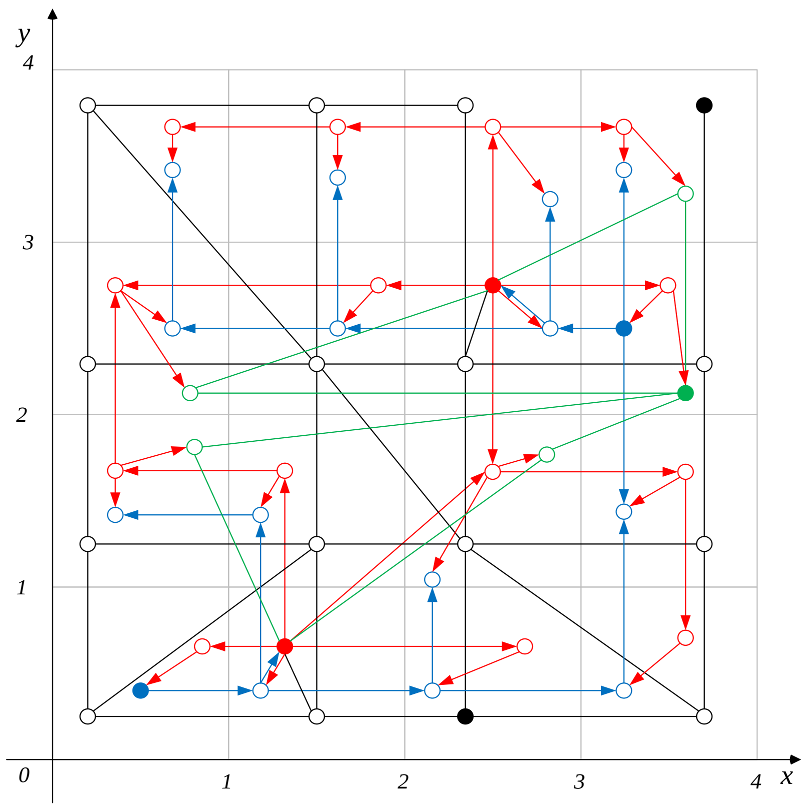
$$r^{\zeta_1}_{\phi} = \rho^{\phi,\zeta_1}_{PA} + \rho^{\phi,\zeta_1}_{RR} = \frac{\int_{R^{\varphi,\zeta_1}_{Rap}} SP^{\phi,\zeta_1}_{0}(t)}{1\times R^{\phi,\zeta_1}_{Rap}} + \frac{\int_{R^{\varphi,\zeta_1}_{Rap}} (R^{\phi,\zeta_1}_{Res}(t)\text{-}SP^{\phi,\zeta_1}_{0}(t))}{1\times R^{\phi,\zeta_1}_{Rap}}$$

$$r^{\zeta_1} = \rho^{\zeta_1}_{PA} + \rho^{\zeta_1}_{RR} = \frac{\int_{\phi}\int_{R^{\varphi,\zeta_1}_{Rap}} SP^{\phi,\zeta_1}_{0}(t)}{1\times R^{\zeta_1}_{Rap}} + \frac{\int_{\phi}\int_{R^{\varphi,\zeta_1}_{Rap}} (R^{\phi,\zeta_1}_{Res}(t)\text{-}SP^{\phi,\zeta_1}_{0}(t))}{1\times R^{\zeta_1}_{Rap}}$$

# 18 | EXAMPLE 3

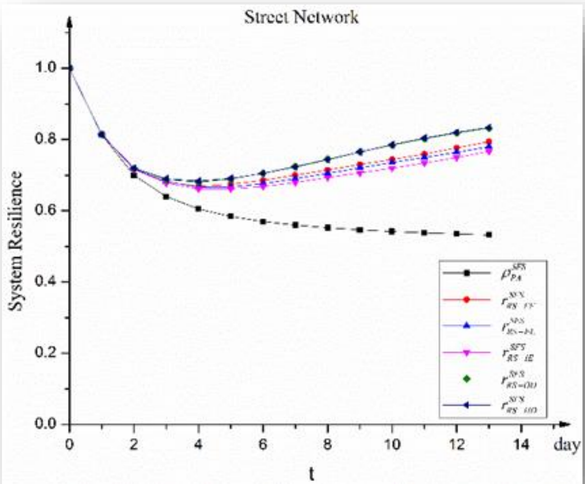
## Urban infrastructure network system

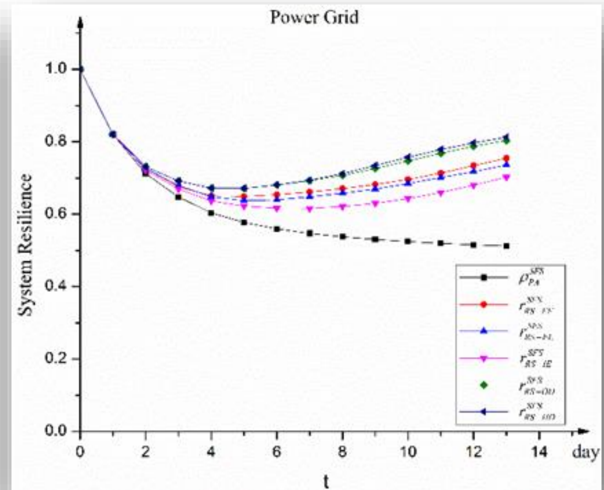
- Test network
  - Four layers of four cells
  - 16 street nodes and 54 street segments
  - 16 water network nodes and 16 water pipes
  - 36 power network nodes and 16 transmission lines
  - 5 information network nodes and 8 information network lines

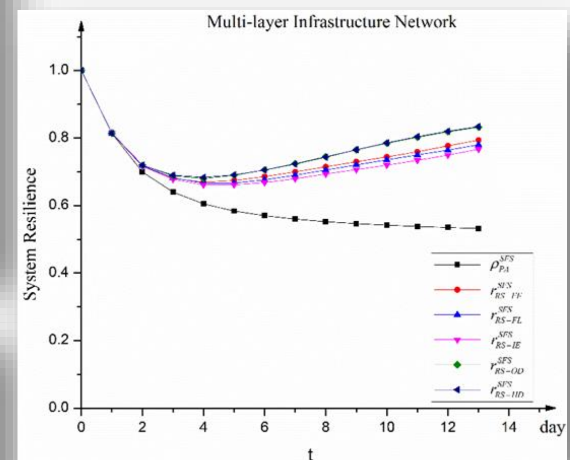


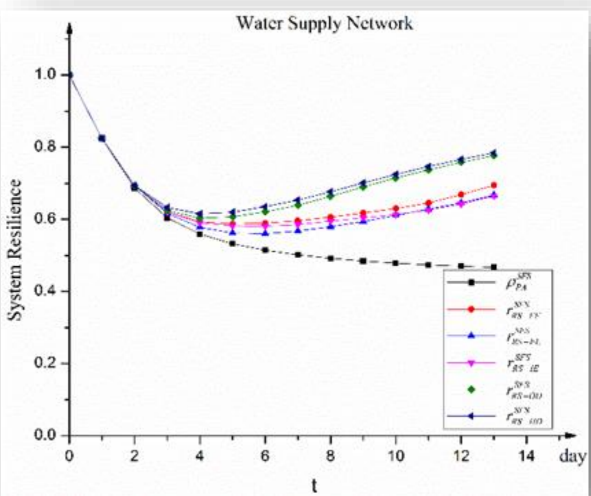
# EXAMPLE 3

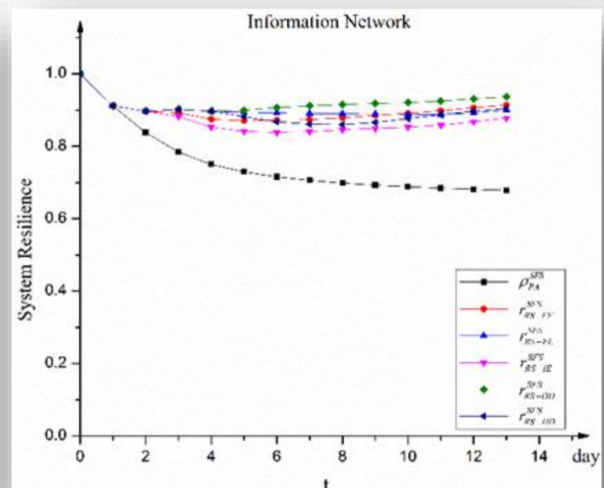
## Urban infrastructure network system



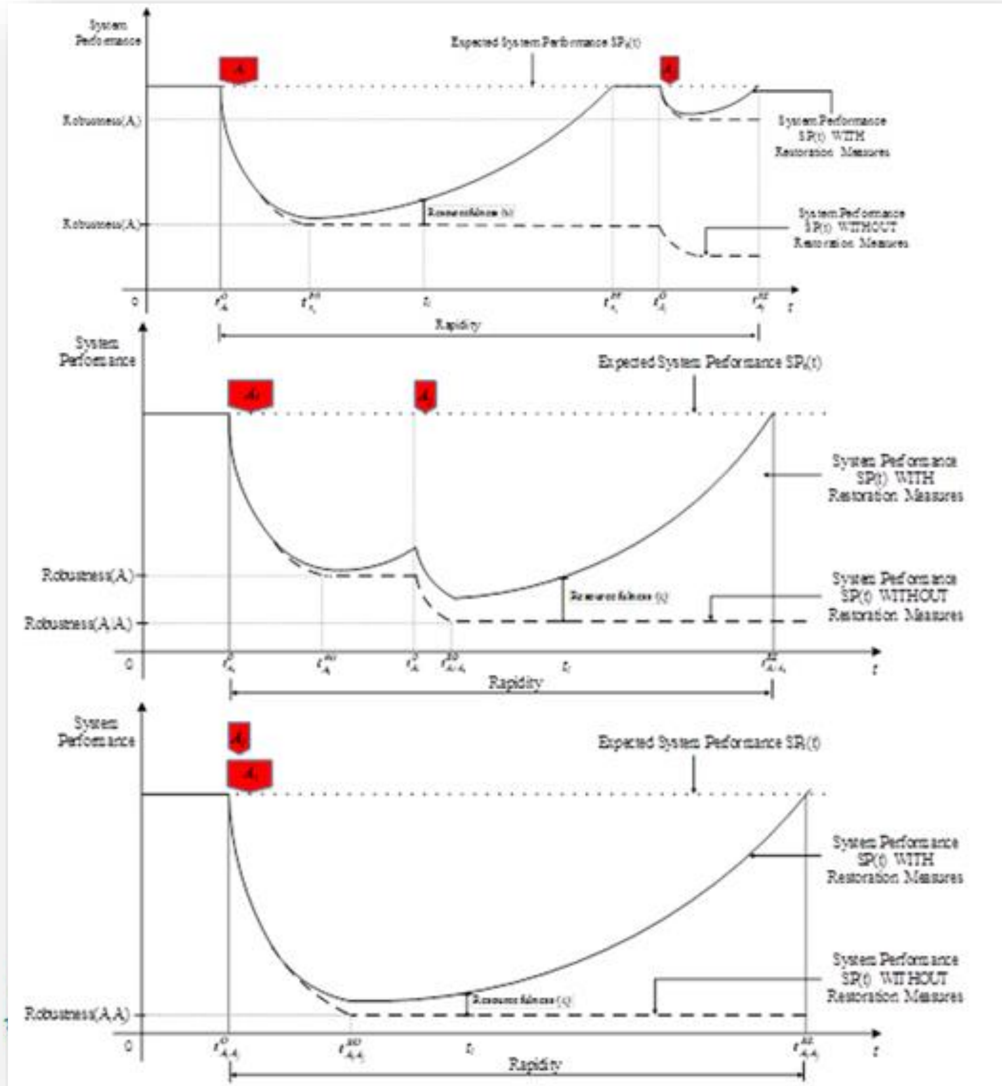



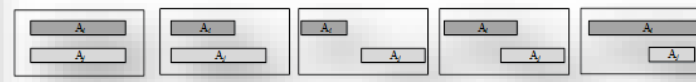



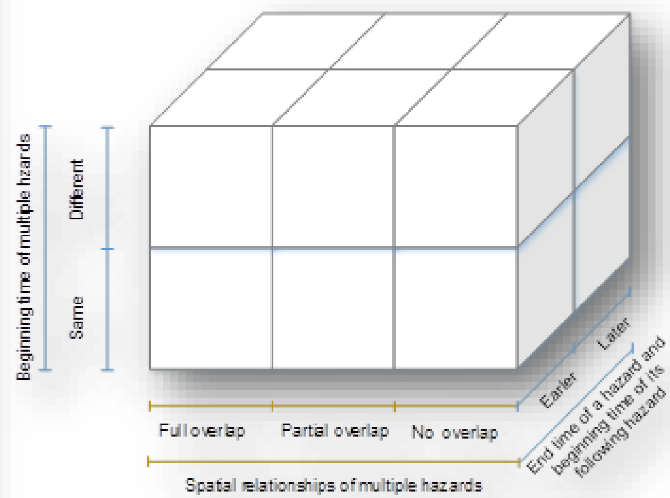
# 20| EXAMPLE 4

## Urban infrastructure network system subject to multiple hazards




$$r_F^{A_1,\ldots,A_m}(t) = \frac{\sum_{i=1}^{m} \int_{t_{A_i}^{0}}^{t_{A_i}} E(SP(t))\,dt}{\int_{t_{A_1}^{0}}^{t} E(SP_0(t))\,dt} = 1 - \frac{\sum_{i=1}^{m} \int_{t_{A_i}^{0}}^{t_{A_i}} E(SL(t))\,dt}{\int_{t_{A_1}^{0}}^{t} E(SP_0(t))\,dt} = 1 - \frac{\sum_{i=1}^{m} \int_{t_{A_i}^{0}}^{t_{A_i}} \frac{\sum_{u=1}^{N} P_u(t) I_u}{N}\,dt}{\int_{t_{A_1}^{0}}^{t} \frac{\sum_{u=1}^{N} P_u^{E}(t) I_u}{N}\,dt}$$





# EXAMPLE 4

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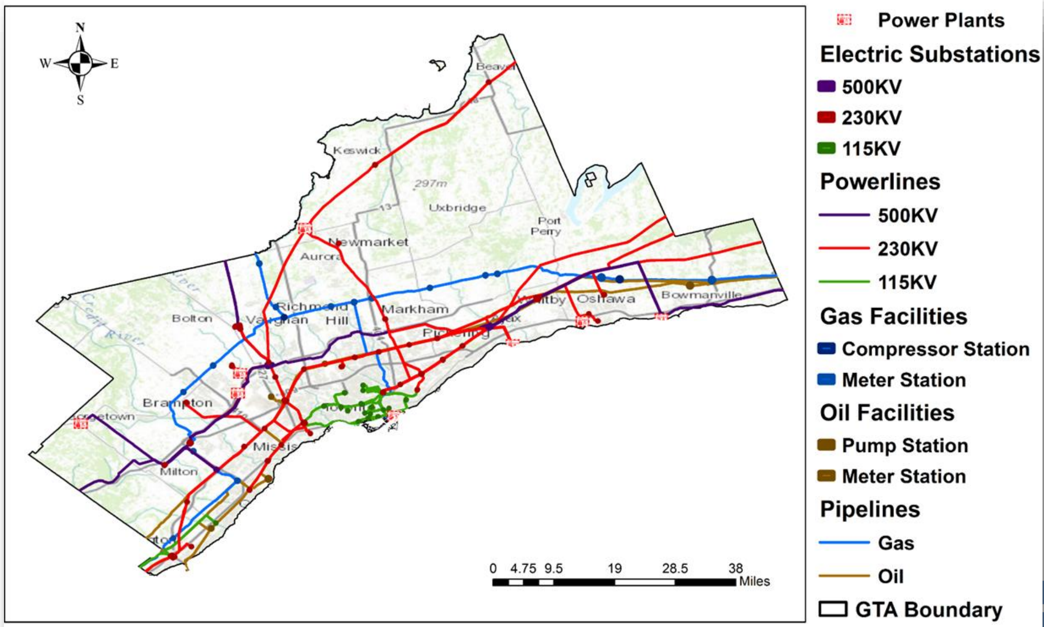
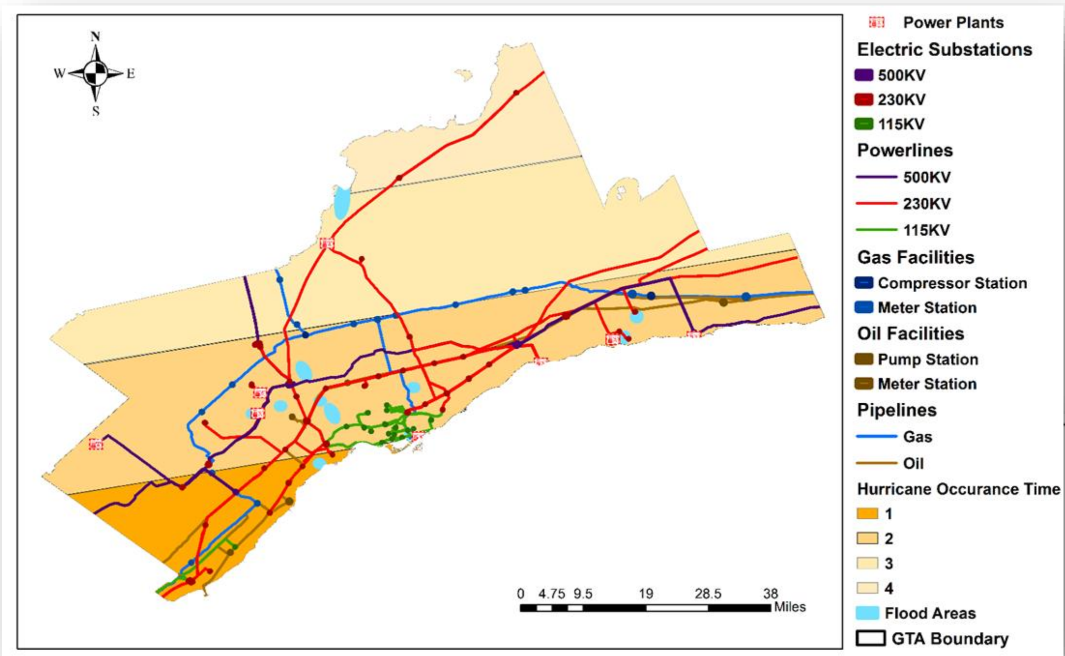
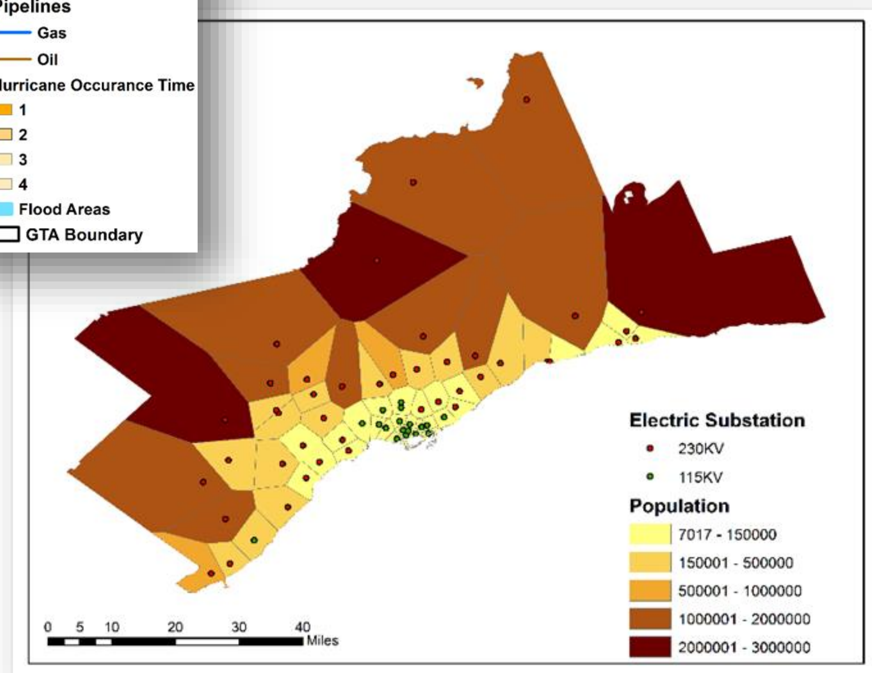



| Infrastructure | | Number |
| --- | --- | --- |
| **Electric Transmission Network** | | |
| Power Generation | Nuclear | 2 |
| | Gas -fired | 6 |
| Transmission Stations | 500kv | 4 |
| | 230kv | 43 |
| | 115kv | 26 |
| Power line | 500kv | 13 |
| | 230kv | 64 |
| | 115kv | 30 |
| **Gas Transmission Network** | | |
| Compressor Stations | | 2 |
| Meter Stations | | 15 |
| Pipelines | | 22 |
| **Oil Transmission Network** | | |
| Pumping Stations | | 4 |
| Meter Stations | | 1 |
| Pipelines | | 6 |

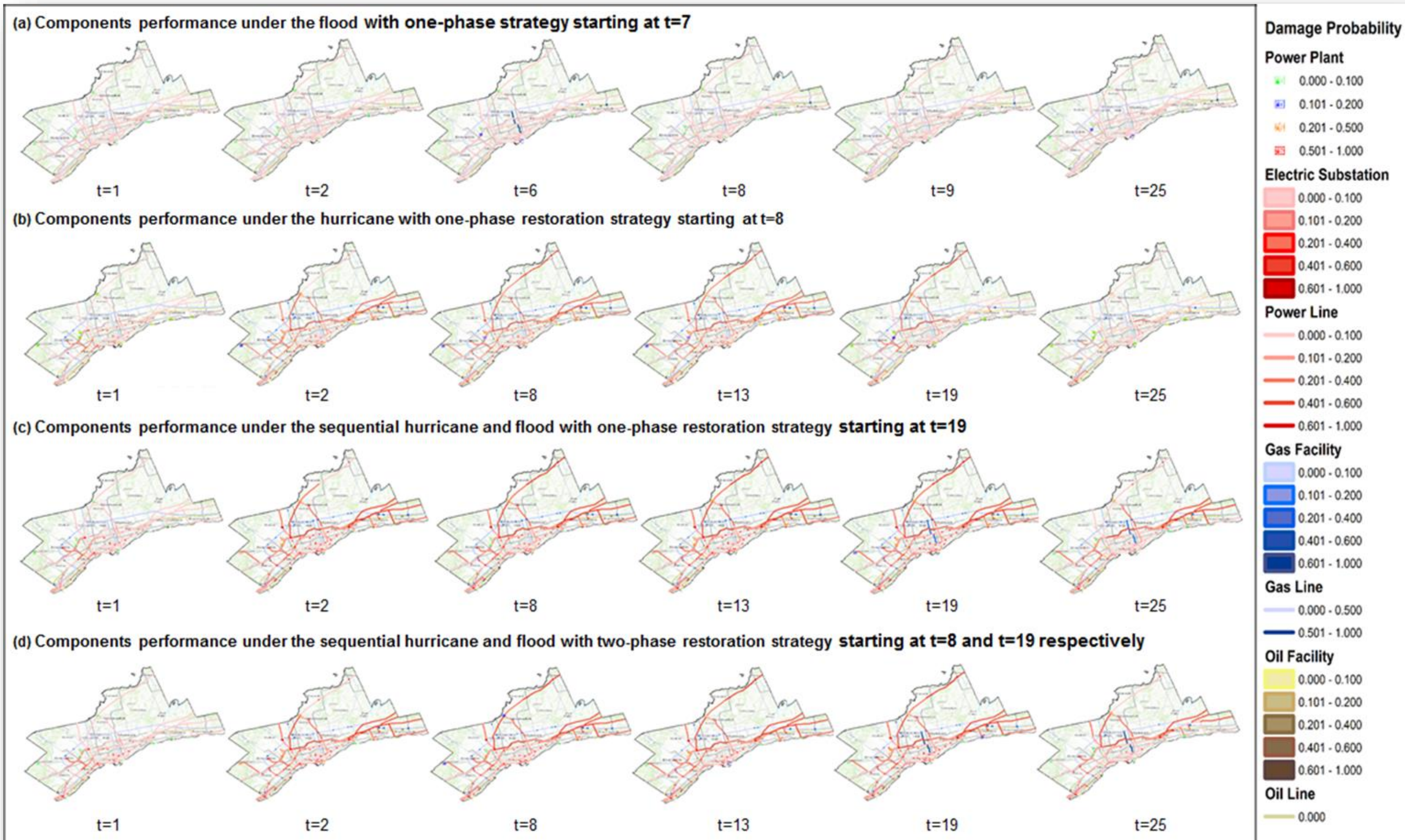
# EXAMPLE 4
Urban infrastructure network system subject to multiple hazards



# 23 | EXAMPLE 4

## Urban infrastructure network system subject to multiple hazards



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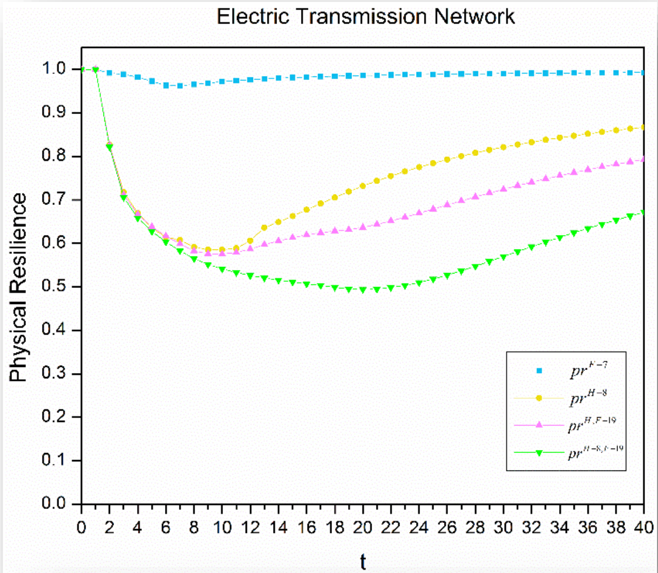
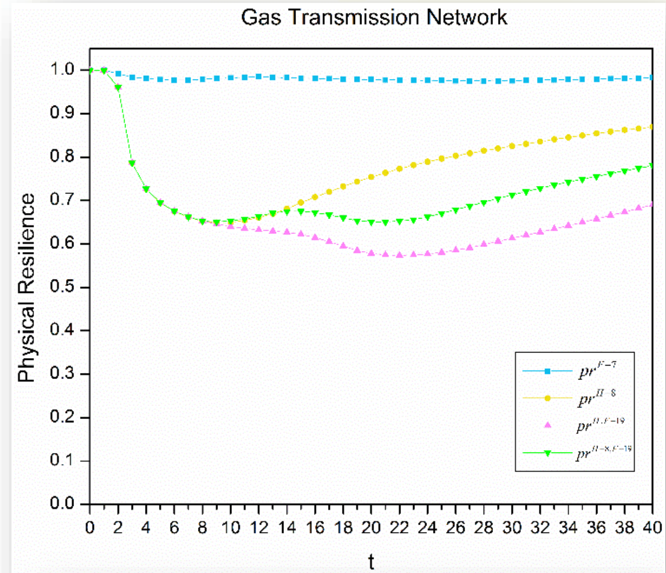
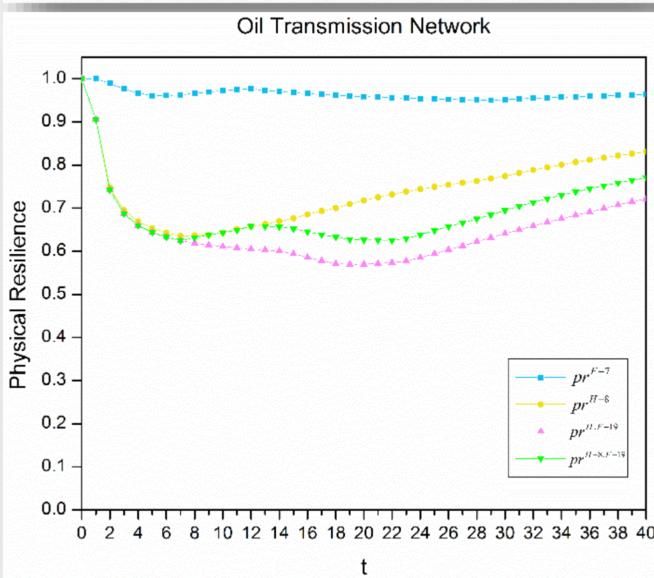
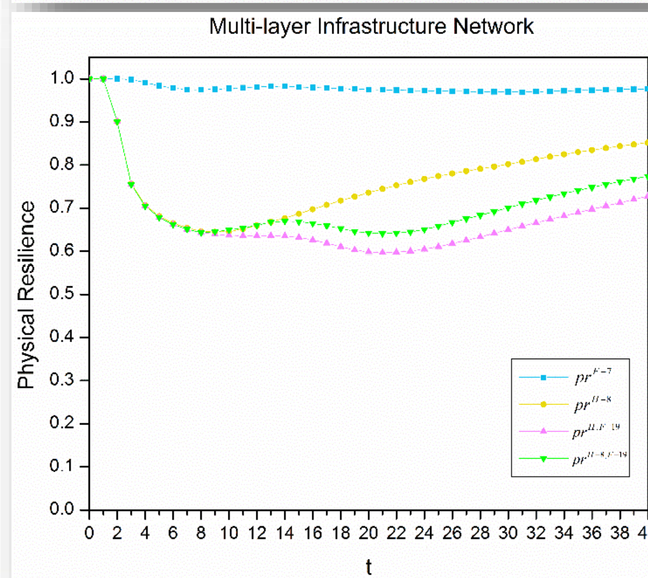


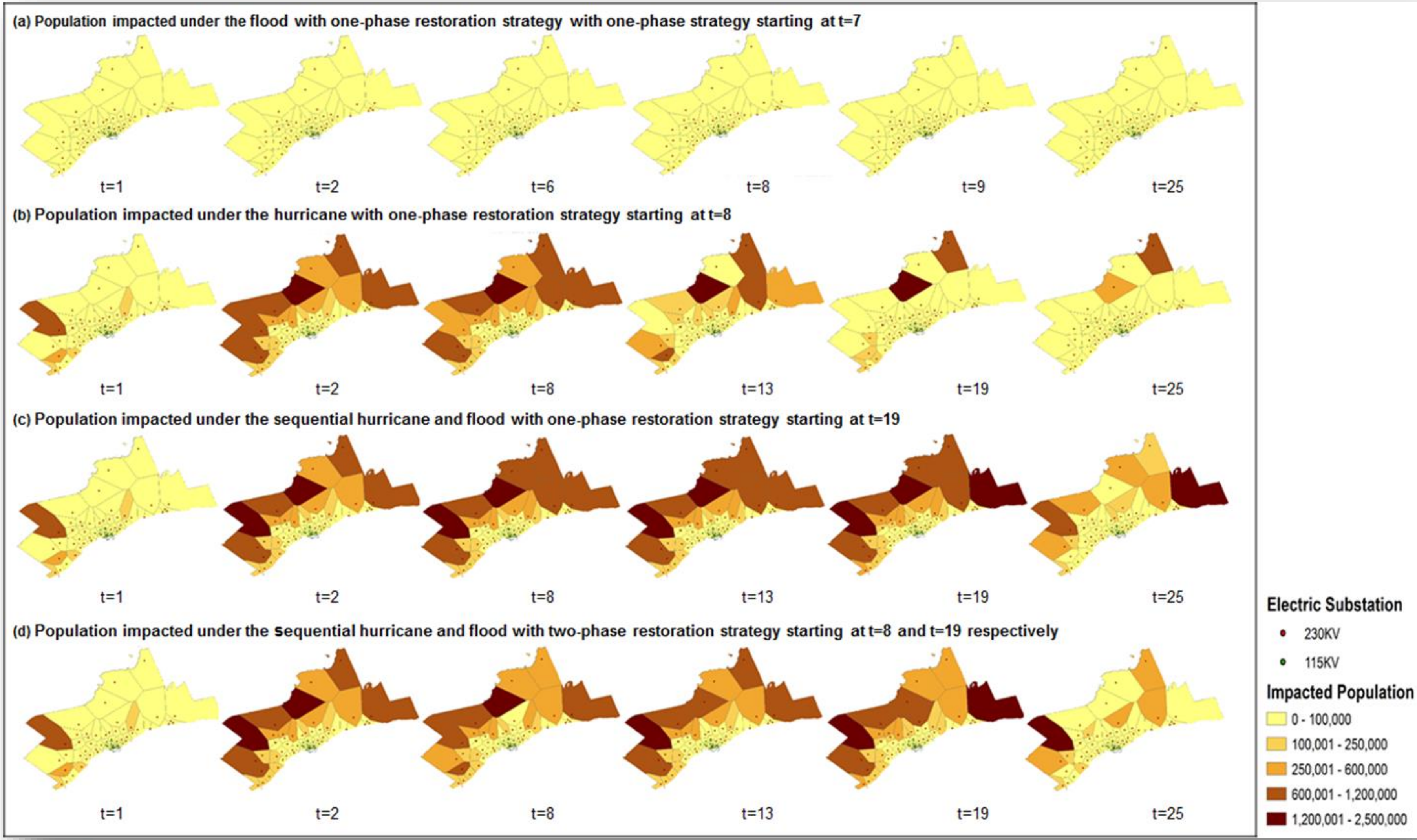



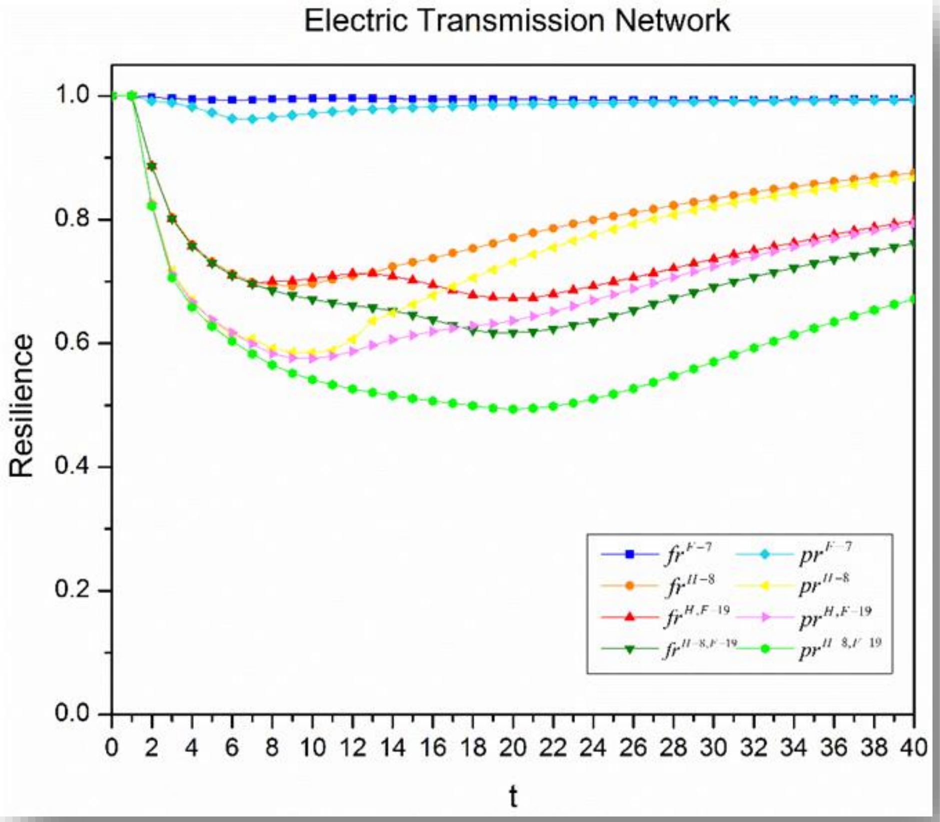
# EXAMPLE 3

## Urban infrastructure network system subject to multiple hazards



# EXAMPLE 4

Urban infrastructure network system subject to multiple hazards



# FUTURE WORK

## Decision support

- Prototype
  - ResilSIM
  - Public data for London and Toronto
  - Flooding
  - Web based
  - www.resilsim-uwo.ca
- Real decision support system for City of Toronto

# CONCLUSIONS

- There are practical links between adaptation to global change and sustainable development leading to:
  - re-enforcing resilience as a new development paradigm
- The main goal of Regional Resilience Assessment Program in Canada and US is to identify and analyze the resilience and interdependencies of water sectors using an all-hazards approach
- Systems approach to quantification of resilience allows:
  - capturing temporal and spatial dynamics of water management
  - better understanding of factors contributing to resilience
  - more systematic assessment of various measures to increase resilience

# RESOURCES

www.slobodansimonovic.com

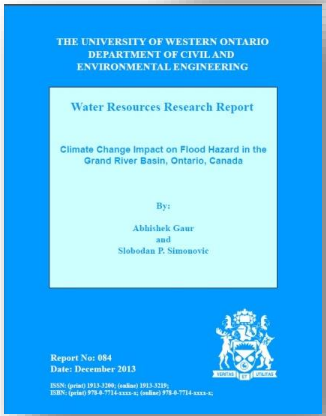
Research -> FIDS -> Research projects


- Simonovic, S.P., and A. Peck, (2013) "Dynamic Resilience to Climate Change Caused Natural Disasters in Coastal Megacities - Quantification Framework", ***British Journal of Environment and Climate Change***, 3(3): 378-401.
- Simonovic, S.P., (2016) “From risk management to quantitative disaster resilience – a paradigm shift”, ***International Journal of Safety and Security Engineering***, 6(1):1–12.
- Simonovic, S.P., and R. Arunkumar, (2016) “Comparison of static and dynamic resilience for a multi-purpose reservoir operation”, ***Water Resources Research***, 52, online first doi:10.1002/2016WR019551.

# 40 | SLOBODAN P. SIMONOVIC

- Computer-based research laboratory
- Research:
  - *Subject Matter* - Systems modeling; Risk and reliability; Water resources and environmental systems analysis; Computer-based decision support systems development.
  - *Topical Area* - Reservoirs; Flood control; Hydropower energy; Operational hydrology; Climatic Change; Integrated water resources management.
- ~ 70 research projects; ~ $11.5 M
- 7 visiting fellows, 15 PosDoc's, 20 PhD's and 40 MESc's
- 3 PosDoc's, 4 PhD's, and 3 MESc's
- Water Resources Research Reports – 95 volumes (~55,000 downloads since 2011)
- Access through my web page

FIDS
CELEBRATING
1989 - 2014


THE UNIVERSITY OF WESTERN ONTARIO
DEPARTMENT OF CIVIL AND
ENVIRONMENTAL ENGINEERING

Water Resources Research Report

Climate Change Impact on Flood Hazard in the Grand River Basin, Ontario, Canada

By:

Abhishek Gaur
and
Slobodan P. Simonovic

Report No: 084
Date: December 2013

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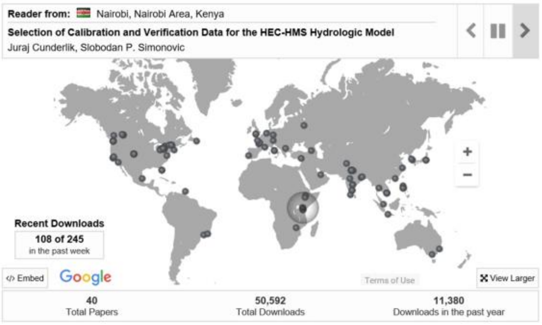
ISBN: (print) 978-0-7714-xxxx-x; (online) 978-0-7714-xxxx-x;

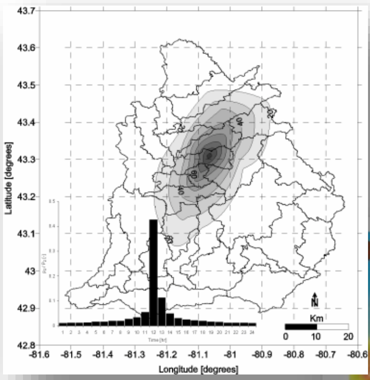


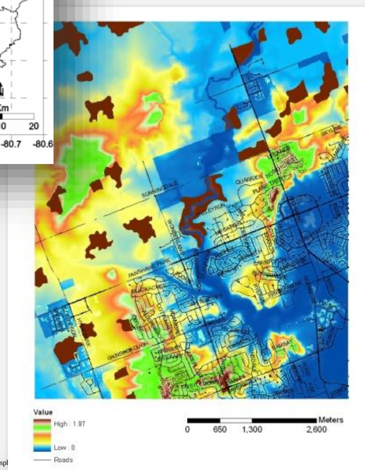
# 41 | SLOBODAN P. SIMONOVIC

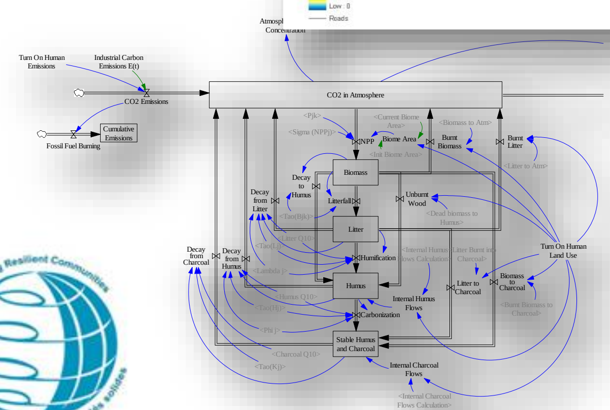

- > 500 professional publications
- 210 in peer reviewed journals
- 3 major textbooks

# 42 | SLOBODAN P. SIMONOVIC

## Current research projects




- Coastal Cities at Risk - Building Adaptive Capacity for Managing Climate Change in Coastal Megacities (spatial and temporal modeling of resilience)
- Extreme Flow Uncertainty Under Changing Climatic Conditions
- Water Resources Management Capacity Building in the Context of Global Change
- Systems Engineering Approach to the Reliability of Complex Civil Infrastructure
- Advanced Disaster, Emergency and Rapid Response Simulation
- Linking hazard, exposure and risk across multiple hazards