Quantification of Multi-purpose Reservoir Resilience to Water Scarcity: a dynamic measure

Slobodan P. Simonović
FCAE, FCSCE, FASCE, FIWRA
Department of Civil and Environmental Engineering
Western University
CONCLUSIONS

• There are practical links between adaptation to global change and sustainable development leading to:
  • re-enforcing resilience as a new development paradigm
• 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
• Understanding of local context of vulnerability and exposure is fundamental for increasing resilience
1. Introductory remarks
2. 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)
3. Example
   • Multi purpose reservoir operation
4. Conclusions
Principal investigator

- Systems Engineering Approach to the Reliability of Complex Hydropower Infrastructure
- Linking Hazard, Exposure and Risk Across Multiple Hazards
  - NSERC CRD with Chaucer Synd.: 2015-2020 $1,375,600

Research team

- Dr. R. Arunkumar – Post Doctoral Fellow
- Ms. L. King – PhD candidate
- Ms. A. Peck – PhD candidate
INTRODUCTION

Global change

• Population growth
• Land use change
• Climate change
• **Complexity and uncertainty**

Infrastructure systems (hard)

• Water
• Energy
• Transport
• Communications

Infrastructure (soft)

• Institutional
• Social
• Cultural
The broad definition

The combination of the probability of an event and its negative consequences.

Risk = Hazard x Consequence

Need for paradigm change
RISK TO RESILIENCE
Need for paradigm change

- Risk management framework
  - Static (in time and space)
  - Difficulties in assessing probability of extreme events
  - Difficult integration of physical, social, economic and ecological concerns

- Resilience framework
  - Dynamic (in time and space)
  - Not only assessment of direct and indirect losses – broader framework
RESILIENCE
Definitions

• Initial ecology-based (Holling, 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...

• Used in this research
  • ...the ability of an infrastructure system and its component parts to anticipate, absorb, accommodate or recover from the effects of a system disruption in a timely and efficient manner, including through ensuring the preservation, restoration or improvement of its essential basic structures and functions...
  • System performance and system adaptive capacity
RESILIENCE
Quantification

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

\[ r(t) = 1 - \left[ \frac{\rho(t)}{P_0 \times (t - t_0)} \right] \]

\( t \in [t_0, t_r] \)
\[
\frac{\partial r(t)}{\partial t} = AC(t) - P(t)
\]
11 | EXAMPLE

Multi purpose reservoir operation

- Reservoir (Koyna Reservoir)
  - Hydropower production
  - Irrigation 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
  \[ SP_{p,t} = \frac{PR_t}{PR_t \text{demand}} \]
  \[ SP_{i,t} = \frac{WS_t}{WS_t \text{demand}} \]
- Resilience
  \[ CSP_{i,t} = \int_{t_0}^{t} [SP_{i,0} - SP_{i,t}] \, dt \]
  \[ DR_{i,t} = 1 - \left( \frac{CSP_{i,t}}{SP_{i,0} \times (t-t_0)} \right) \]
  \[ SR_t = \left[ \prod_{i=1}^{I} DR_{i,t} \right]^{1/I} \]
Multi purpose reservoir operation

- Failure scenario 1
  - Single event
  - Turbine failure
Example
Multi purpose reservoir operation

- Failure scenario 2
  - Two failure events
  - Consecutive turbine failures
• **Failure scenario 3**
  • Three failure events
  • Turbine failure and two water demand failures
CONCLUSIONS

- There are **practical links** between adaptation to global change and sustainable development leading to:
  - re-enforcing **resilience** as a new development paradigm
- **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
- Understanding of **local context** of vulnerability and exposure is fundamental for increasing resilience


Application of the Systems Approach to the Management of Complex Water Systems

Special Issue Editor
Prof. Dr. Slobodan P. Simonovic

University of Western Ontario, London, Canada
Email: simonovic@uwo.ca
Submission Deadline: 31 March 2020

This Special issue offers an opportunity to review numerous applications of the systems approach to water resource management and draw lessons from worldwide experience relevant to the solution of future water problems.

Keywords
• Water resource management
• Systems analysis
• Sustainability
• Complexity
• Climate change
• Uncertainty
• Risk
• Resilience
• Decision support

Water Editorial Office
St. Alban-Anlage 66
4052, Basel, Switzerland
Email: water@mdpi.com
Website: www.mdpi.com/journal/water
@Water_MDPI
Slobodan P. Simonović

Research facility

- 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
- Completed: 8 visiting fellows, 18 PosDoc, 21 PhD and 43 MESc
- Current: 1 PosDoc (+1), 3 PhD, 1 MESc (+1) and 1 visiting (+2)
Slobodan P. Simonović
Research results

- > 540 professional publications
- > 230 in peer reviewed journals
- 3 major textbooks

- Water Resources Research Reports
  105 volumes
- > 73,000 downloads since 2011
• Water Resources Management Capacity Building in the Context of Global Change
• Systems Engineering Approach to the Reliability of Complex Hydropower Infrastructure
• Linking Hazard, Exposure and Risk Across Multiple Hazards