A SYSTEMS APPROACH TO MODELLING THE WATER-ENERGY-FOOD NEXUS

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Conclusions

- WEF nexus
  - Old/New challenges
  - High level of integration
  - High level of complexity
  - Common concerns

- Systems approach
  - Modelling of the whole system
  - System dynamics simulation (and optimization)

- ANEMI model example
3 WEF Modelling

Outline

- Challenges of the old/new context
- Integration
- Systems approach
- Example
  - ANEMI model
  - Lessons learned
- Conclusions
WEF Context
Definitions

• Nexus?
  • A center point of something!
  • A center of various connections!

• Water, energy and food – pillars of global security, prosperity and equity

• Perspectives
  • Water perspective – food and energy systems are users of resources
  • Food perspective – water and energy are inputs
  • Energy perspective – water is the input and food is the output

• Vast individual areas
• Silo policy and regulations often create sub-optimal solutions
WEF Context
Challenges

- Water-Energy-Food common concerns
  - Access to services
  - Environmental impacts
  - Price volatility

- Global change
  - Population (poverty, health)
  - Land use (urbanization)
  - Climate change (mitigation – energy, adaptation – land and water)

- Sustainable management
  - Enormous opportunities for higher efficiency
  - Study of the whole complex system
  - Understanding interactions – it is all about feedbacks

- Scale
  - 1.4 billion people without access to electricity
  - 3 billion without access to modern fuels or technologies for cooking and heating
  - 900 million people without access to safe drinking water
  - 2.6 billion do not have sanitation
  - 900 million people are chronically hungry
  - 2 billion people lack food security

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Consideration of all three areas together with other related sectors
- Systems view
  - Complexity
  - Whole system approach
  - Difficult to translate into government policy making processes
- System structure
- Feedbacks
- System behavior
• **System Dynamics 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.
  • System Dynamics simulation approach relies on understanding complex inter-relationships existing between different elements within a system.
  • This is achieved by developing a model that can simulate and quantify the behavior of the system.
  • Simulation of the model over time is considered essential to understand the dynamics of the system.
NSERC Discovery Grant (2005 – 2007) ANEMI ver 1
NSERC Strategic Grant (2007 – 2011) ANEMI ver 2
NSERC Discovery Grant (2016 – 2021) ANEMI ver 3

Long-term project objectives

i. To develop system dynamics-based model of society-biosphere-climate system

ii. To provide support for communication between the science and policy communities.

iii. To examine the effects of climate change on socio-economic and environmental sustainability through the model outputs.

Interdisciplinary team

- Systems modelling – engineering
- Climate policy – political science
- Economics – economics

Partners

- Environment Canada
- Natural Resources Canada
- Department of Finance
- Department of Fisheries and Oceans
- Department of Agriculture
WEF Modelling
Example ANEMI

- Selection of the methodological approach
- *Initial communication*
- ANEMI model development
  - Structure
  - Sectors
  - Preliminary results
- Identification of key issues
  - Communication with the project collaborators
  - Selection of simulation scenarios
- *Model introduction*
- ANEMI model expansion
  - Economy-energy integration
  - Model regionalization
- Model use
  - Scenario analyses
  - Model limitations
- *Model transfer*
  - Model transfer
  - Future work

Water stress Effects: Canada

<table>
<thead>
<tr>
<th>Year</th>
<th>Water Stress Effects (dimensionless)</th>
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<tbody>
<tr>
<td>2020</td>
<td>0.12</td>
</tr>
<tr>
<td>2040</td>
<td>0.14</td>
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<tr>
<td>2060</td>
<td>0.16</td>
</tr>
<tr>
<td>2080</td>
<td>0.18</td>
</tr>
<tr>
<td>2100</td>
<td>0.20</td>
</tr>
</tbody>
</table>

Time (Year)

- 2020
- 2040
- 2060
- 2080
- 2100

Water stress Effects: Canada

- Base Condition
- 2 degree with transfer
- 3 degree with transfer
- 4 degree with transfer
- 2 degree
- 3 degree
- 4 degree
WEF Modelling
Example ANEMI

• Version 1 – 8 sectors representing basic social and biophysical feedbacks

• Version 2 – Food and energy sectors added and Population sector expanded

• Version 3 – Carbon cycle expanded to include coupled nutrient cycles of Nitrogen and Phosphorus to allow better representation of water quality; Energy-economy sector expanded with water production
1. Biogeochemical Cycle (expanded Carbon)
2. Climate
3. Water Demand
4. Water Quality
5. Hydrologic Cycle
6. Population
7. Land Use
8. Food Production
9. Energy-Economy

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WEF Modelling
Example ANEMI – Stock and flow diagrams
Available water resources
- Two stocks (oceans and land surface)
- Flows (evaporation, evapotranspiration, advection, precipitation, snow and ice melt, percolation, ocean runoff)

\[
A_M = \int \left( E_M - \text{Adv} - P_O \right) \cdot dt
\]
\[
A_L = \int \left( \text{Adv} + ET - P_R - P_S \right) \cdot dt
\]
\[
LS = \int \left( P_R - ET - SF - GP \right) \cdot dt
\]
\[
O = \int \left( SF + GD + P_O + M - E_M \right) \cdot dt
\]
\[
GS = \int \left( GP - GD \right) \cdot dt
\]
\[
IS = \int \left( P_S - M \right) \cdot dt
\]
\[
E_M = E_{M0} \cdot T_{\text{feedback}}
\]
\[
\text{Adv} = \text{Adv}_0 \cdot (1 + \delta_{adv} / 100)
\]
\[
P_O = P_{O0} \frac{A_M}{A_{M0}}
\]
\[
P_R = P_L - P_S + C_{wl}
\]
\[
GP = GP_0 \frac{LS}{LS_0} + C_{gw}
\]
\[
GD = GD_0 \frac{GS}{GS_0} + GW
\]

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Policy communication process
- Set of interviews
- Identification of policy questions by the research team
- Identification of scenarios

Initial set of scenarios
- Carbon pricing
- Economic growth rate
- Water pricing
- North American water stress
- Irrigation
- Energy subsidies and pricing
- Land use change

Final choice
- Carbon tax
- Increased water use
- Food production increase
WEF Modelling
Example ANEMI – Carbon tax scenario (global)

Energy Used for Electricity Production

GDP

Atmospheric CO₂ Concentration

Global Population
WEF Modelling
Example ANEMI – Increased water use scenario (global)
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Example ANEMI – Increased food production scenario (global)

Available Surface Water

Atmospheric CO₂ Concentration

Global Population

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Example ANEMI – conclusions

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Papers


• **Technical documents**
www.slobodansimonovic.com
FIDS->Products

ANEMI2 software available upon request
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
• 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
• Completed: 8 visiting fellows, 19 PosDoc, 22 PhD and 43 MESc
• Current: 2 PosDoc, 2 PhD, 2 MESc and 2 visiting scholars
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Research results

- > 540 professional publications
- > 235 in peer reviewed journals
- 3 major textbooks

- Water Resources Research Reports
  105 volumes
- > 75,000 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