WHAT CAN WE LEARN FROM INTEGRATING WATER RESOURCES WITH A GLOBAL MODEL OF THE SOCIAL–ECONOMIC–ENVIRONMENTAL SYSTEM?

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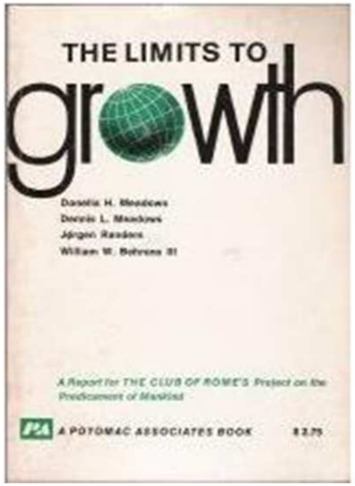
2 | GLOBAL WATER RESOURCES MODELLING
Outline

- Introduction
- Personal story
  - A question
  - Learning
  - An answer
- ANEMI model
- Use of ANEMI model for modelling water resources systems at the global level

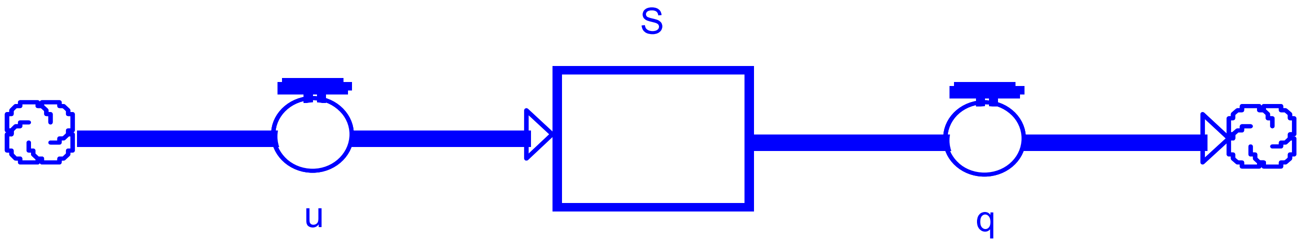
3 | INTRODUCTION
A question



- Graduate course assignment
- The Limits to Growth
  - 12 million copies in 37 languages
  - MIT – Prof. Jay Forrester's research group
  - The Club of Rome
- *World* Model with 12 development scenarios
- Lessons
  - There are limits to economic growth
  - Delays in global decision making would cause the human economy to overshoot planetary limits before the growth in the human ecological footprint slowed
- Two possible paths
  - "Managed decline" organized by humanity.
  - "Collapse" induced by nature or the market.

System dynamics simulation

- System Dynamics
  - 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 links the behavior of a system to its underlying structure.
- Generic approach for systems analysis
  - Physical, biologic, social,, economic,……



$$\frac{d}{dt}S(t) = u(t) - q(t)$$

5 | ANSWER
Modifications of the *World* model

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World water dynamics: global modeling of water resources

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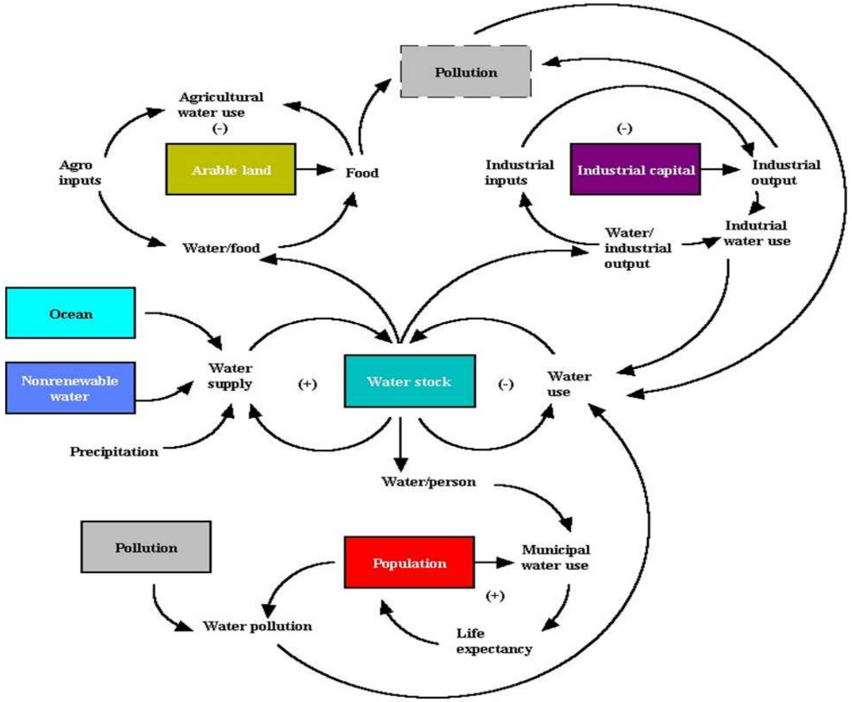
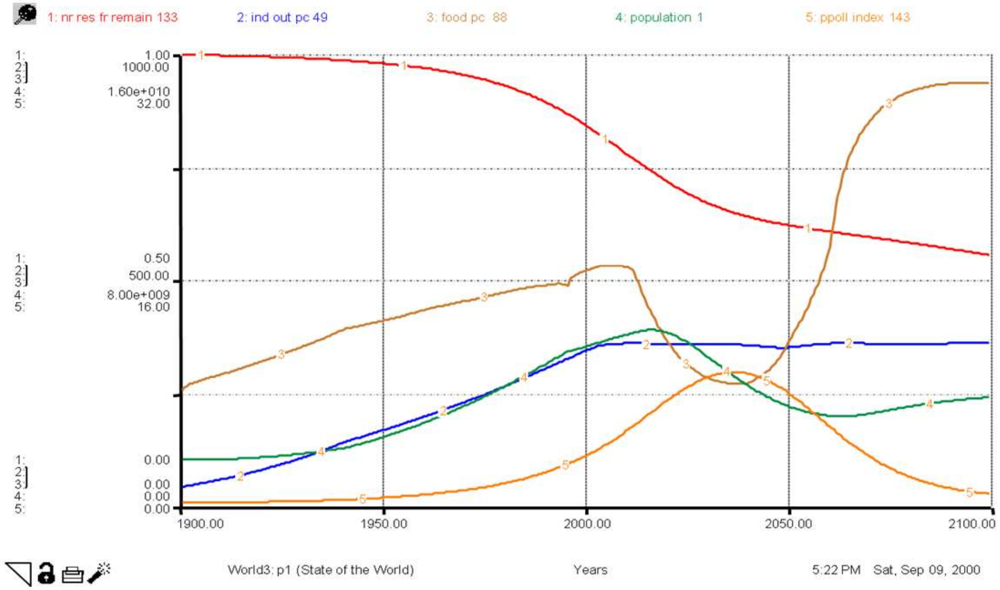
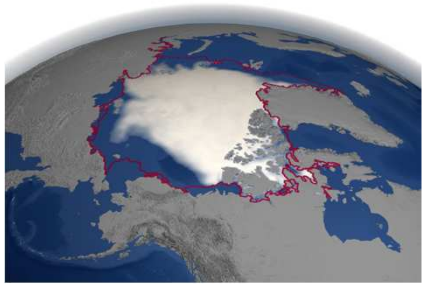
The growing scarcity of fresh and clean water is among the most important issues facing civilization in the 21st century.



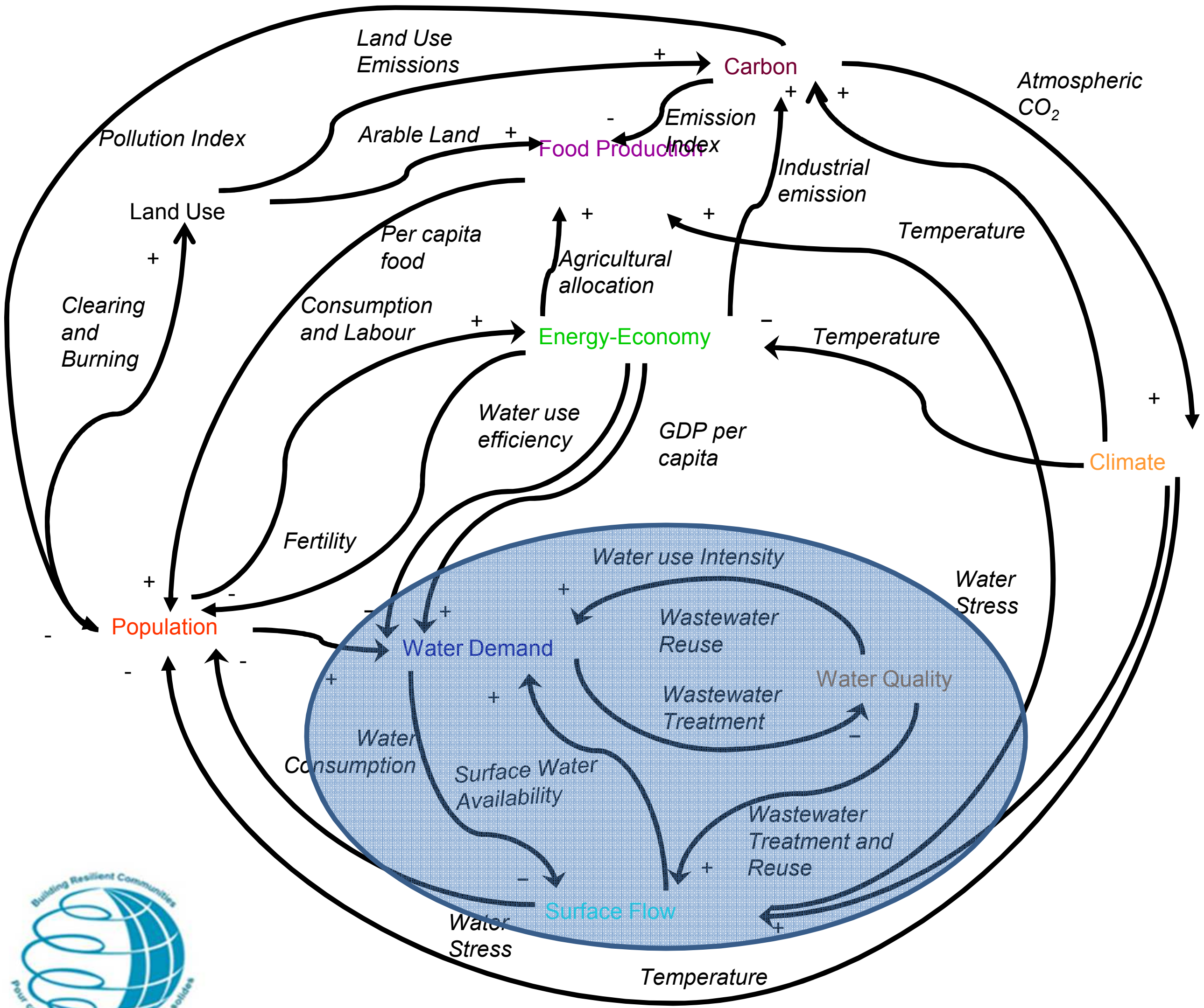


6 | CONTINUATION
Development of the *ANEMI* model

- New research questions
  - Much more detailed representation of the water sectors
  - Climate change – Food - Energy
  - Rapid population growth
- New data
- Development of a new/original model

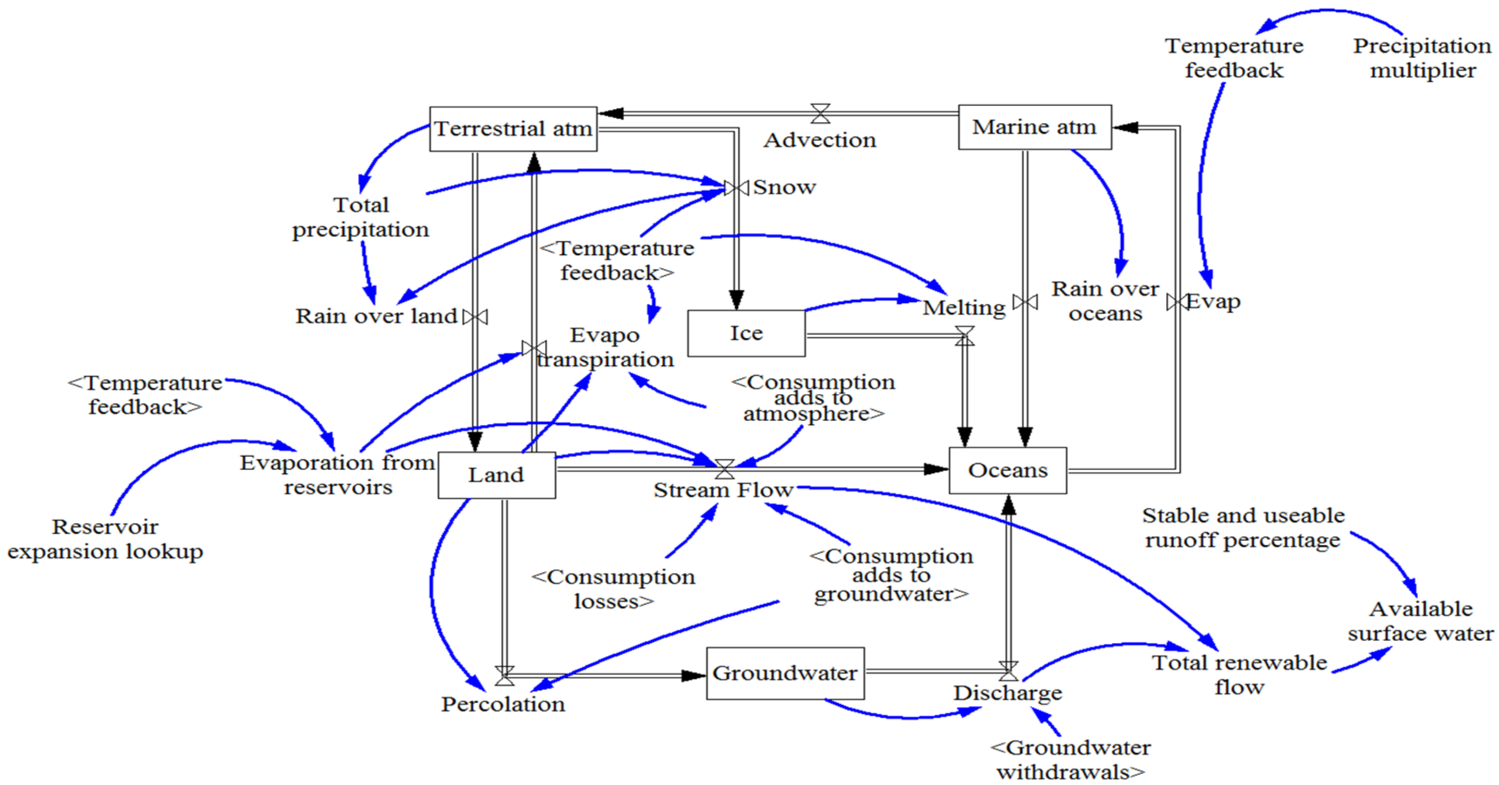


7| ANEMI
Model



1. Carbon cycle
2. Climate
3. Water demand
4. Water quality
5. Available water
6. Population
7. Land use
8. Food production
9. Energy - Economy

8 | # ANEMI
Water resources modeling



ANEMI
Water resources modeling

- Available water resources
  - Two reservoirs (oceans and land surface)
  - Transfers (evaporation, evapotranspiration, advection, rainfall, snow and ice melt, ground water percolation, and surface runoff into the oceans

$$A_M = \int (E_M - Adv - P_O) \cdot dt$$

$$A_L = \int (Adv + ET - P_R - P_S) \cdot dt$$

$$LS = \int (P_R - ET - SF - GP) \cdot dt$$

$$O = \int (SF + GD + P_O + M - E_M) \cdot dt$$

$$GS = \int (GP - GD) \cdot dt$$

$$IS = \int (P_S - M) \cdot dt$$

$$E_M = E_{M0} \cdot T_{feedback}$$

$$Adv = Adv_0 \cdot (1 + \delta_{adv} / 100)$$

$$P_O = P_{O0} \, {}^{A_M}\!/_{A_{M0}}$$

$$ET = ET_0 \cdot {}^{LS}\!/_{LS_0} \cdot T_{feedback} + E_{res} + C_{wa}$$

$$P_R = P_L - P_S + C_{wl}$$

$$GP = GP_0 \cdot {}^{LS}\!/_{LS_0} + C_{gw}$$

$$GD = GD_0 \cdot {}^{GS}\!/_{GS_0} + GW$$

$$M = M_0 \cdot {}^{IS}\!/_{IS_0} \cdot T_{feedback}{}^2$$

10 | ANEMI

Water resources modeling

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Global water resources modeling with an integrated model of the social–economic–environmental system

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A R T I C L E   I N F O

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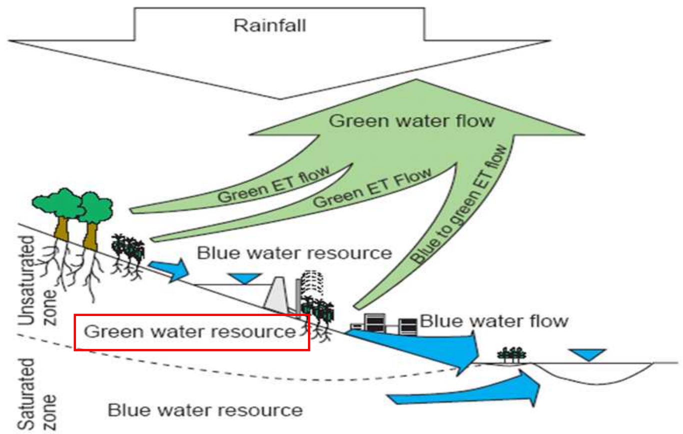
A B S T R A C T

Awareness of increasing water scarcity has driven efforts to model global water resources for improved insight into water resources infrastructure and management strategies. Most water resources models

- Integrated modeling approach
- Planning of water infrastructure
- Development of new water policy options

11 | ANEMI
Water resources modeling

- ANEMI simulates changes in
  - Surface runoff
  - Surface water availability
  - Domestic, agricultural (both blue and green) and industrial water use
  - Reservoir evaporation losses
  - Treated and reused wasterwater volumes
  - Groundwater extraction and desalination volumes
  - Measurement of water scarcity – water stress



ANEMI
Water resources modeling

- Water use
  - Domestic
  - Industrial
  - Agricultural

$$W_{eff_d} = C_d + \delta_d R_{p_d}$$
$$W_{eff_i} = C_i + \delta_i R_{p_i}$$
$$W_{eff_a} = C_a + \delta_a R_{p_a} + \delta_r R_r + \delta_g R_g$$

- Water stress (> 0.2 ‘mid stress’ - > 0.4 ‘severe stress’)

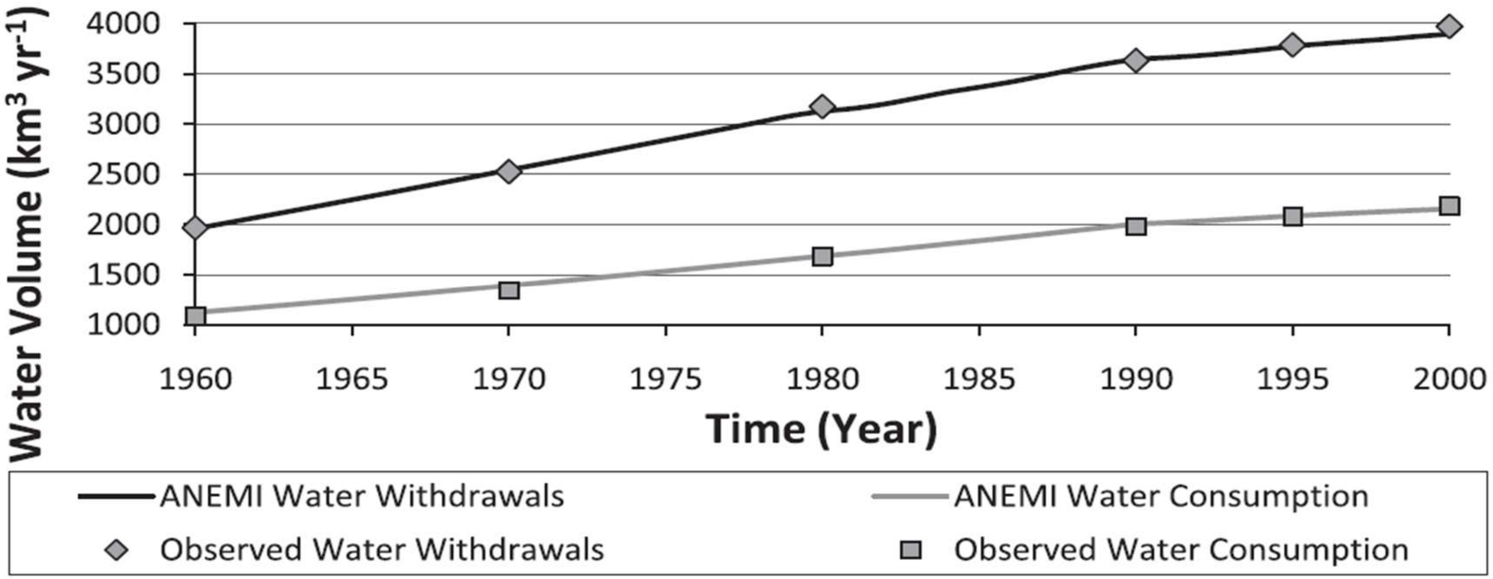
$$wta = W/R$$

$$wta = \left(\sum_{d,i,a} W_{eff} \right) / R$$

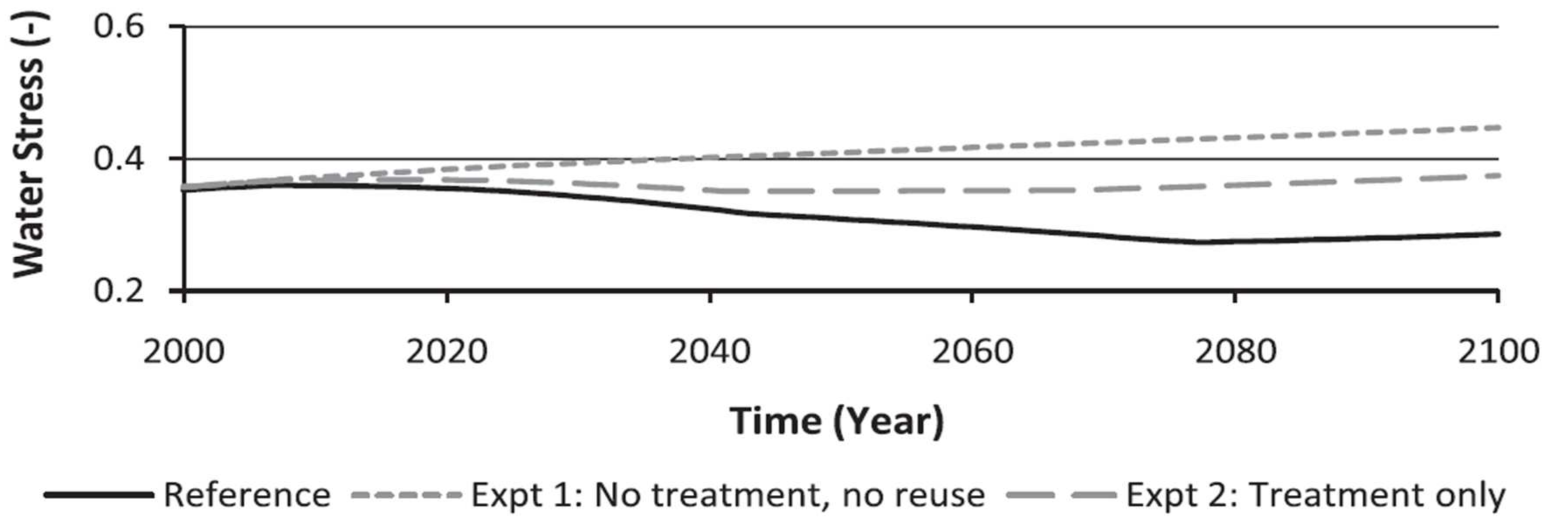
ANEMI
Water resources modeling

- Model use
  - Feedback tracing – 5 scenarios
  - Scenario 1 – low treatment, no reuse
  - Scenario 2 – high treatment, no reuse
  - Scenario 3 – irrigation expansion
  - Scenario 4 – more animals
  - Scenario 5 – dilution requirements
  - Reference simulation

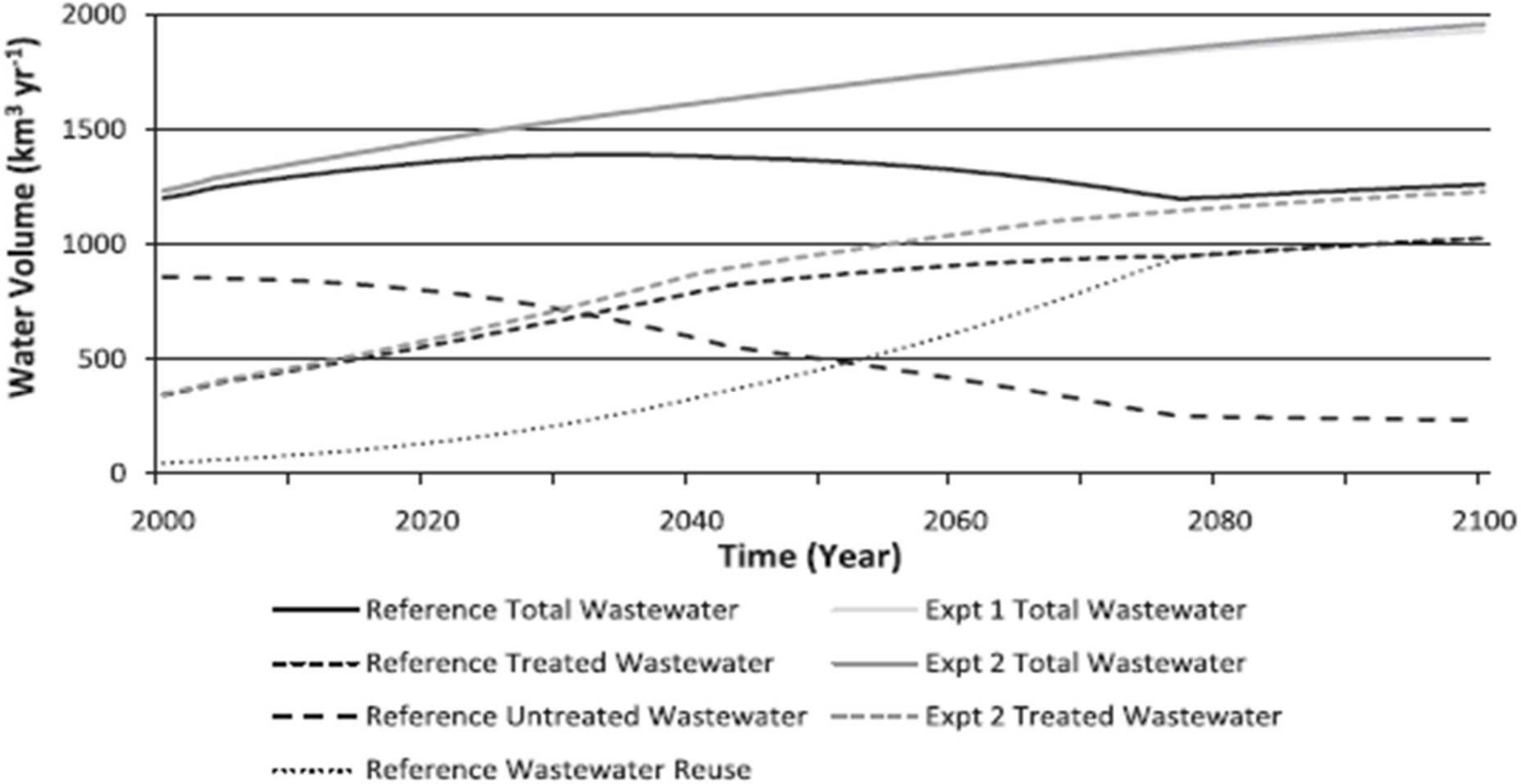
ANEMI
Water resources modeling



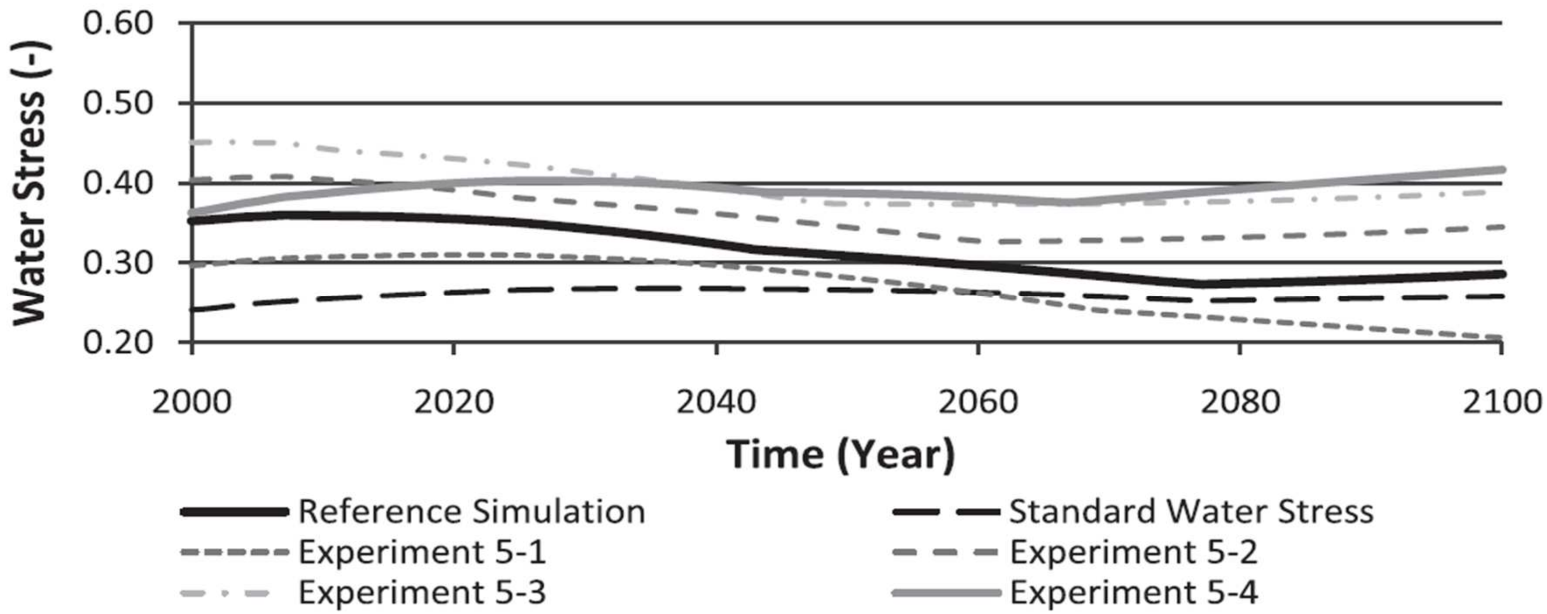
ANEMI
Water resources modeling



ANEMI
Water resources modeling



17 | ANEMI
Water resources modeling



18 | GLOBAL WATER RESOURCES MODELING
Conclusions

- Global modeling of water resources is difficult:
  - Complexity and dynamic behavior of water resources systems
  - Interactions with the number of different real-world systems (population, climate, land use, energy, economy,…)
- There is a need for different modeling approach
- System dynamics simulation
- ANEMI model
- Simulation of 5 scenarios:
  - Water quality problems related to limited wastewater treatment and reuse could cause major water scarcity.
  - There are considerable benefits of implementing extensive wastewater treatment and reuse programs.
  - Greater consumption of animal products not only affects the global agricultural area, but also water resources systems.
  - There are benefits from a water stress definition that incorporates water quality as well as water quantity.

19| ADDITIONAL RESOURCES

www.slobodansimonovic.com -> research -> fids