Climate Change and Water Management

The Renaissance of Systems Approach

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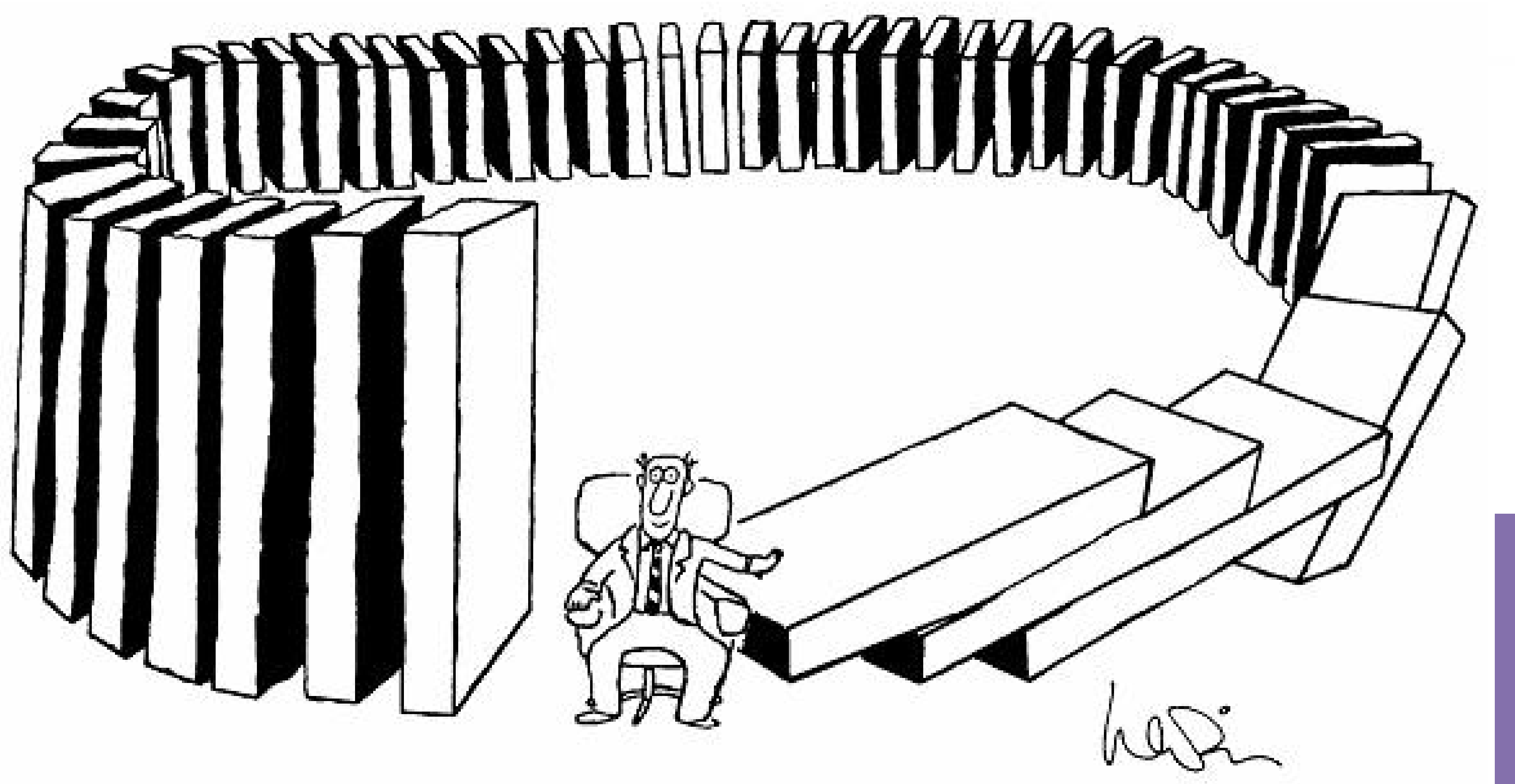
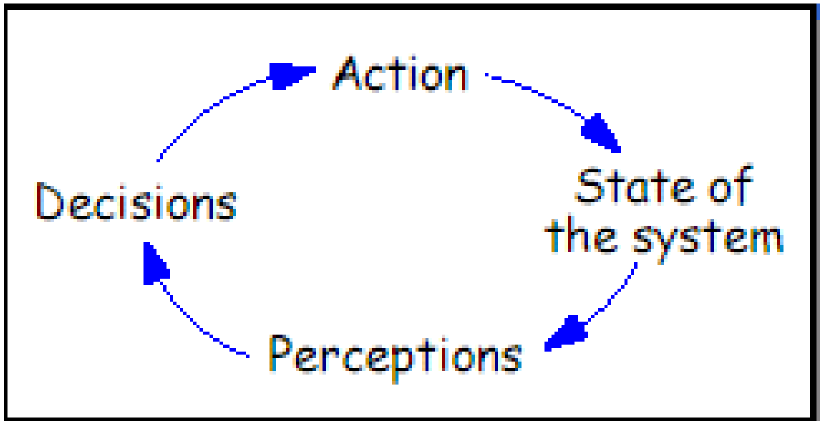
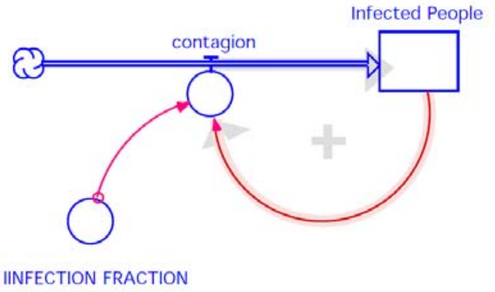
Main messages

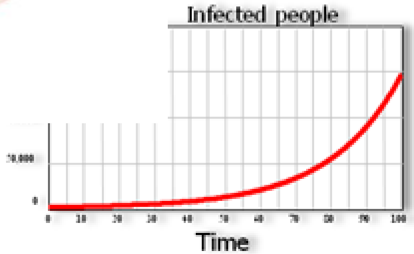
- It is all about feedbacks!
- Climate change is real and more serious than expected
  - Temperature
  - Concentration of GHG
  - See ice and glaciers
  - See level rise
- Climate change is hydrologic change
- Water management – what are we trying to manage?
- Systems approach – examples
  - Integrated system modeling of the social-economic-climatic system
  - Modeling impacts of climate change on management of water resources on local scale
- It is all about feedbacks!

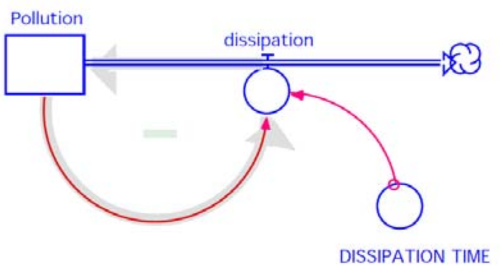


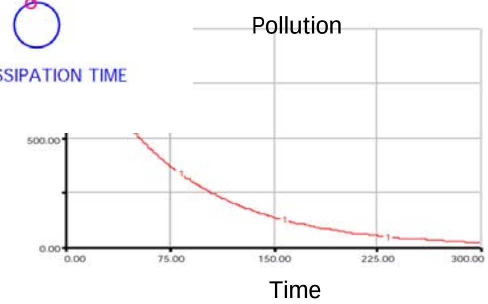
Feedback


Action
State of the system
Perceptions
Decisions


Infected People
contagion
+
IINFECTION FRACTION


Infected people
Time


Pollution
dissipation
–
DISSIPATION TIME


Pollution
500.00
0.00
0.00
75.00
150.00
225.00
300.00
Time

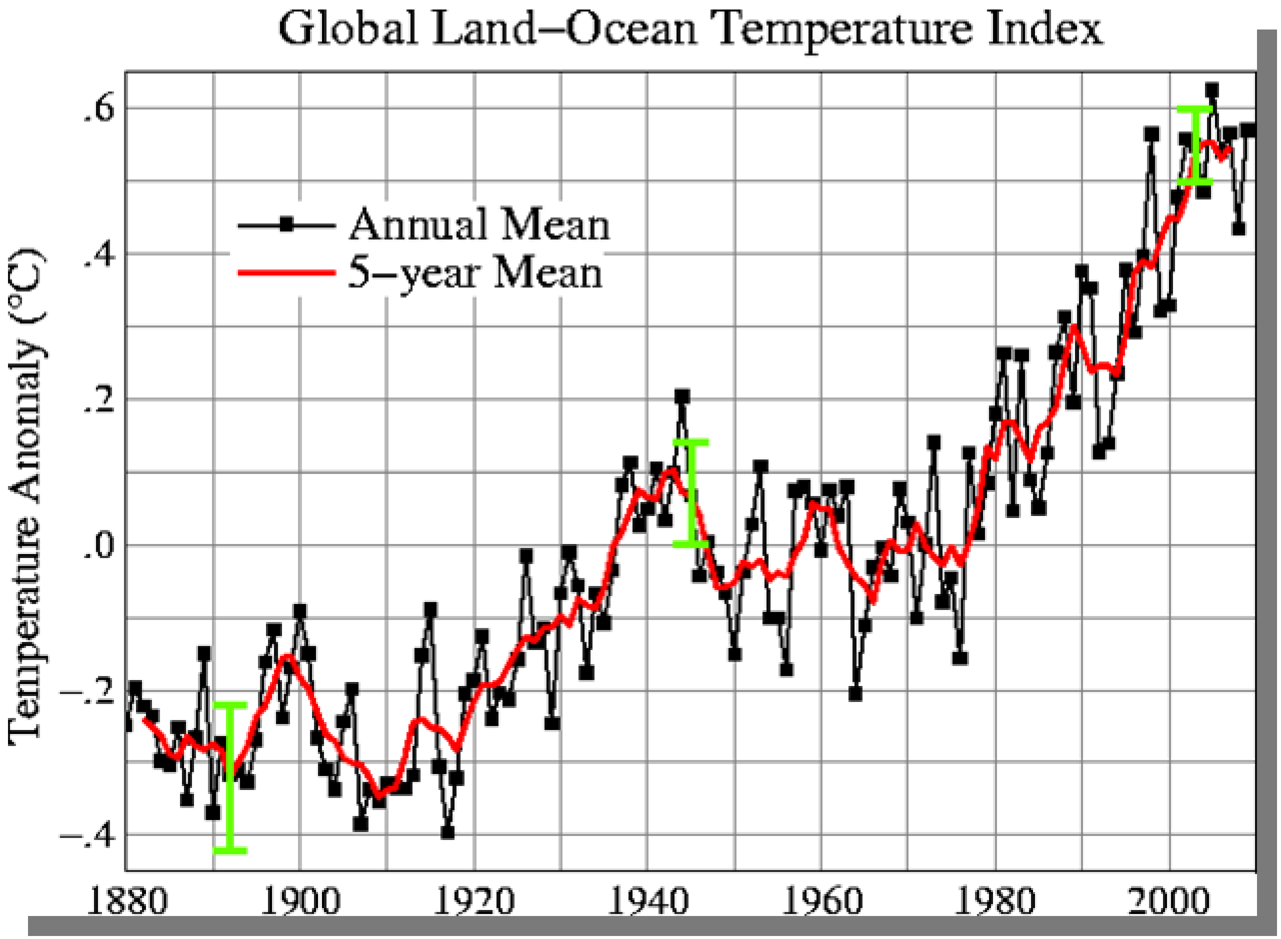
- Climate change

Climate change – we know

- “Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea level”
- “Global atmospheric concentrations of CO_2, CH_4 and N_2O have increased markedly as a result of human activities since 1750 and now far exceed pre-industrial values”

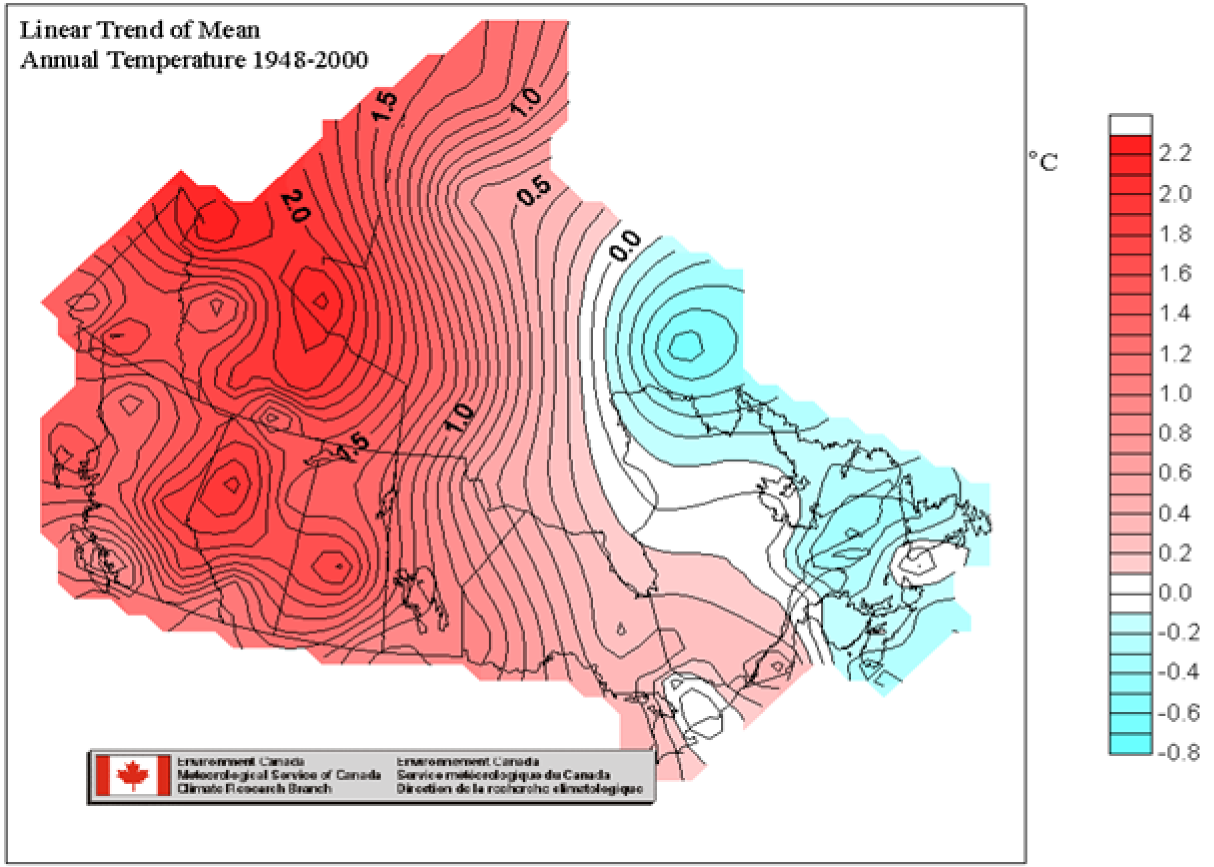
IPCC (2007)

Climate change – we know



Hansen et al, Proc. Natl. Acad. Sci., (2006)

Climate change – we know

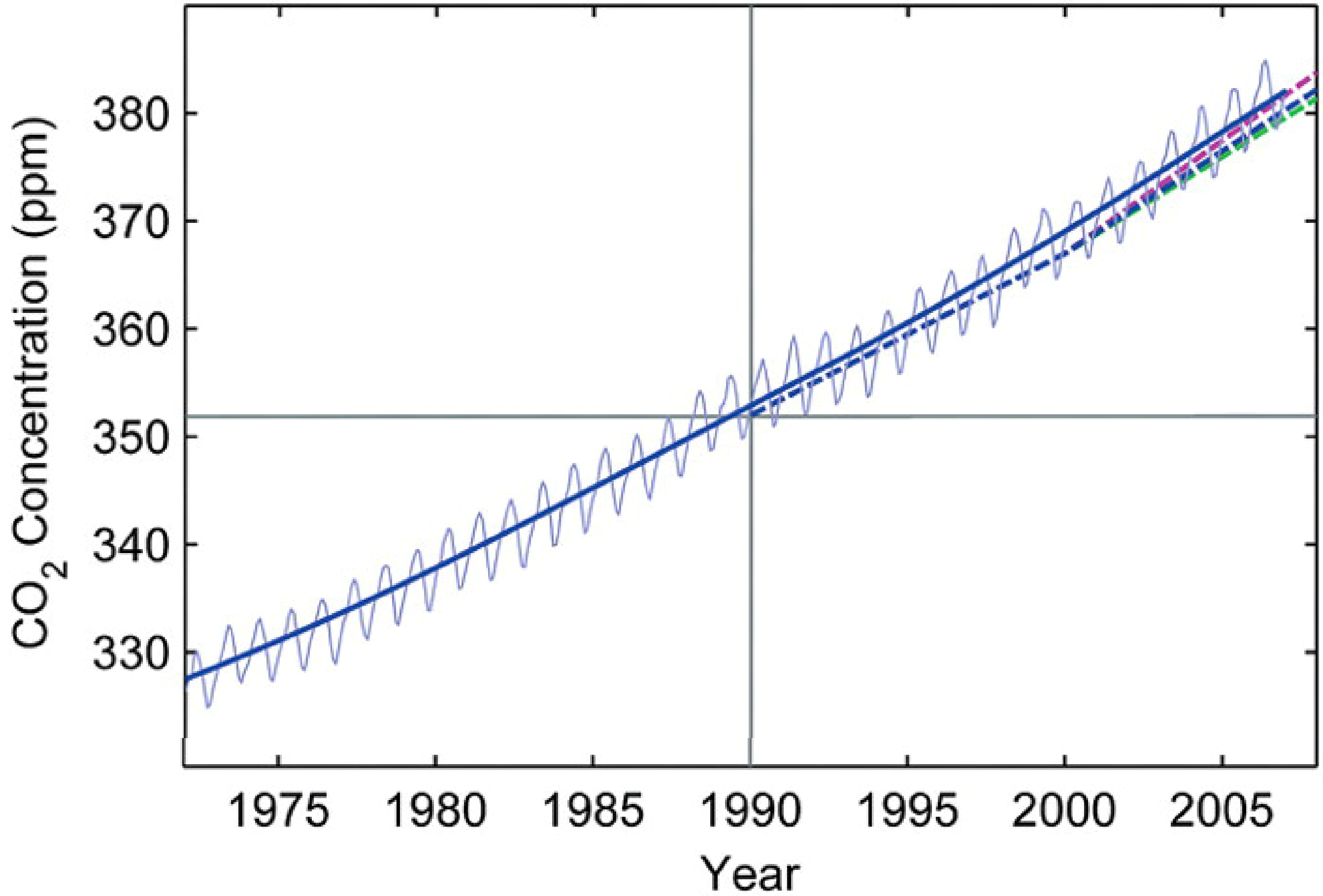


Climate change – we know

- Recent global temperatures demonstrate human-induced warming
  - Over the past 25 years temperatures have increased at a rate of 0.19°C per decade.
- Very good agreement with predictions based on greenhouse gas increases.
- Over the past ten years, despite a decrease in solar forcing, the trend continues to be one of warming.
- Natural, short-term fluctuations are occurring as usual, but there have been no significant changes in the underlying warming trend (~0.6^{0}C).

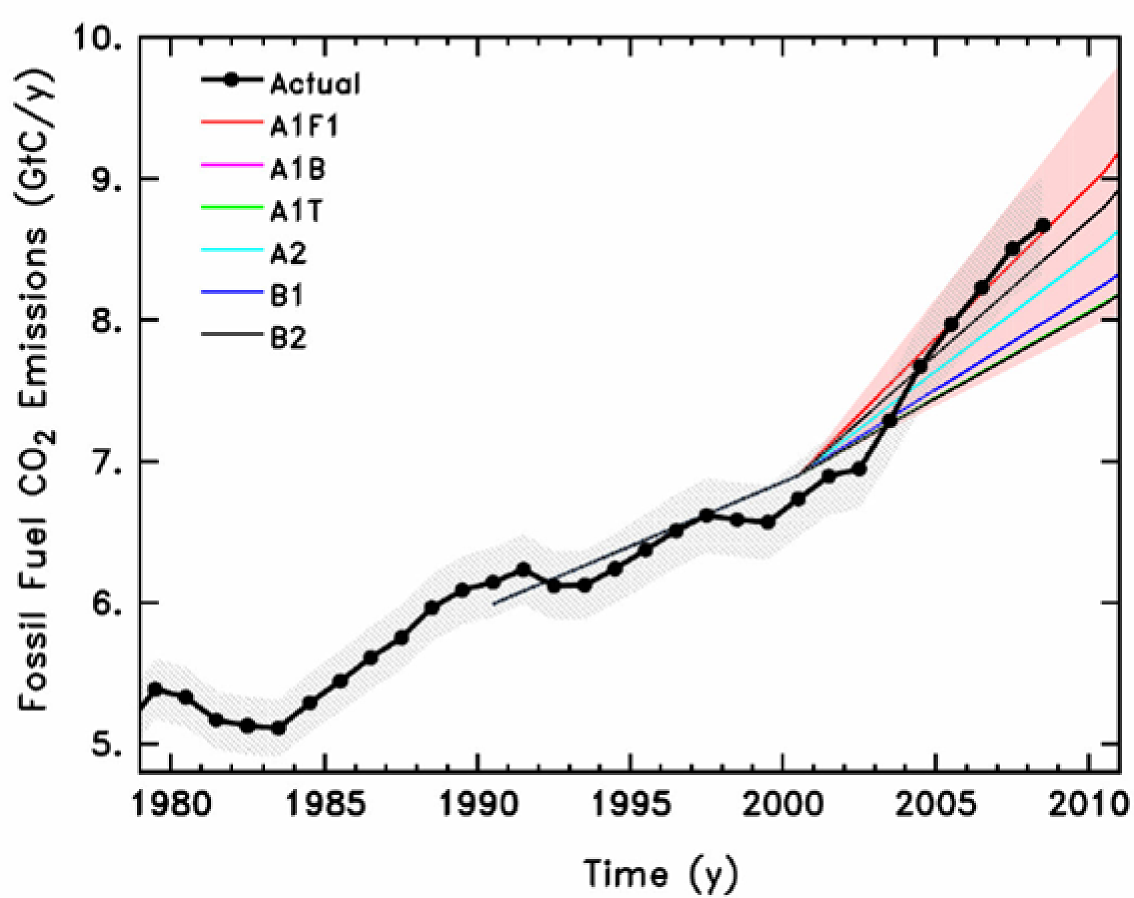
Copenhagen Diagnosis (2009)

Climate change – we know



Rahmstorf et al, Science, (2007)

Climate change – we know



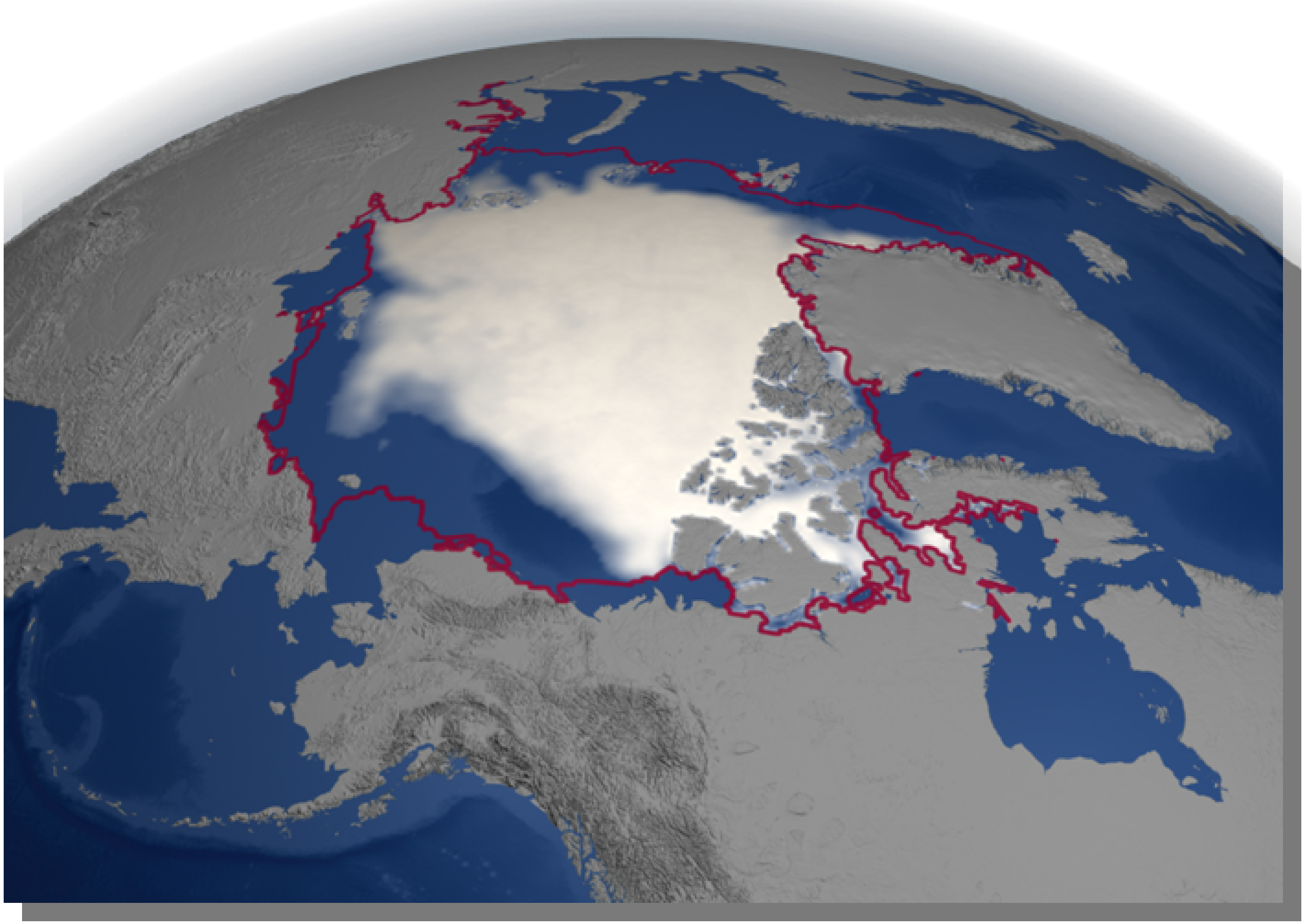
Le Quere et al, Nature Geosciences (2009)

Climate change – we know

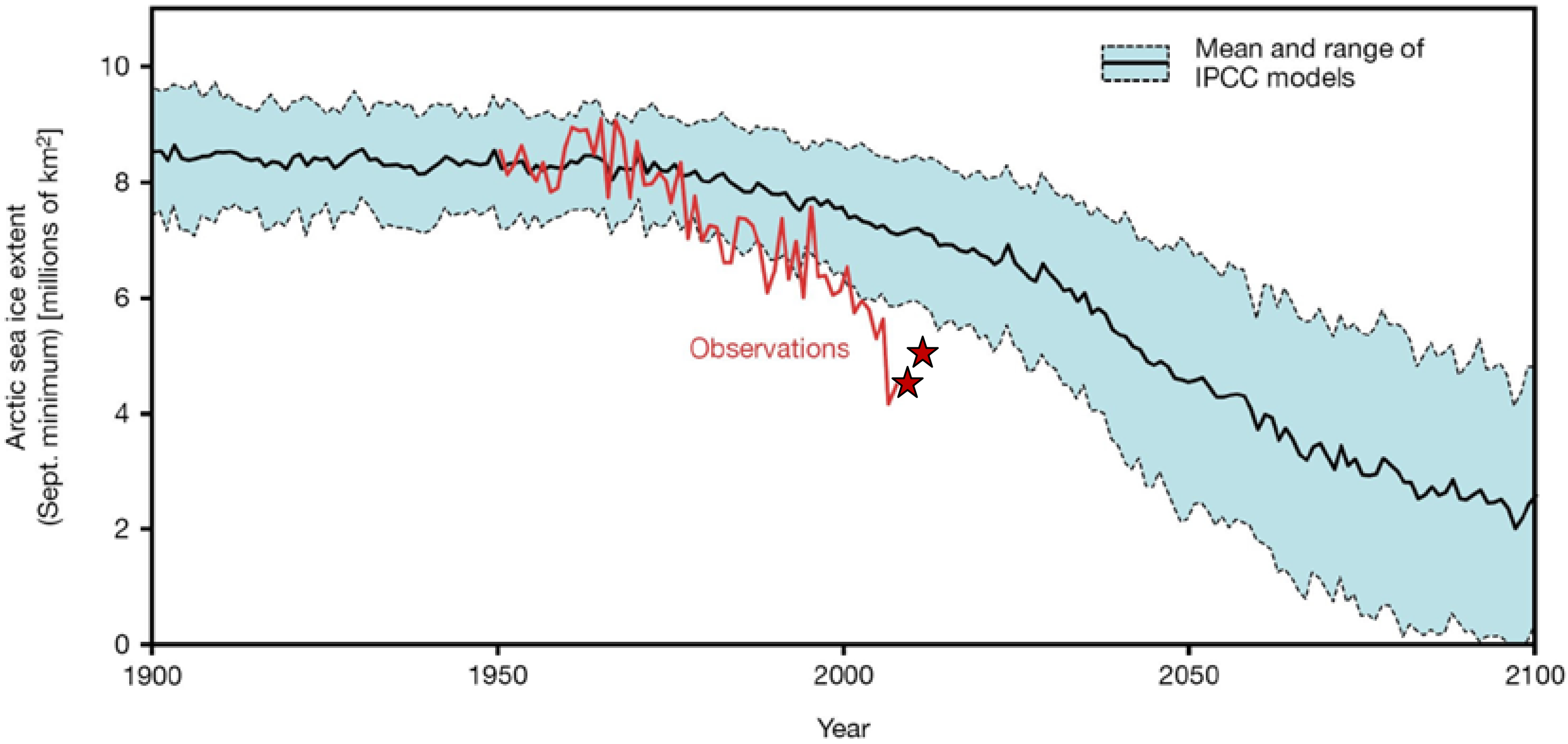
- Greenhouse gas emissions are surging
  - Global carbon dioxide emissions from fossil fuels in 2008 were nearly 40% higher than those in 1990.
- Even if global emission rates are stabilized at present-day levels, just 20 more years of emissions would give a 25% probability that warming exceeds 2°C, even with zero emissions after 2030.
- Every year of delayed action increases the chances of exceeding 2°C warming.

Copenhagen Diagnosis (2009)

Climate change – we know



Climate change – we know



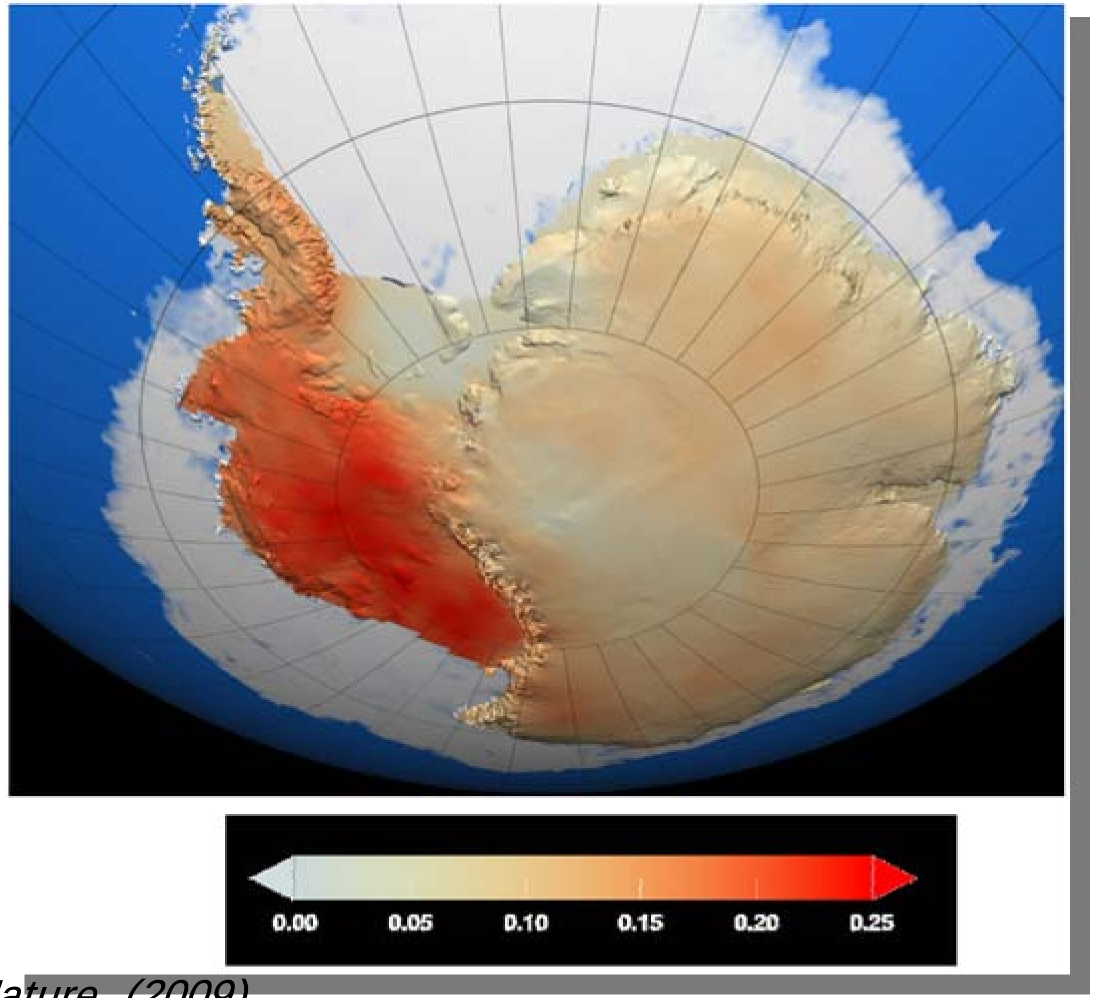
Stoeve et al, Geophysical Research Letters, (2007)

Climate change – we know

Melt descending
into a moulin,
a vertical shaft
carrying water
to ice sheet base -
Greenland

Roger Braithwaite, University of Manchester (UK)

Climate change – we know



Steig et al, Nature, (2009)

Climate change – we know

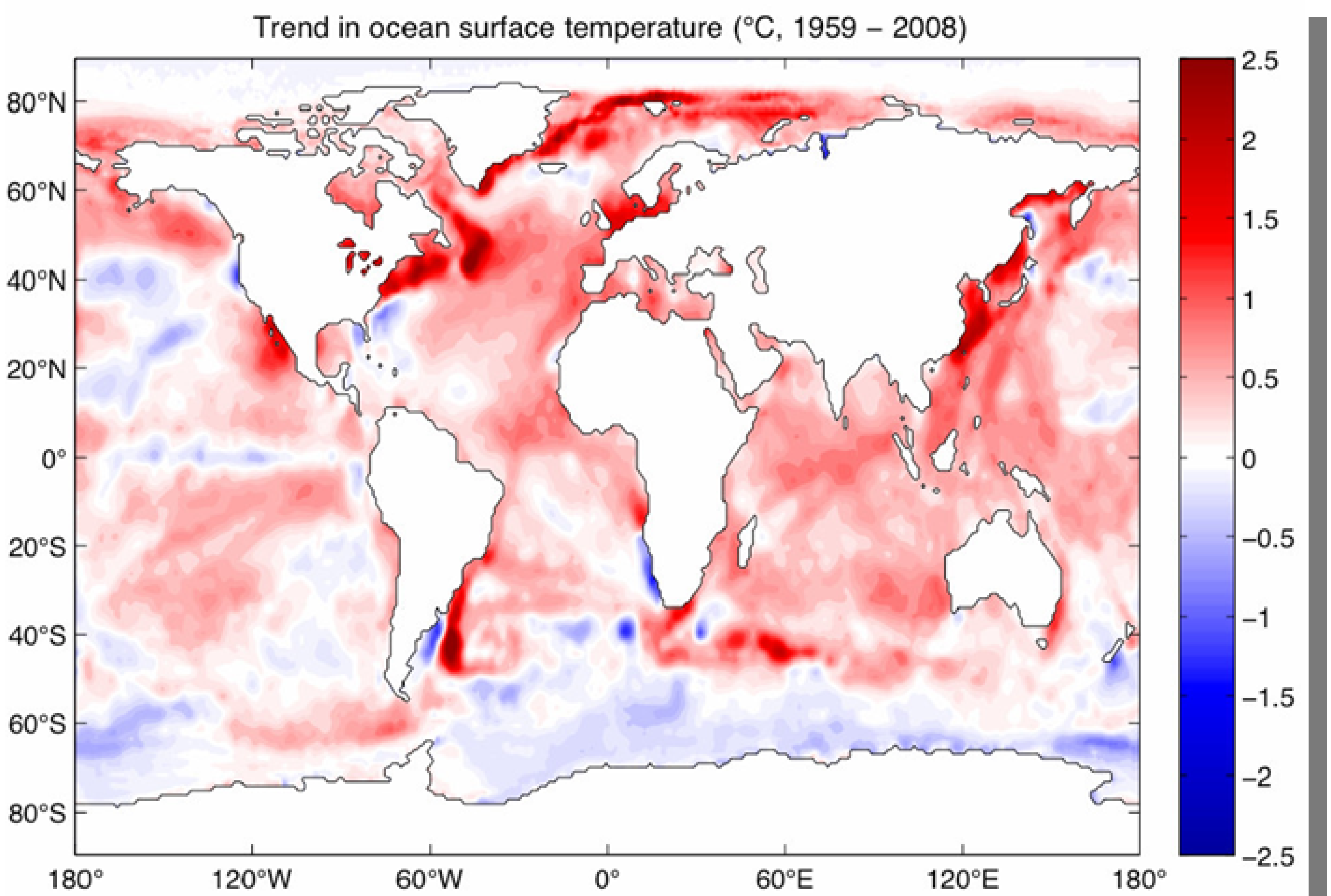
Photograph: Erwin Schneider/Alton Byers/The Mountain Institute

Climate change – we know

- Rapid Arctic sea-ice decline
  - Summer-time melting of Arctic sea-ice has accelerated far beyond the expectations of climate models.
  - The area of sea-ice melt during 2007-2009 was about 40% greater than the average prediction from IPCC AR4 climate models.
- Ice sheets, glaciers and ice caps are showing accelerated melting
  - The surface area of the Greenland ice sheet which experiences summer melt has increased by 30% since 1979.
  - Antarctica is also losing ice mass at increasing rate. Ice shelves (connections between continental ice sheets and the ocean) are destabilized (7 collapses in last 20 years)

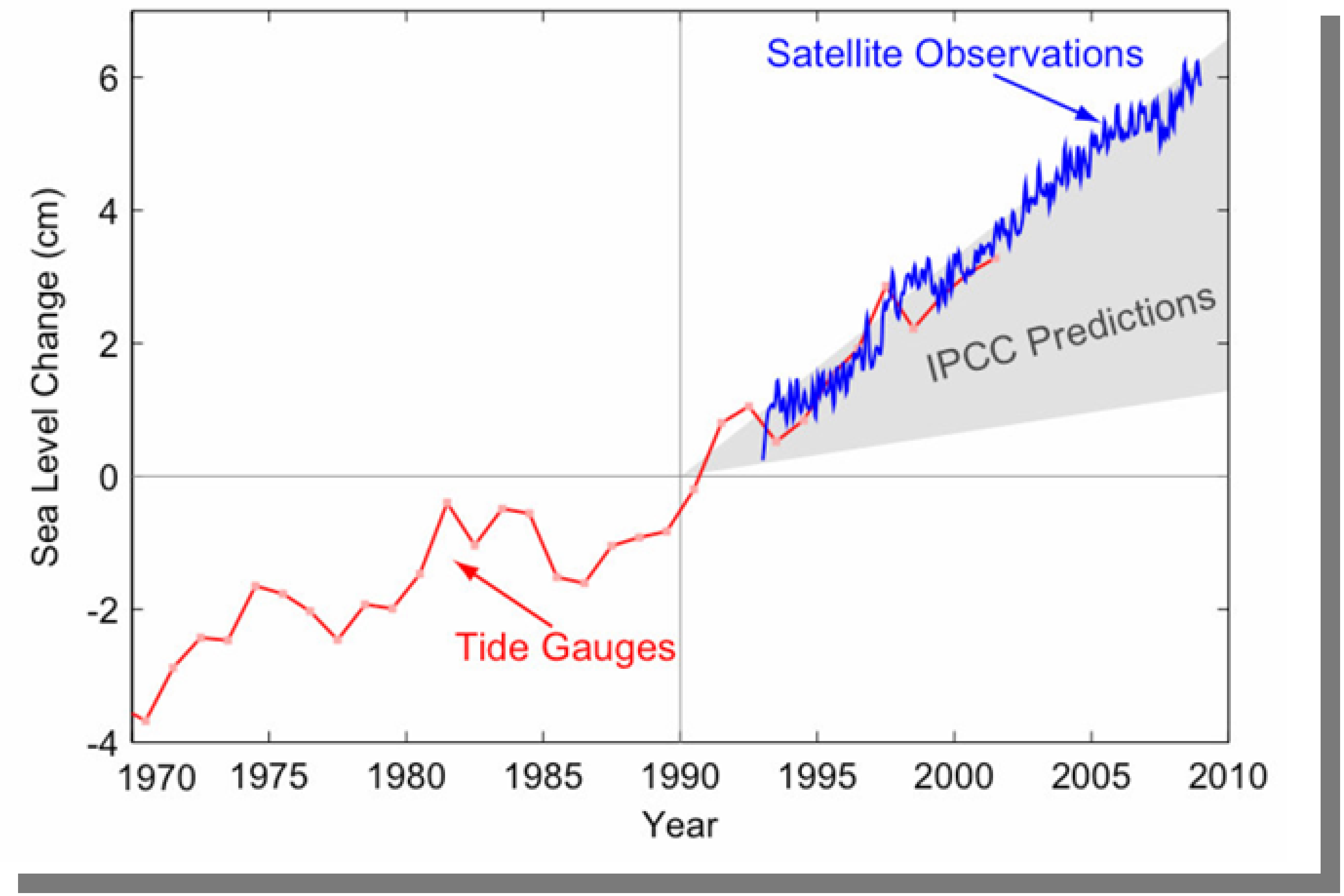
Copenhagen Diagnosis (2009)

Climate change – we know



Copenhagen Diagnosis (2009)

Climate change – we know



Church and White , Geophysical Research Letters, (2006)
Cazenave et al, Global and Planetary Change, (2009)

Climate change – we know

- "Overall, these observational data underscore the concerns about global climate change. Previous projections, as summarized by IPCC, have not exaggerated but may in some respects even have underestimated the change, in particular for sea level."

Rahmstorf et al, Science, (2007)

Feedbacks

- *Interaction* between socio-economic and natural systems causes climate change

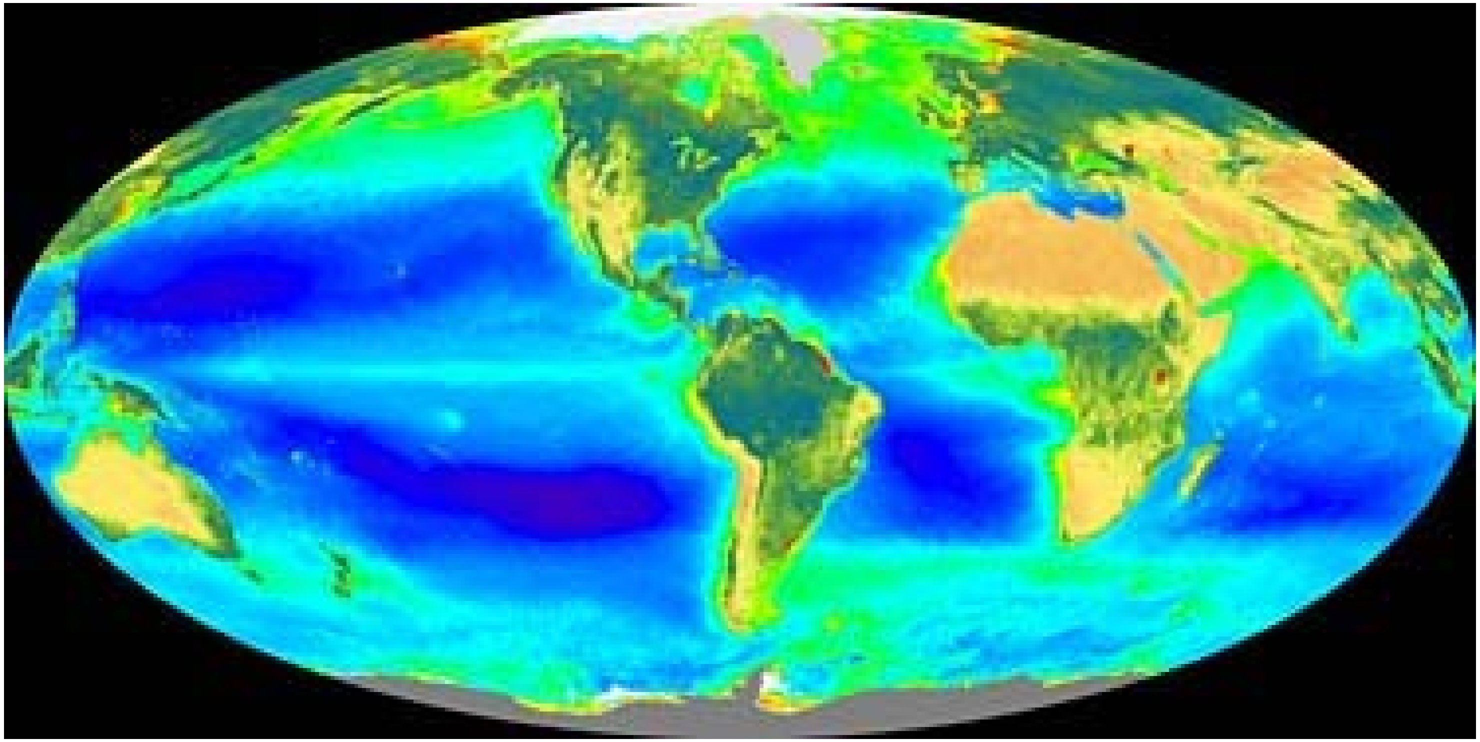
Climate Change → Social Adaptation

- *Interaction* determines the entire system's evolution

Feedbacks

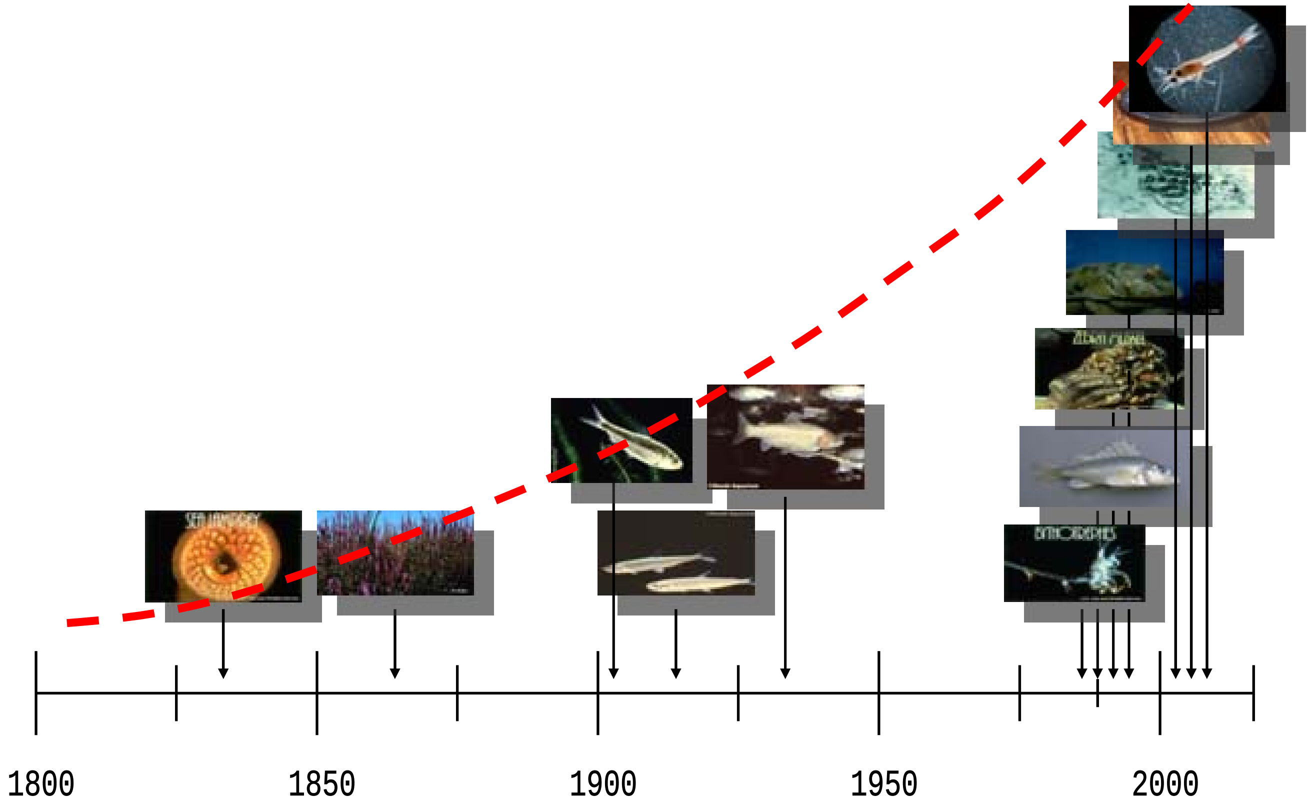
- Strong positive feedbacks (amplification of the surface temperature response)
  - Higher temperature – Warmer oceans - Increase in evaporation - Water vapor increase (amount is function of temperature) – Temperature increase
  - Higher temperature – Snow and ice melt – Larger absorption of sunlight - Temperature increase
  - Higher ocean temperature – less algae – more heating
- Big and dangerous feedbacks (unstoppable if the emperature goes 2 – 3^{o}C up)
  - Higher temperature – Higher release of methane from the Arctic and the oceans – Higher temperature
  - Movement of climate zones – Change in vegetation distribution – Change of species distribution – Climate zone change

Feedbacks



Polovina, Geophysical Research Letters, (2008)

Feedbacks



Mahon, (2009)

Climate change – we don't know

- The speed at which the global average temperature will rise with change of CO_2 concentration (non-linear relationship).
- What is the tipping point for making dangerous feedbacks unstoppable.

- Water resources management

What are we trying to manage?

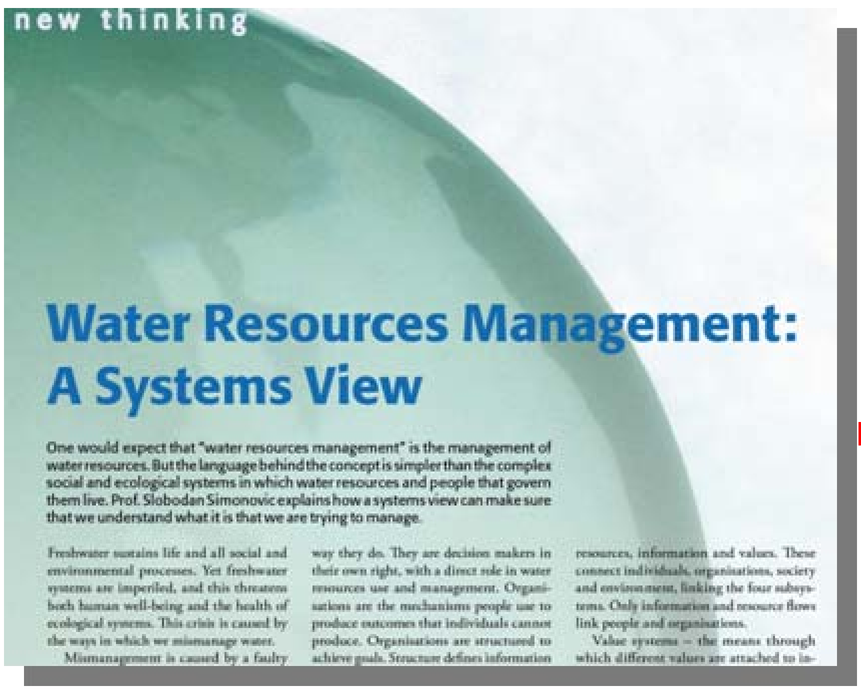
- Traditional view
  - We keep trying to manage environments (water, land, air, etc).
  - We keep trying to manage people within environments.
- It seems that every time we push at one point, it causes unexpected change elsewhere – first fundamental systems principle.

What are we trying to manage?

- The system in our focus is a social system. It describes the way water resources are used by people.
- The system exhibits a high level of complexity.
- It includes all sources of uncertainty: variability and ambiguity.

New thinking – A systems view

Stockholm Water Front, No.1, May 2009, page 12


new thinking

Water Resources Management: A Systems View

One would expect that "water resources management" is the management of water resources. But the language behind the concept is simpler than the complex social and ecological systems in which water resources and people that govern them live. Prof. Slobodan Simonovic explains how a systems view can make sure that we understand what it is that we are trying to manage.

Freshwater sustains life and all social and environmental processes. Yet freshwater systems are imperiled, and this threatens both human well-being and the health of ecological systems. This crisis is caused by the ways in which we mismanage water.

Mismanagement is caused by a faulty

way they do. They are decision makers in their own right, with a direct role in water resources use and management. Organisations are the mechanisms people use to produce outcomes that individuals cannot produce. Organisations are structured to achieve goals. Structure defines information

resources, information and values. These connect individuals, organisations, society and environment, linking the four subsystems. Only information and resource flows link people and organisations.

Value systems – the means through which different values are attached to in-

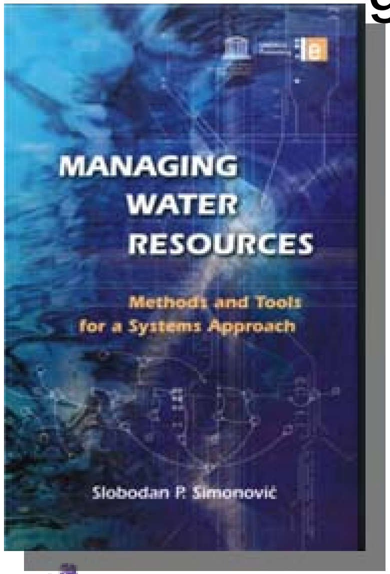
- Water resources management integrates four subsystems: individual, organization, society and environment.
- Resource and information flows link the individual, organization, society and environment subsystems.

New thinking – A systems view

- Information is used to determine resource use by subsystems.
- Values provide meaning to information flows.
- The ongoing need of subsystems for resources from one another sets the limits of their exploitation of one another and of the environment, and determines the system behavior.

The systems approach

- The systems approach establishes the proper order of inquiry and helps in the selection of the best course of action that will accomplish a prescribed goal:
  - by broadening the information base of the decision-maker;
  - by providing a better understanding of the system, and the interrelatedness of its component subsystems; and
  - by facilitating the prediction of the consequences of several alternative courses of action.



Western

The systems approach

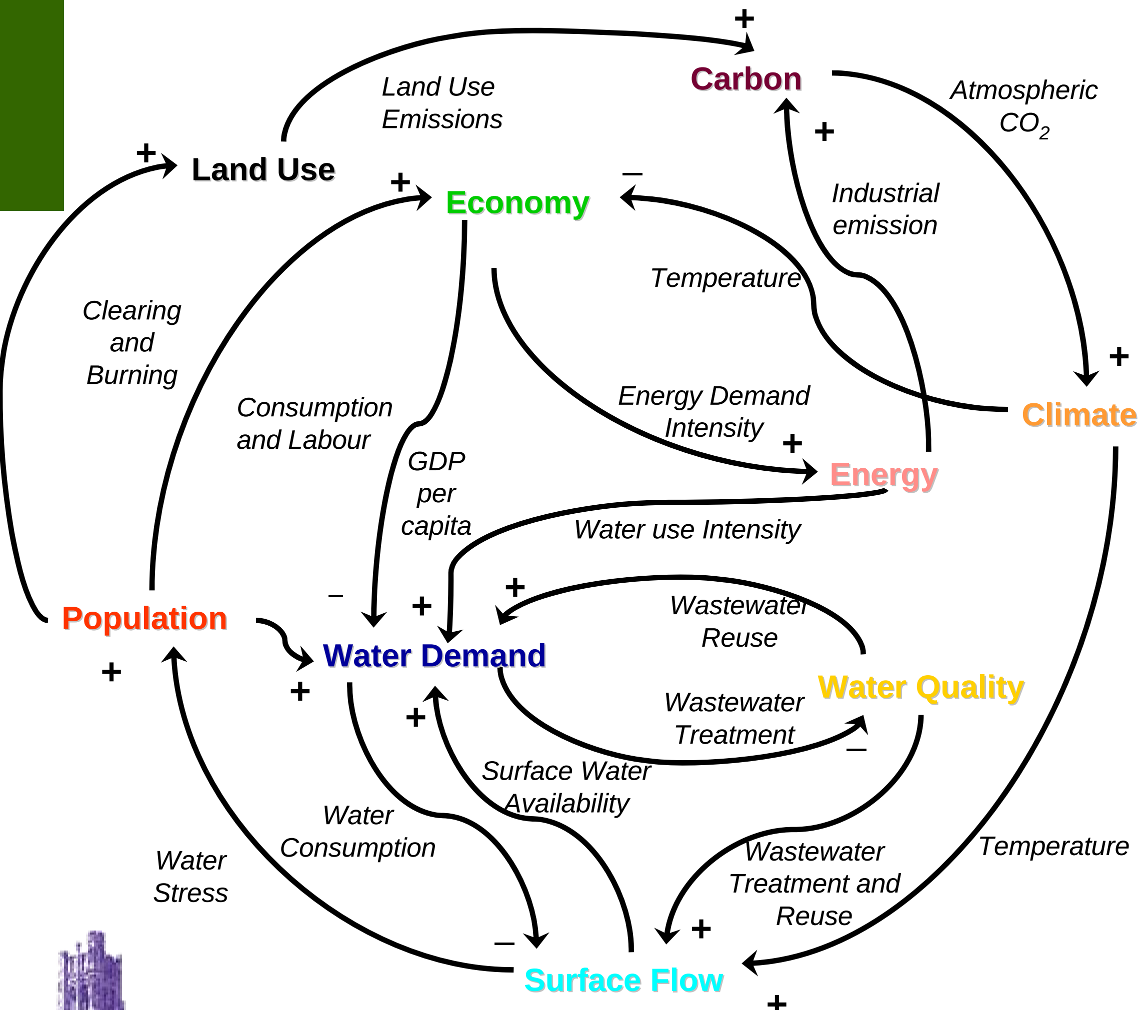
- System analysis tools
  - Simulation
  - Optimization
  - Multi-objective analysis

- Example 1

An Integrated System Dynamics Model of the Social-Economic-Climatic System

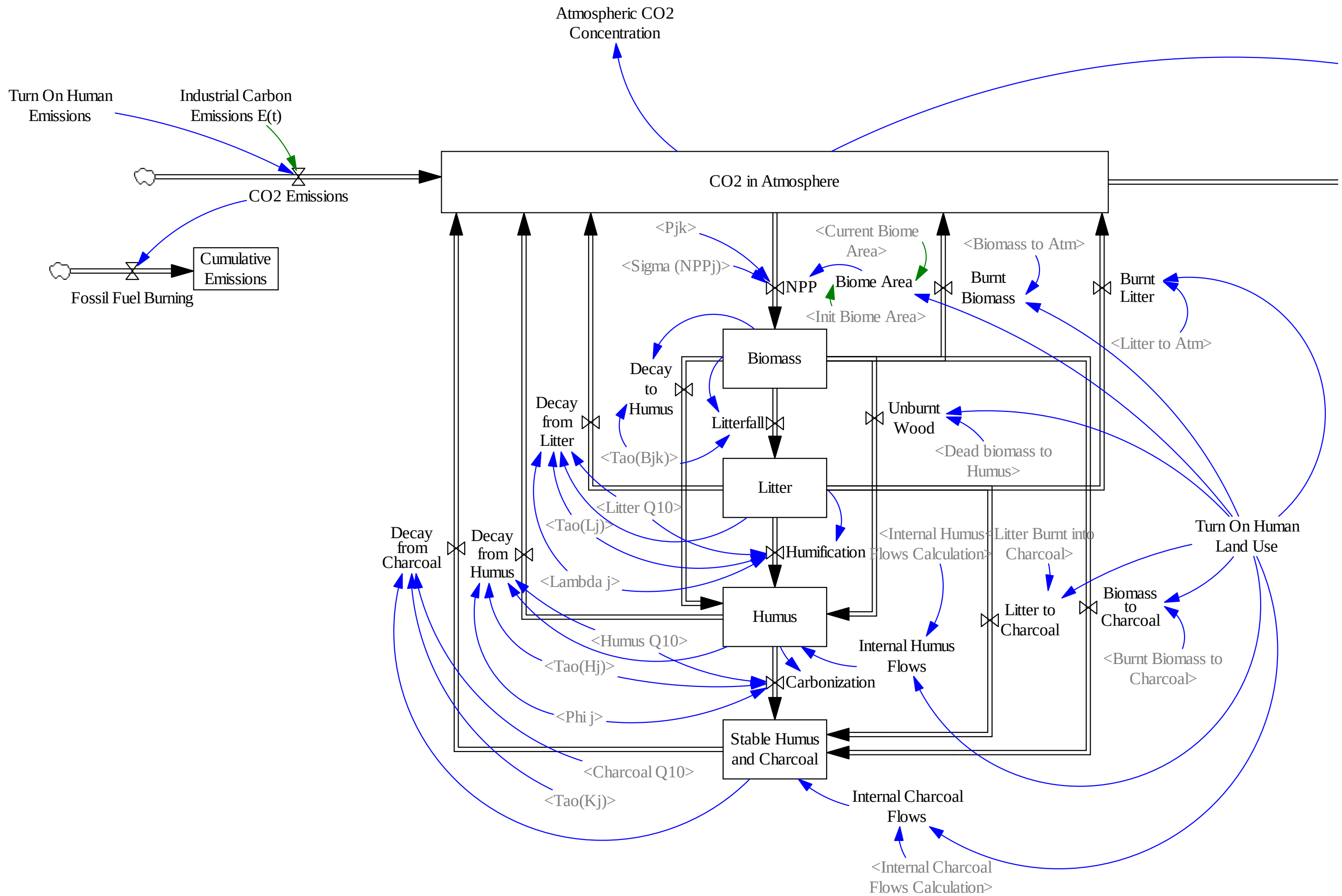
NSERC Strategic Research Grant

ANEMI



- Number of Model Elements:
  - 740 variables
  - 230 Stocks (many in arrays)
  - 2300 total
- 600 equations
  - 99 major equations
- Thousands of feedbacks
  - Population: 4468 loops
  - Water stress: 2756 loops
  - Economic output: 203 loops
  - Industrial emissions: 47 loops

ANEMI



Atmospheric CO2 Concentration
Turn On Human Emissions
Industrial Carbon Emissions E(t)
CO2 in Atmosphere
CO2 Emissions
Cumulative Emissions
Fossil Fuel Burning
<Pjk>
<Sigma (NPPj)>
<Current Biome Area>
<Biomass to Atm>
NPP
Biome Area
Burnt Biomass
Burnt Litter
<Init Biome Area>
<Litter to Atm>
Biomass
Decay to Humus
Decay from Litter
Litterfall
Unburnt Wood
<Tao(Bjk)>
<Dead biomass to Humus>
Litter
<Litter Q10>
<Tao(Lj)>
Decay from Charcoal
Decay from Humus
Humification
<Internal Humus Flows Calculation>
<Litter Burnt into Charcoal>
Turn On Human Land Use
<Lambda j>
Litter to Charcoal
Biomass to Charcoal
Humus
<Humus Q10>
Internal Humus Flows
<Tao(Hj)>
Carbonization
<Burnt Biomass to Charcoal>
<Phi j>
Stable Humus and Charcoal
<Charcoal Q10>
<Tao(Kj)>
Internal Charcoal Flows
<Internal Charcoal Flows Calculation>

ANEMI

- Atmosphere

$$A = \int \left(D_B + D_L + D_H + D_K - NPP + B_B + B_L + E - F_O \right) \cdot dt$$

- Biomass

$$B_{jk} = \int \left(NPP_{jk} - FL_{B\,jk} - FH_{B\,jk} - FK_{B\,jk} - B_{B\,jk} - UB_{jk} \right) \cdot dt$$

- Net Primary Productivity

$$NPP_{jk} = p_{jk} \cdot \sigma(NPP_j) \cdot SA_j \big/ 1 \times 10^{15}$$

$$\sigma(NPP_j) = \sigma(NPP_j)_0 \times \left(1 + \beta \ln\left(A / A_0\right)\right)$$

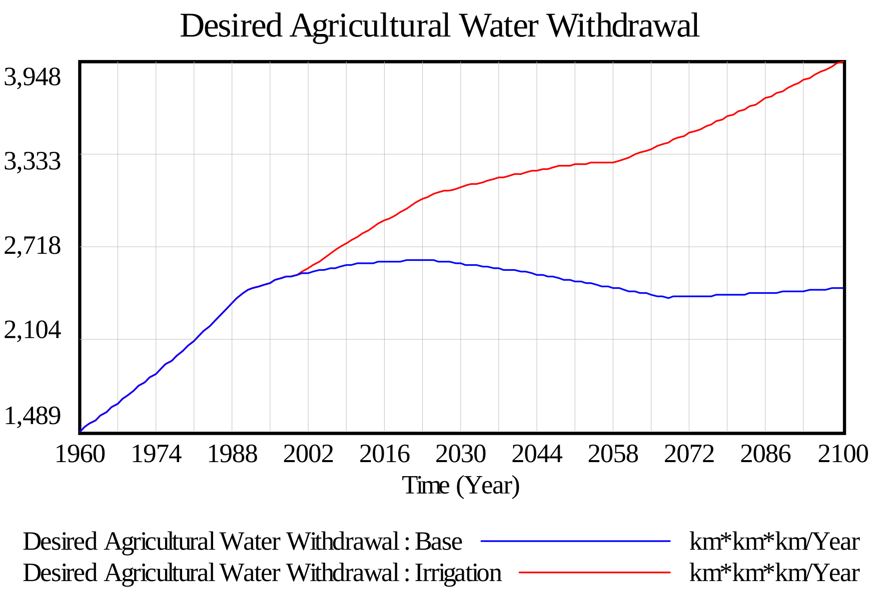
- Root Decay

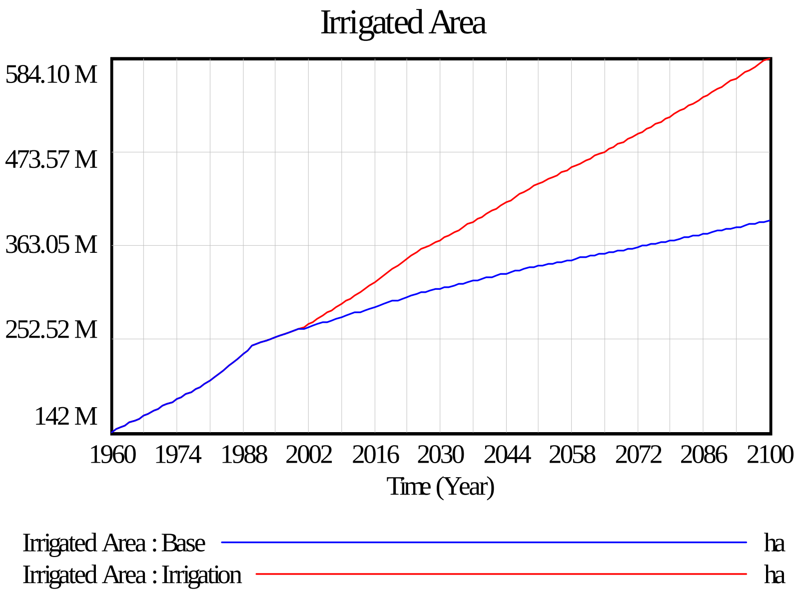
$$FH_{B\,j4} = B_{j4} \big/ \tau(B_{j4})$$

ANEMI

- Irrigation Expansion
  - Individual Simulation
    - Effects of increased irrigation on system
- Approach: Compare experiment against base case results

ANEMI





More irrigation - more area for food production

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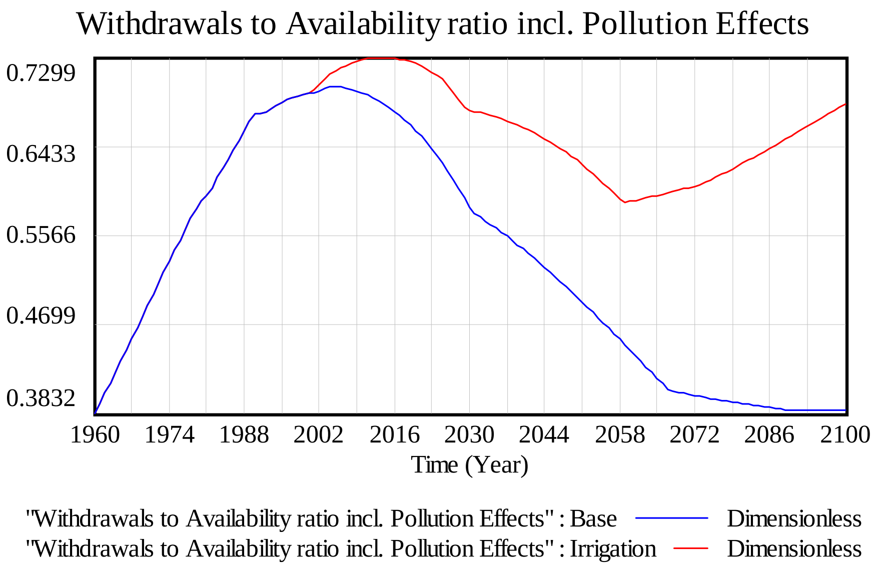
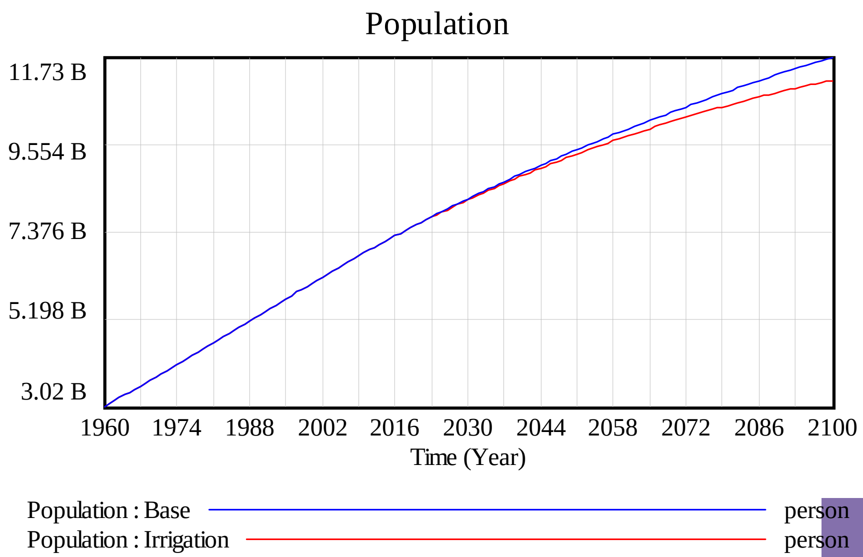




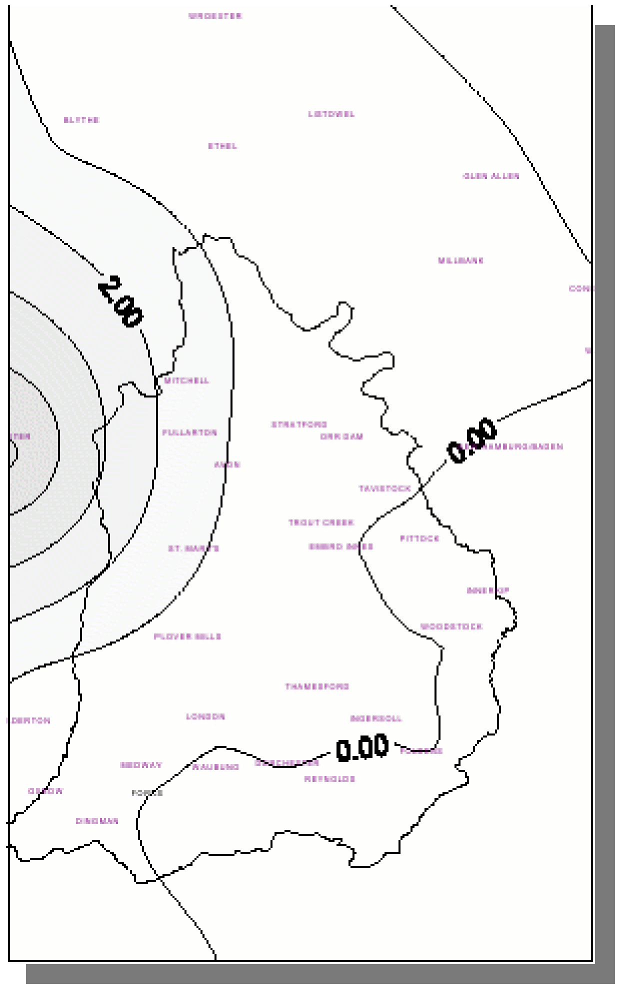
More irrigation - more pollution
More pollution - lower population
FEEDBACK –> MORE FOOD – LOWER POPULATION

- Example 2

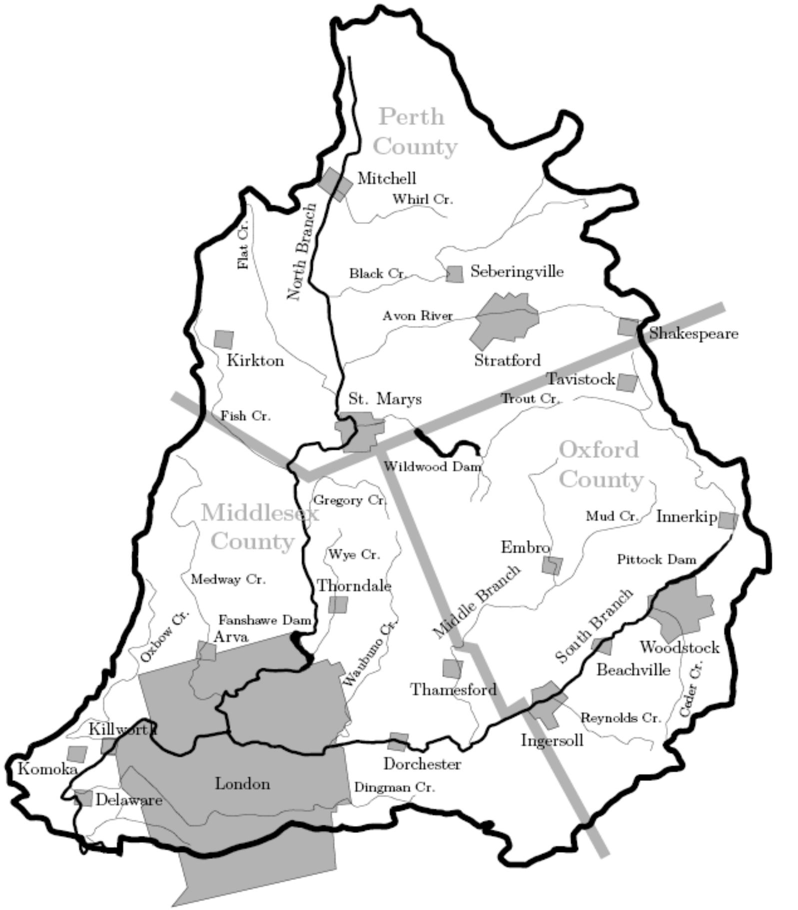
Understanding the impacts of climate change on management of water resources on local scale

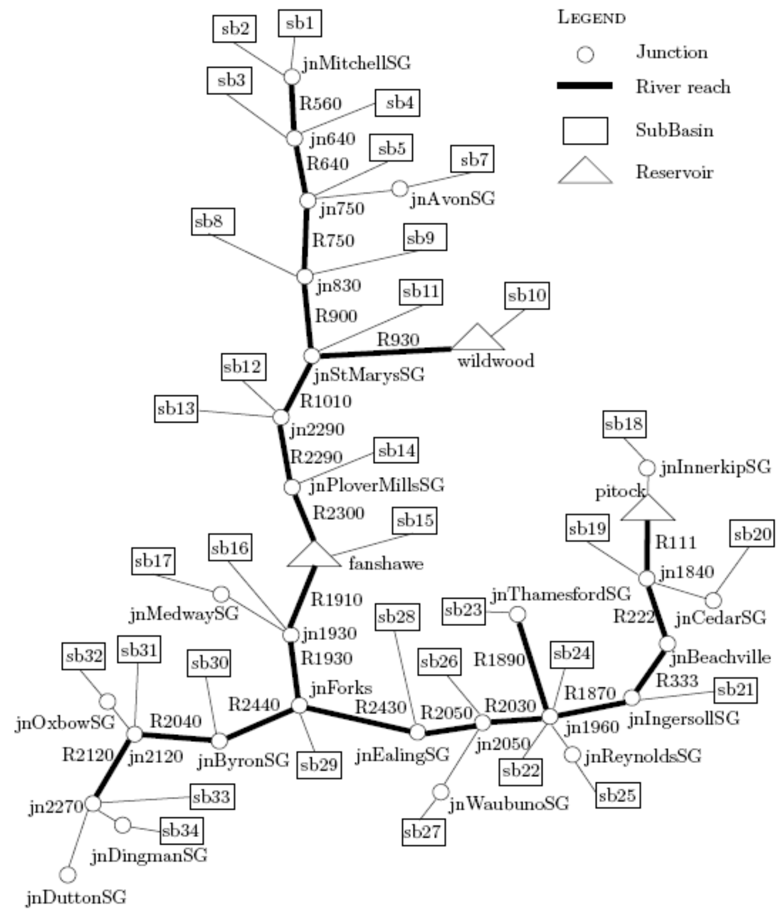
Two projects - *Canadian Foundation for Climate and Atmospheric Sciences*
Three projects – *City of London*

Upper Thames River Basin

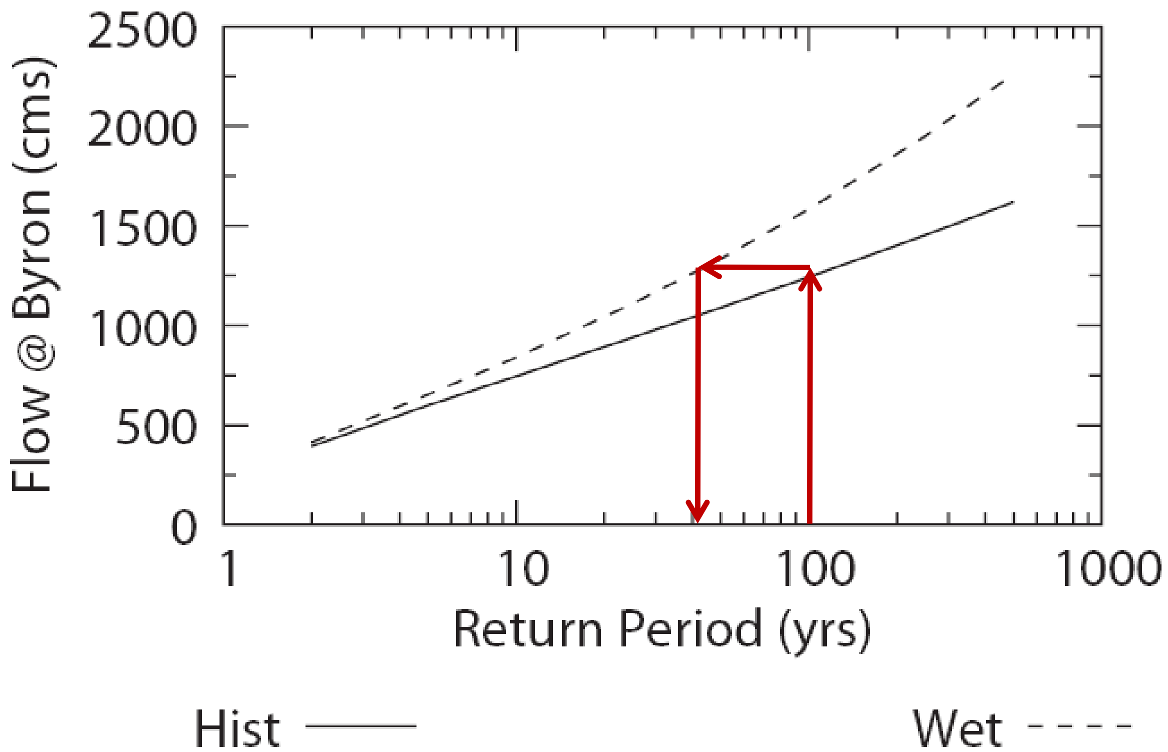


Upper Thames River Basin



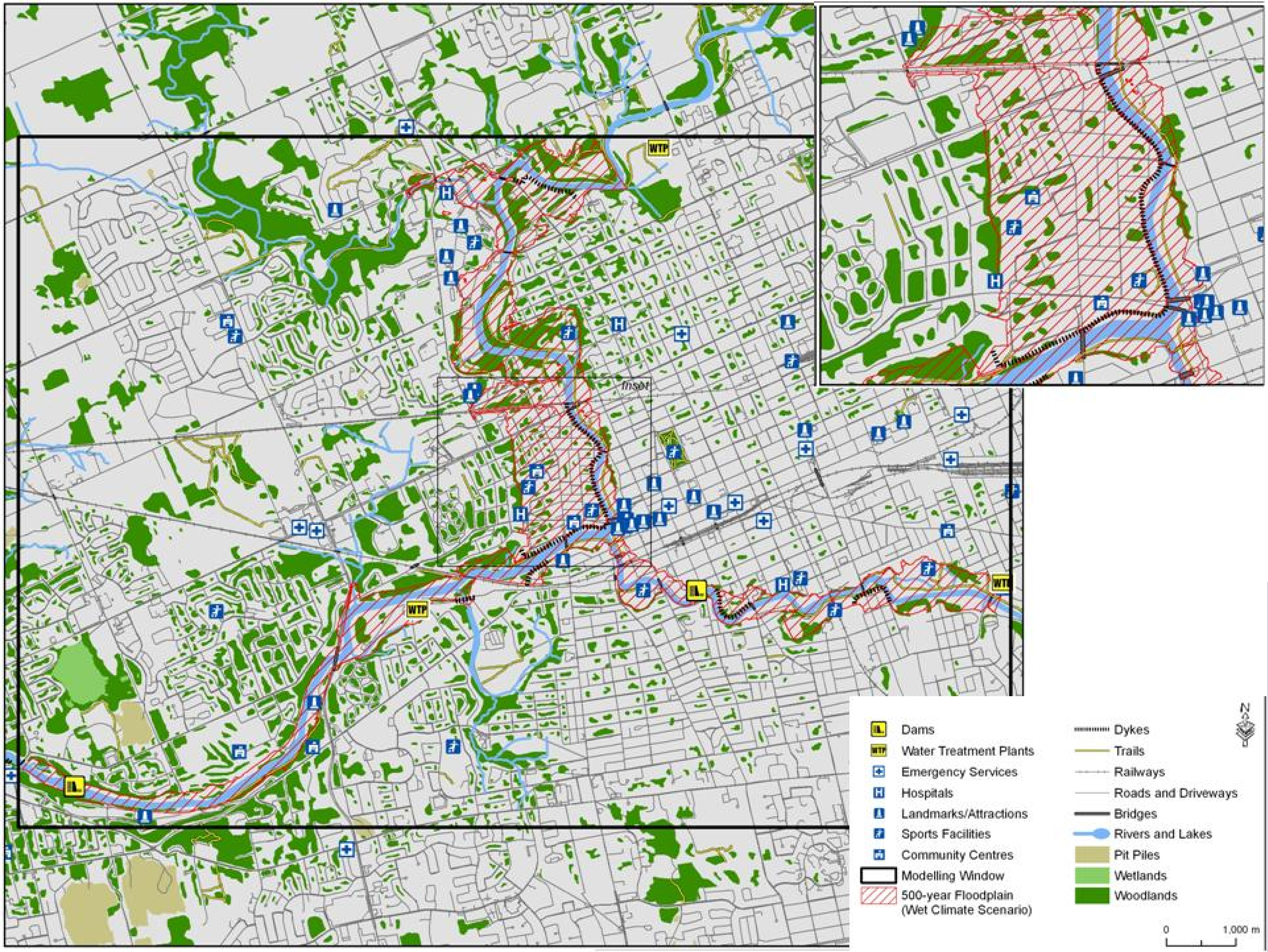


Upper Thames River Basin

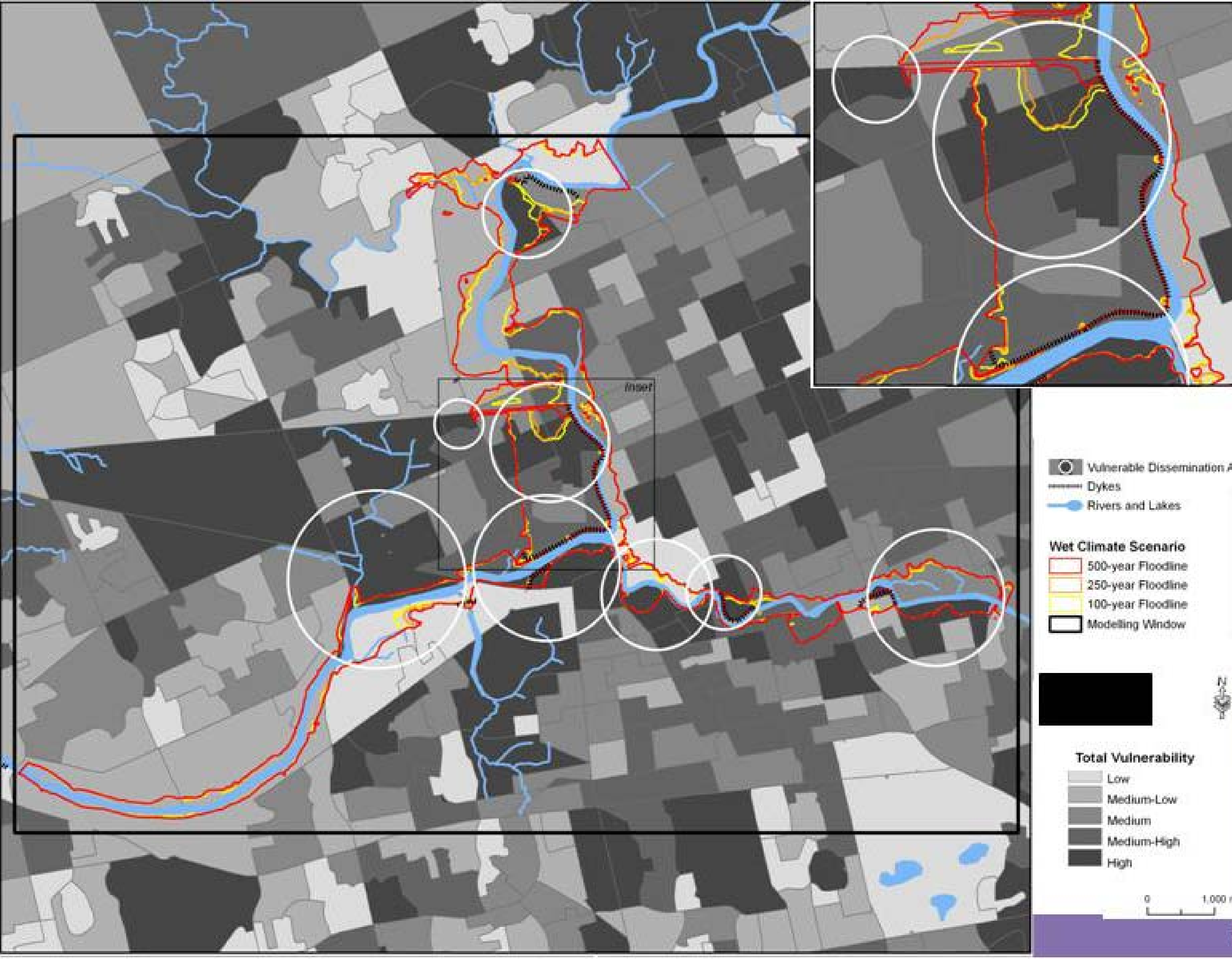



10PM - 6AM
HELP STOP THE SNEAK THIEF

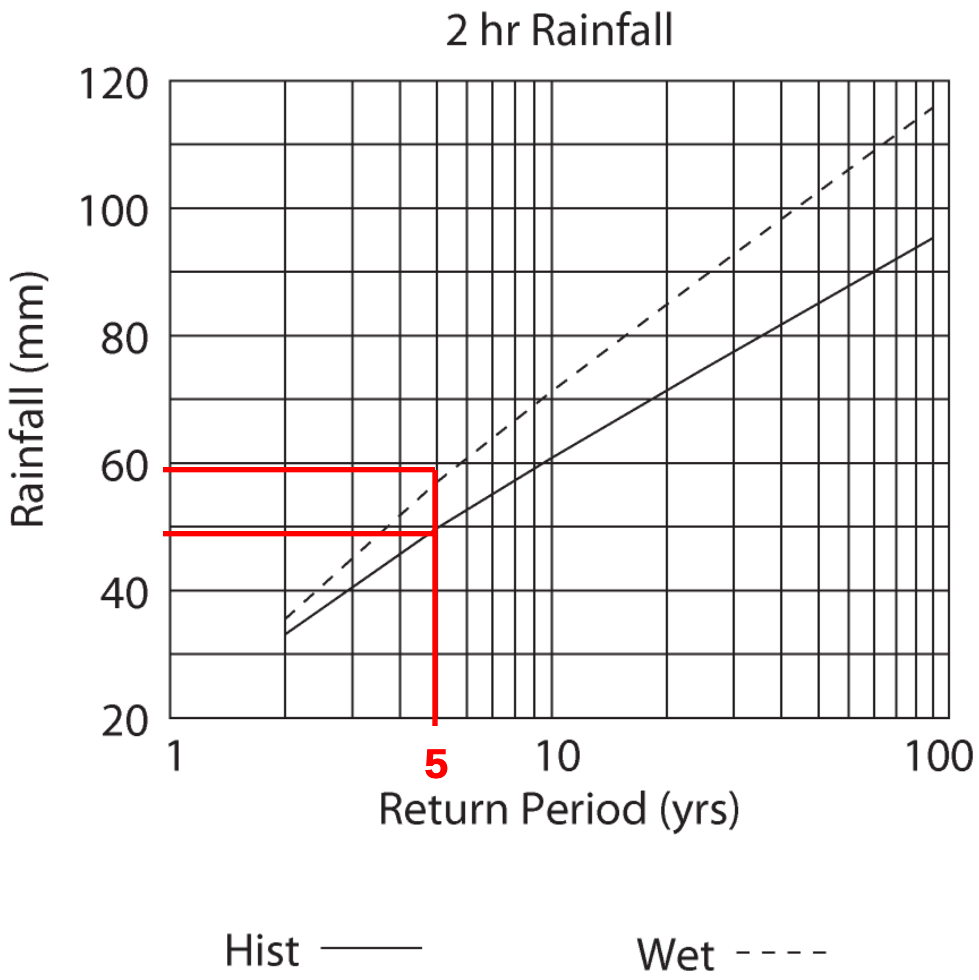
Upper Thames River Basin



WTP
Inset
Dams
Water Treatment Plants
Emergency Services
Hospitals
Landmarks/Attractions
Sports Facilities
Community Centres
Modelling Window
500-year Floodplain (Wet Climate Scenario)
Dykes
Trails
Railways
Roads and Driveways
Bridges
Rivers and Lakes
Pit Piles
Wetlands
Woodlands
N
0
1,000 m

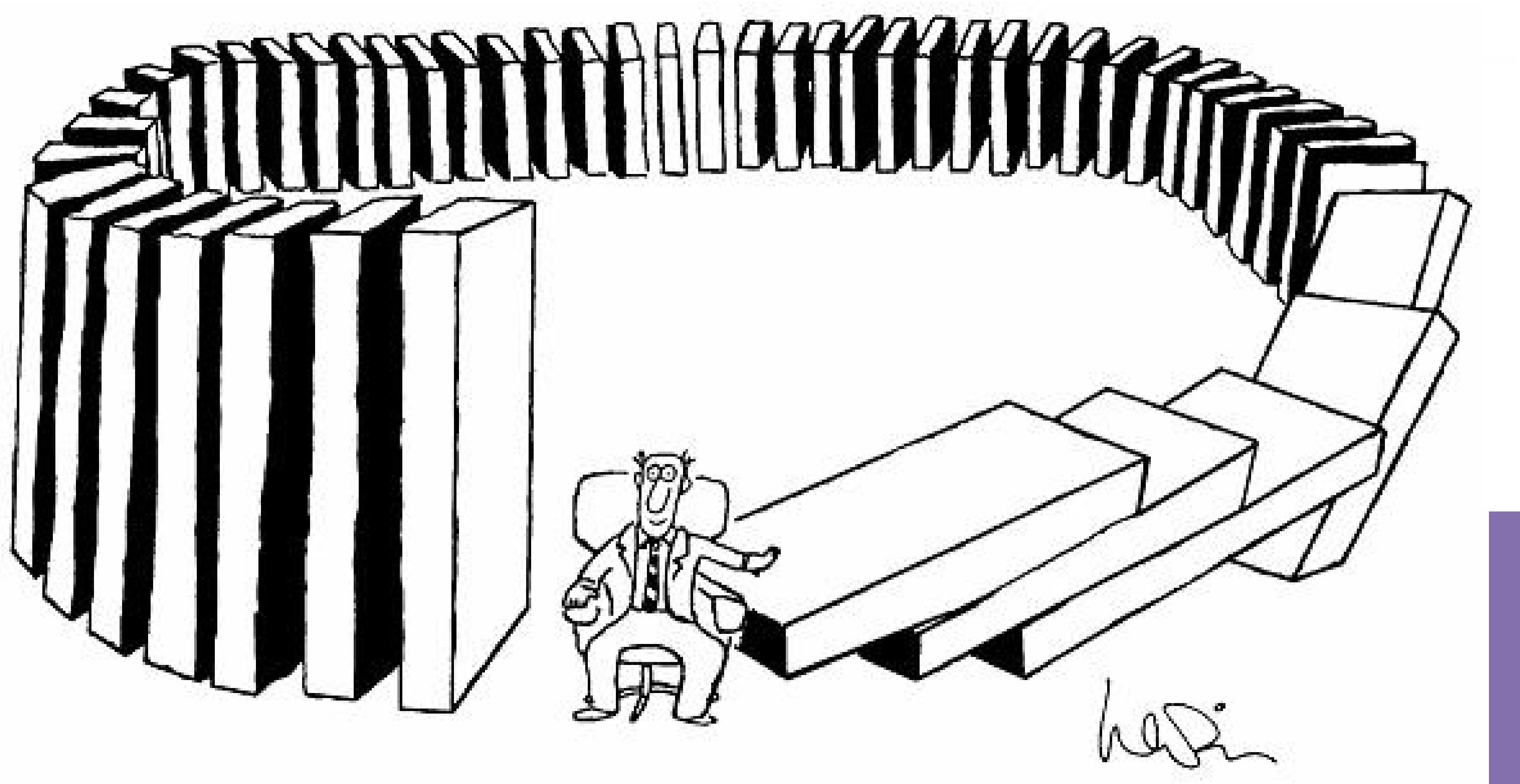

Inset
Vulnerable Dissemination Areas
Dykes
Rivers and Lakes
Wet Climate Scenario
500-year Floodline
250-year Floodline
100-year Floodline
Modelling Window
N
Total Vulnerability
Low
Medium-Low
Medium
Medium-High
High
0
1,000 m

Feedbacks


2 hr Rainfall
Rainfall (mm)
120
100
80
60
40
20
1
5
10
100
Return Period (yrs)
Hist
Wet

What can we do?

- Do not forget – It is all about feedbacks!
  - Be aware of positive feedbacks.
  - Learn what are the tipping points of dangerous feedbacks.
  - Find out what are the tipping points that will make our politicians do something.
- It is not about the planet – it is about us!



Resources

- Copenhagen Diagnosis: *Updating the World on the Latest Climate Science* (2009) http://copenhagendiagnosis.com
- Hansen J. (2009) “Storms of my grandchildren”, Bloomsbury, http://www.columbia.edu/~jeh1/
- www.slobodansimonovic.com