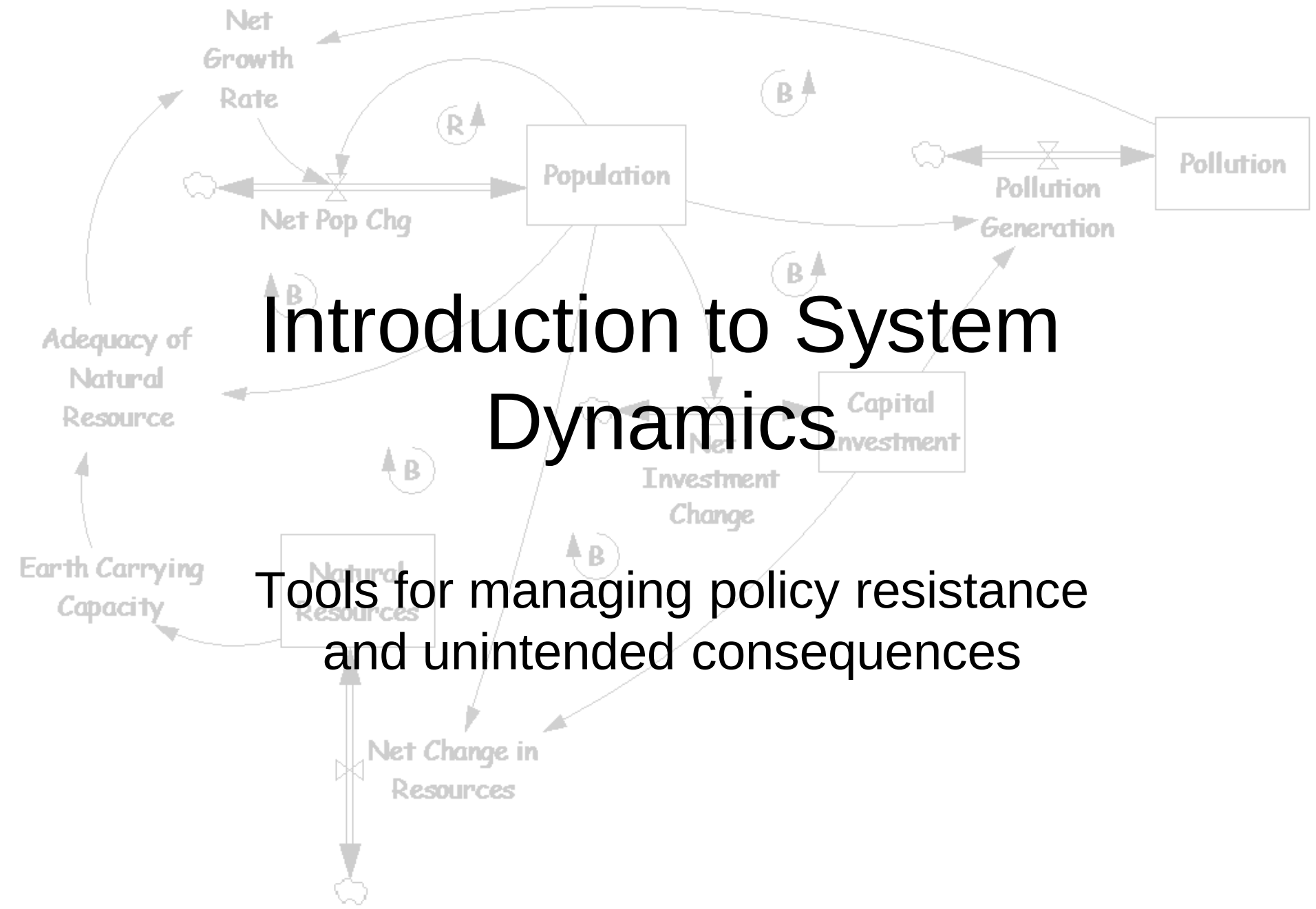



# Introduction to System Dynamics

Tools for managing policy resistance and unintended consequences

# System Dynamics?

- Simulation-based
- Objectives
  - Understand how problematic outcomes develop over time
  - Evaluate policies for affecting those outcomes

"All decisions are taken on the basis of models…The question is not to use or ignore models. The question is only a choice among alternative models. … "

Jay W. Forrester. *Counterintuitive Behavior of Social Systems.* Testimony before U.S. Congress, October, 1970

# The Modeler's Dilemma

That's another thing we've learned from your nation," said Mein Herr, "map making. But we've carried it much further than you. What do you consider the largest map that would really be useful?"

*"About six inches to the mile."*

"Only about six inches!" exclaimed Mein Herr. "We very soon got to six yards to the mile. Then we tried a hundred yards to the mile. And then came the grandest idea of all! We actually made a map of the country on a scale of a mile to the mile!"

*"Have you used it much?" I inquired.*

"It has never been spread out yet," said Mein Herr. "The farmers objected: they said it would cover the whole country, and shut out the sunlight! So now we use the country itself, as its own map, and I assure you it does nearly as well."

Lewis Carroll (1893) – ***Sylvie and Bruno Concluded***

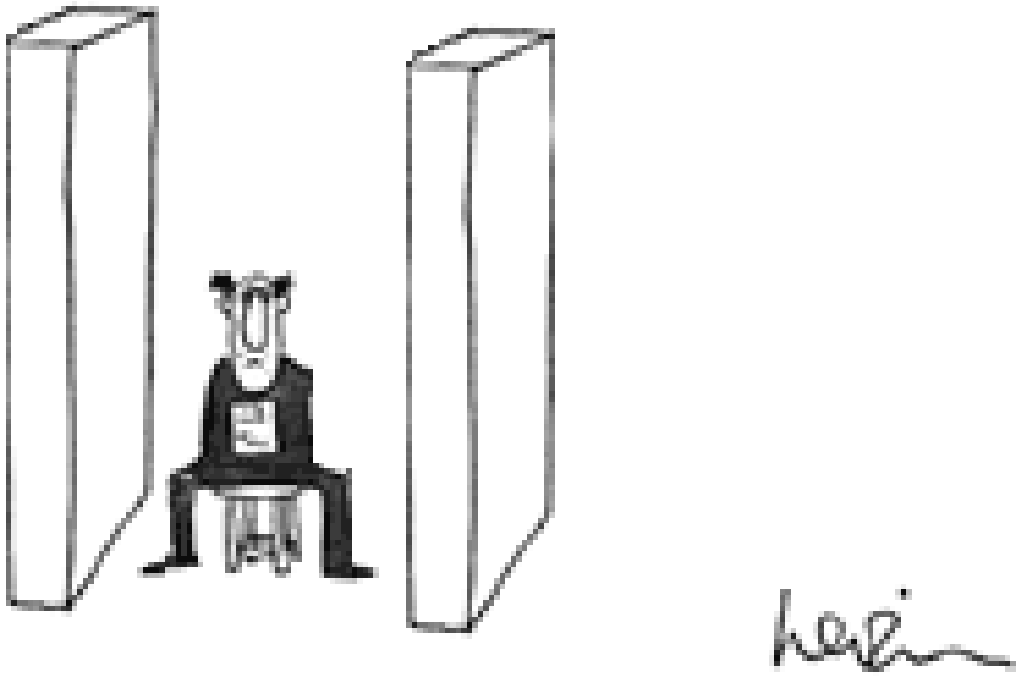
# System Dynamics Uses in Decision Making

- Exposing and testing ***mental models*** that shape policy
- Looking for ***unintended consequences*** of policy actions
- Evaluating ***dynamic hypotheses*** for understanding problematic system behavior
- Facilitating ***group learning*** to understand system behavior

# Today's Discussion

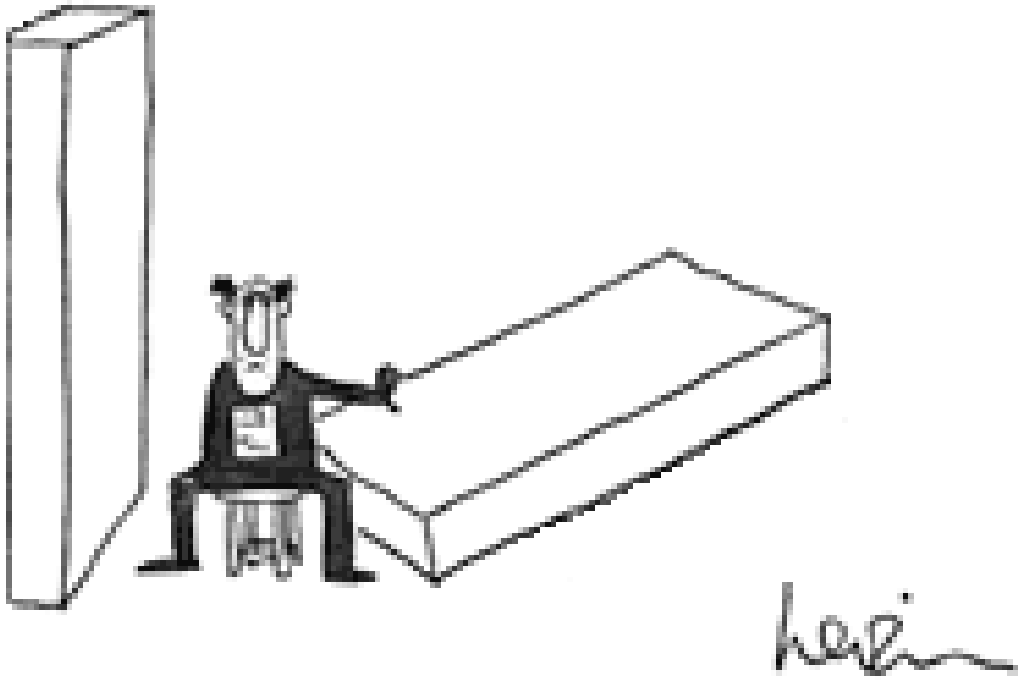
- Managing Complex Systems: Mental models and unintended consequences
- System Dynamics Intro
- Example applications
- Reflections on the role of SD in Health ↔ Environment studies

# Managing Complexity



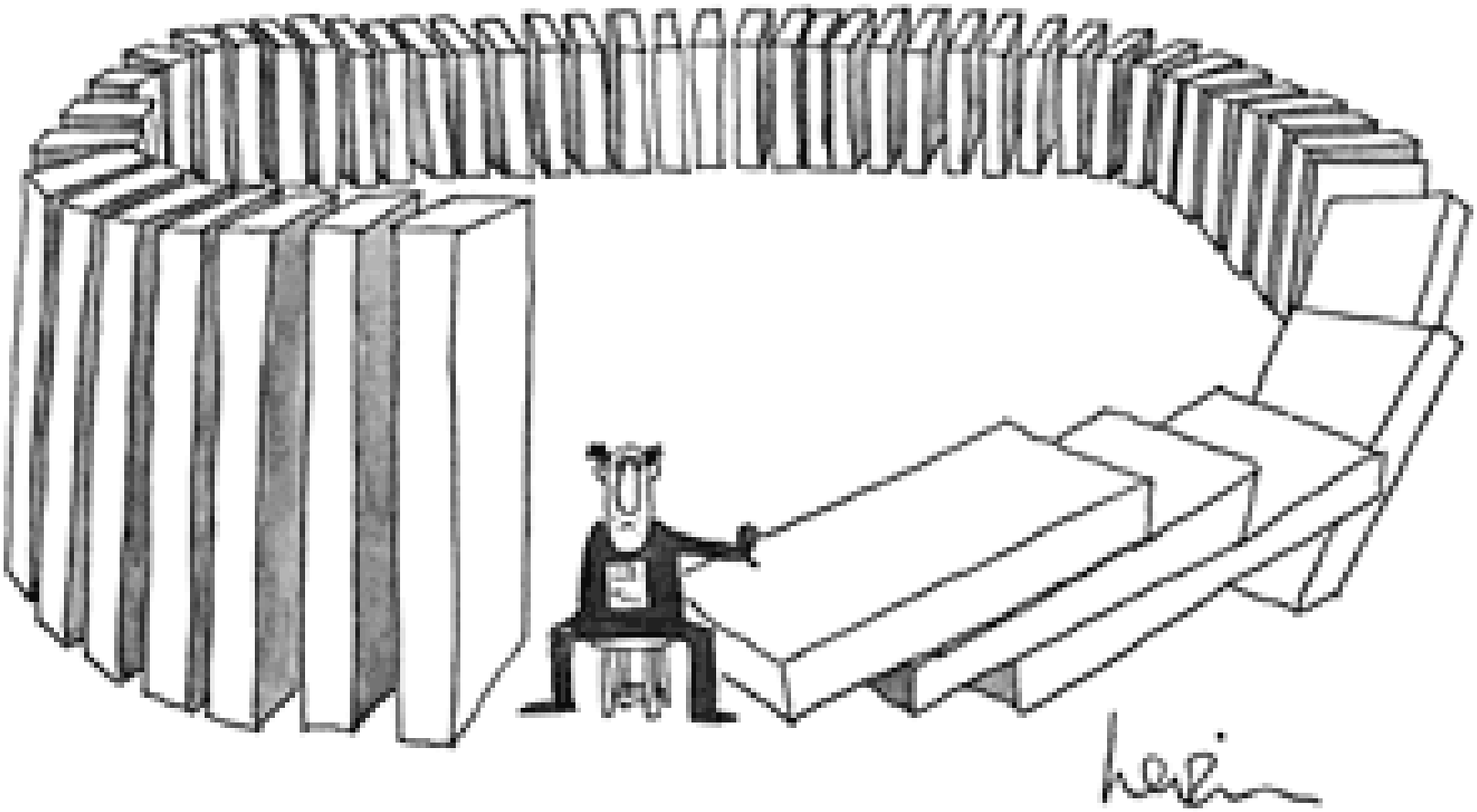
*Arnie Levin, New Yorker, December 27, 1976*

# Managing Complexity



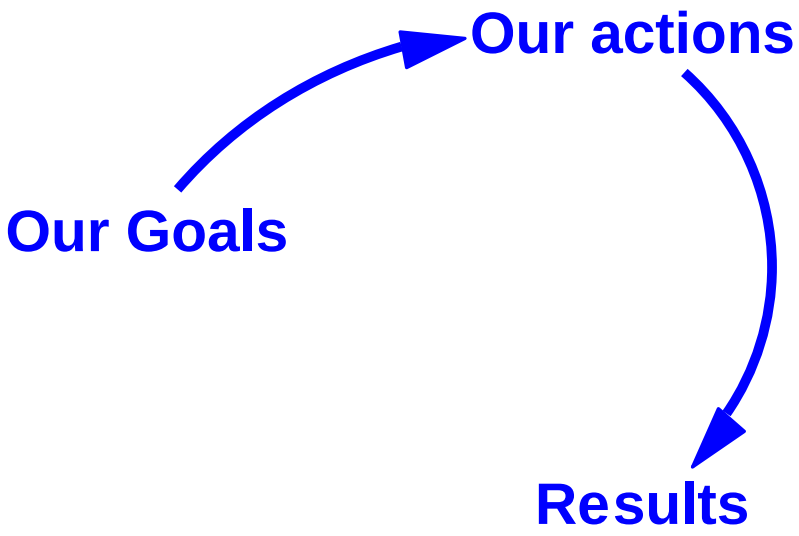
*Arnie Levin, New Yorker, December 27, 1976*

# Complexity
# & Unintended Consequences



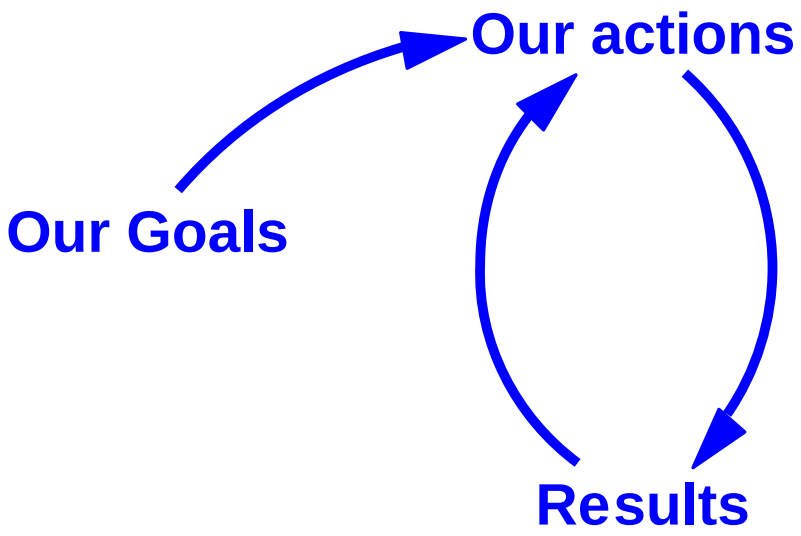
*Arnie Levin, New Yorker, December 27, 1976*

# Basic Problem Solving Model



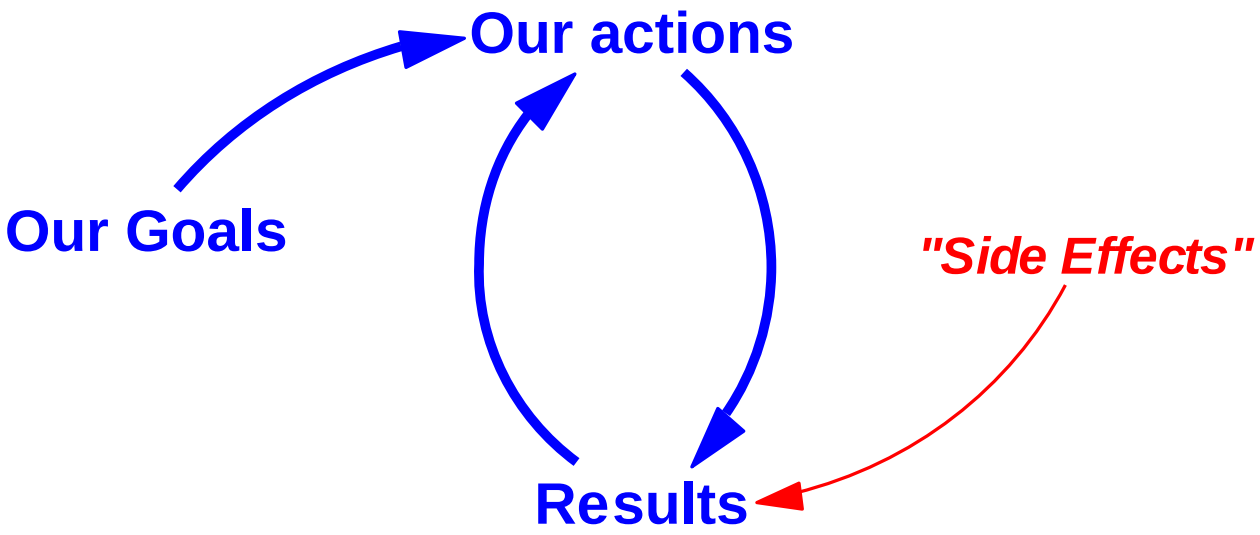

Sterman, ***Business Dynamics***

# Basic Problem Solving Model



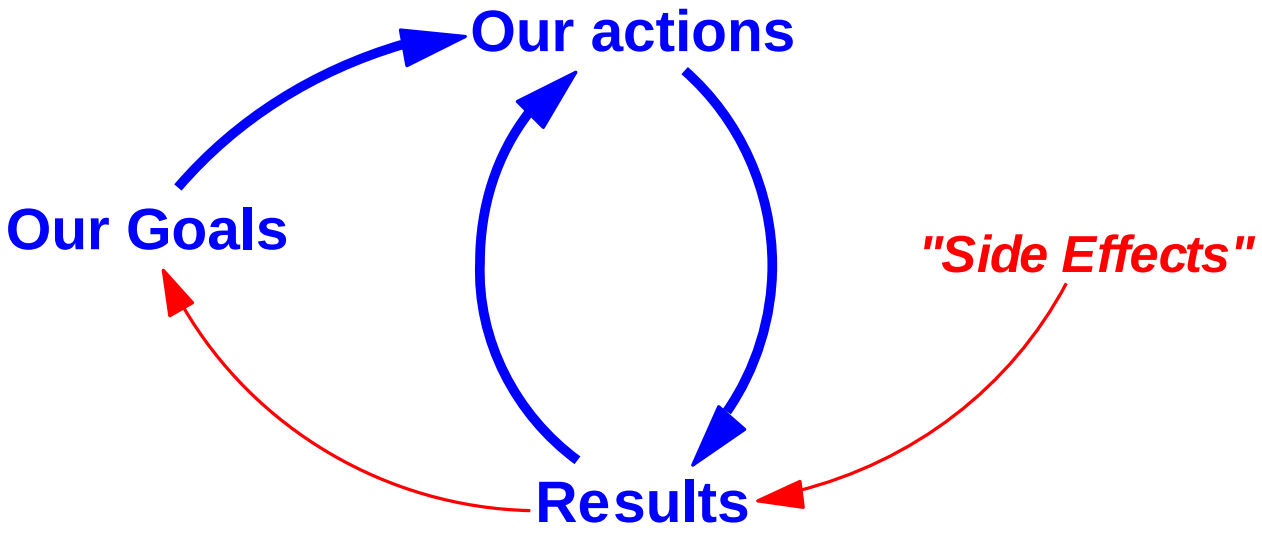

Sterman, ***Business Dynamics***

# Bad Luck?




Sterman, ***Business Dynamics***

# Bad Luck?

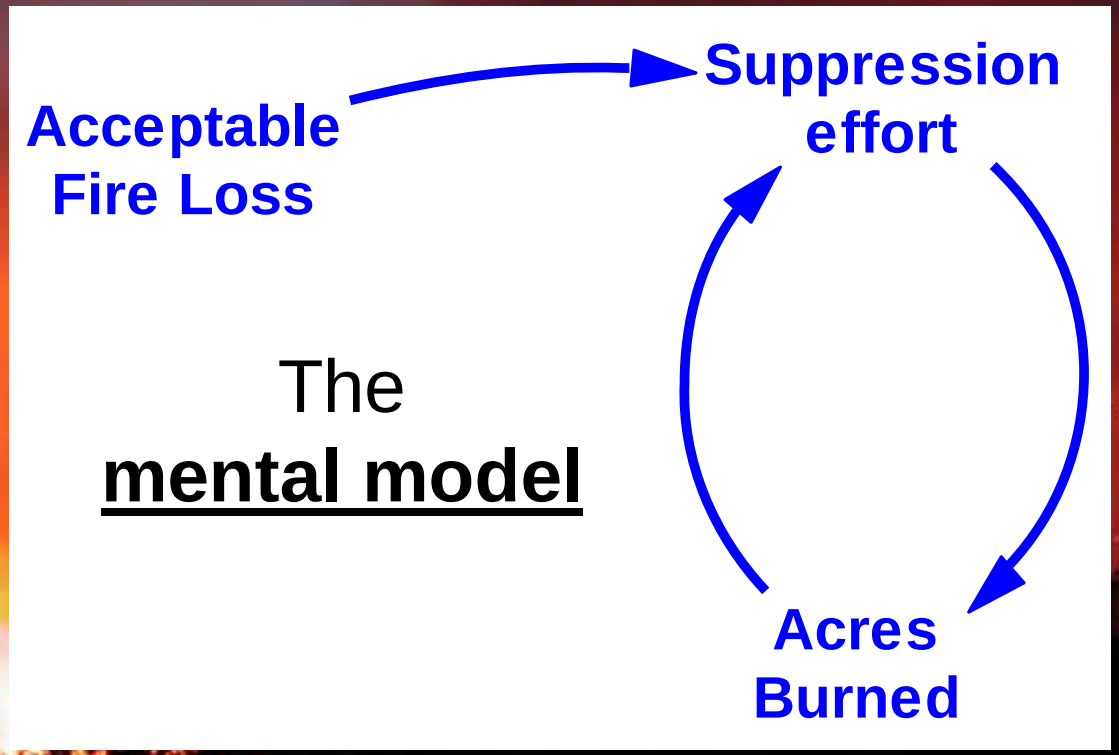



Sterman, ***Business Dynamics***

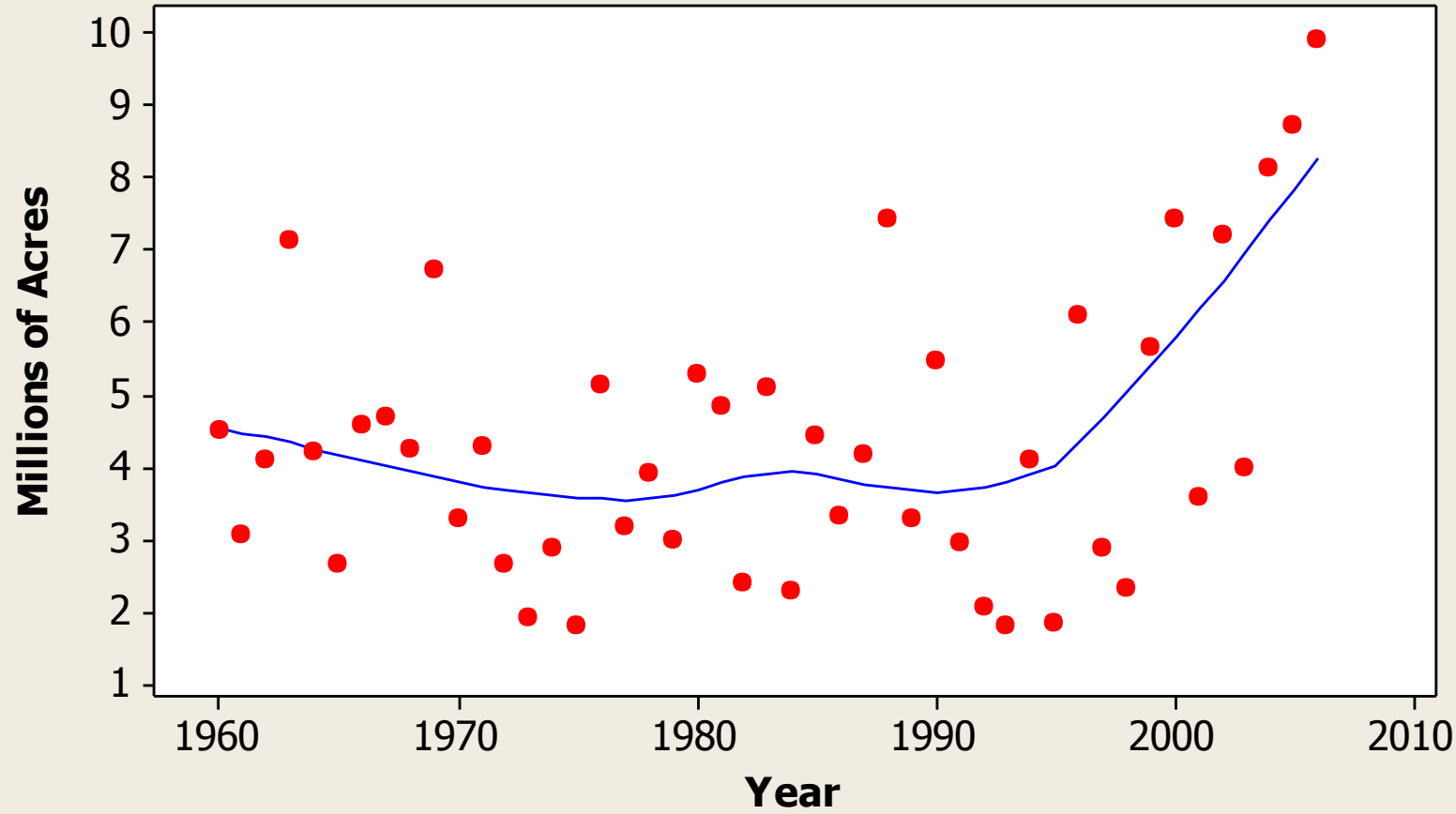
# Complexity Beneath the Surface


Sterman, ***Business Dynamics***

# Example: Wildfire Suppression

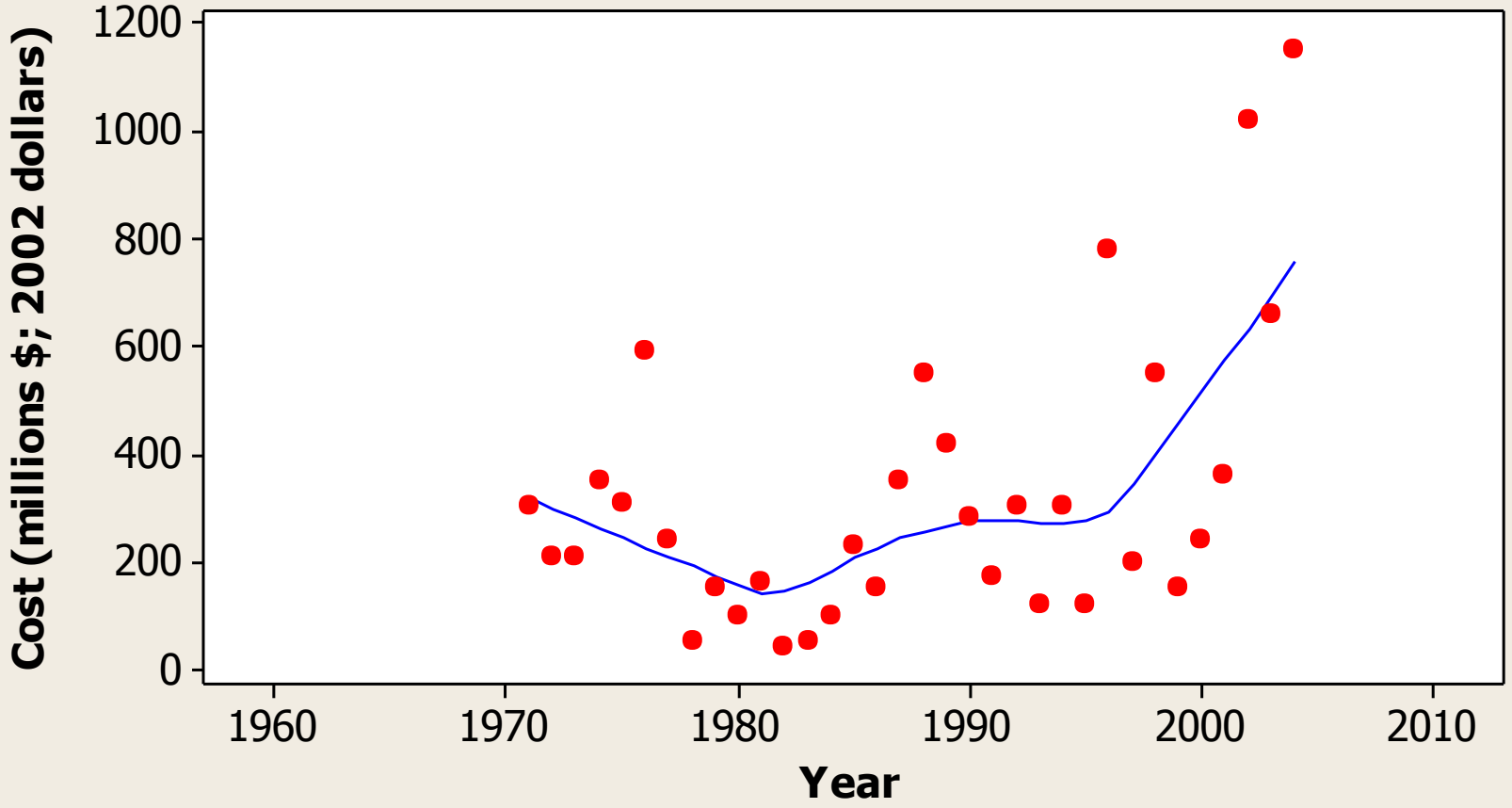



The
**mental model**



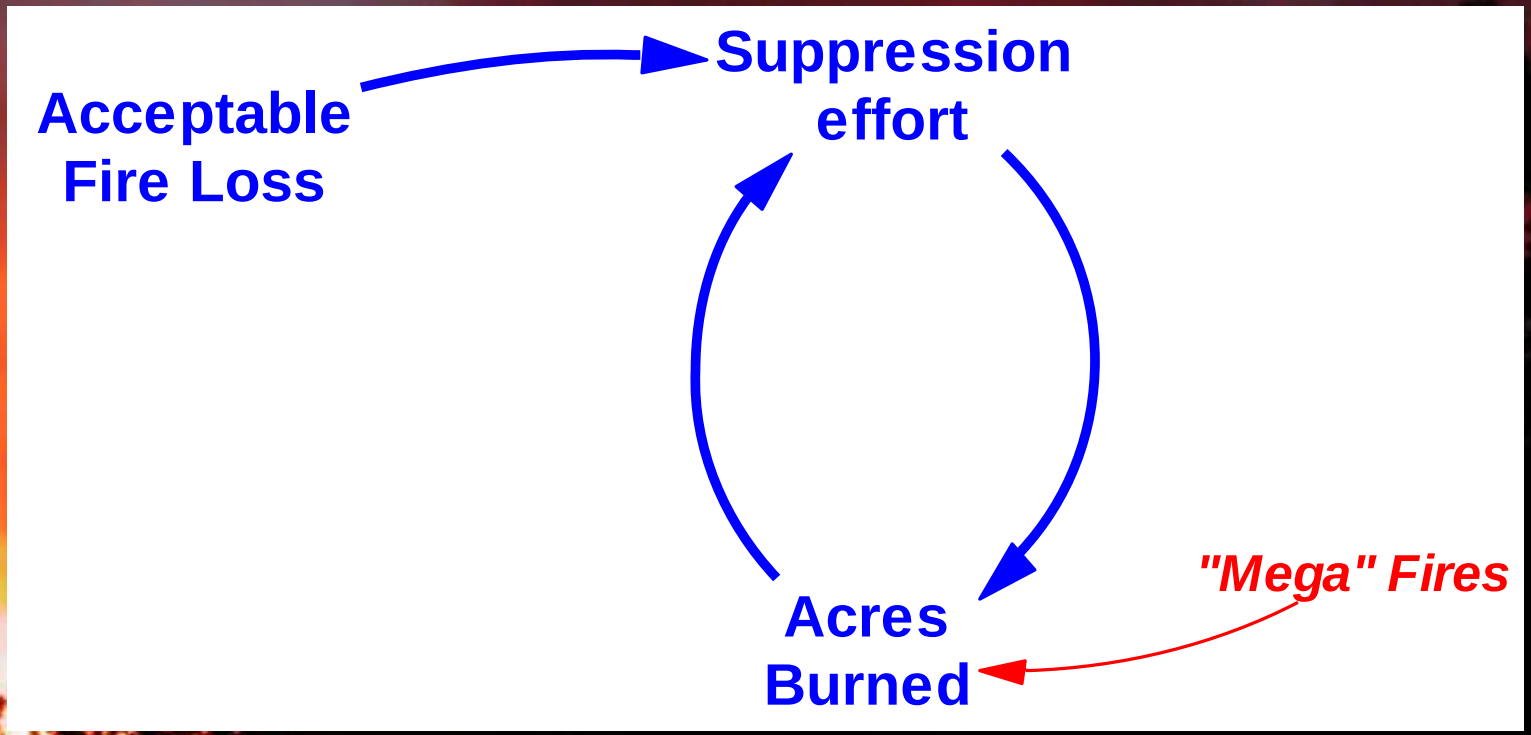

*Source: http://www.nifc.gov/stats/fires_acres.html; Downloaded on 04Apr07*

## U.S. Forest Service Fire Fighting Expenditures

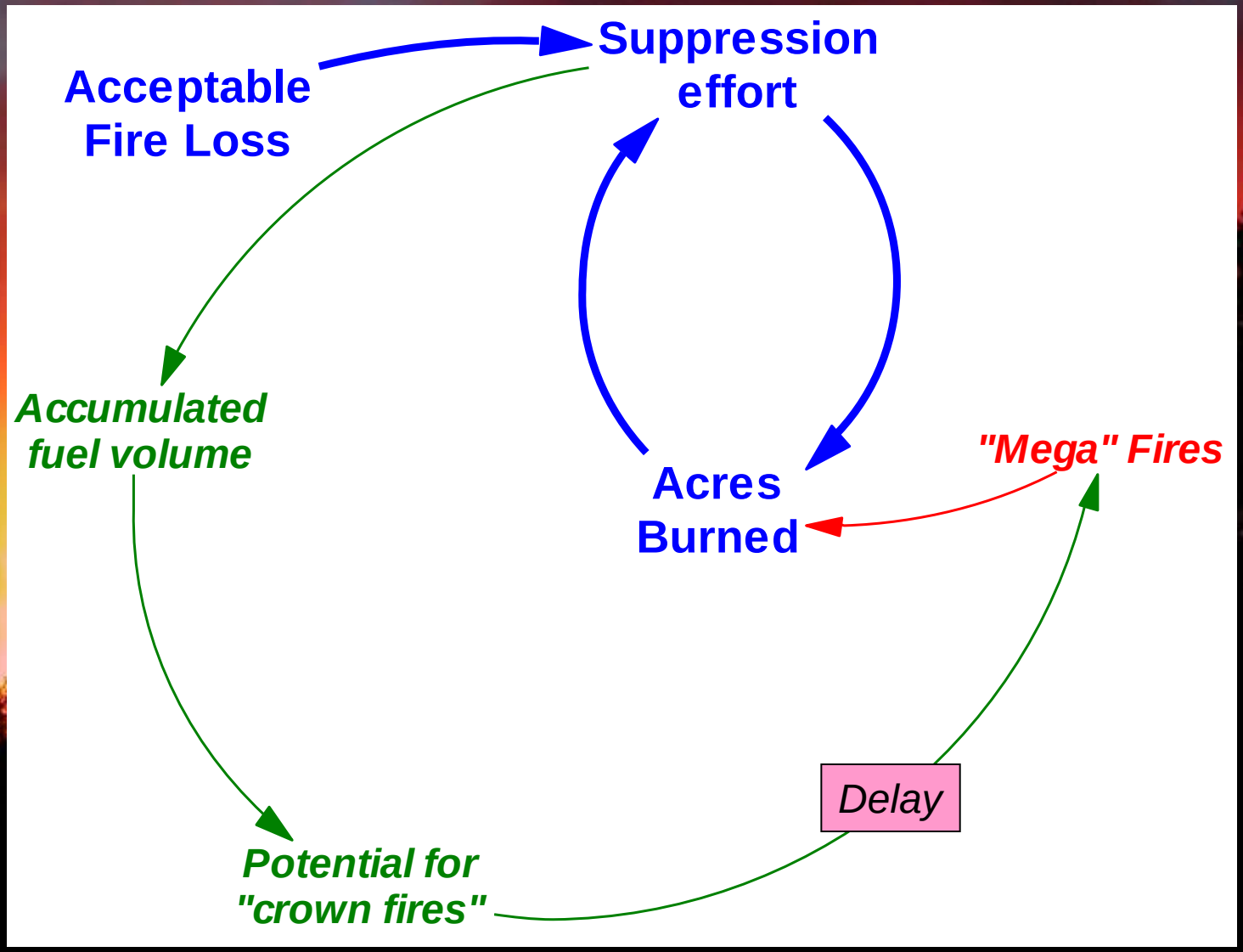



*Calkin, "Forest Service Large Fire Area Burned and Suppression Expenditure Trends, 1979-2002 Journal of Forestry, 103(4), 2005*

# Side Effect?


Acceptable
Fire Loss
Suppression
effort
Acres
Burned
"Mega" Fires

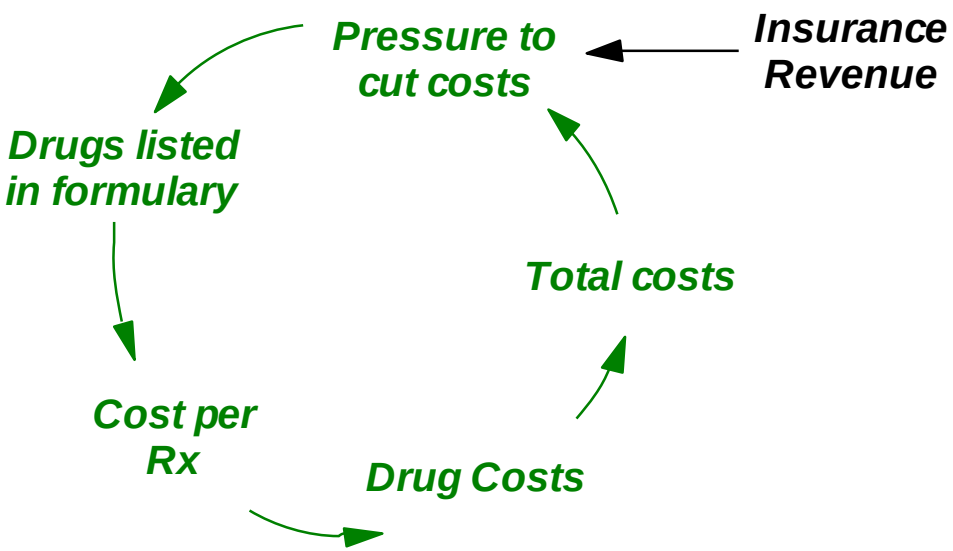
# A More Complete Mental Model!



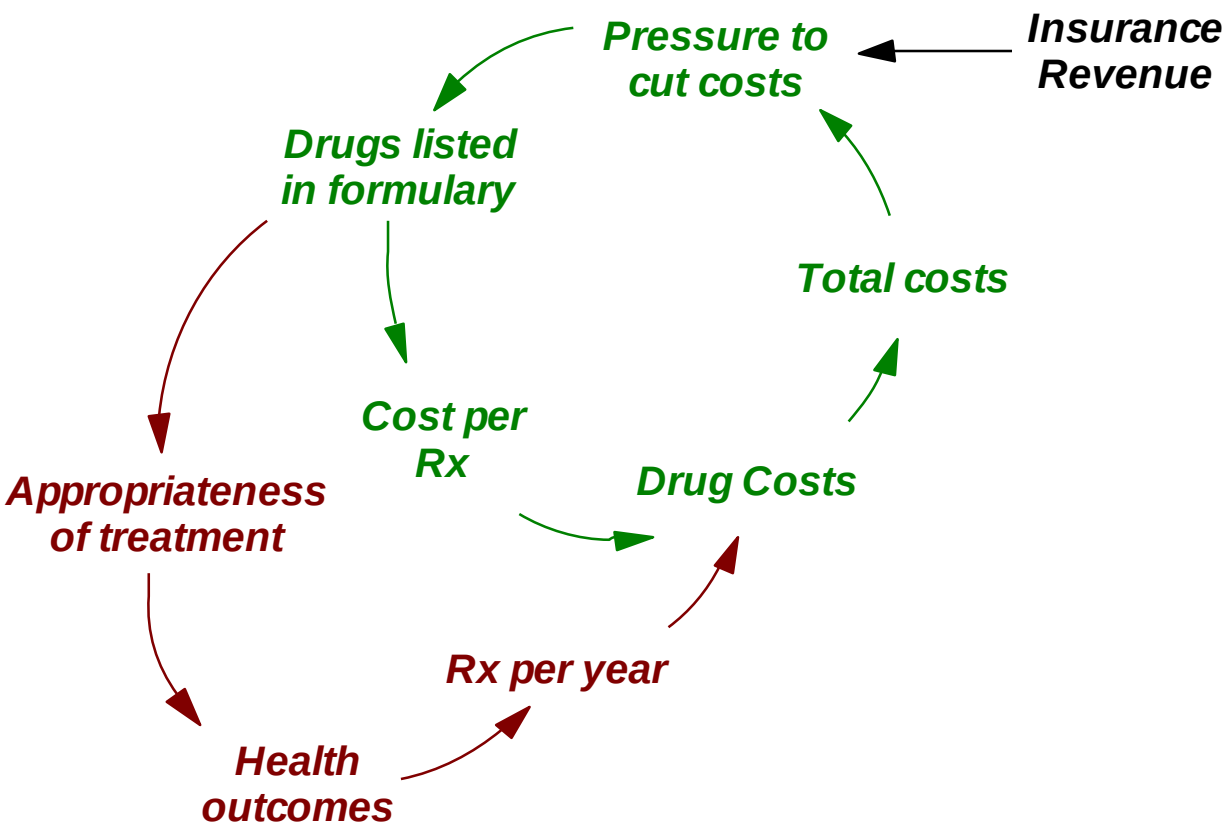
# Unintended Consequences of Policy in Dynamic Systems

- Antibiotics
- Road improvements
- War on drugs
- Flood control
- Economic growth and happiness

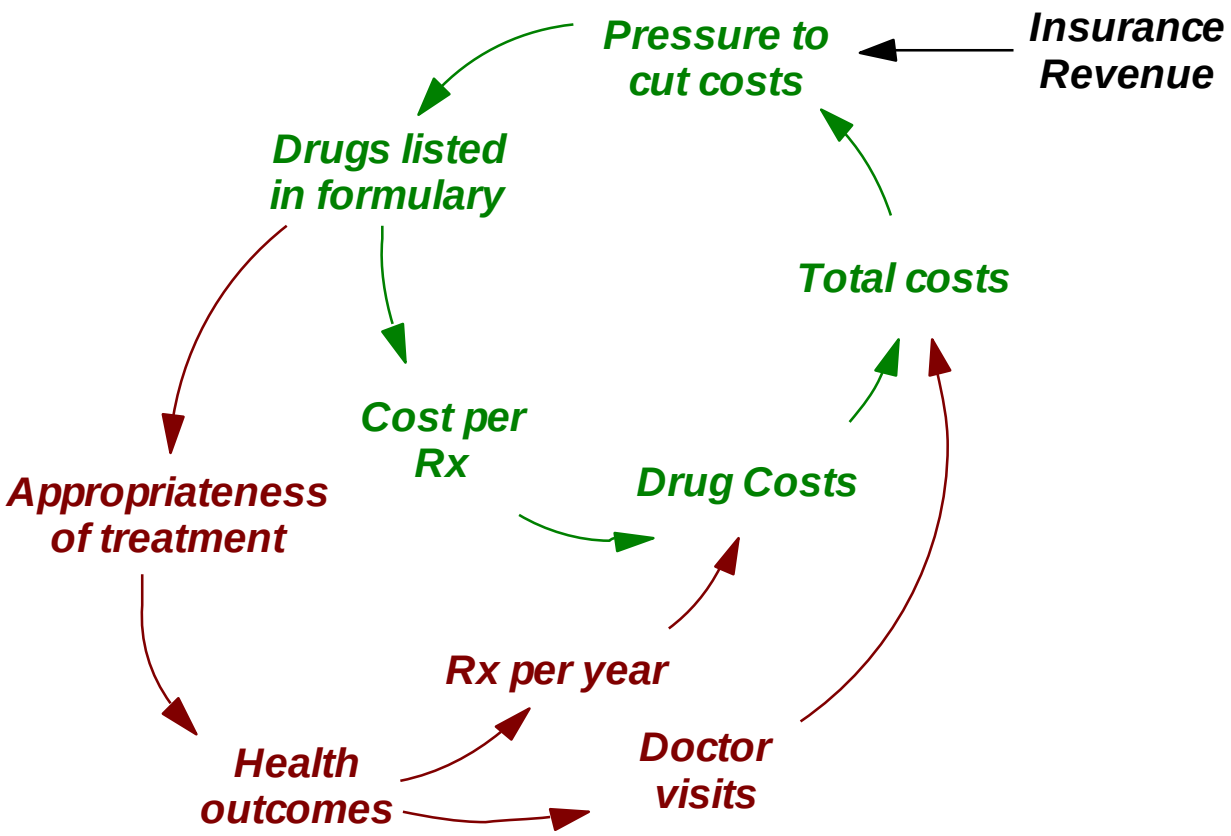
# Formularies



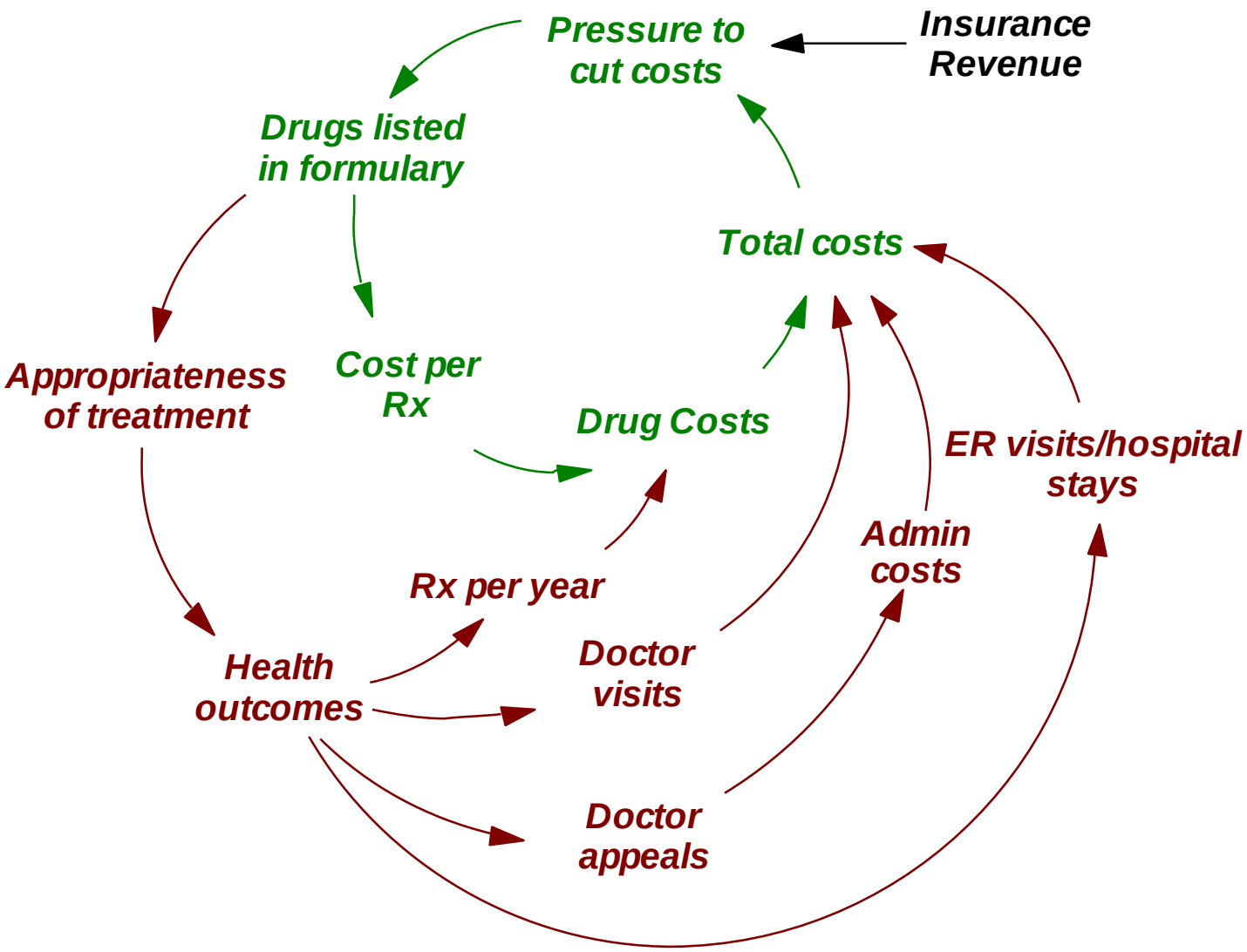
# Formularies



# Formularies



# Formularies



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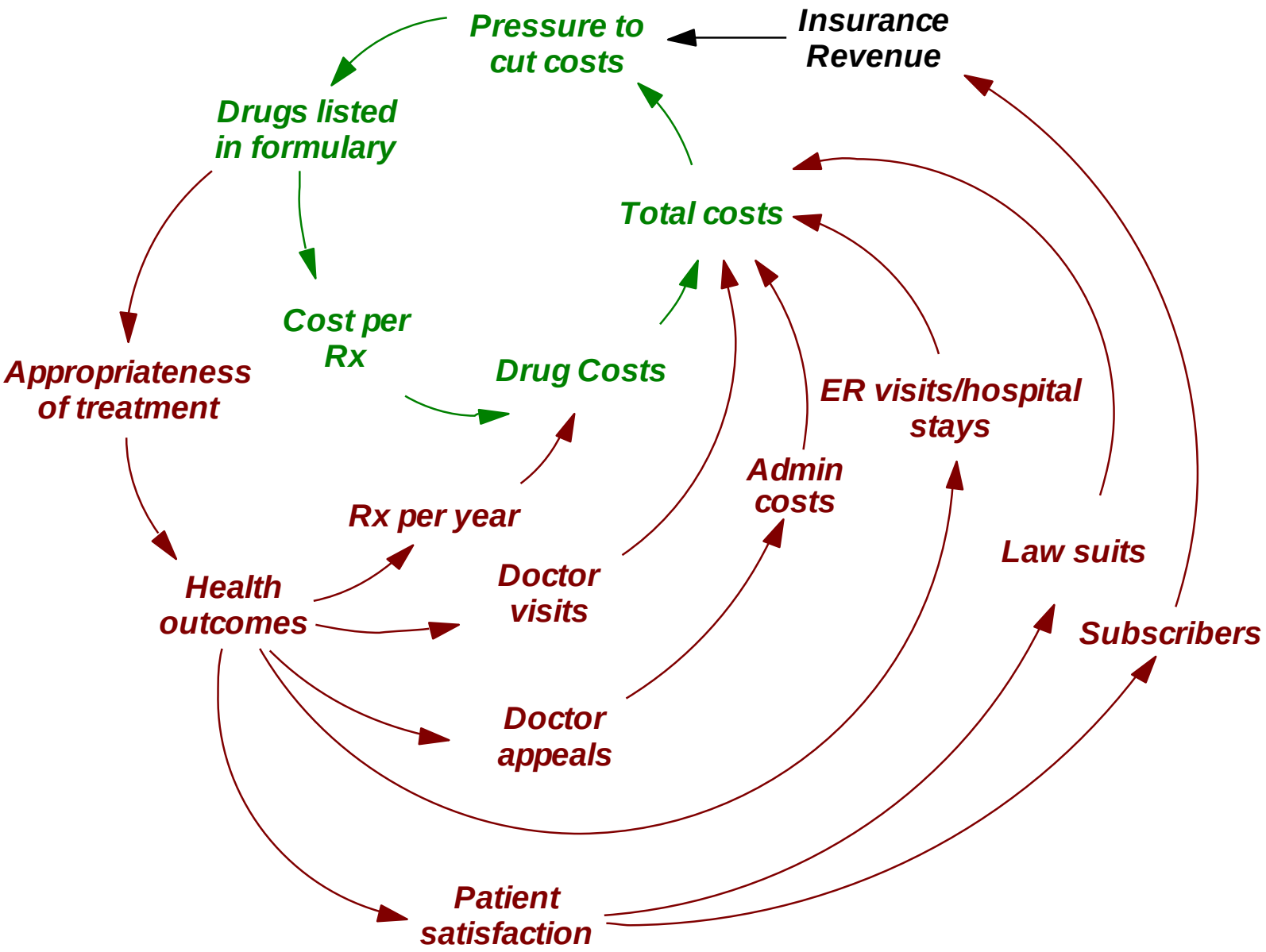
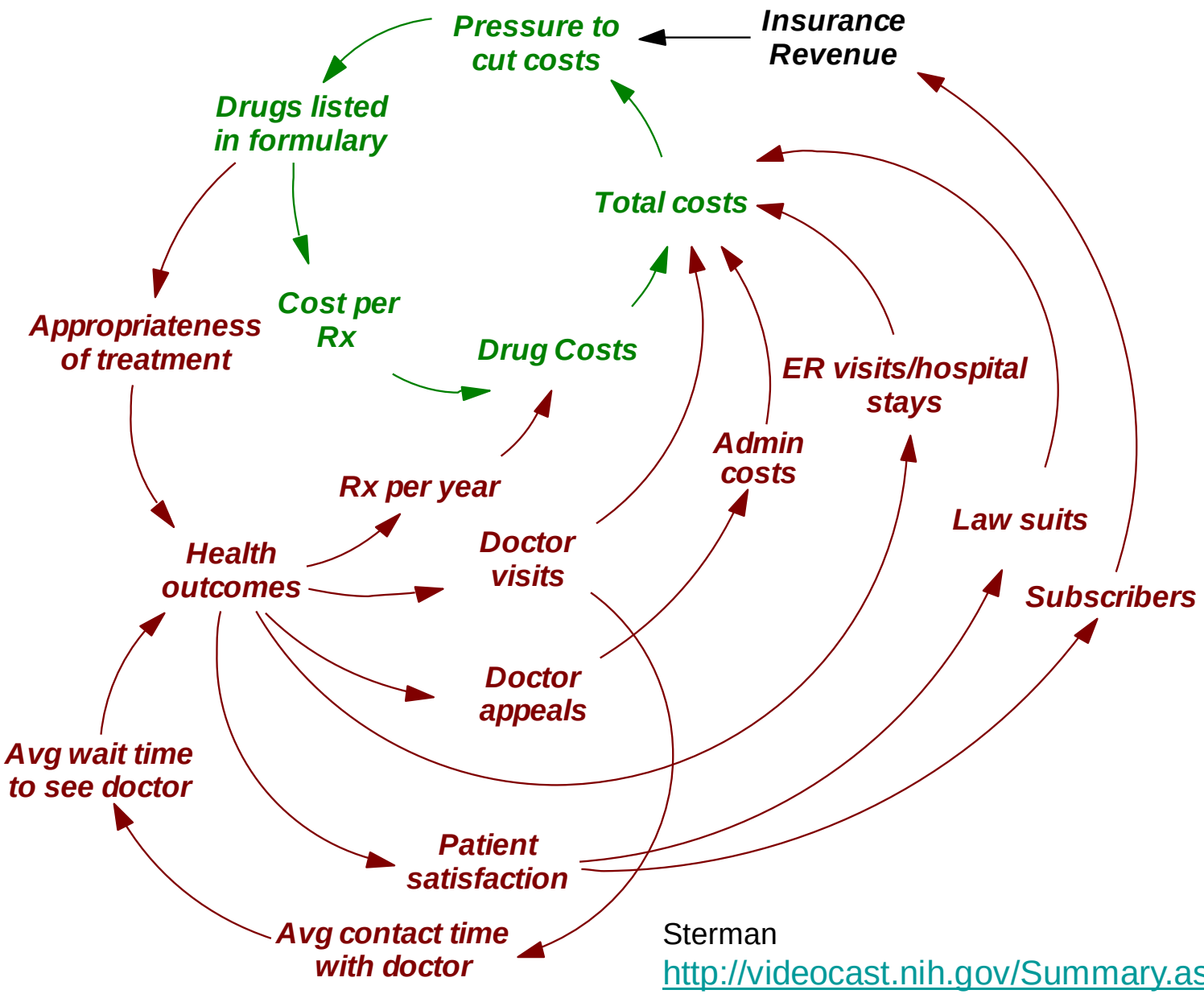


# Formularies




Sterman
http://videocast.nih.gov/Summary.asp?file=13712
Horn, et al. ***Am. J. Manag Care***, 1996; 2(3):253-264

# Why Unintended Consequences?

**Our Mental Models**

- Static
- One-way cause-effect
- Single-cause orientation
- Narrow boundaries
- Short time horizons
- Linear

**The System**

- Dynamic; Adaptive
- Governed by Feedback
- Multiple actors with competing goals
- Tightly-coupled across multiple scales
- Delays betw action & effect
- Nonlinear

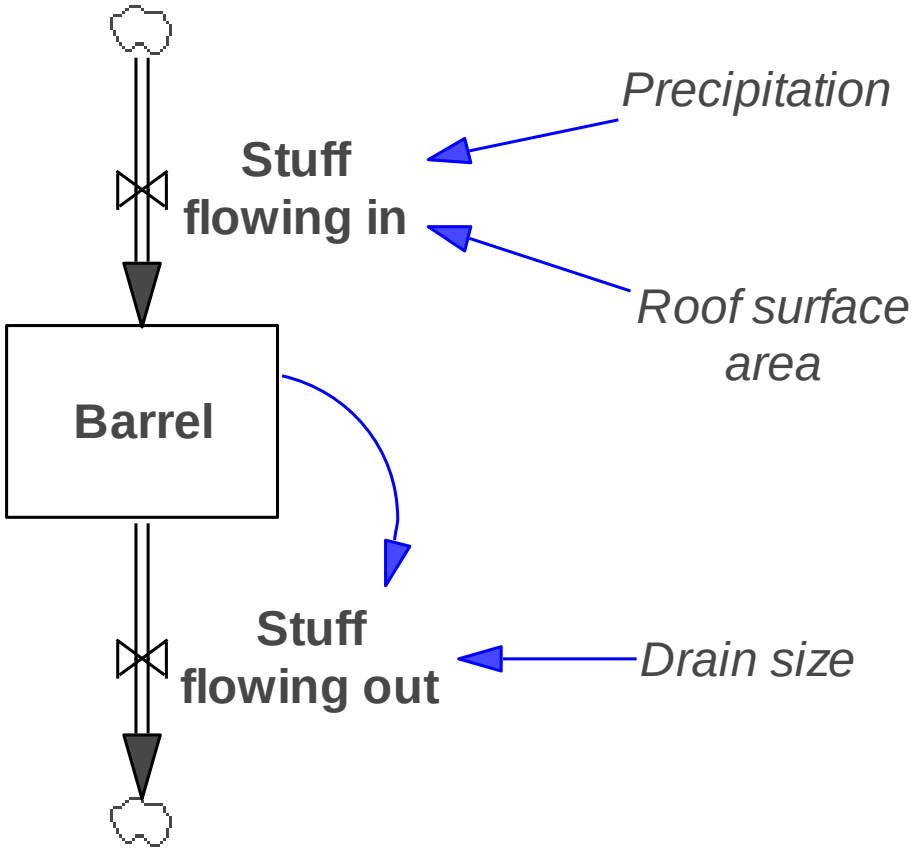
*We learn best from our experience, but we never directly experience the consequences of many of our most important decisions*

Peter Senge, ***The Fifth Discipline***

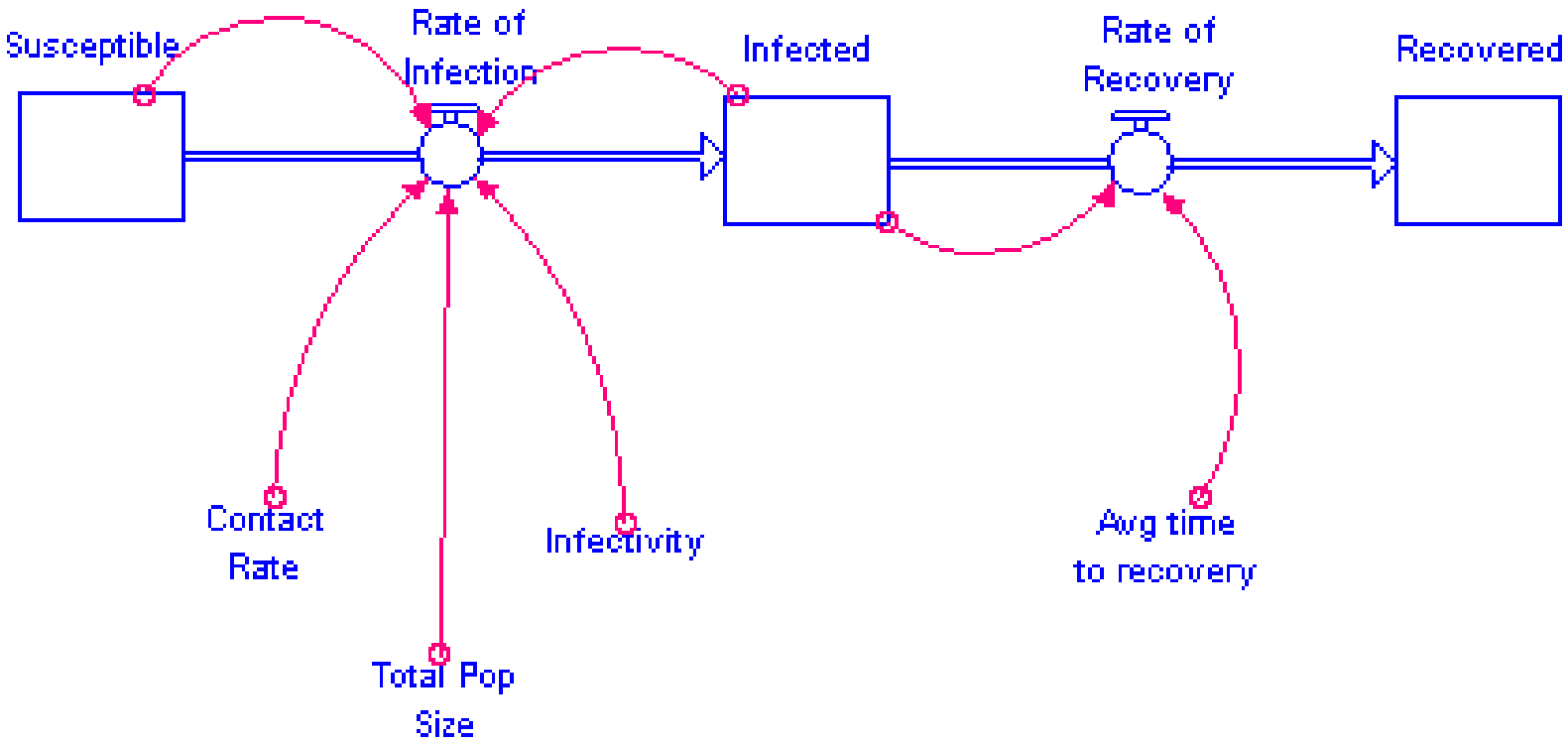
# System Dynamics Intro

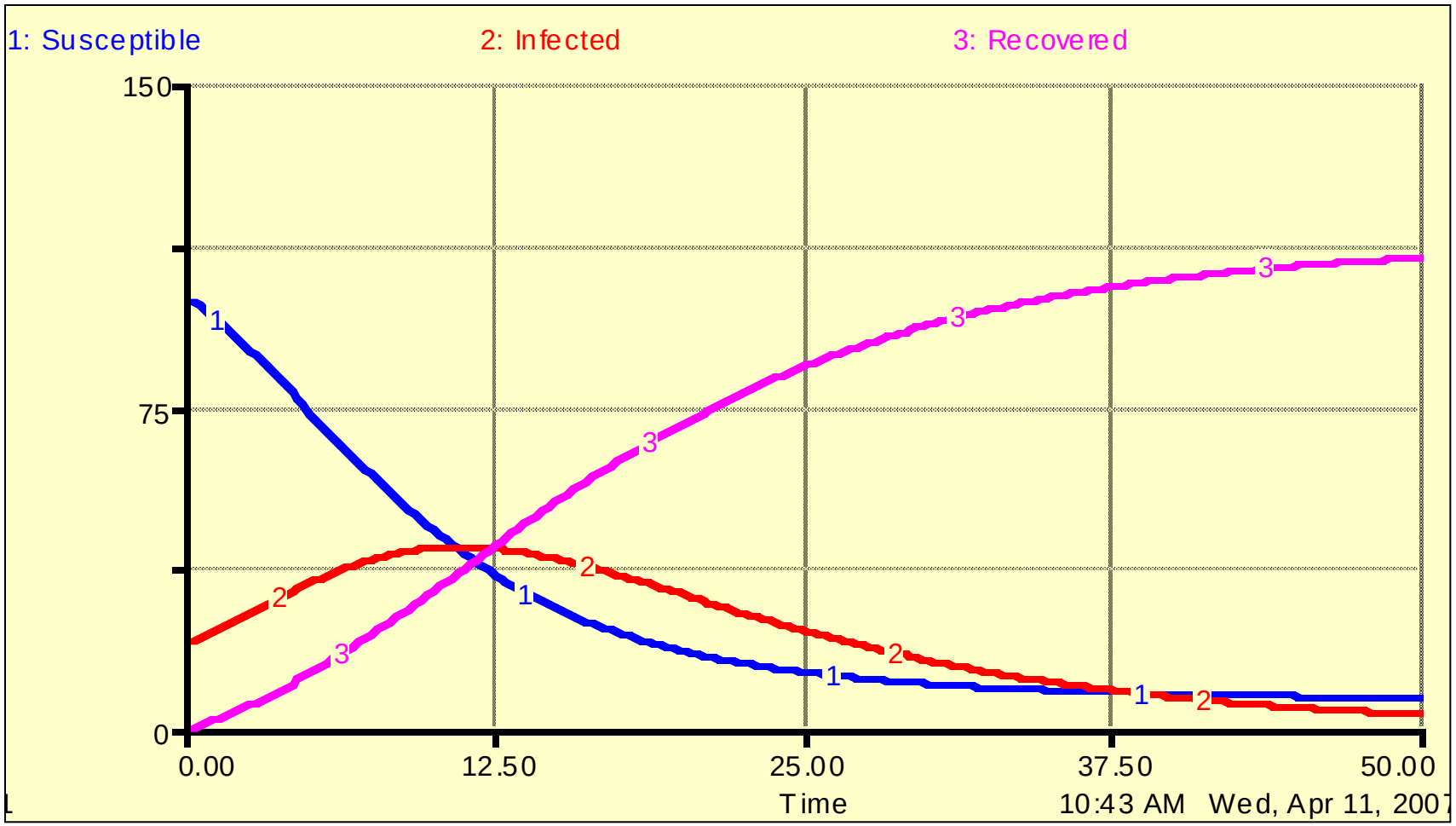
- Key Features
  - Stocks (accumulators)
  - Flows (rates at which stocks change)
  - Ancillary variables affecting the flows
  - Causal or Information Links
  - Feedback
  - Delay dynamics

# Stocks, Flows, and Causal/Information Links

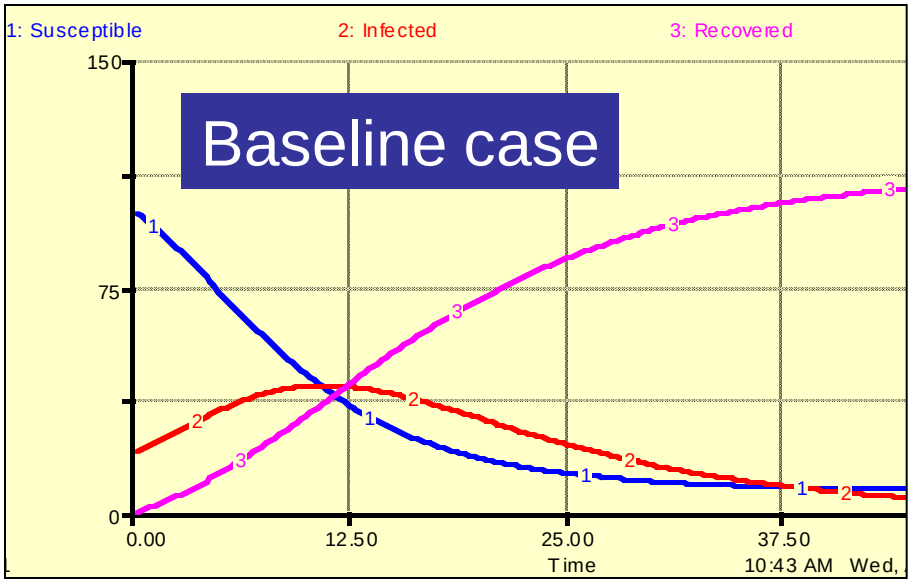


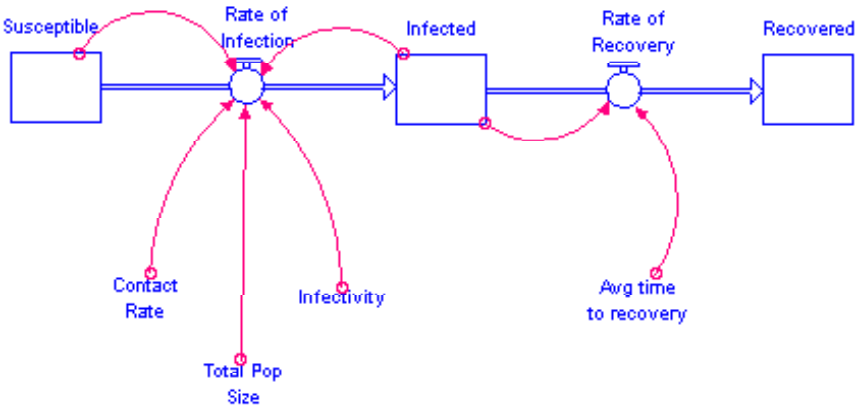
# Stocks and Flows
# Keys to dynamic behavior

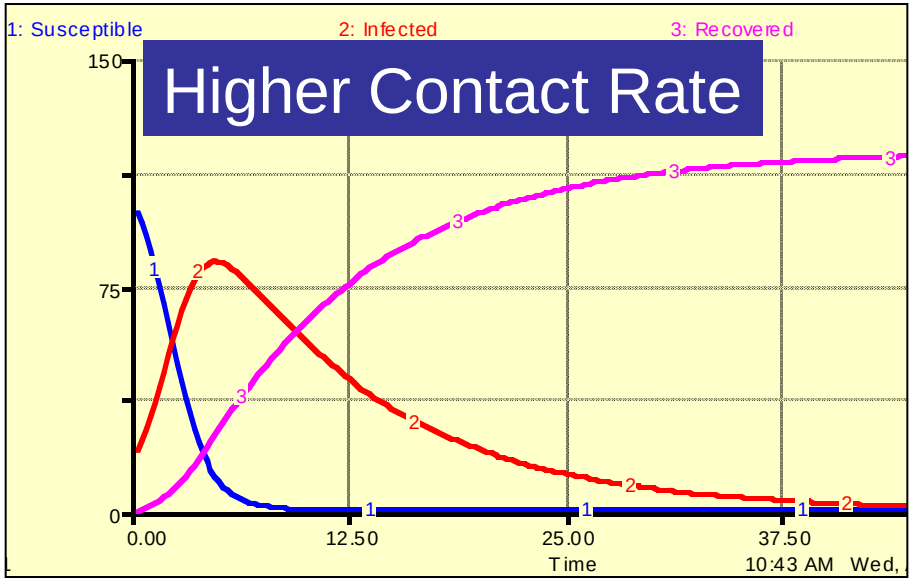


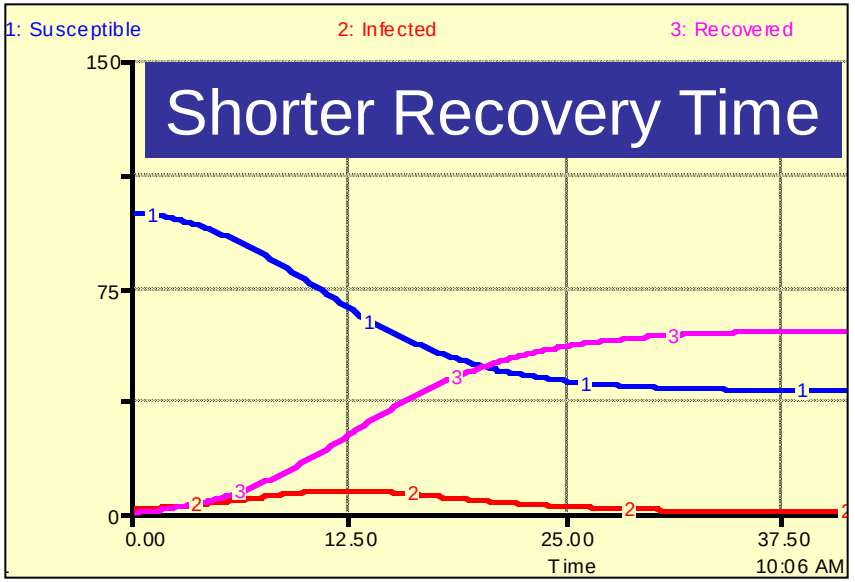

1: Susceptible
2: Infected
3: Recovered
150
75
0
0.00
12.50
25.00
37.50
50.00
Time
10:43 AM Wed, Apr 11, 2007

# Bathtub Dynamics of Stocks and Flows

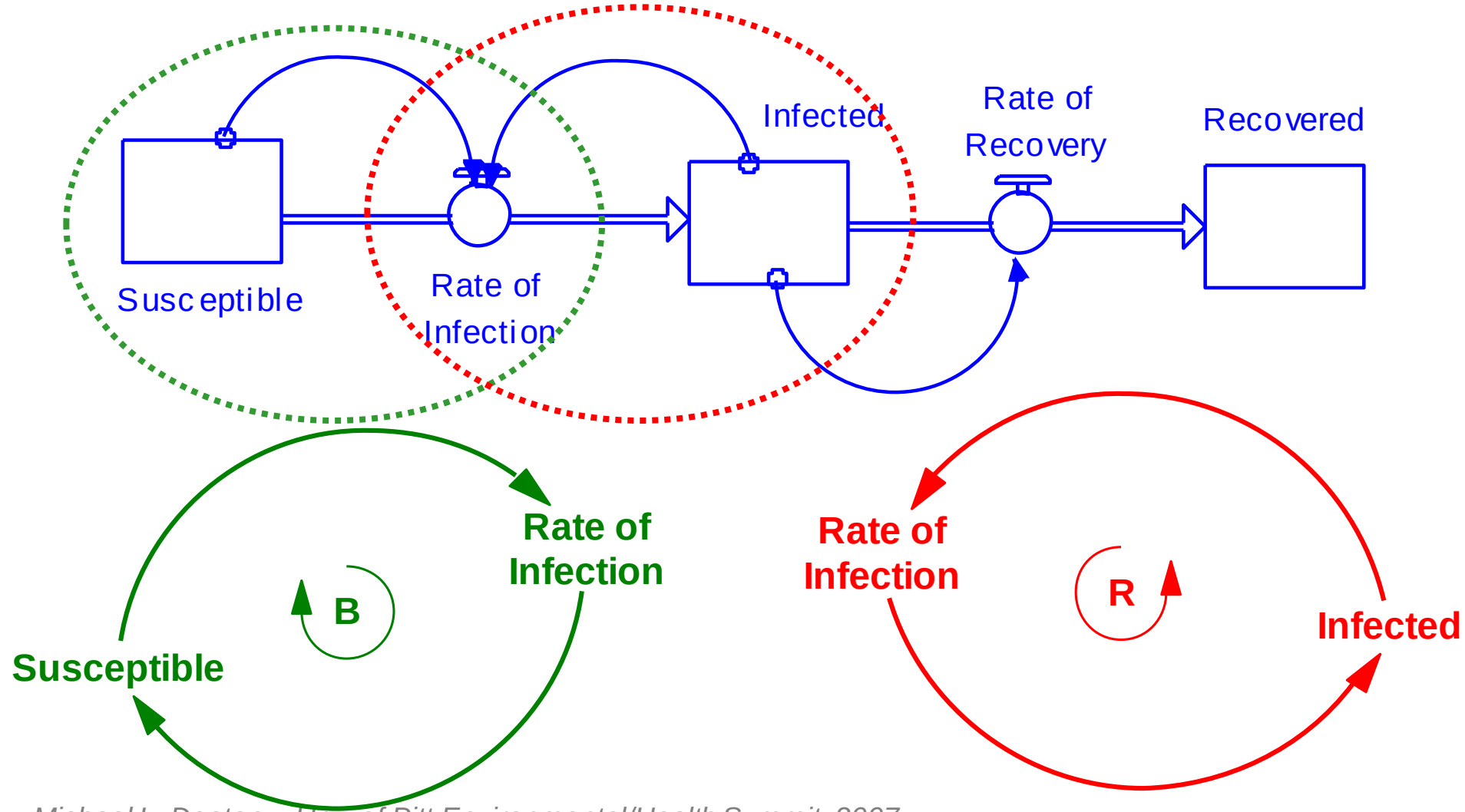


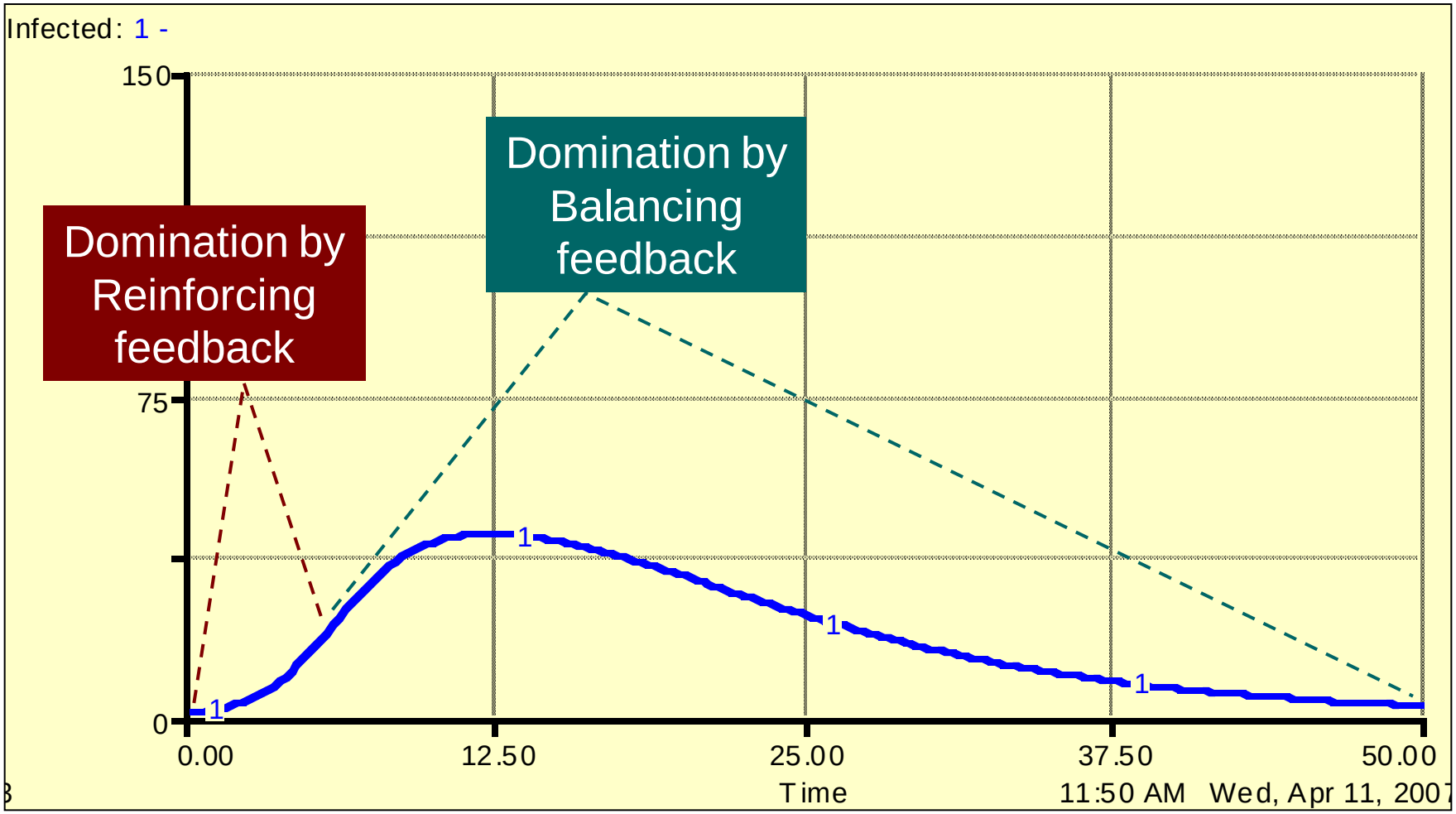



# Feedback

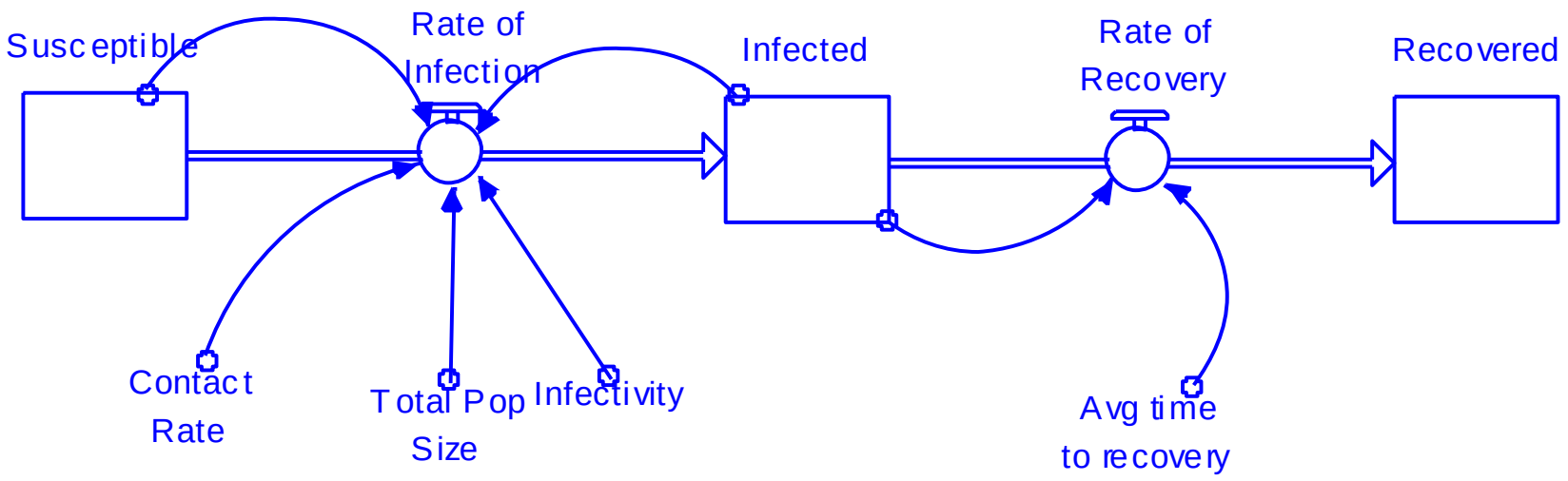

Susceptible
Rate of Infection
Infected
Rate of Recovery
Recovered
Rate of Infection
B
Susceptible
Rate of Infection
R
Infected

# Dueling Feedback Loops

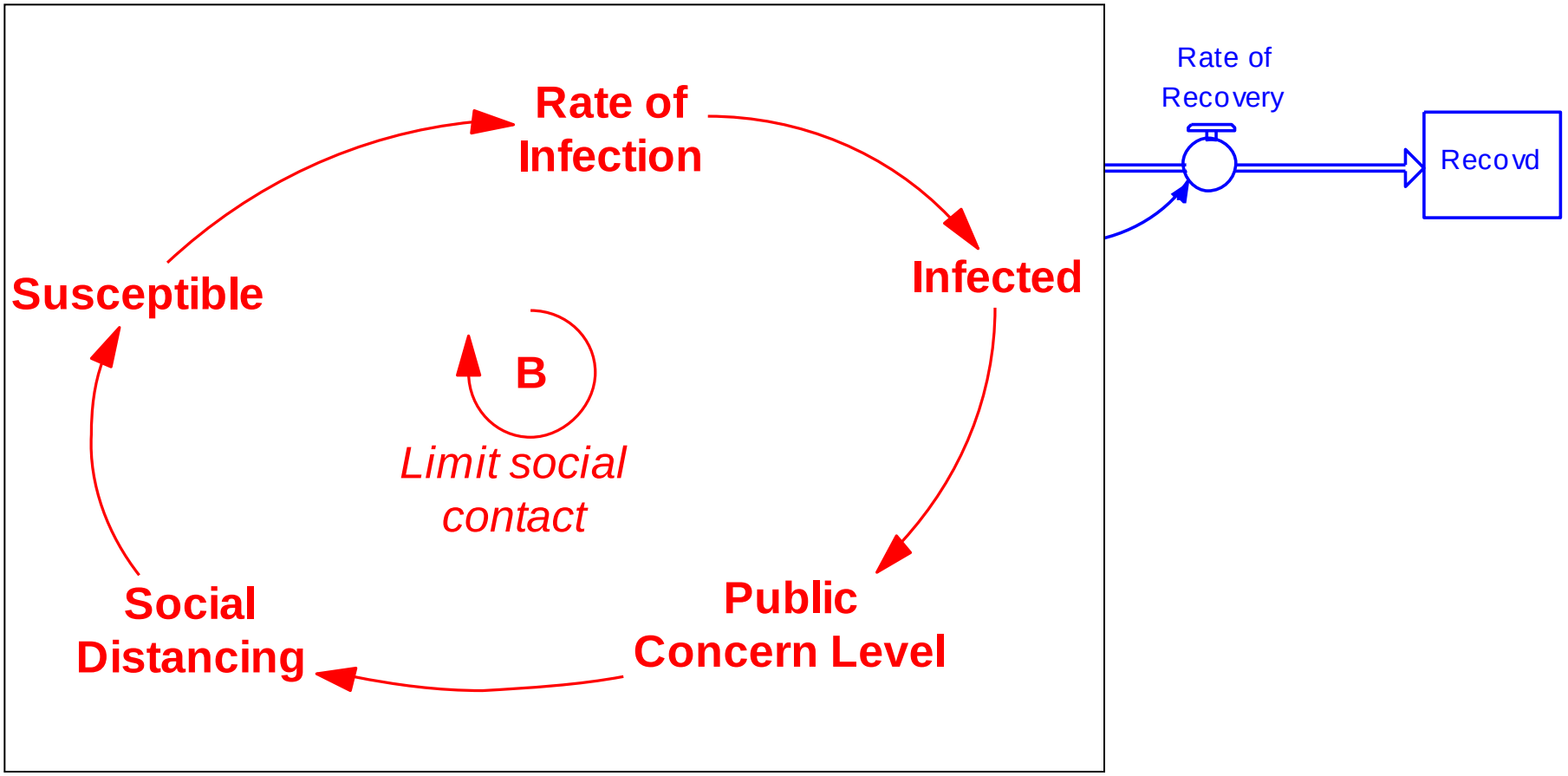
## *Dynamic Loop Dominance*



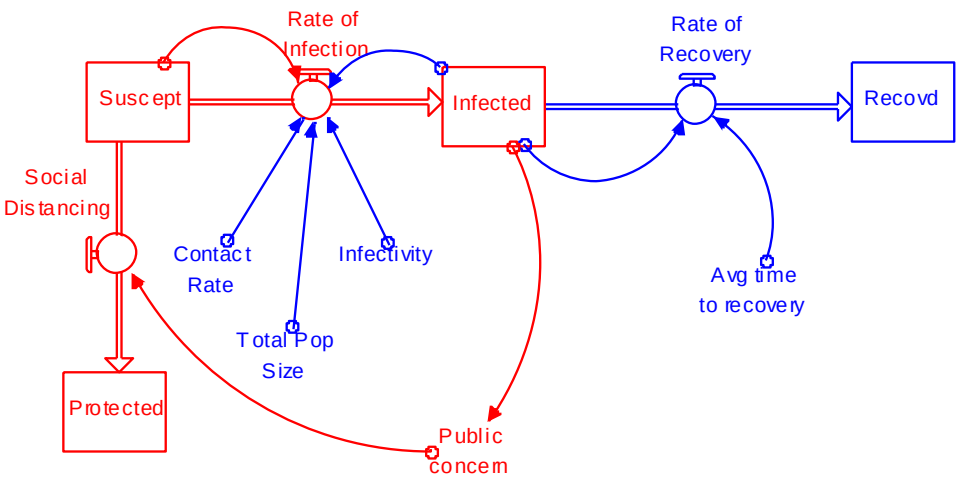
# “Nearly Everything is Endogenous” Look for Feedback!

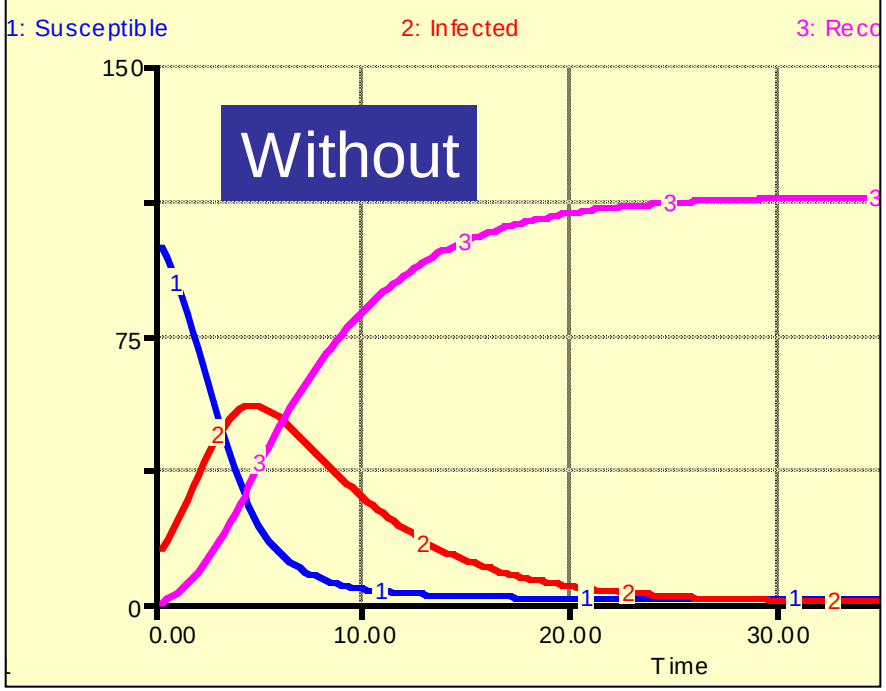


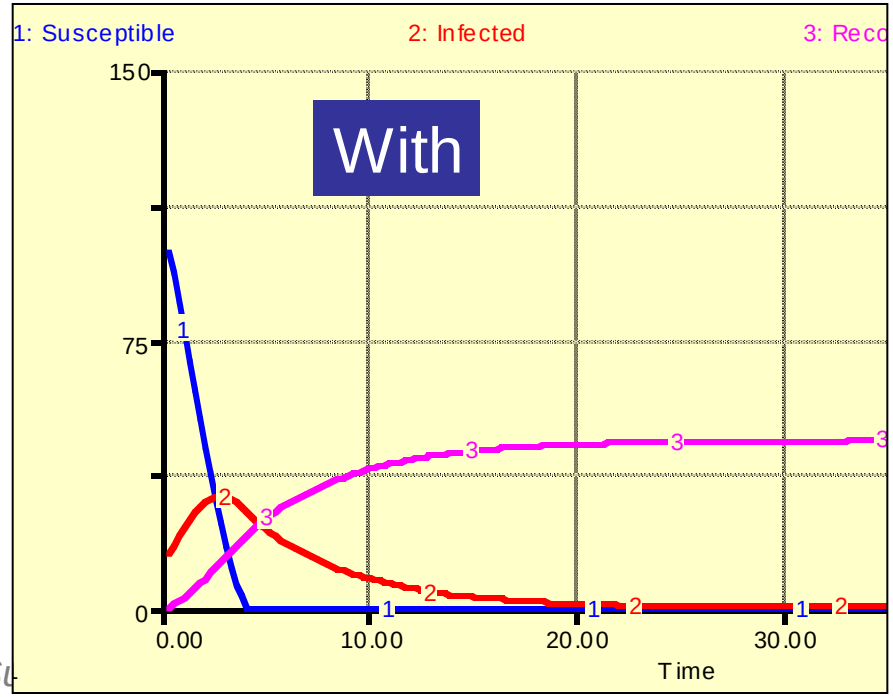
# “Nearly Everything is Endogenous”



# Effects of Social Distancing Balancing Feedback



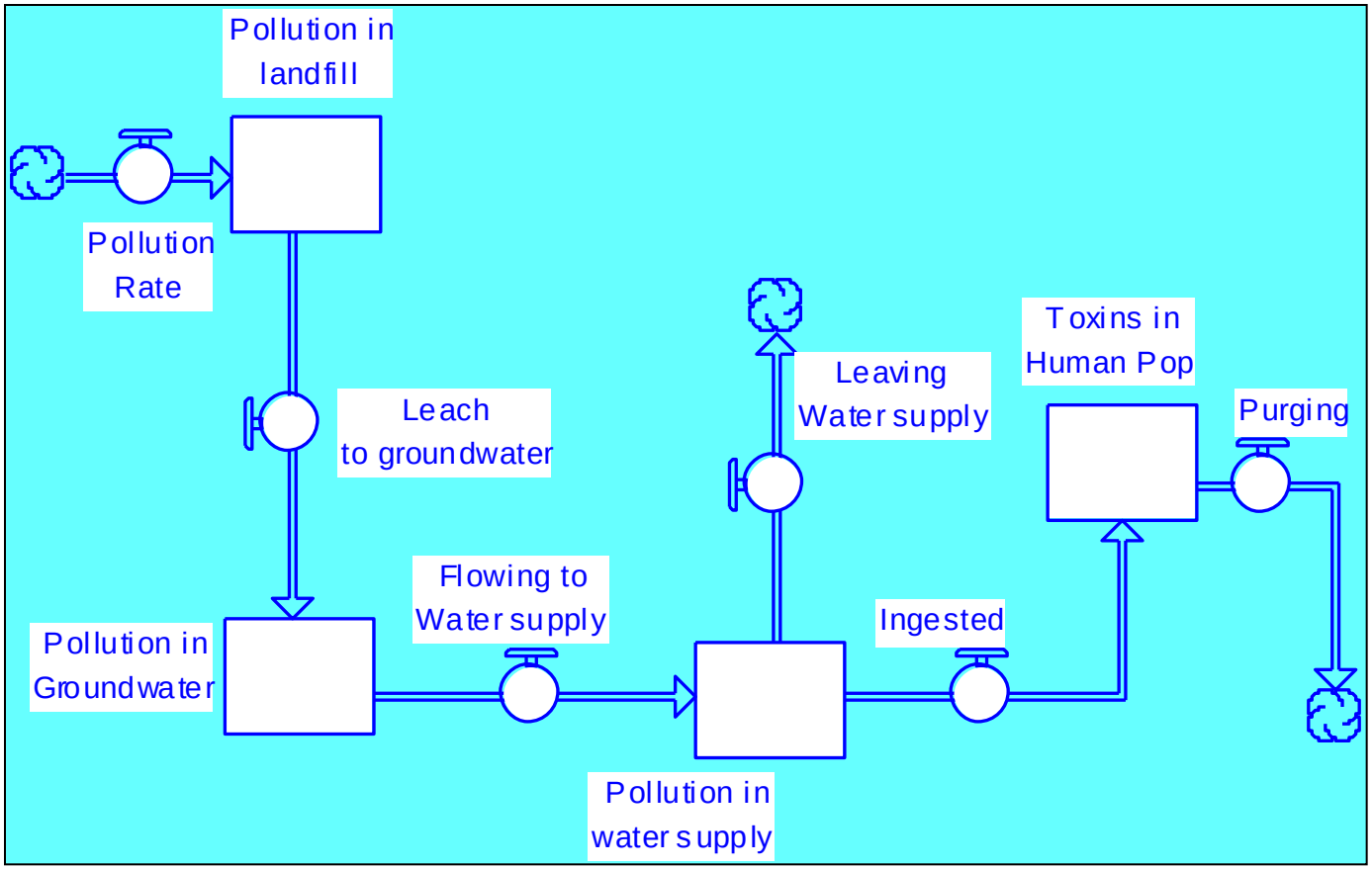



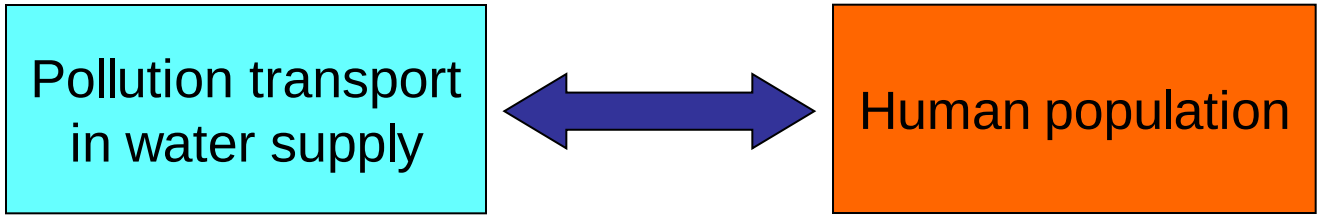
# Delay Dynamics of Stocks and Flows

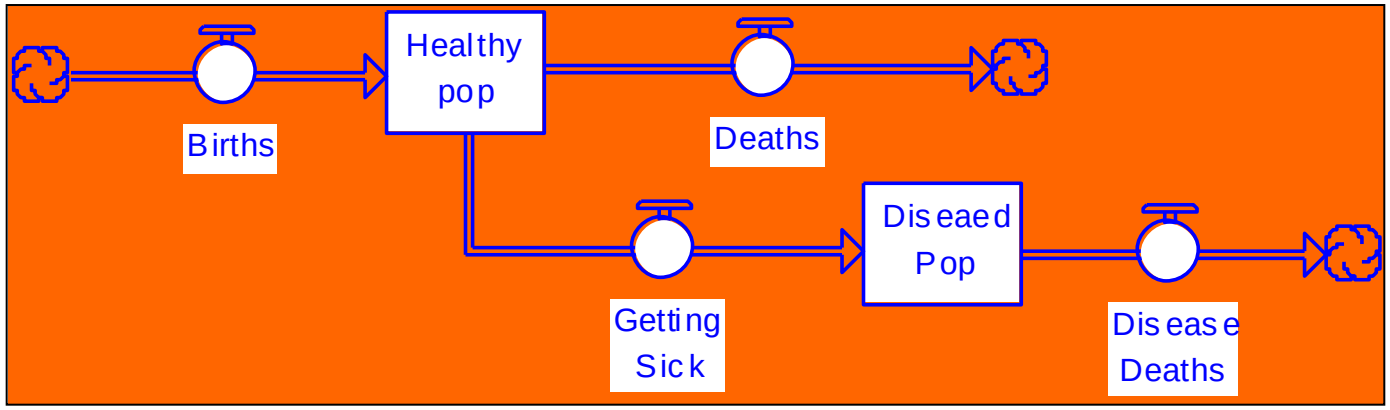
Pollution transport in water supply

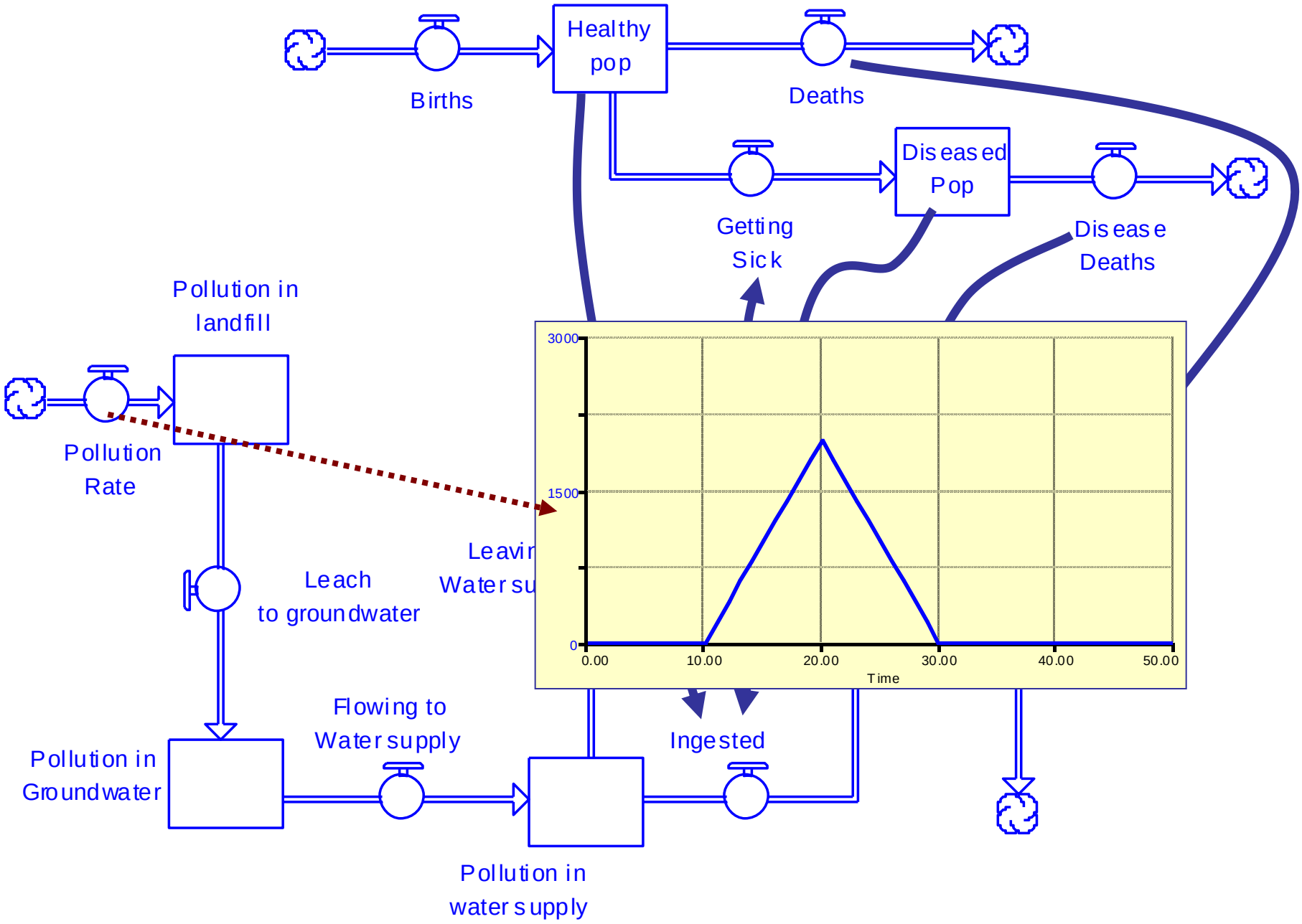
Human population



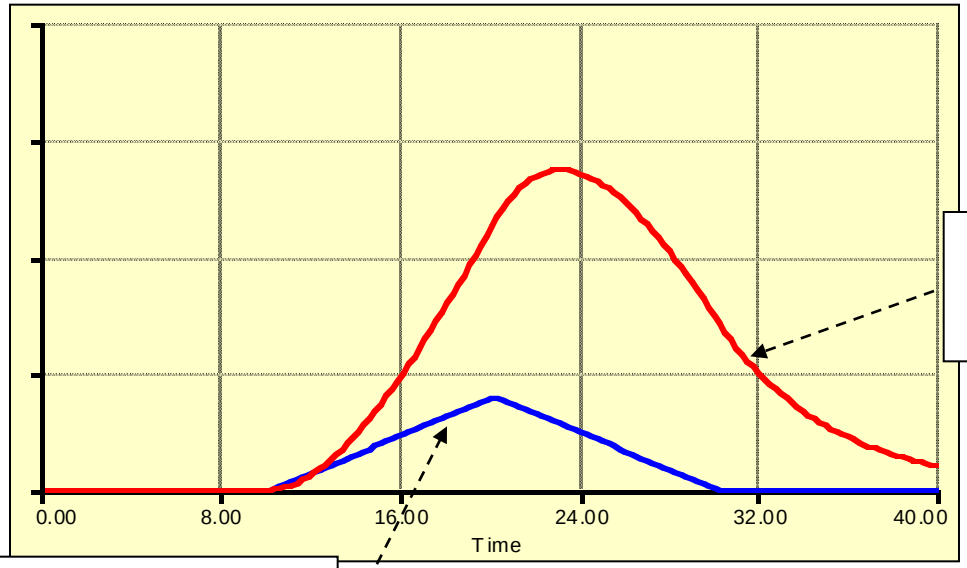
# Delay Dynamics of Stocks and Flows



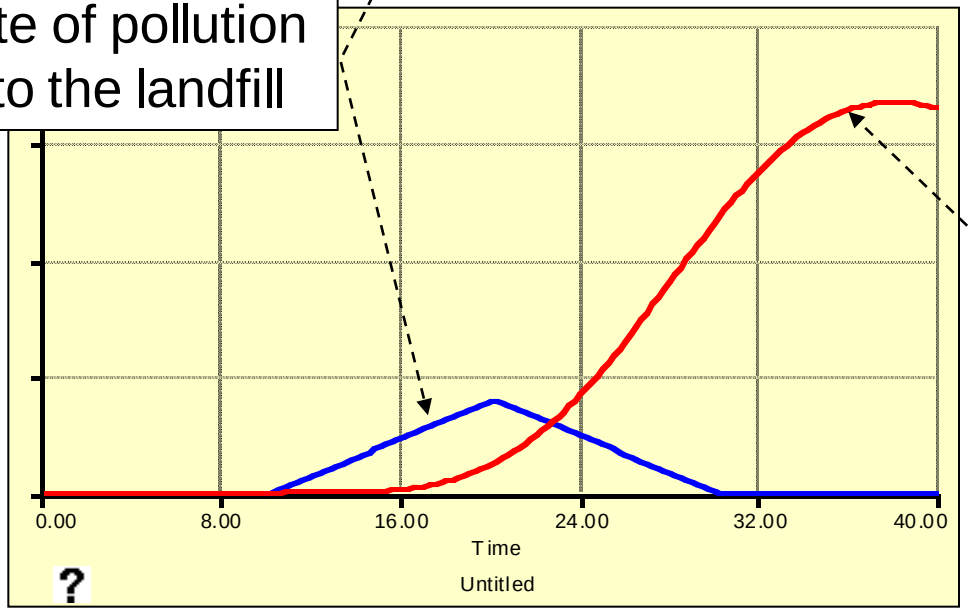

Healthy pop
Births
Deaths
Diseased Pop
Getting Sick
Disease Deaths
Pollution in landfill
Pollution Rate
Leach to groundwater
Leavir
Water su
3000
1500
0
0.00
10.00
20.00
30.00
40.00
50.00
Time
Flowing to Water supply
Ingested
Pollution in Groundwater
Pollution in water supply

# Stocks and Flows - Delay Dynamics

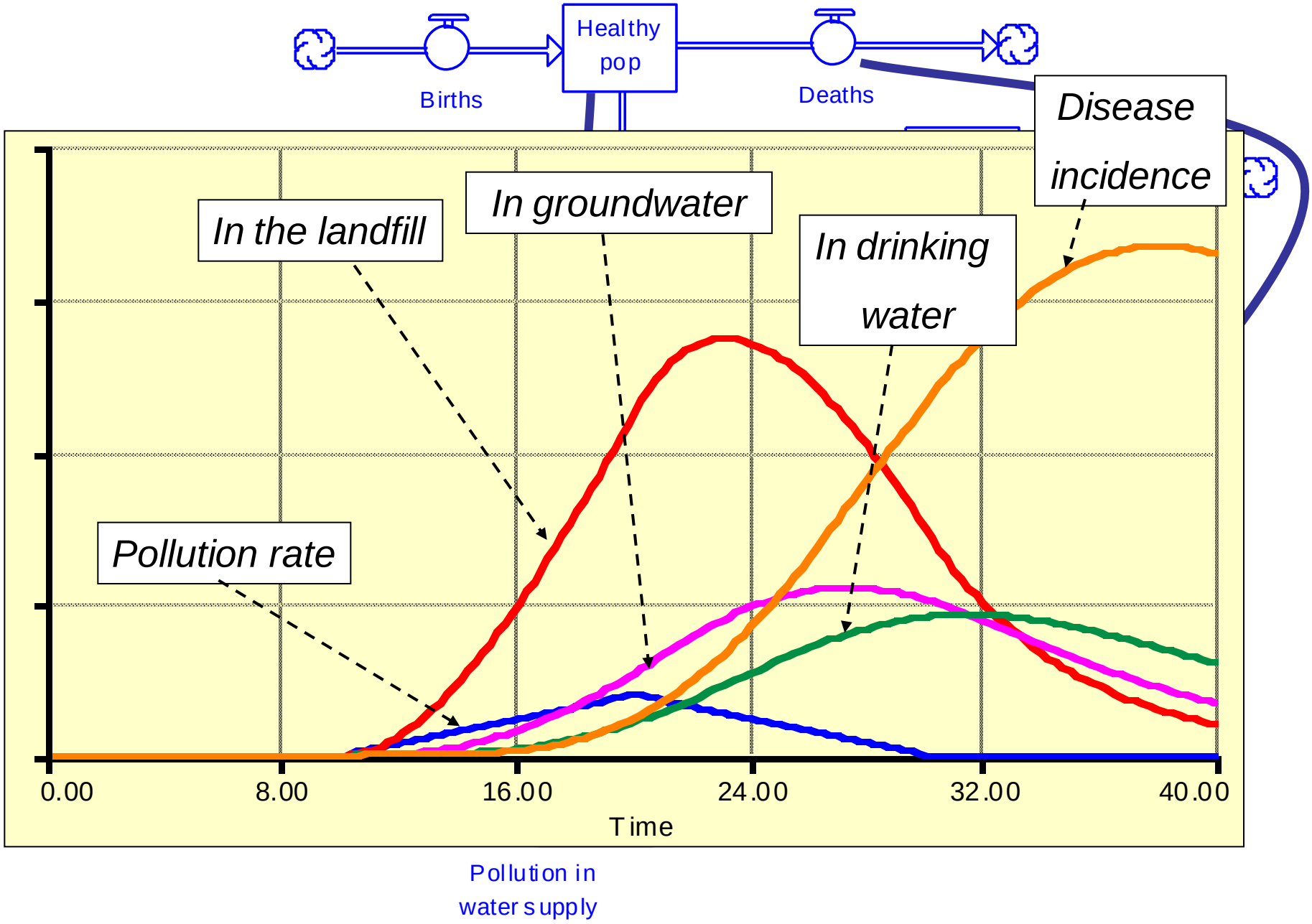



Pollution in the landfill

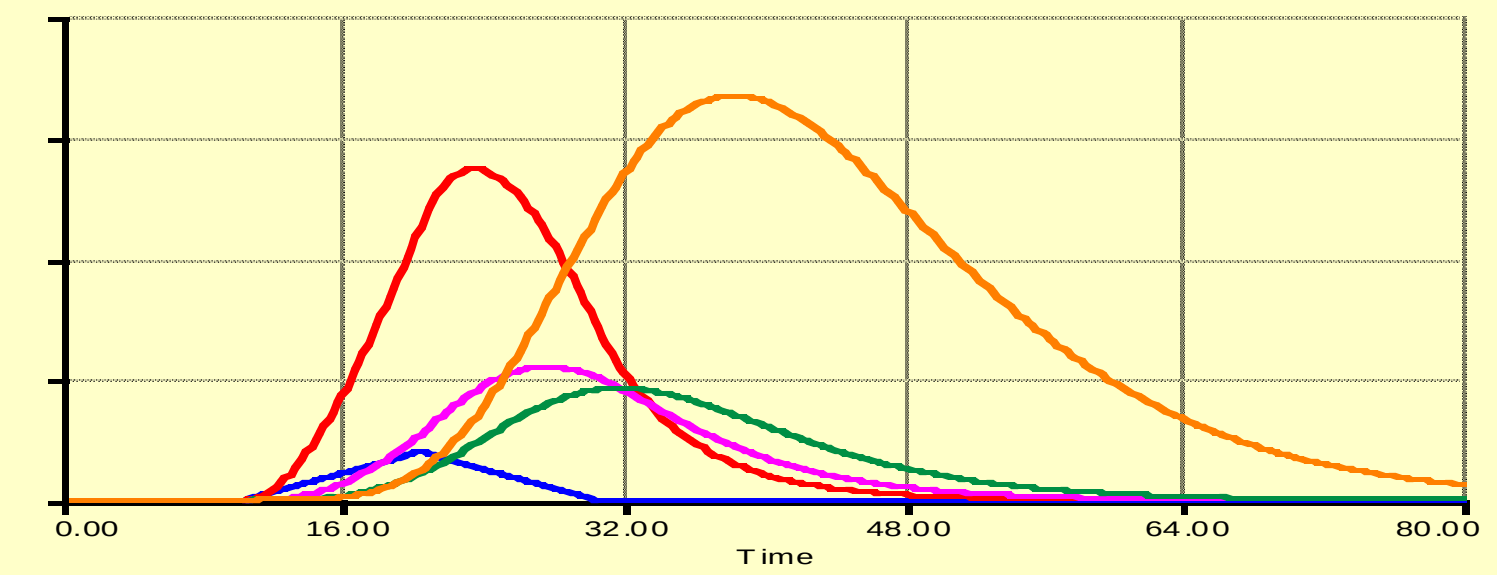
Rate of pollution into the landfill




Disease Incidence rate in the population


Healthy pop
Births
Deaths
Disease incidence
In the landfill
In groundwater
In drinking water
Pollution rate
0.00
8.00
16.00
24.00
32.00
40.00
Time
Pollution in water supply

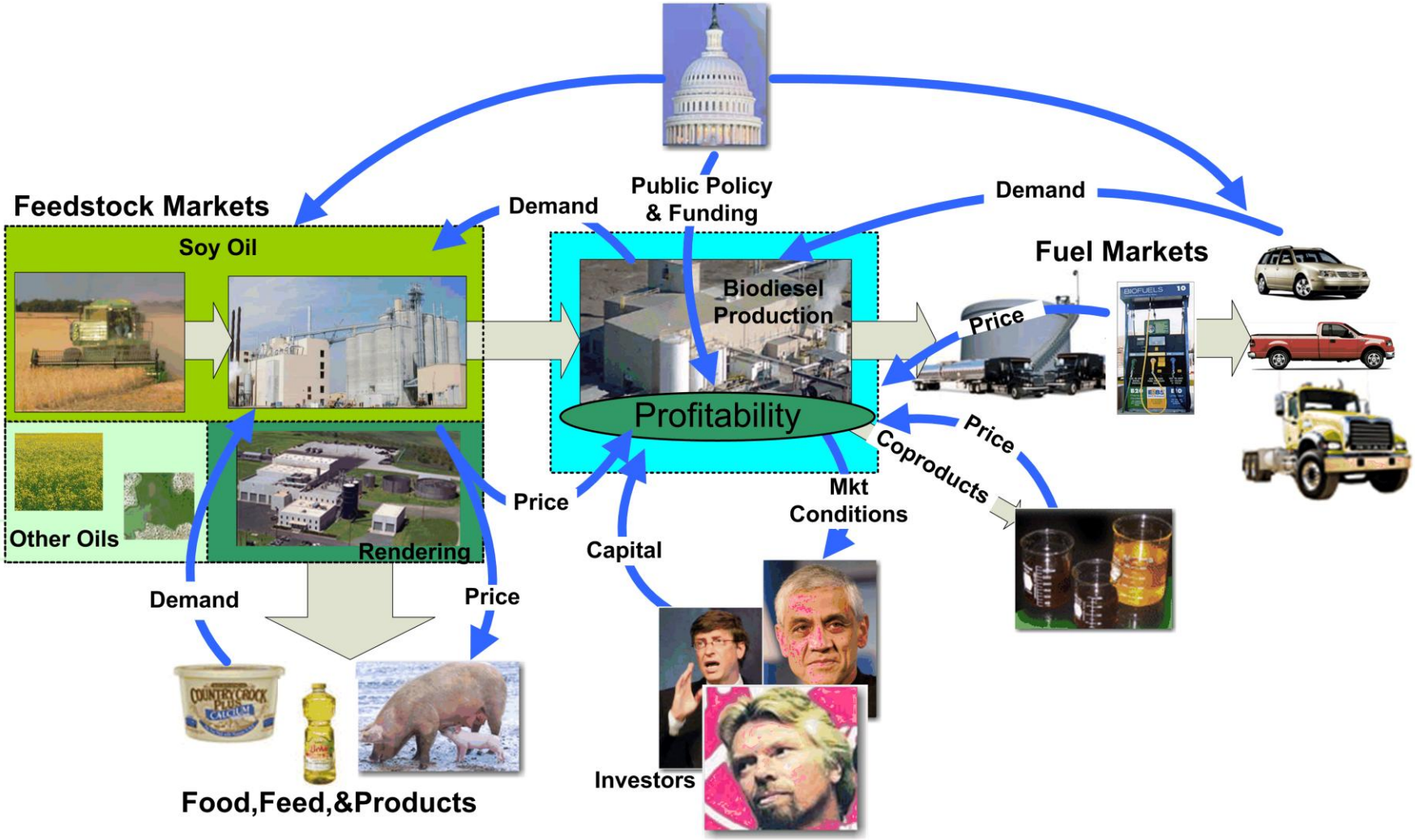
# The Long-Term Perspective



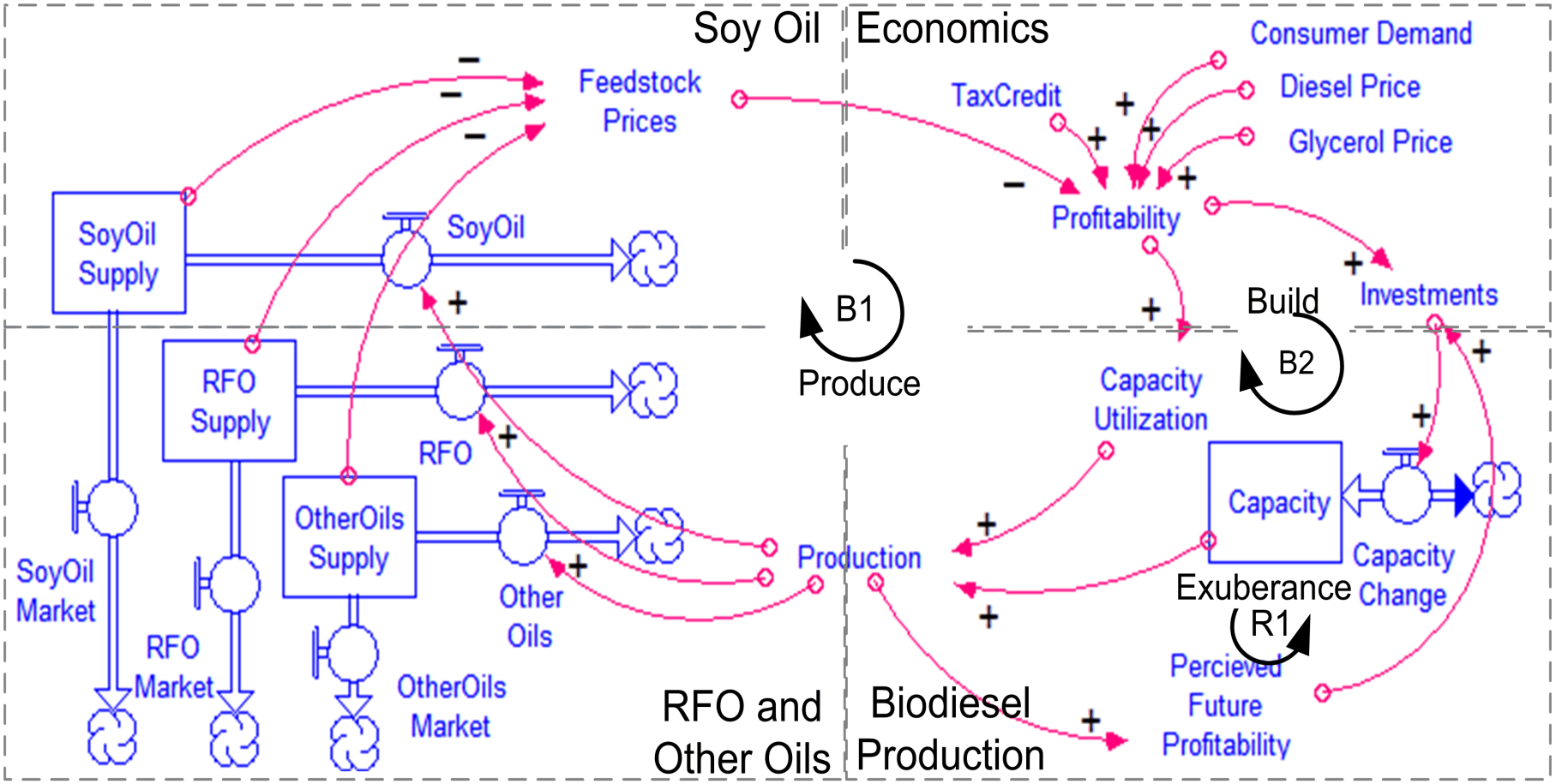
# Some Example SD Applications Energy Policy

- ***IDEAS*** – "Integrated Dynamic Energy Analysis Simulation"
  - Now maintained and used for DOE by Applied Energy Services, Arlington, VA
  - Policy options for mitigating greenhouse gas emissions
  - Includes industry, transportation, utilities sectors,etc
- ***FREE*** (Feedback Rich Energy Economy model)
  - Tom Fiddaman, MIT, 1997
  - Feedback structure between energy economy and global climate
- Numerous models now used or under development
  - ***NREL*** – Biomass Scenario Model
  - ***BIGS*** – Biodiesel Industry Growth Simulator (Bantz/Deaton, 2007)
  - etc

# Biodiesel Industry Growth Model Overview

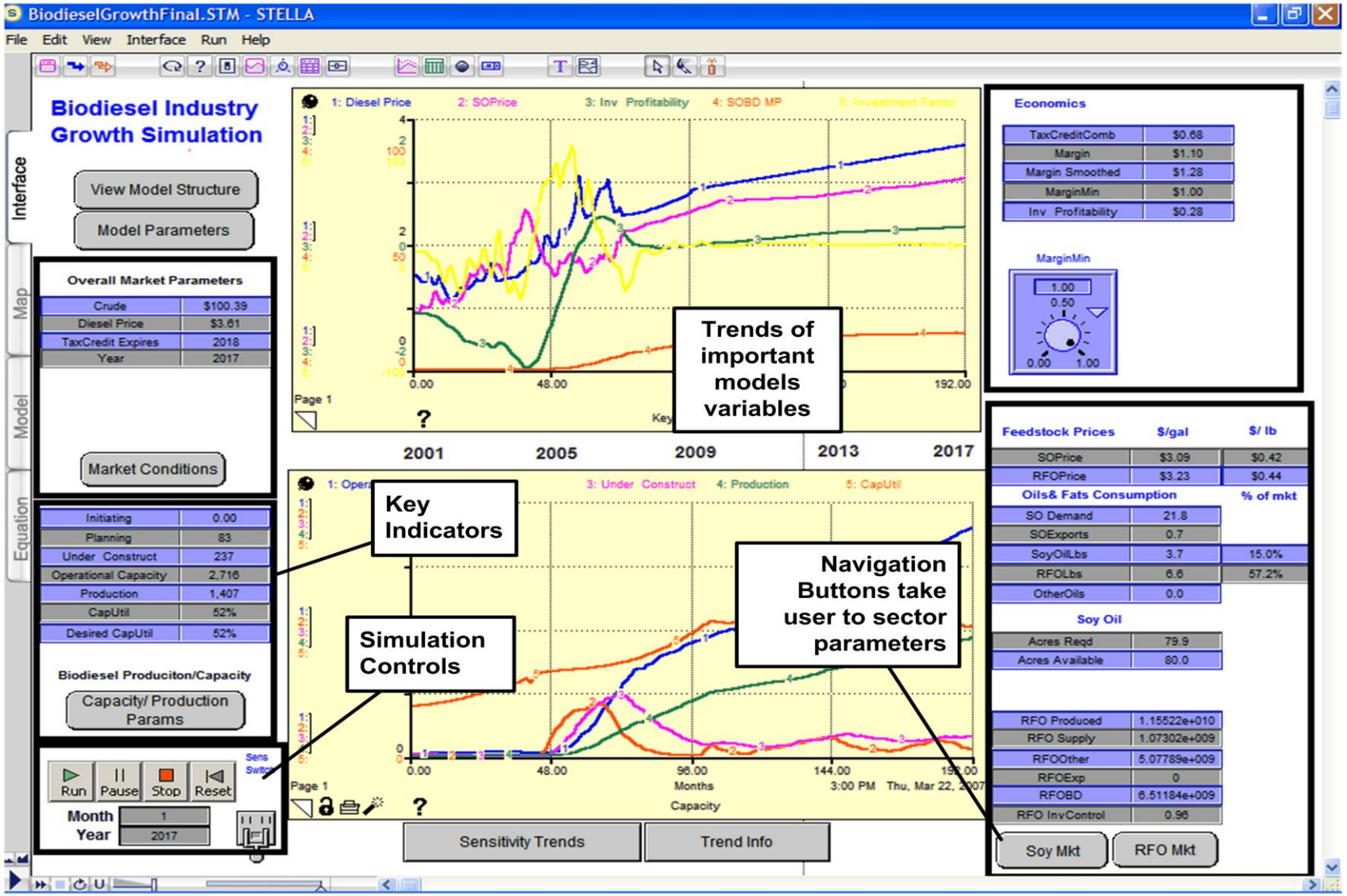


# BIGS Model
# Overview of Stock and Flow Structure




*Bantz (2007)*

# User Interface – BIGS Model




*Bantz (2007)*

# Example SD Applications
# Health and Health Systems

- *…HIV/AIDS – Consequences of highly active antiretroviral therapy* (Dangerfield, et al. ***Sys. Dyn. Rev, 17:2***, 2001.)
- *Understanding Diabetes Population Dynamics…* (Jones, et al (***Am. J. Pub Hlth***, 96:3, 2006)
- *Background in System Dynamics Simulation Modeling With a Summary of Major Public Health Studies* (Milstein, B., and J. B. Homer, CDC Syndemics Prevention Network, 2006).
  Includes a bibliography of many applications of SD to health policy. www.cdc.gov/syndemics
- *Building community consensus for cost-effective chronic disease care* (Homer, et al, ***Sys. Dyn. Rev.*** *20:3*, 2004)

# Whatcom County, WA Chronic Disease Care

- Issues

**"P2" Program Elements**

- Disease prevention/education
- Screening (for diabetes)
- Disease management – to slow disease progression


"Pursuing Perfection" (P2)

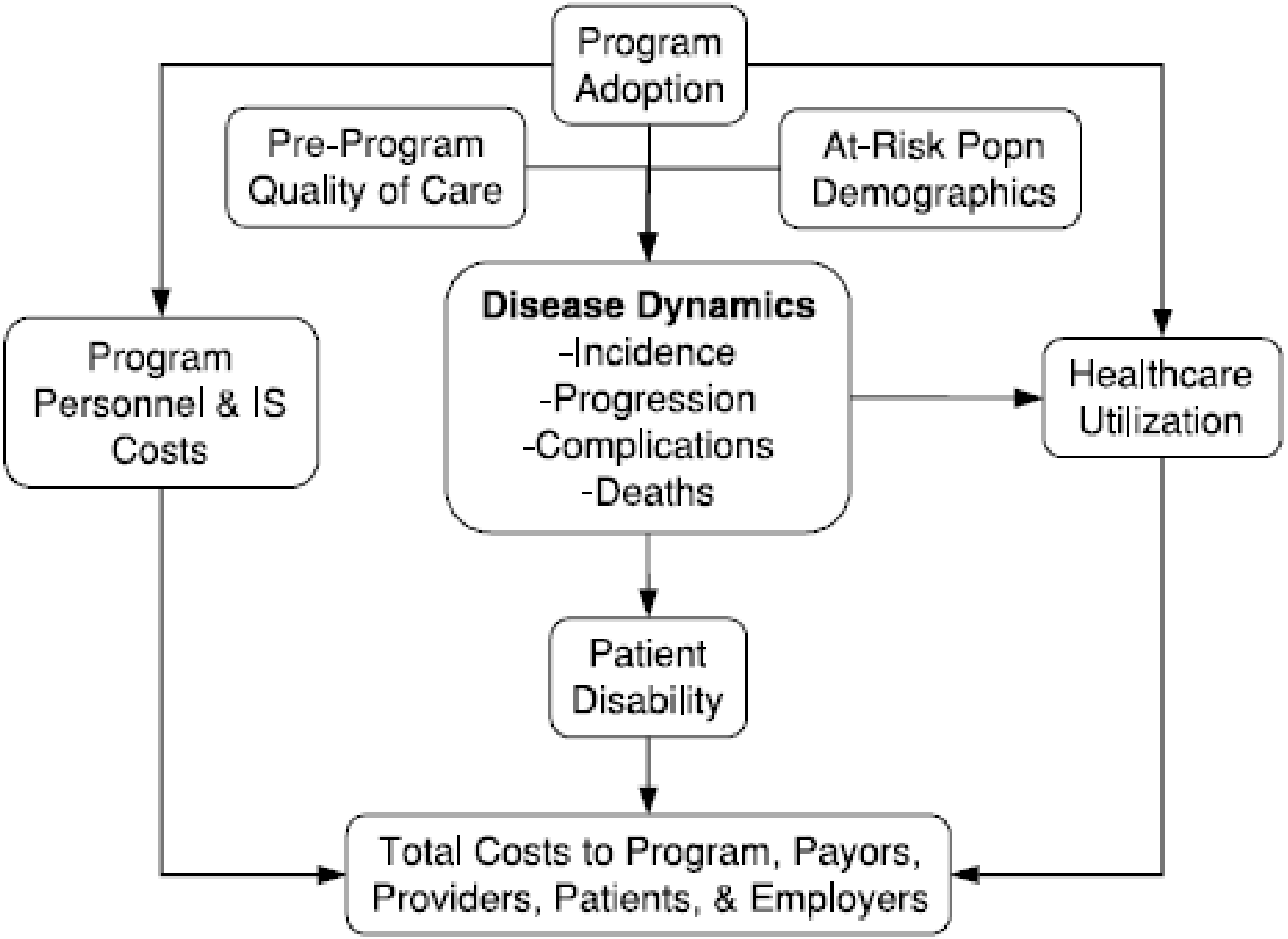
- 
  - "Create a community-based system of chronic care that is patient-centered, evidence-based, safe, timely, and equitable."
- Initial focus: Type 2 diabetes; Heart Disease

Homer, et al (2004). *Models for collaboration: How system dynamics helped a community organize cost-effective care for chronic illness.* ***Sys. Dyn. Rev., 20:3***, 199-222.

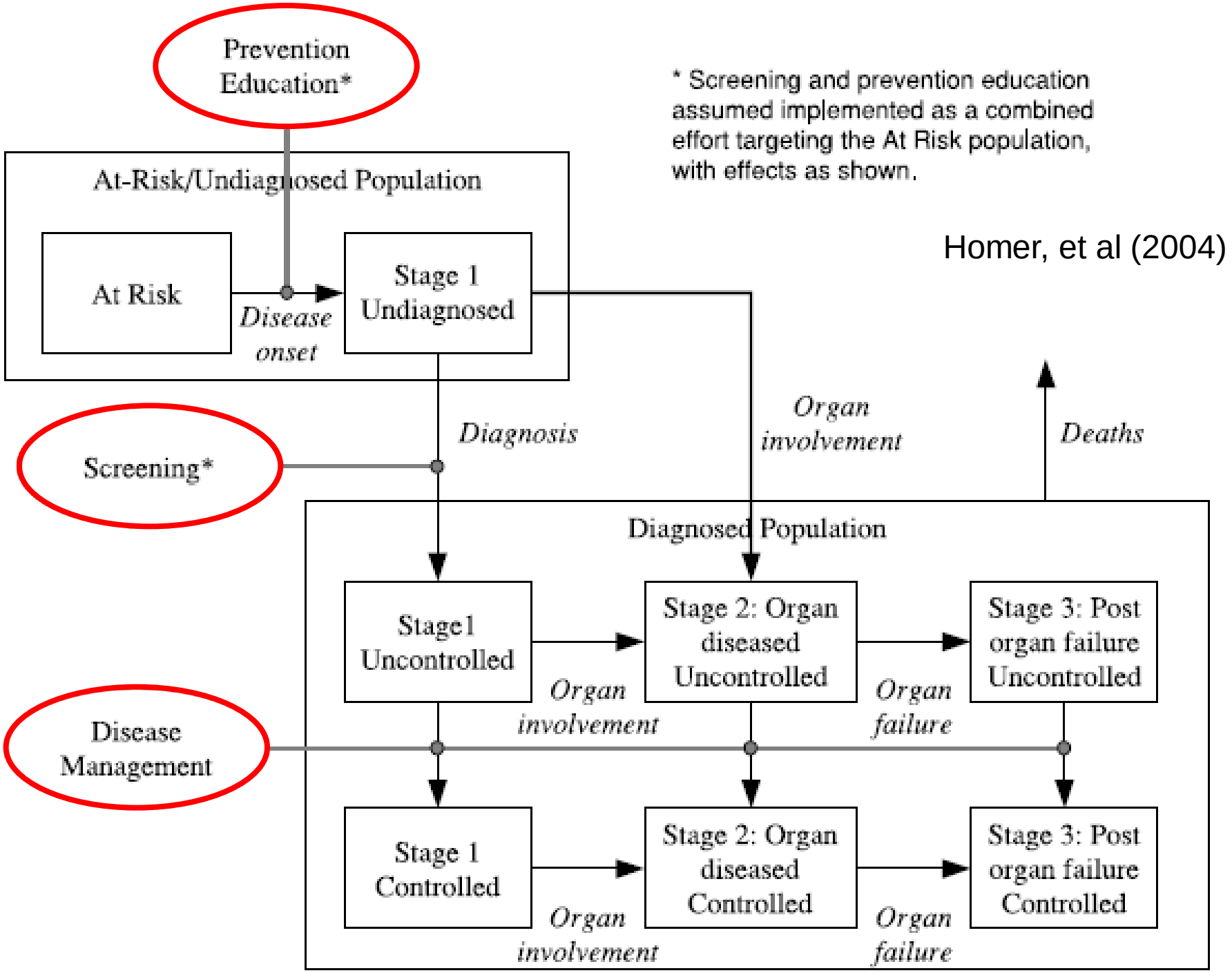
# Whatcom County, WA
# SD Models Uses

- Evaluate overall long-term of “P2” health interventions on…
  - Diabetes/Heart Disease Prevalence
  - Health care utilization and cost
  - Mortality and disability rates
- Understand the impact of these interventions on individual stakeholder groups
  - Providers (Prim. Care MD, Specialists, Hospitals)
  - Suppliers (pharmaceuticals, implanted devices)
  - Insurers
  - Employers
  - Individuals

Homer, et al (2004)



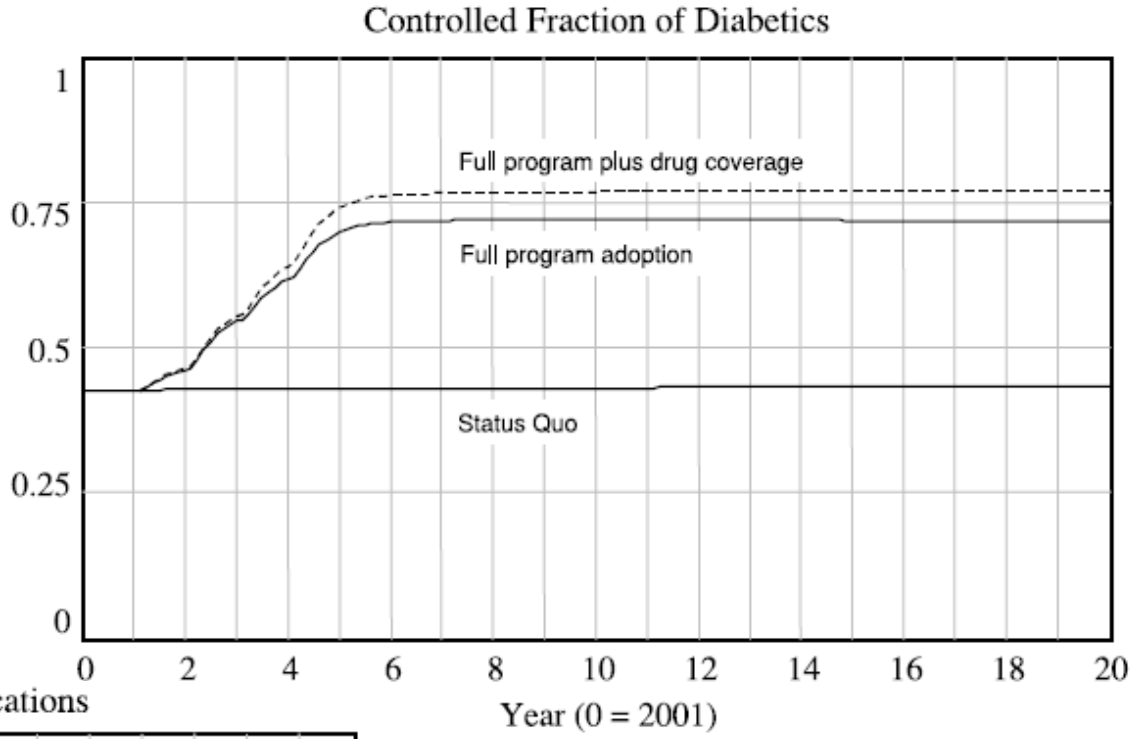

Homer, et al (2004)

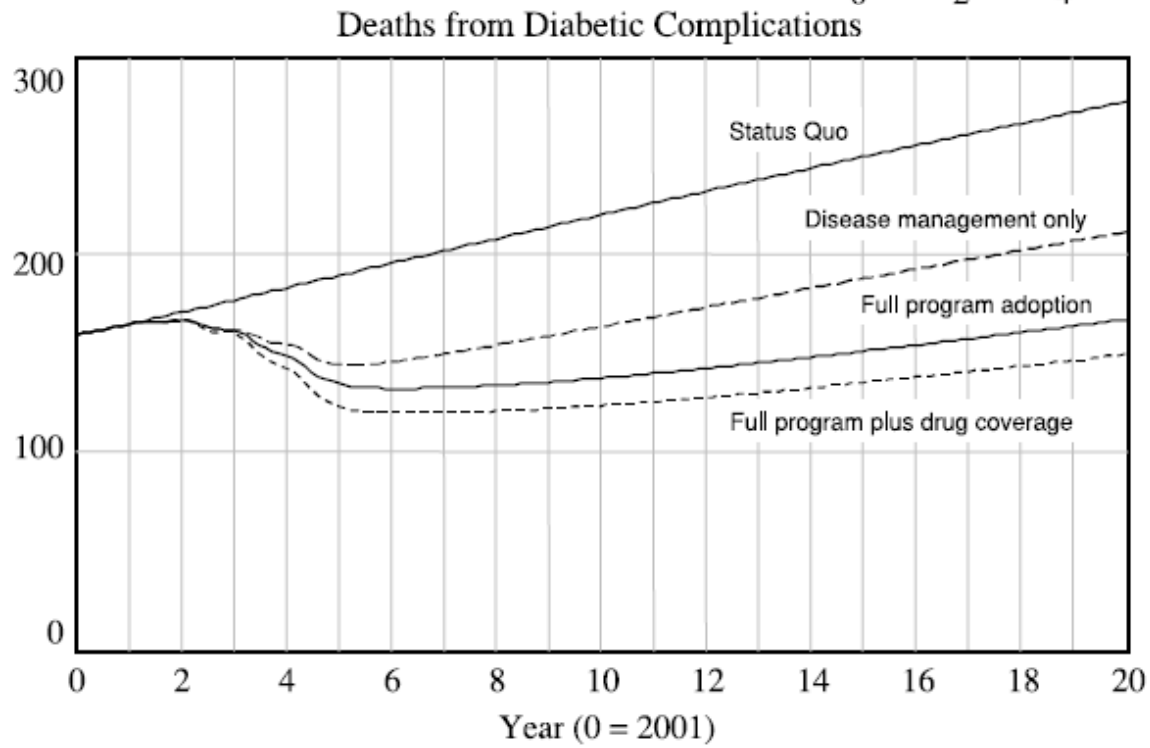

Prevention Education*
* Screening and prevention education assumed implemented as a combined effort targeting the At Risk population, with effects as shown.
At-Risk/Undiagnosed Population
At Risk
Disease onset
Stage 1 Undiagnosed
Homer, et al (2004)
Screening*
Diagnosis
Organ involvement
Deaths
Diagnosed Population
Stage1 Uncontrolled
Stage 2: Organ diseased Uncontrolled
Stage 3: Post organ failure Uncontrolled
Organ involvement
Organ failure
Disease Management
Stage 1 Controlled
Stage 2: Organ diseased Controlled
Stage 3: Post organ failure Controlled
Organ involvement
Organ failure

# Whatcom County Scenarios 20-year time horizon

1. Status Quo
2. Full “P2” Program Adoption
   - Screening and prevention education
   - Risk mgmt for heart failure
   - Disease management
3. Disease Management Only
4. Full “P2” + comprehensive Medicare drug coverage (+65 yrs)

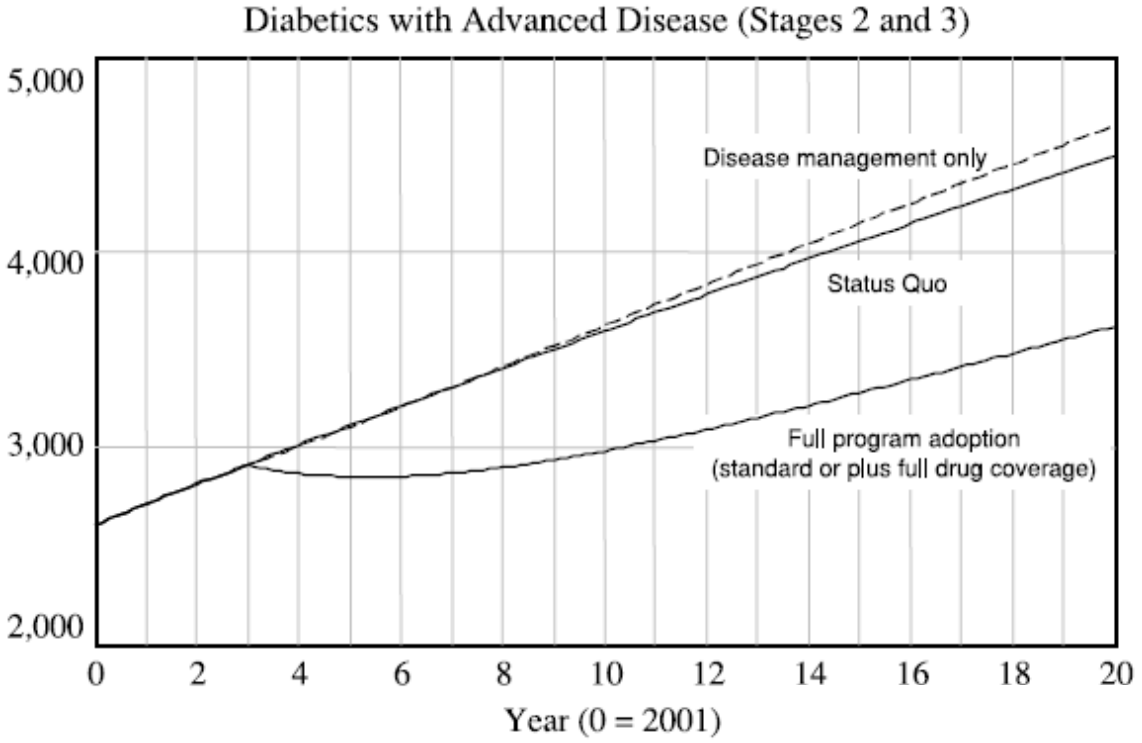
Homer, et al (2004)

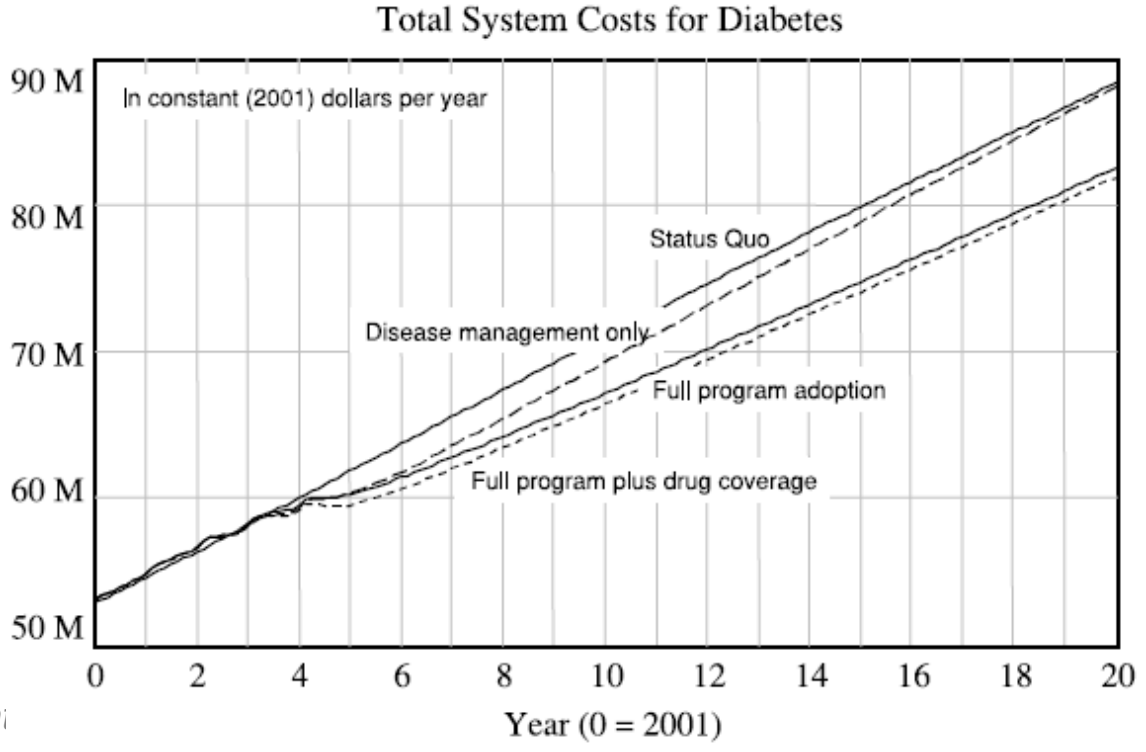


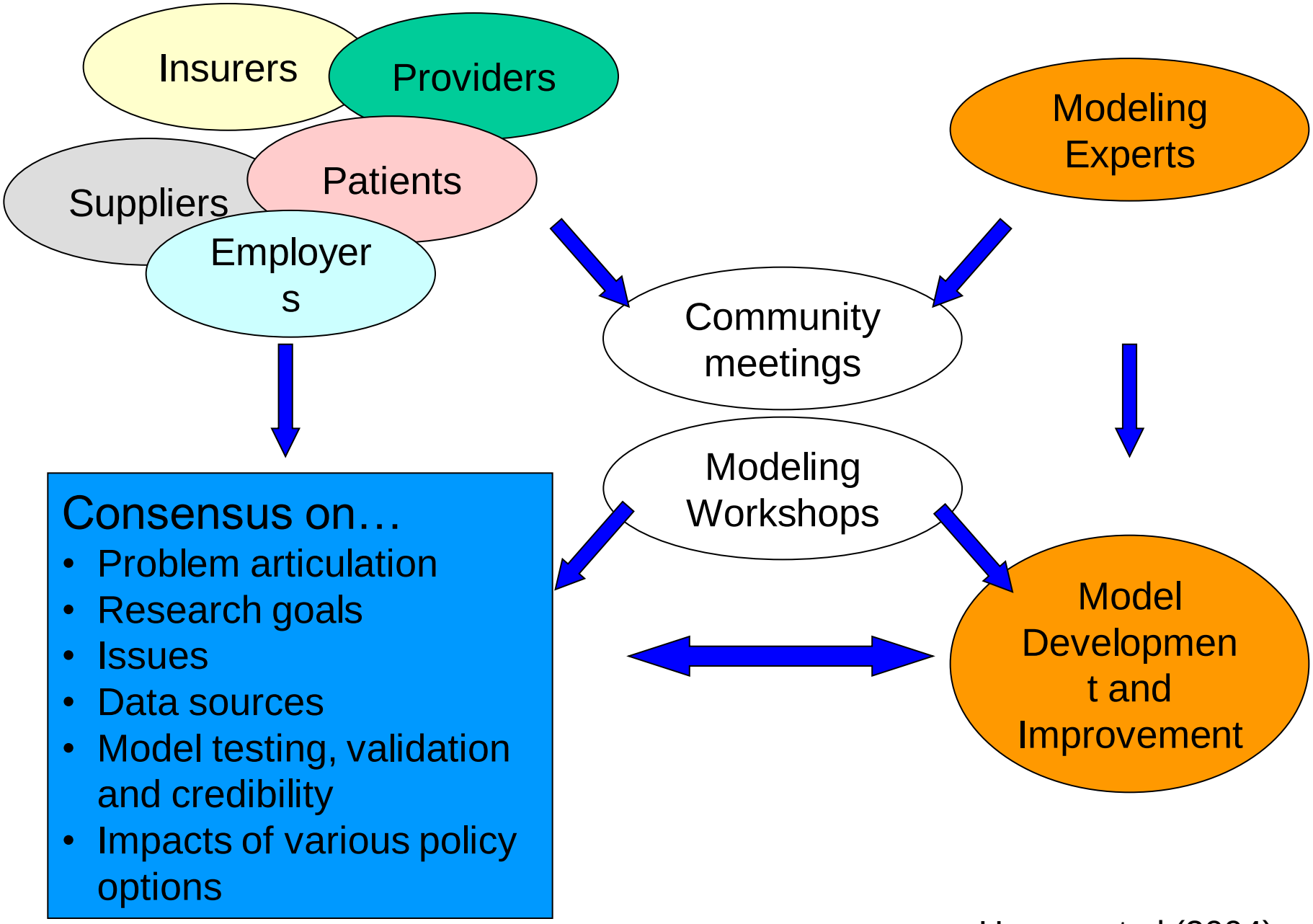




Homer, et al (2004)

Homer, et al (2004)






Homer, et al (2004)

# Whatcom County, WA
# From Understanding to Action

- A major insurer increased interim P2 funding
- Decision to continue increasing preventative care and risk management
- Meetings with representatives from around WA state
- Presentation to AHA to guide Medicare reform lobbying efforts

Homer, et al (2004)

# Reflections on the Role of SD in Health ↔ Environment Studies

- ***Long-term health-environment dynamics*** (pollution transport in the environment and into human population cohorts)
- ***Mutually reinforcing afflictions*** or health conditions ("syndemics")
- ***Program dynamics*** – system-wide impacts of comprehensive programs with interacting components
- ***Regional dynamics*** – Dynamic impacts on health from regional differences; potential for significant alterations in migration patterns and impacts on health system
- ***Life trajectory dynamics*** – Long-term population health dynamics, based on existing or predicted health trends, demographic trends, etc
- ***Public education*** on long-term dynamics connecting public health, health costs, and environmental issues

# "*All Models are Wrong. Some are Useful*" G.E. P. Box

- Useful models of complex systems are…
  - Causal
  - Dynamic
  - Behavioral
  - Grounded in empirical tests
  - Have broad model boundaries
  - Collaborative
  - Transparent
  - Enable learning
  - Explicitly define and test mental models

# Putting our Mental Models on the Table

"All decisions are taken on the basis of models…The question is not to use or ignore models. The question is only a choice among alternative models. … Mental models are fuzzy, incomplete, and imprecisely stated. … Fundamental assumptions differ [from one person to another], but are never brought into the open. Goals are different, but left unstated. It is little wonder that compromise takes so long. And even when consensus is reached, the underlying assumptions may be fallacies that lead to laws and programs that fail. The human mind is not adapted to understanding correctly the consequences implied by a mental model."

Jay W. Forrester. *Counterintuitive Behavior of Social Systems.*
Testimony before U.S. Congress, October, 1970

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