Habits of a Systems Thinker

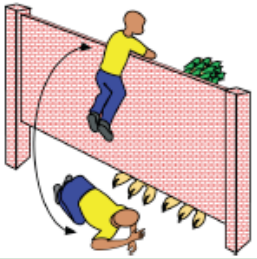
Seeks to understand the big picture

Observes how elements within systems change over time, generating patterns and trends

Recognizes that a system's structure generates its behavior

Identifies the circular nature of complex cause and effect relationships

Changes perspectives to increase understanding



Surfaces and tests assumptions

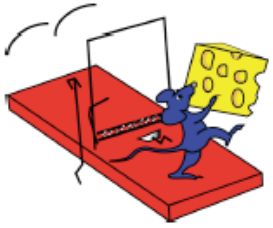
Considers an issue fully and resists the urge to come to a quick conclusion

Considers how mental models affect current reality and the future

Uses understanding of system structure to identify possible leverage actions

Considers both short and long-term consequences of actions

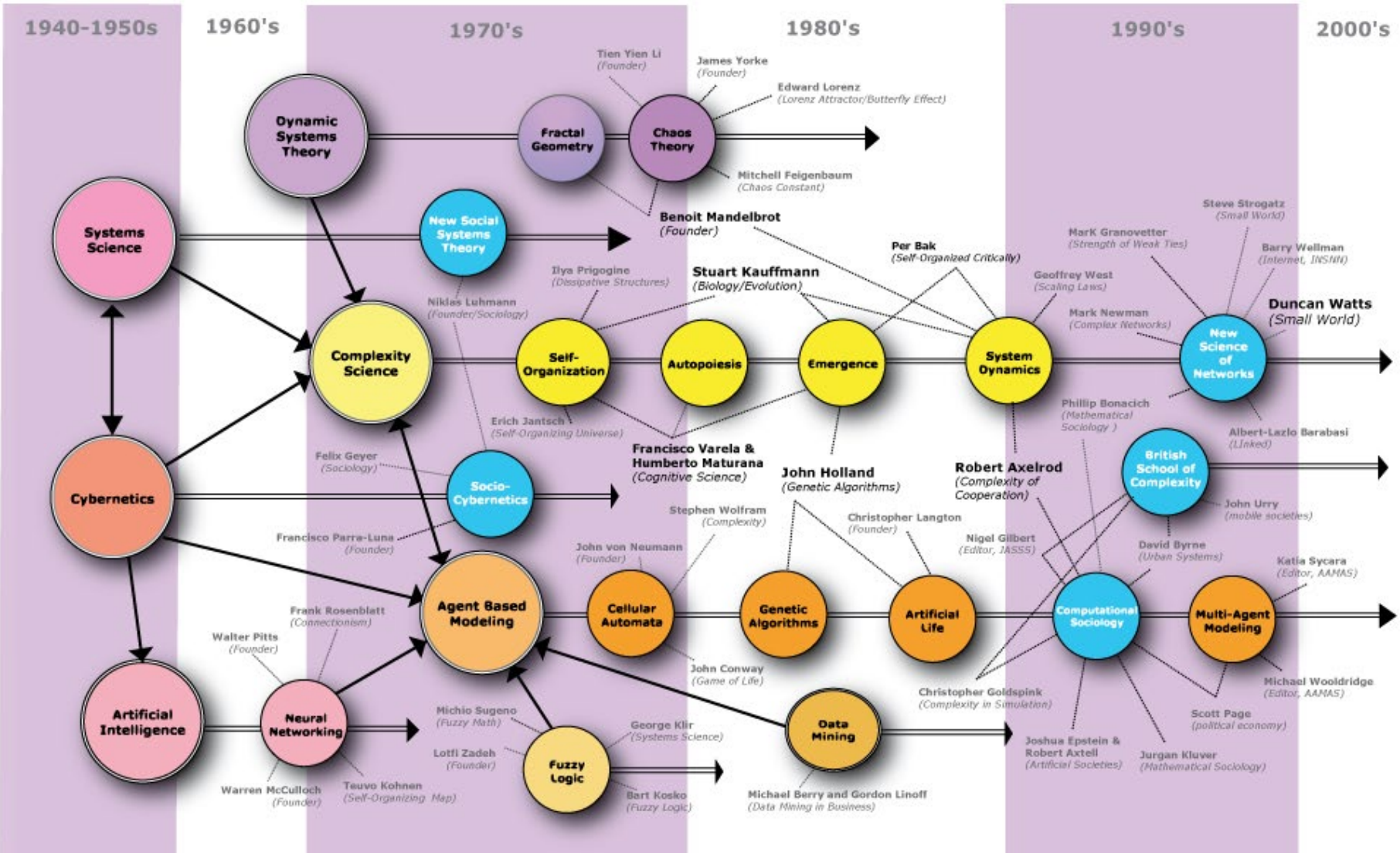
Finds where unintended consequences emerge



Recognizes the impact of time delays when exploring cause and effect relationships

Checks results and changes actions if needed: "successive approximation"

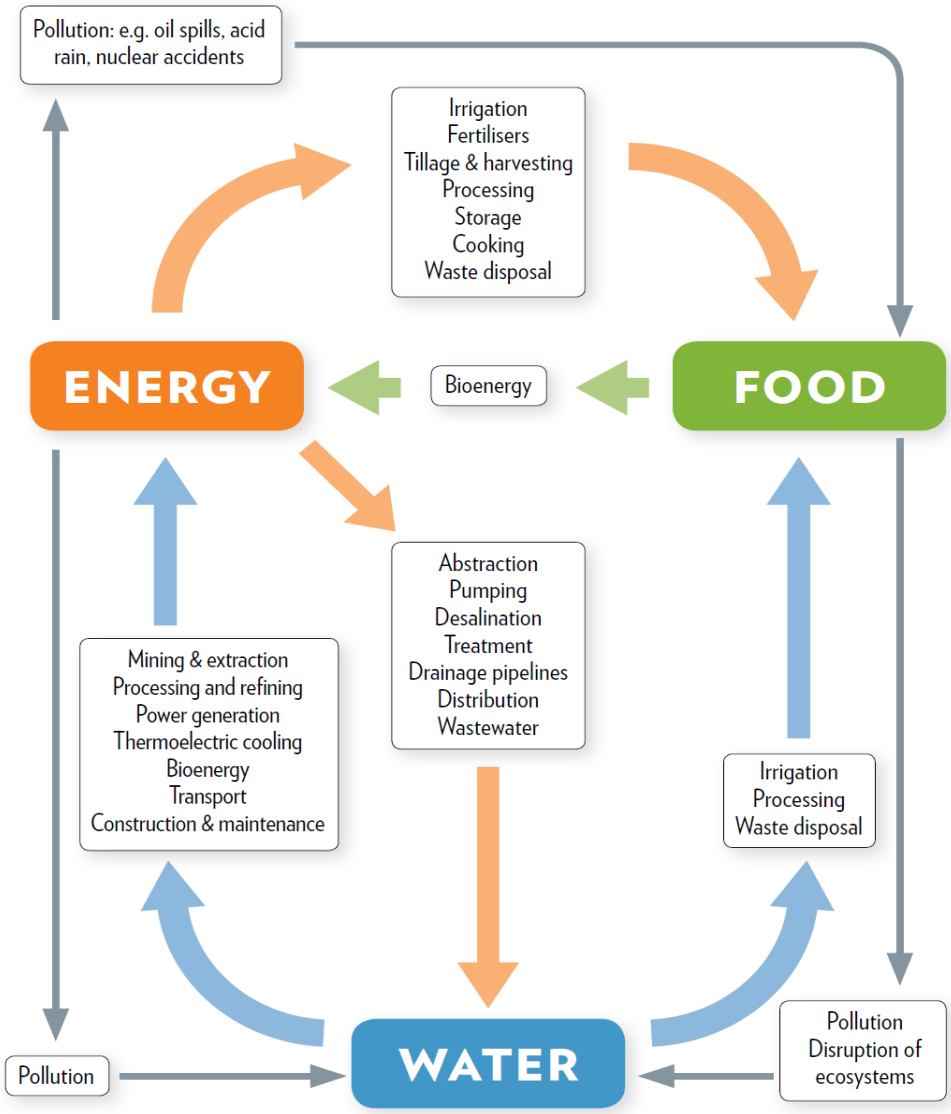
System Science(s): Study of systems



Soft and Hard Systems Approaches

Checkland and Poulter (2006):

- A soft system approach uses a systemic process of inquiry, an "action oriented [learning] process" to address "problem situations' but does not emphasize the structure of the problems.
- A hard system approach, is more about the development of systems models (such as the system dynamics models in this book) to address problem situations *and* the structure of the problems.


Pollution: e.g. oil spills, acid rain, nuclear accidents
Irrigation
Fertilisers
Tillage & harvesting
Processing
Storage
Cooking
Waste disposal
ENERGY
Bioenergy
FOOD
Abstraction
Pumping
Desalination
Treatment
Drainage pipelines
Distribution
Wastewater
Mining & extraction
Processing and refining
Power generation
Thermoelectric cooling
Bioenergy
Transport
Construction & maintenance
Irrigation
Processing
Waste disposal
Pollution
WATER
Pollution
Disruption of ecosystems

	Water Security	Energy Security	Food/Ag Security	Land/Soil/Veg Security
Water Resources		Water for energy extraction and production, and biofuel processing	Water for agricultural production and irrigation	Water contributes to soil and aquifer replenishing and vegetation growth
Energy Resources	Energy to run water infrastructure, pumping, irrigation, and desalination		Energy for mechanized agriculture, land preparation, irrigation, fertilization, etc.	Energy for field preparation, irrigation, and harvest
Food/Ag Resources	Agricultural practices, food demand and diet impact water use	Food, agricultural residues and biomass used for production of biofuels and biogas		Agricultural practices impact land and vegetation
Land/Soil/Veg Resources	Soil type and vegetation regulate soil water saturation and groundwater	Soil type and vegetation affect the energy consumption for land use	Soil type and land characteristics affect crop yield	

Climate change linkages and impacts

Impact of climate change on poverty

- Poor hit earliest and hardest with the least capacity to adapt. Climate change may led to:
- Loss of habitats & biodiversity,
- Loss of livelihoods / new opportunities, Increased frequency / severity of natural disasters, flooding and extreme weather,
- Water scarcity & desertification,
- Conflict, civil unrest and migration,
- Health impacts & food insecurity.
- Complex trade-offs: e.g. biofuels could boost or undermine livelihoods of poor, carbon markets could reduce or entrench poverty.

Impact of climate change on globalisation

- The impacts of carbon trading and the shift towards a low carbon economy especially in energy, transport, foodstuffs, manufacturing, construction & tourism markets,
- Localisation of supply chains & markets due to higher transport costs,
- Increased risk, uncertainty & market volatility. Disruption to agriculture & infrastructure,
- Failure to address climate change undermines global economy and support for globalisation processes.

Impact of climate change on engineering

- New markets and opportunities in renewable energy, alternative fuels, energy conservation & waste reduction,
- New research / innovation opportunities,
- Disaster preparedness and relief and post-disaster reconstruction,
- Low carbon economy especially in energy, infrastructure & construction markets.

Impact of poverty on climate change

- Farming, energy, transport, urbanisation and development choices of developing nations are critical if global CO2 reduction targets are to be met especially in rapidly industrialising economies (Brazil, Russia, India & China).
- Global carbon trading and emissions targets must recognise the needs and rights of the poor and the obligations of industrialised nations.

Poverty linkages and impacts

Impact of poverty on globalisation

- The responsibility to act ethically, contribute to poverty reduction and involve poor in decision making is becoming recognised by global corporations,
- Failure to act responsibly or to address poverty undermines support for (current models of) globalisation.
- Globalisation criticised by international development & trade reformers.

Impact of poverty on engineering

- Requires low cost solutions that are appropriate to cultural, political, social and economic environment,
- Requires participation of the poor and local knowledge,
- Developing countries are often high risk / high return markets.

Impact of globalisation on climate change

- International supply chains increase energy and transport impacts,
- Reduced production costs increase waste and consumerism fuelling carbon emissions
- Environmental impacts displaced to less developed country (LDC) production centres.

Impact of globalisation on poverty

- Social, legal & environmental safeguards often lower in less developed countries (LDCs),
- Offers economic opportunities esp. in natural resources & agriculture, tourism, manufacturing and fair-trade goods,
- LDC economies vulnerable to capital flight and brain drain, trade rules disadvantage LDCs and undermine national sovereignty.

Globalisation linkages and impact

Impact of globalisation on engineering

- Growth in LDC markets esp. in utilities, infrastructure & the extractive industries,
- International supply chains promote technology transfer & standardised systems,
- Growth in labour mobility, access to knowledge.

Impact of engineering on climate change

- Transport, energy, agriculture, infrastructure and manufacturing choices determine impacts,
- Engineering and innovation key to mitigation and adaptation,
- Engineering key to disaster preparedness and reconstruction.

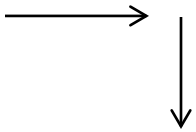
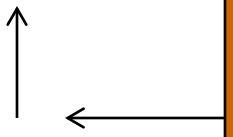
Impact of engineering on poverty

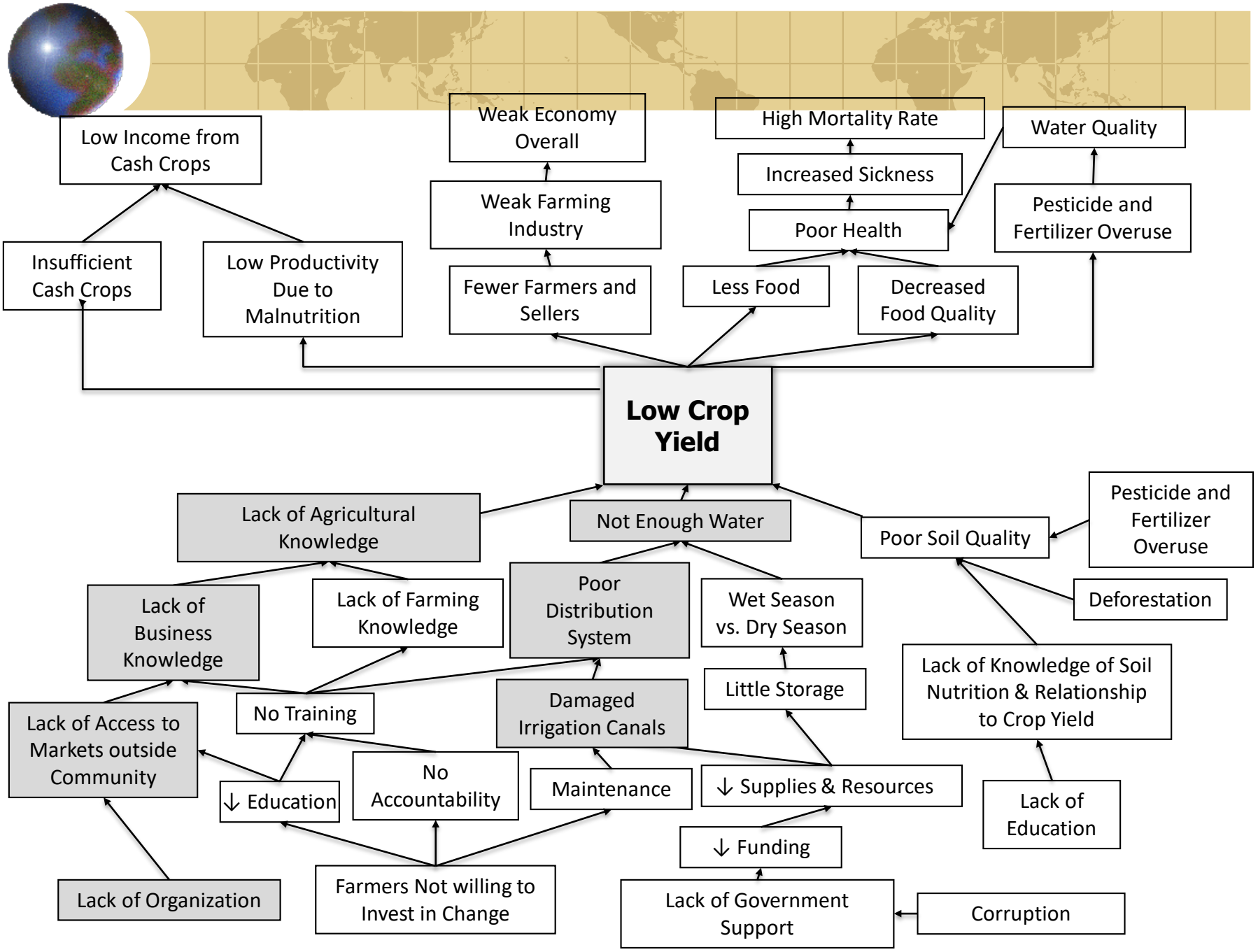
- Engineering key to providing pro-poor energy, transport, shelter, health and water products and services,
- Platform infrastructure and technologies provide an enabling environment for growth,
- Engineering supply chains and technology transfer offer poverty reduction opportunities.

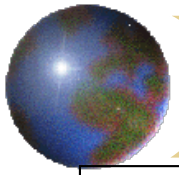
Impact of engineering on globalisation

- Engineering knowledge and innovation especially in transport, energy, manufacturing and ICT are the drivers behind economic integration and globalisation,
- Sustainability and climate change will force a revised model of engineering and globalisation.

Engineering linkages and impacts

Water	Impact of Water on All Children Reading	Impact of water on governance	Impact of water on empowering agriculture	Impact of water on Saving Lives at Birth
Impact of All Children Reading on Water	All Children Reading			
Impact of governance on water		Governance		
Impact of powering agriculture on water			Powering Agriculture	
Impact of Saving Lives at Birth on water				Saving Lives at Birth


Low Income from Cash Crops
Weak Economy Overall
High Mortality Rate
Water Quality
Increased Sickness
Weak Farming Industry
Pesticide and Fertilizer Overuse
Poor Health
Insufficient Cash Crops
Low Productivity Due to Malnutrition
Fewer Farmers and Sellers
Less Food
Decreased Food Quality
Low Crop Yield
Lack of Agricultural Knowledge
Not Enough Water
Poor Soil Quality
Pesticide and Fertilizer Overuse
Lack of Business Knowledge
Lack of Farming Knowledge
Poor Distribution System
Wet Season vs. Dry Season
Deforestation
Lack of Knowledge of Soil Nutrition & Relationship to Crop Yield
Little Storage
Lack of Access to Markets outside Community
No Training
Damaged Irrigation Canals
↓ Education
No Accountability
Maintenance
↓ Supplies & Resources
Lack of Education
↓ Funding
Lack of Organization
Farmers Not willing to Invest in Change
Lack of Government Support
Corruption



Increase Income from Cash Crops

Strong Economy Overall

Decreased Mortality Rate

Improved Water Quality

Decreased Sickness

Strong Farming Industry

Decreased Use of Pesticide and Fertilizer

Improved Health

Sufficient Cash Crops

High Productivity Due to Good Nutrition

More Farmers and Sellers

More Food

Increased Food Quality

Increased Crop Yield

Increase Knowledge of Agriculture

Increase in Water

Improved Soil Quality

Pesticide and Fertilizer improvement

Increase Business Knowledge

Increase Farming Knowledge

Improve Distribution System

Water Storage during Dry Season

Reforestation

Increase access to markets outside the Community

Training Programs

Repair/New Irrigation Canals

Increase Storage Capacity

Knowledge of Soil Nutrition & Relationship to Crop Yield

Farmers are Educated

Accountability among farmers

Learned Maintenance Techniques

Available Supplies & Resources

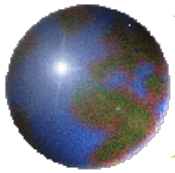
Increase in Education

Increase Funding

Farmers Organized for Cooperative Program

Farmers Willing to Invest in Change

Government Support



System Dynamics

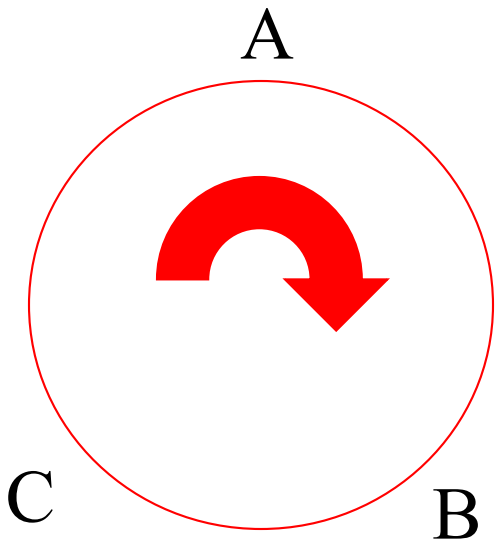
"An approach to understanding the behaviour of complex systems over time. It deals with internal feedback loops and time delays that affect the behaviour of the entire system. What makes using system dynamics different from other approaches to studying complex systems is the use of feedback loops and stocks and flows. These elements help describe how even seemingly simple systems display baffling nonlinearity." (Wikipedia, 2014)

Linear Causality

A → B → C

Cause → Effect

Circular Causality



Feedback: shows how actions can reinforce (positive feedback) or counteract (balance through negative feedback) each other

Variables are organized in a circle or loop of cause-effect relationship called a "feedback process"

Feedback Processes

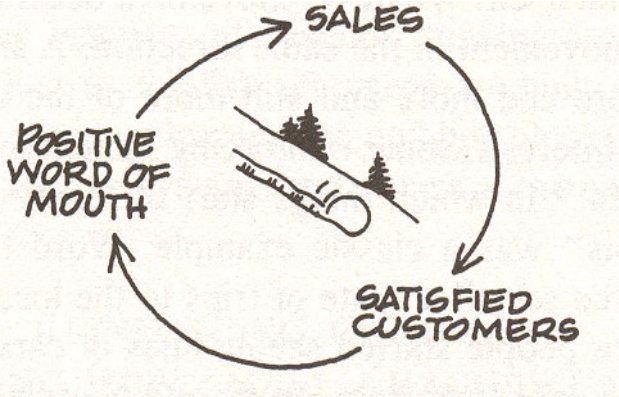
Reinforcing (R) or Amplifying

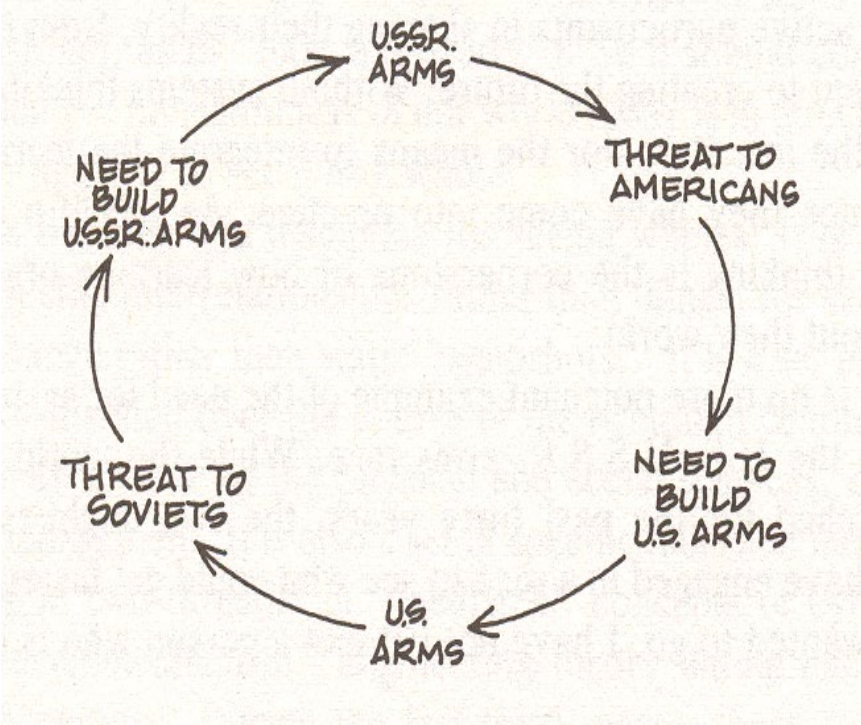
- Cause dramatic growth or collapse
- Amplifies change
- Snowballing effect
- Make something greater or less
- Accelerating growth or decline
- “Vicious cycles”, “self fulfilling prophecies”, “Virtuous cycles”

Balancing (B) or Stabilizing

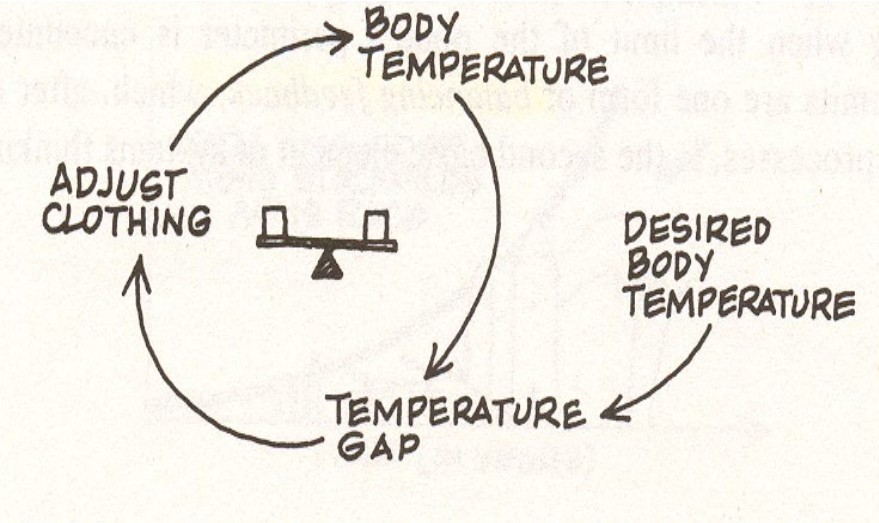
- Operates when there is a goal oriented behavior (implicit or explicit)
- Keep things under control
- Limit dramatic growth
- Ensure that systems fulfills its purpose
- Seeks equilibrium and stability
- Self correction to keep goal or target

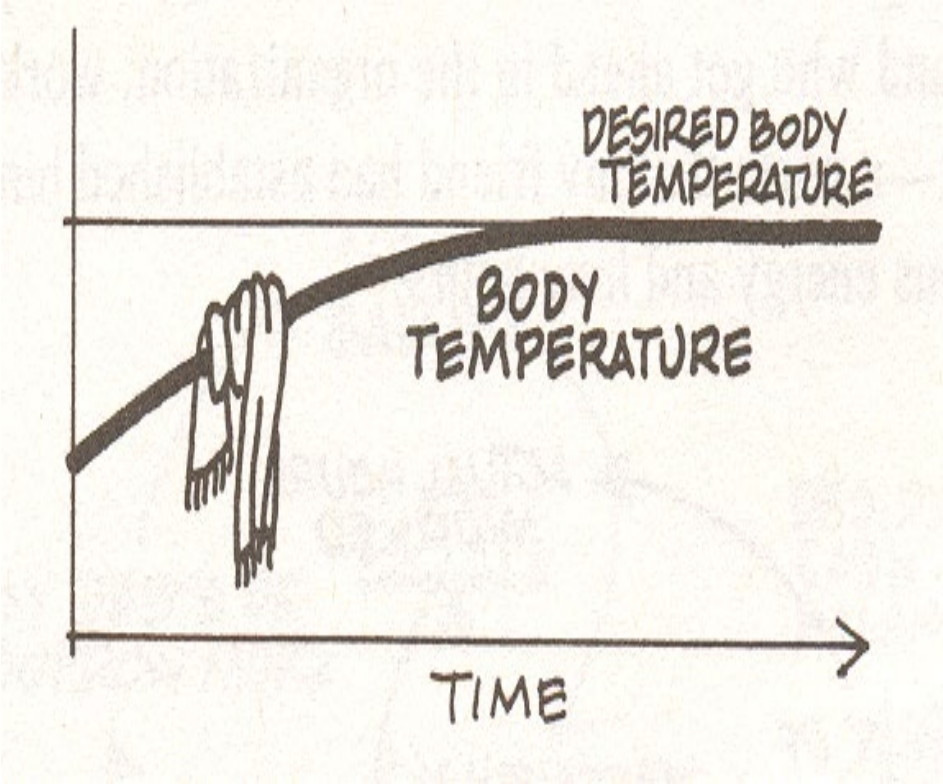
Reinforcing Feedback



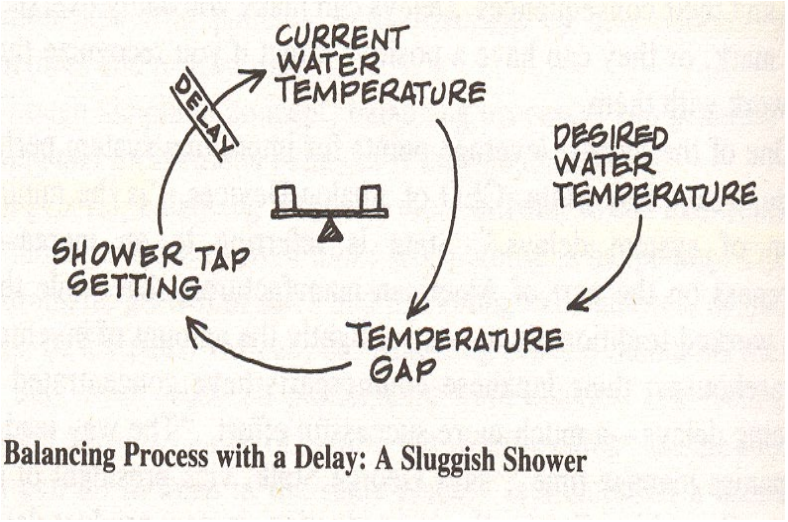


Balancing Feedback

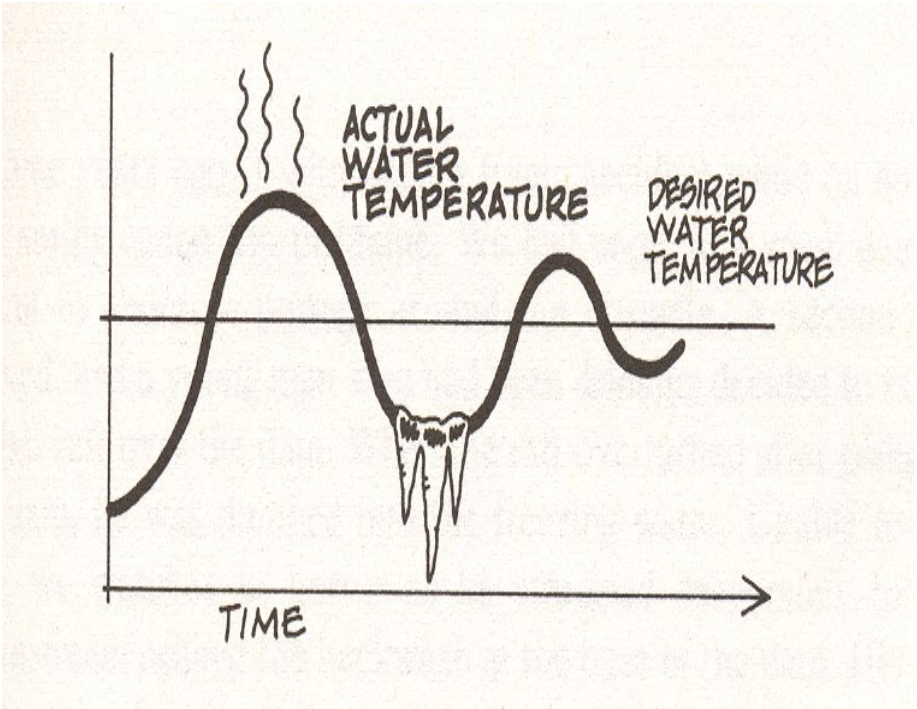




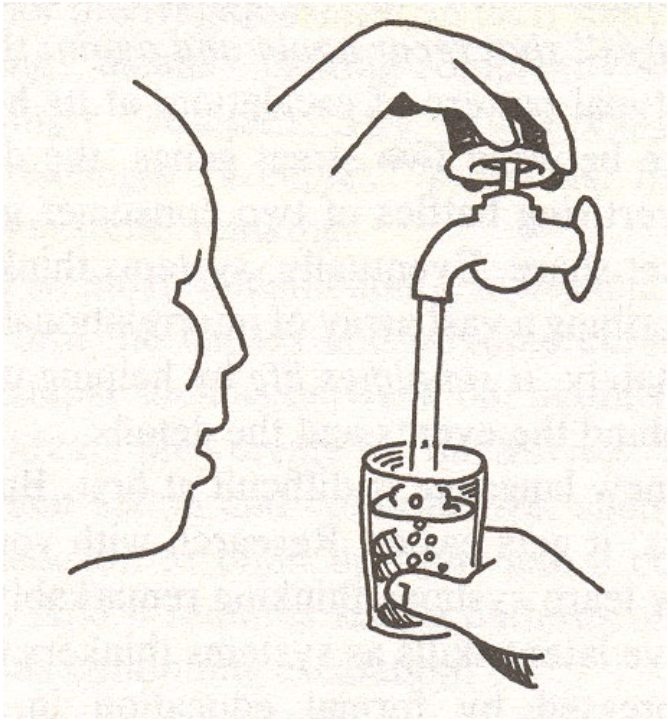
Delay = interruption between actions and their consequences

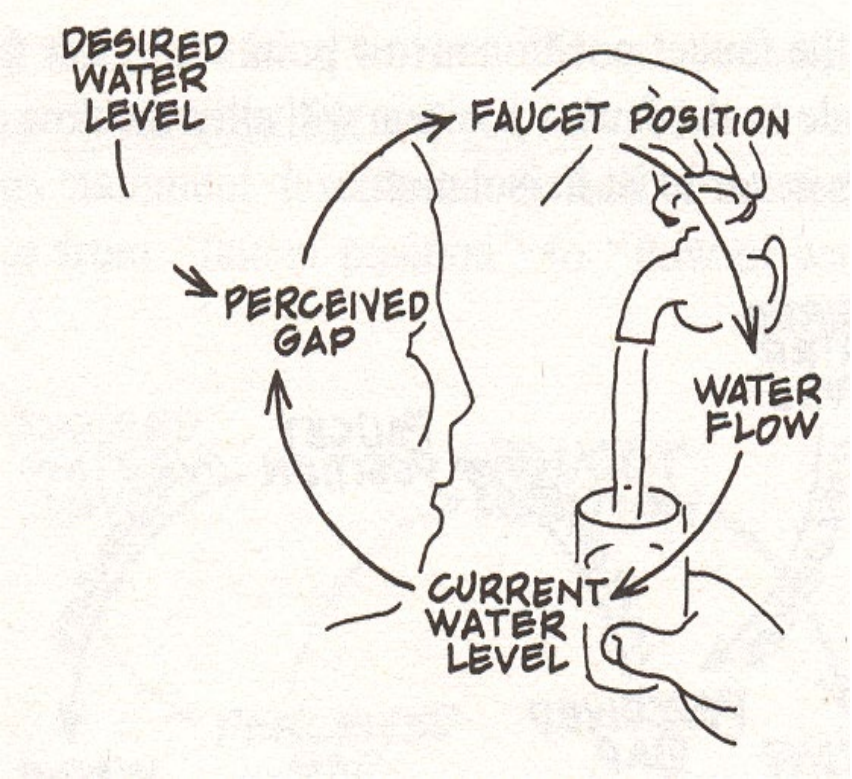


Balancing Process with a Delay: A Sluggish Shower

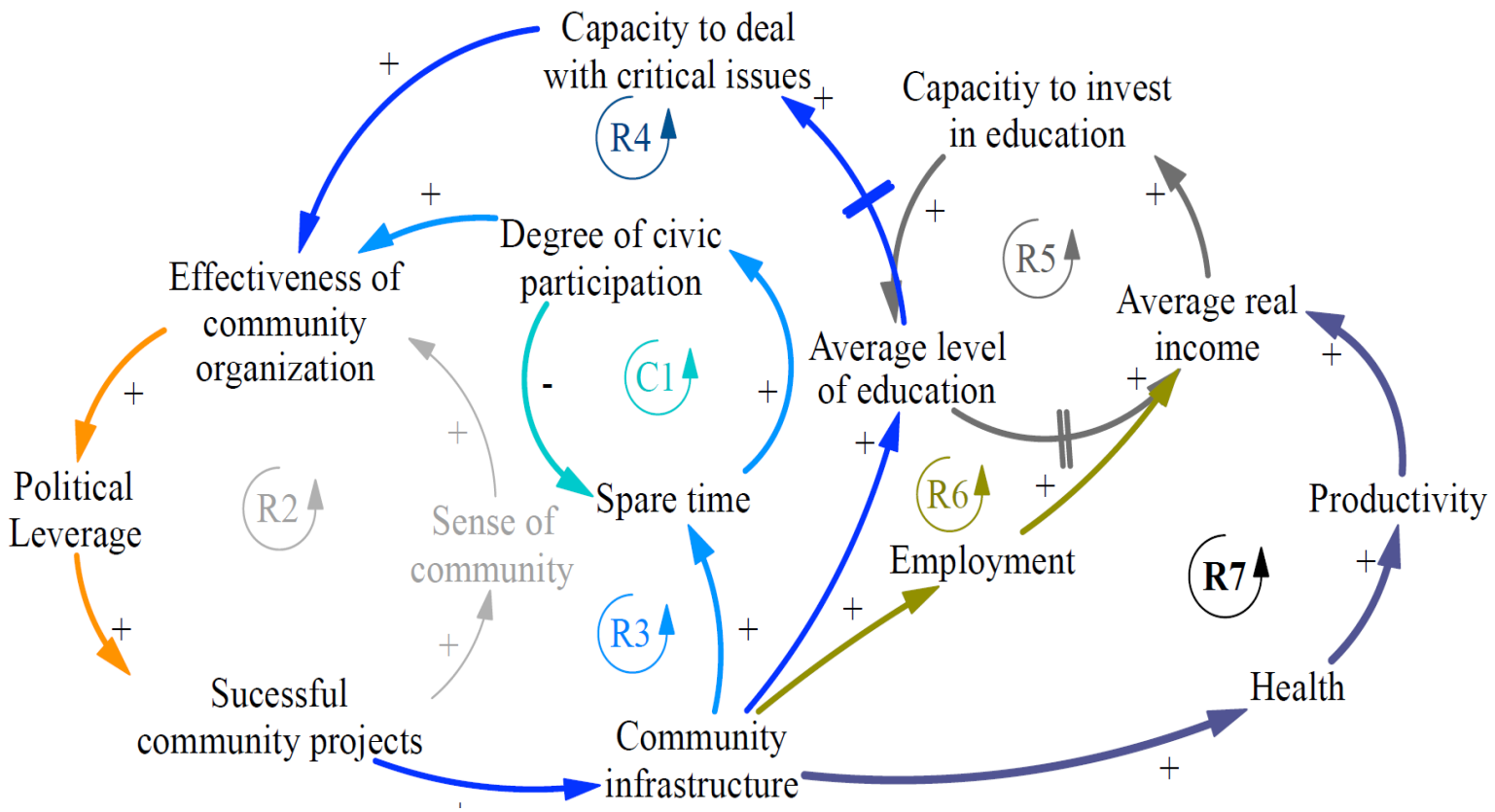


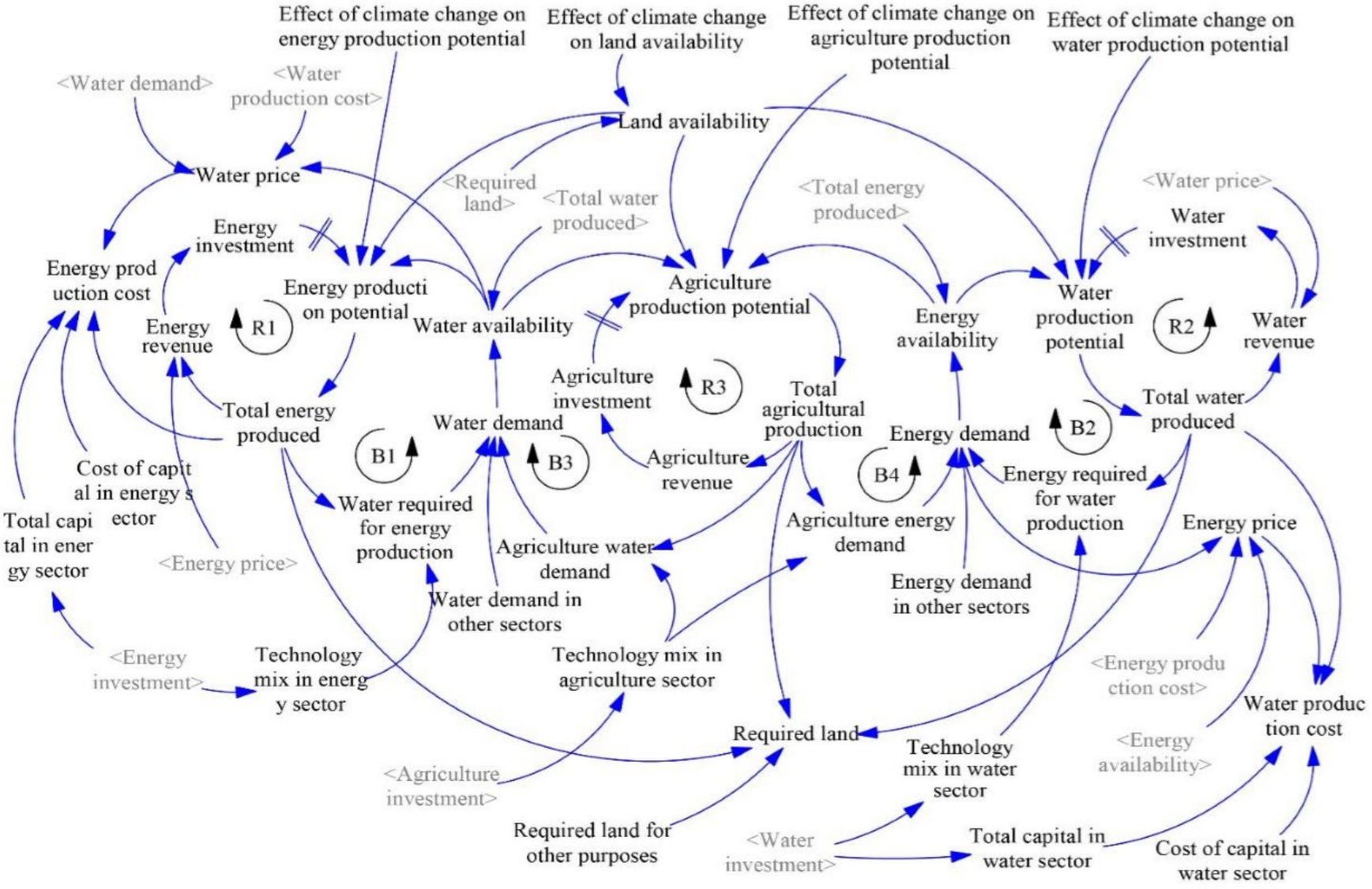
"I am filling a glass of water"

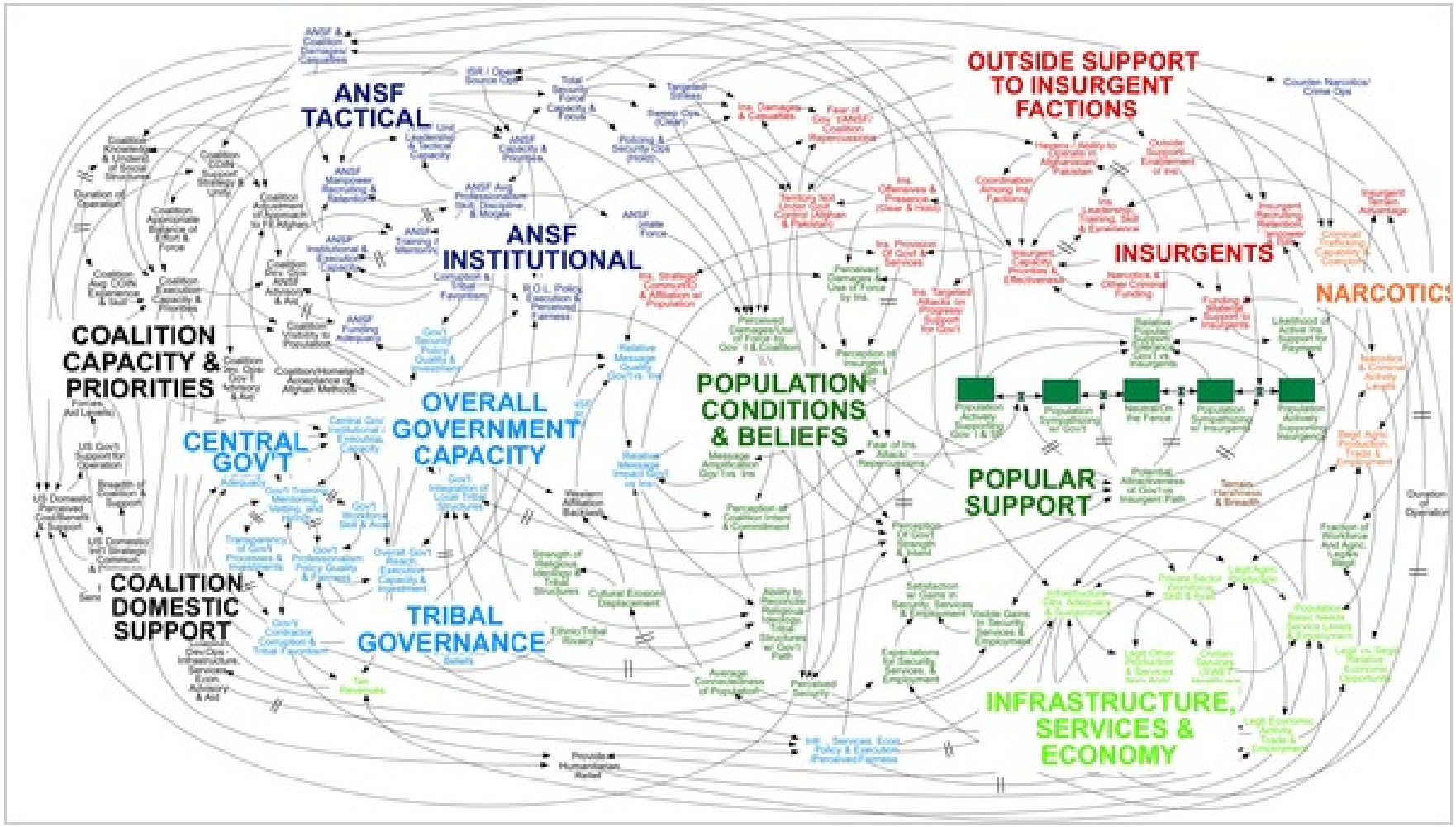




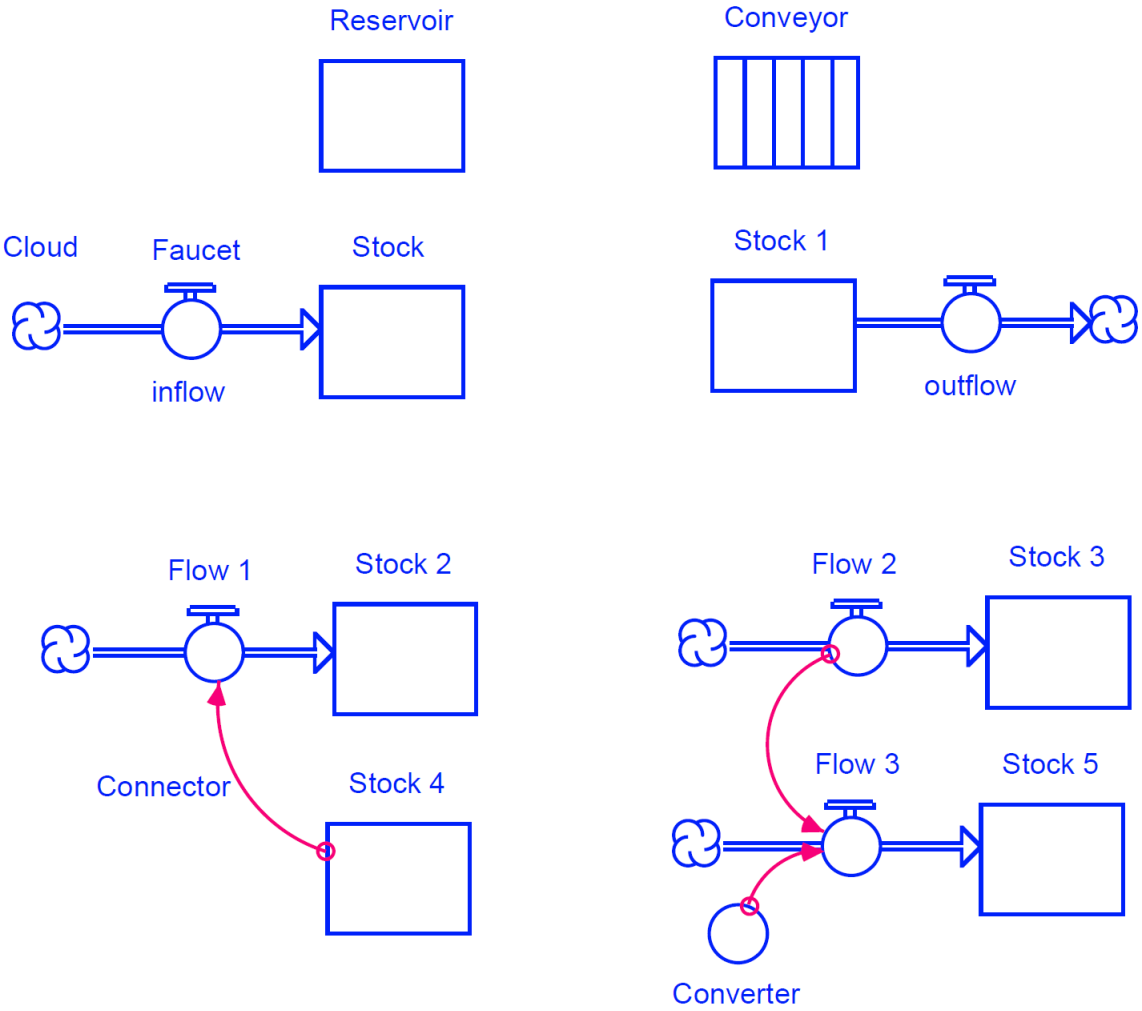
From *The 5th Discipline* by Peter Senge (1990)

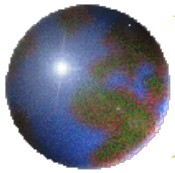

Capacity to deal with critical issues
R4
Capacitiy to invest in education
Degree of civic participation
R5
Effectiveness of community organization
Average real income
Average level of education
C1
Political Leverage
R2
Sense of community
Spare time
R6
Productivity
Employment
R7
R3
Health
Sucessful community projects
Community infrastructure


Effect of climate change on energy production potential
Effect of climate change on land availability
Effect of climate change on agriculture production potential
Effect of climate change on water production potential
<Water demand>
<Water production cost>
Land availability
Water price
<Required land>
<Total water produced>
<Total energy produced>
<Water price>
Water investment
Energy investment
Energy production cost
Energy production potential
Water availability
Agriculture production potential
Energy availability
Water production potential
Water revenue
Energy revenue
R1
R2
Agriculture investment
R3
Total agricultural production
Total water produced
Total energy produced
Water demand
Energy demand
B1
B2
B3
B4
Agriculture revenue
Cost of capital in energy sector
Energy required for water production
Water required for energy production
Agriculture energy demand
Energy price
Total capital in energy sector
<Energy price>
Agriculture water demand
Water demand in other sectors
Energy demand in other sectors
<Energy investment>
Technology mix in energy sector
Technology mix in agriculture sector
<Energy production cost>
Water production cost
Required land
<Energy availability>
Technology mix in water sector
<Agriculture investment>
Required land for other purposes
<Water investment>
Total capital in water sector
Cost of capital in water sector


ANSF TACTICAL
ANSF INSTITUTIONAL
OUTSIDE SUPPORT TO INSURGENT FACTIONS
INSURGENTS
NARCOTICS
COALITION CAPACITY & PRIORITIES
OVERALL GOVERNMENT CAPACITY
POPULATION CONDITIONS & BELIEFS
CENTRAL GOV'T
POPULAR SUPPORT
COALITION DOMESTIC SUPPORT
TRIBAL GOVERNANCE
INFRASTRUCTURE, SERVICES & ECONOMY

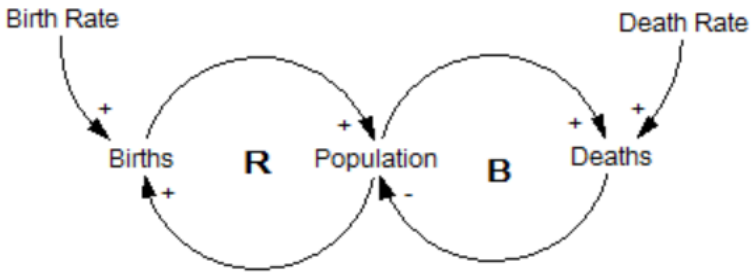
Stock and Flow Diagrams

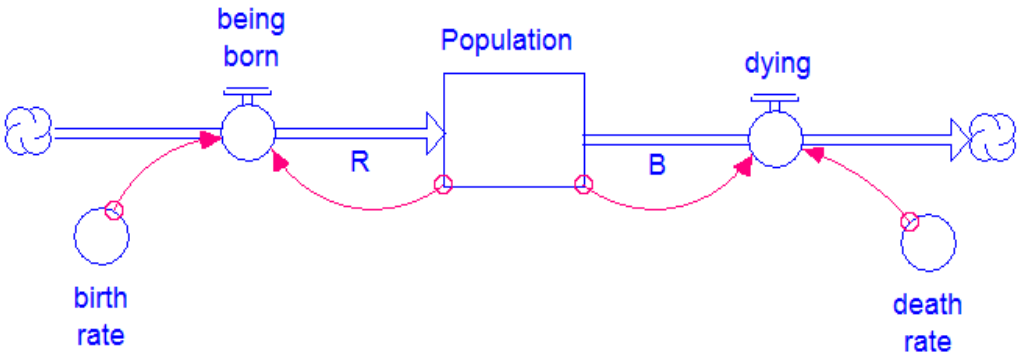


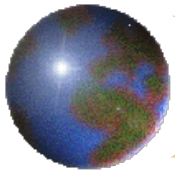


Flow and Stock

- Stock: Anything that accumulate and can be measured at one point in time (water in bathtub or behind a dam, population, wood in the forest, etc.)
- Flow: Anything that changes over time (number of births, inflation rate, etc.). Inflows and outflows
- Stock and flow obey laws of conservation and accumulation


Birth Rate
Death Rate
Births
R
Population
B
Deaths
+
+
+
+
+
-

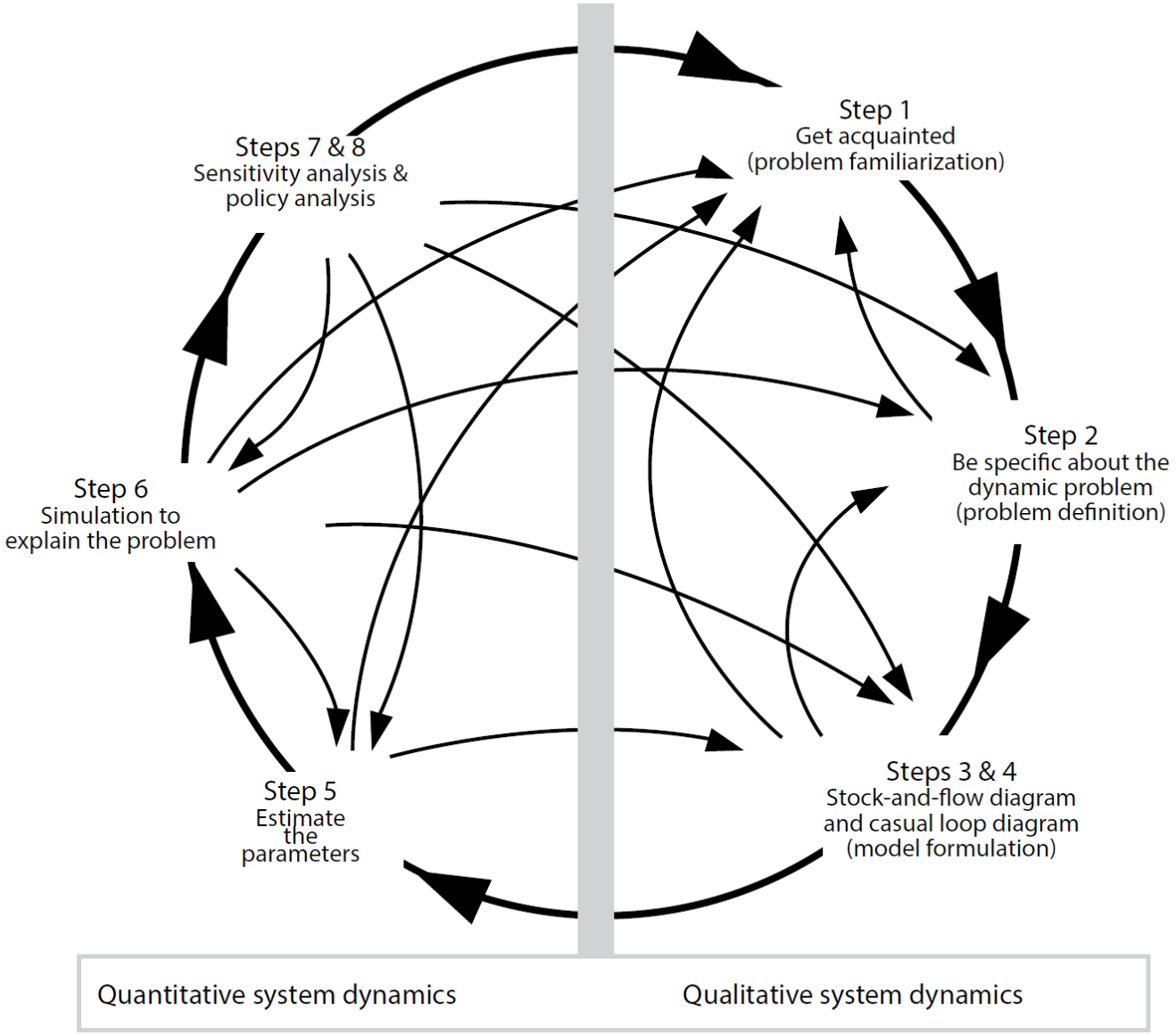

being born
Population
dying
R
B
birth rate
death rate



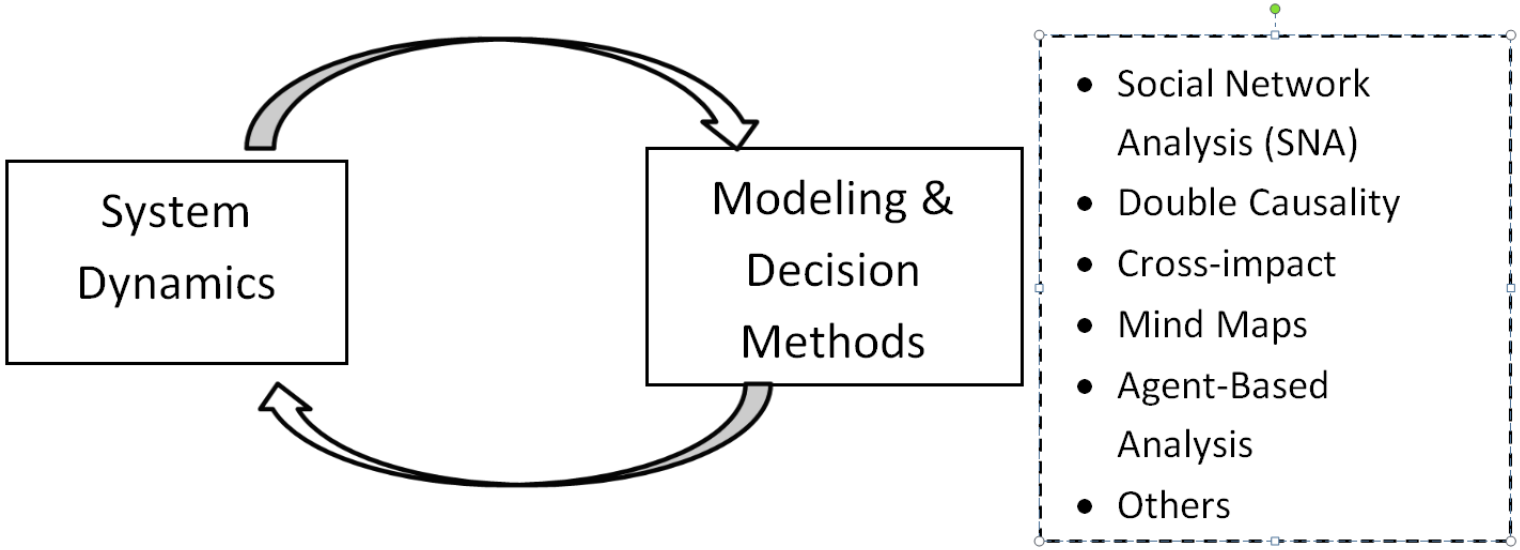
	Tangible	Intangible
Stocks	Populations (male, female) Food Energy Resources Land Houses Labor (jobs) Trees Roads, traffic, vehicles Water, Pollutants Cash Cattle Equipment	Poverty or wealth Quality of life Happiness Health Hunger Quality Anger Satisfaction Confidence Morale Motivation Attractiveness Leadership
Flow	Hiring, lay-off Saving Producing Being born, dying Constructing Depreciating Being infected Adopting Earning, spending Pumping, recharging Evaporating, infiltrating	Learning Growing Becoming aware Contributing Leading Managing Changing behavior Liking, disliking Becoming sustainable Understanding Assuming

Using Stella Pro or Architect

- Trademark of Isee systems (www.iseesystems.com)
- Introduction to Systems Thinking by Richmond (2004 a,b).
- Other SD software include Vensim and Powersim.

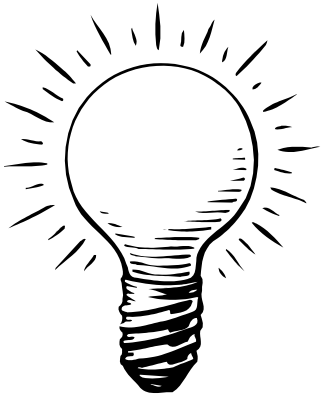

Step 1
Get acquainted
(problem familiarization)
Step 2
Be specific about the
dynamic problem
(problem definition)
Steps 3 & 4
Stock-and-flow diagram
and casual loop diagram
(model formulation)
Step 5
Estimate
the
parameters
Step 6
Simulation to
explain the problem
Steps 7 & 8
Sensitivity analysis &
policy analysis
Quantitative system dynamics
Qualitative system dynamics

Mixed Modeling Methods



"The significant problems we face today cannot be solved at the same level of thinking we were at when we created them."

Albert Einstein



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