united nations
educational, scientific
and cultural
organization

international atomic
energy agency

the
abdus salam
international centre for theoretical physics

smr.1242-1

Earth Systems Science Course in Watersheds & Coastal Zone Simulation Modeling
2 - 13 October 2000

"Global Limits to Human Niche..."

T. S. HOPKINS
North Carolina State University
MEAS
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USA

GLOBAL LIMITS TO HUMAN NICHE

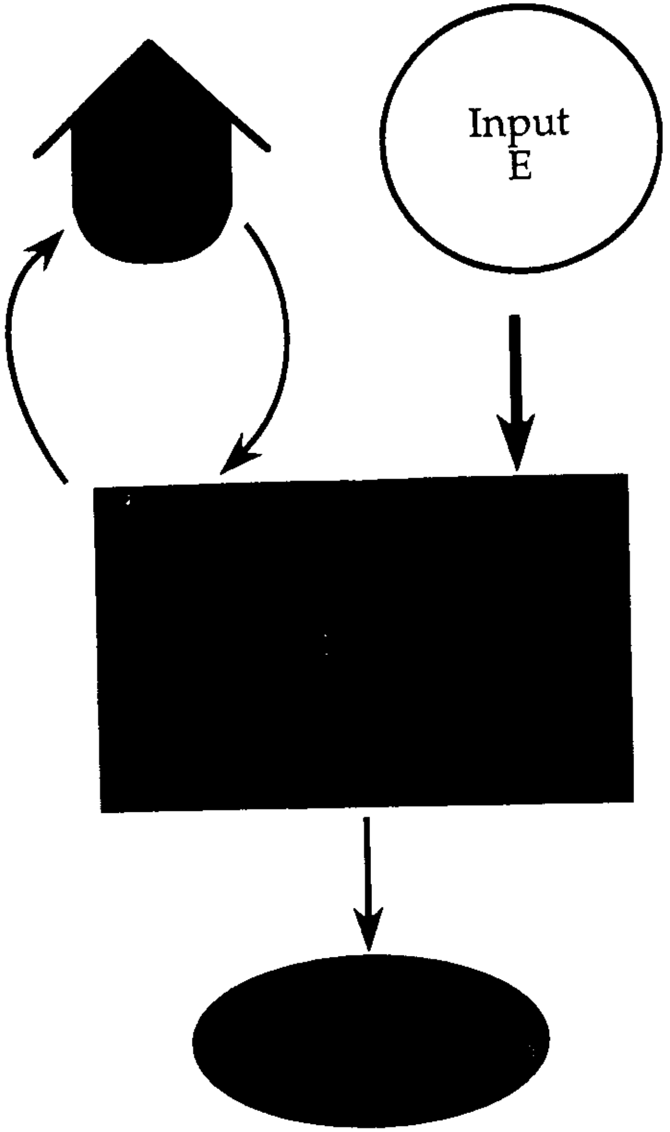
IN VIOLATION OF NATURAL LAWS

TRANSITION TO SUSTAINABLE SOCIETY

MUST ADD SOCIAL AND NATURAL CAPITAL ACCOUNTING

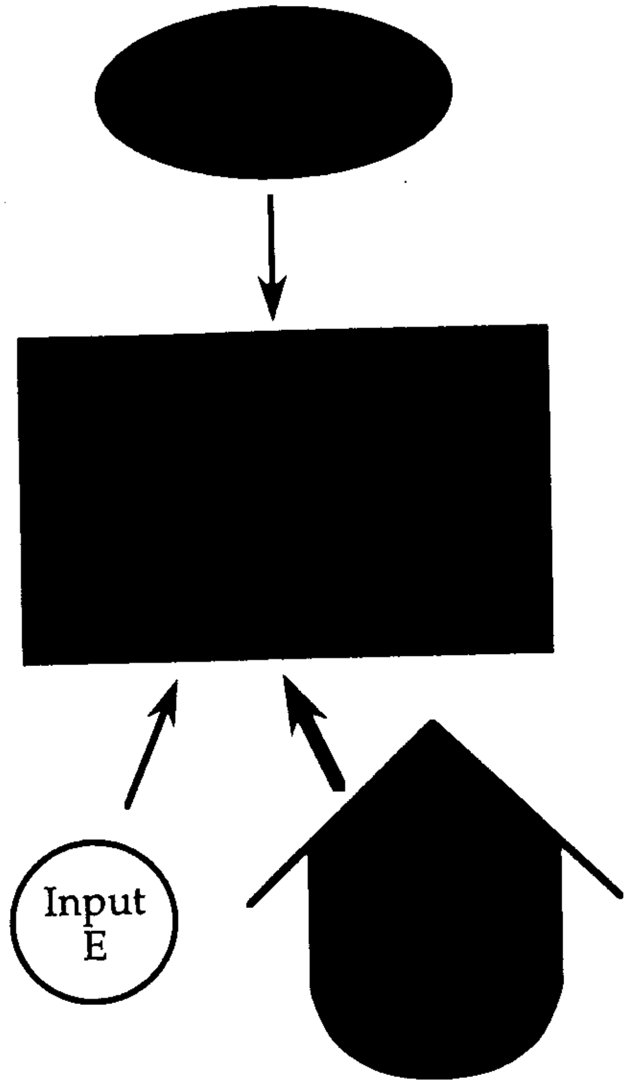
USE OF NATURAL CAPITAL ACCOUNTING REQUIRES EARTH SYSTEMS SCIENCE

HOLISTIC IN DESIGN
REDUCTIONIST IN DETAIL
NON-LINEAR
TIME DEPENDENT
CHANGES IN STATE
BEHAVIORAL
SIMULATION
INPUT: TIME AND SPACE FIELDS
OUTPUT: SOCIAL-ECONOMIC INDICATORS
& INTERACTIVE SCIENCE



Resource Based System

Population is maintained
by available energy input.



Demand Based System

Population burns up
stored energy and crashes.

ECONOMIC SYSTEM

PRIMITIVE → FRONTIER → COMMAND → CAPITALISTIC → SUSTAINABLE

MANAGEMENT STRATEGY

RESOURCE → DEMAND → RESOURCE

SCALE

LOCAL → REGIONAL → GLOBAL

Renewable Resources -

- *Three concepts difficult to accept*

That humans become vulnerable in overextending their niche

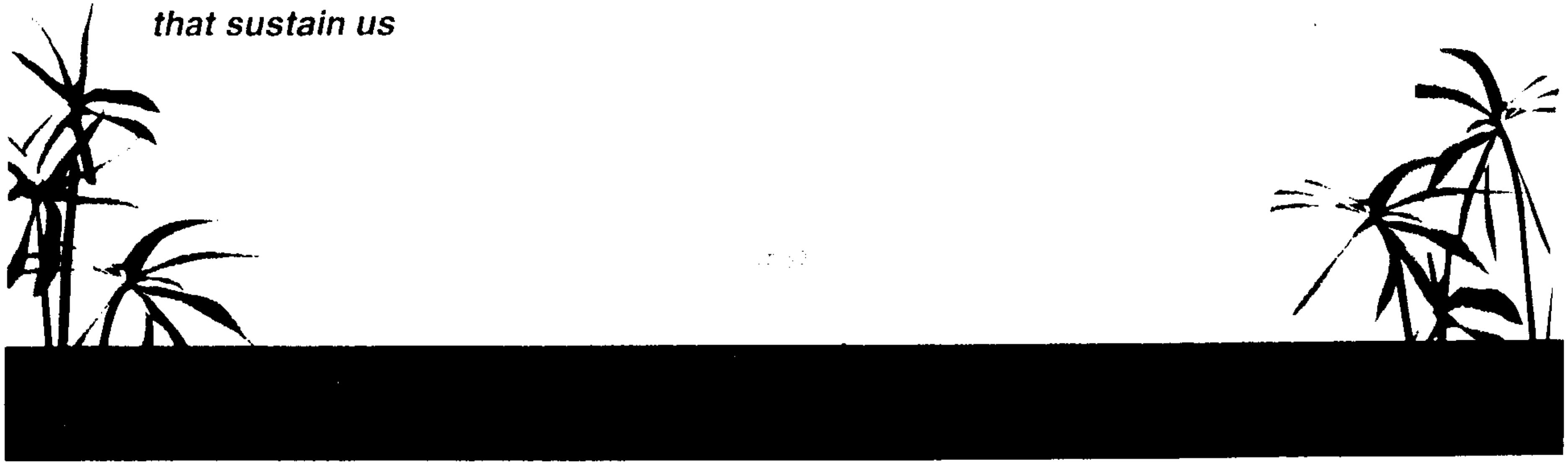
- *By utilizing stored energy to disoccupy other organisms, we must spend more energy to sustain oursleves; and in the face of increased energy costs we become susceptable to 'niche collapse'*

That destroying our bio-wealth is inadviseable

- *If our population is so large that we destroy our bio-wealth, then we have exceeded our carrying capacity by definition: we are "eating our reserves'"*

That the free market rewards our the destruction of our support system

- *We recieve short-term profit for liquidizing the natural resources that sustain us*



Constraints on Human Expansion

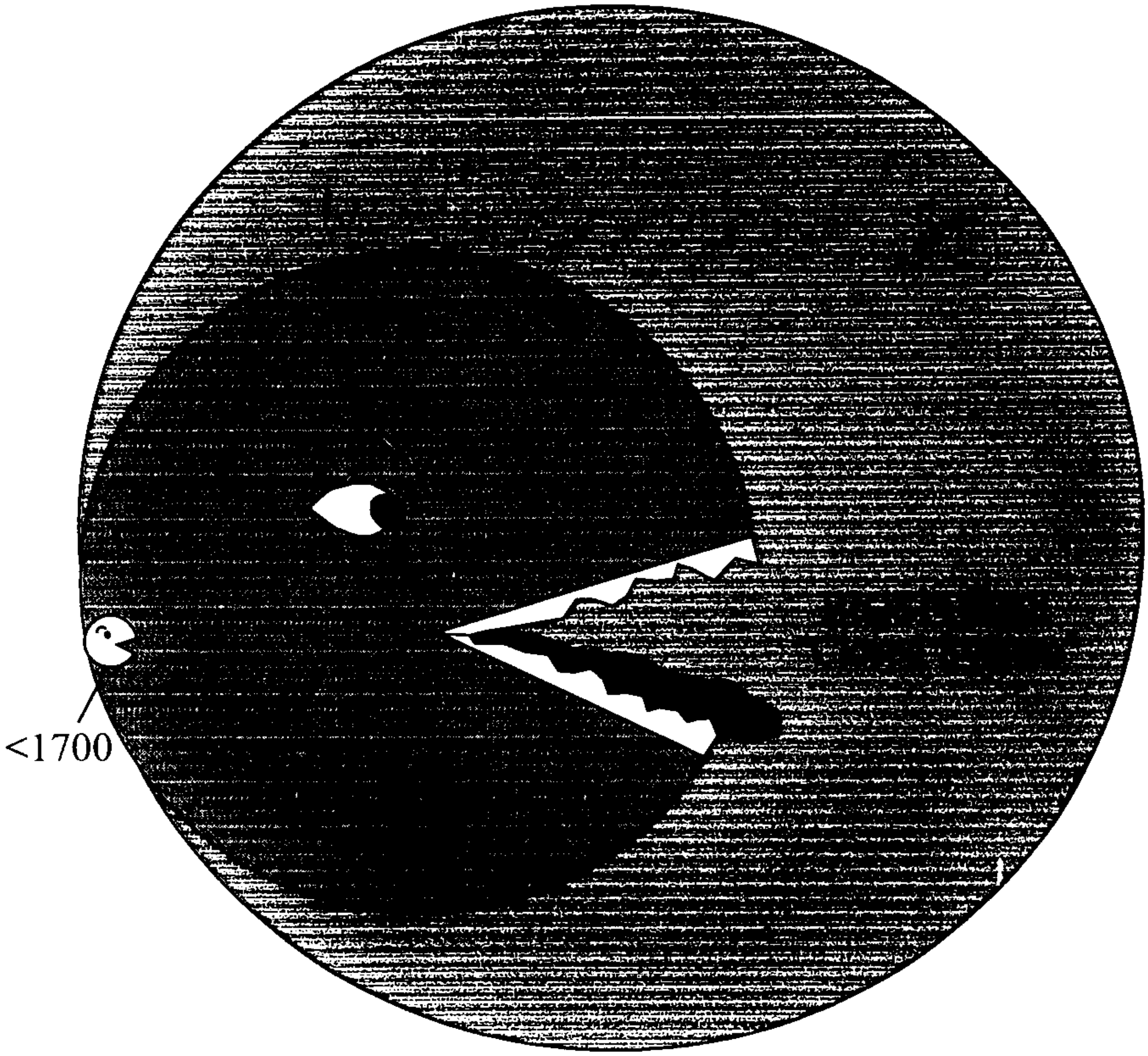
Human Survival is impossible without sustainable use of Natural Systems, because:

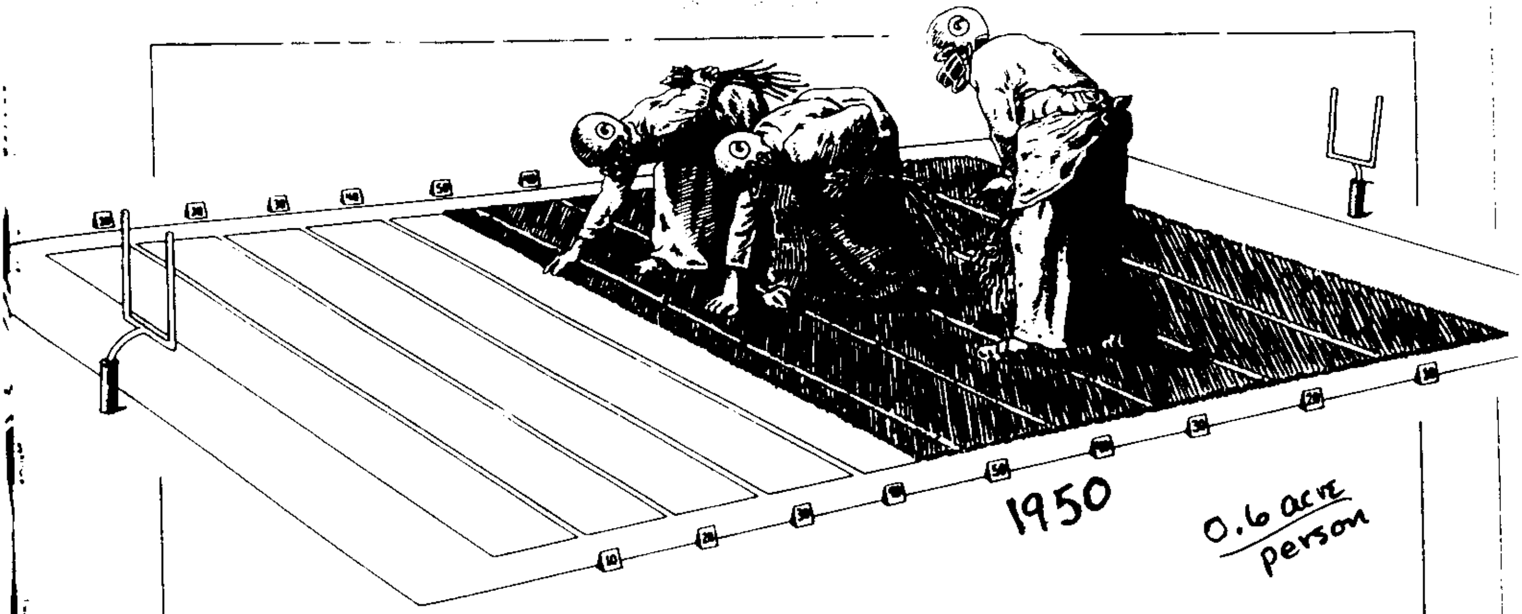
Exponential growth in a closed system is not sustainable - ***Conservation of mass***

Energy inefficient systems do not survive
- ***Maximum Power Law***

Political/Economic Systems can not mange Natural Systems without the methodology of Science

Anthropogenic Sequestration of Terrestrial Net Primary Production





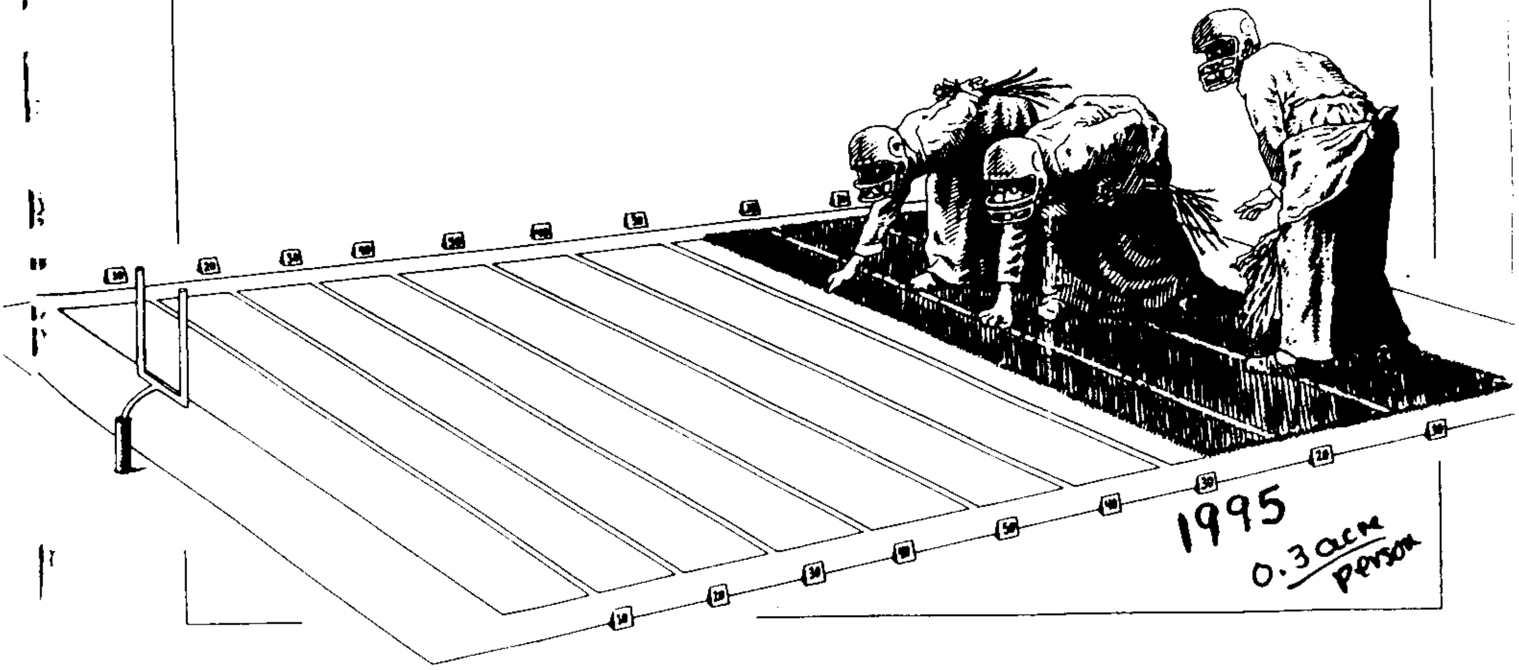
1950

0.6 acre
person

IF LIFE WERE FOOTBALL...

In 1950, the amount of grainland in the world per person was .23 hectare (.57 acre)—the equivalent of just over half of an American football field. Since then, the area per person has declined by almost half, to .12 hectare—equivalent to being pushed from the 52-yard-line back to the 27-yard line. In defending the global food supply, we're not far from having our backs to the goal-line.

.06 by 2020
.15 acre



1995

0.3 acre
person

ILLUSTRATION BY RJ MATSON

Post WWII Changes

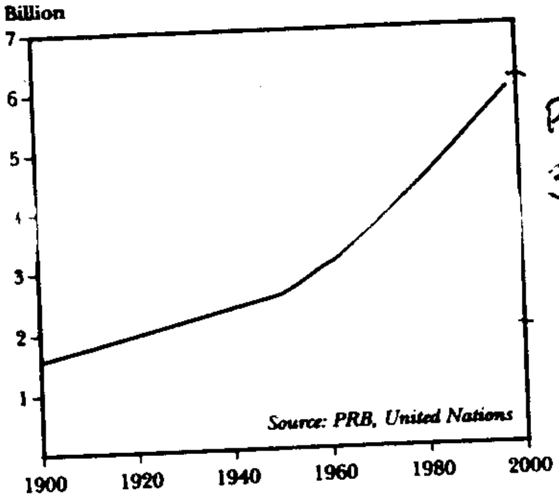


Figure 1–1. World Population, 1900–98

Population
3 times

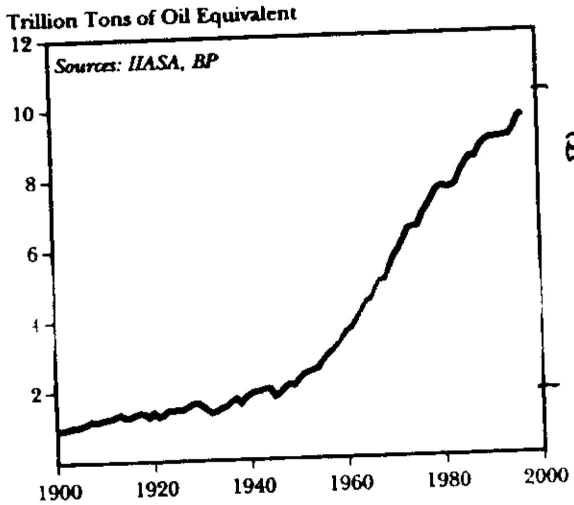


Figure 2–5. World Energy Consumption, 1900–97

Energy
5 times

Lumber	3 times
Paper	6 times
Fish	5 times
Grain	3 times
Fossil fuel	5 times
Economic Output	6 times
Fertilizer	9 times
Irrigated area	5 times
Air.Water Pollution	7 times
Water	3 times

Table 1-3. Human-Induced Land Degradation Worldwide, 1945 to Present

Region	Over-grazing	Deforestation	Agricultural Mismanagement	Other[1]	Total	Degraded Area as Share of Total Vegetated Land
	(million hectares)					(percent)
Asia	197	298	204	47	746	20
Africa	243	67	121	63	494	22
South America	68	100	64	12	244	14
Europe	50	84	64	22	220	23
North & Cent. Amer.	38	18	91	11	158	8
Oceania	83	12	8	0	103	13
World	679	579	552	155	1,965	17

[1] Includes exploitation of vegetation for domestic use (133 million hectares) and bioindustrial activities, such as pollution (22 million hectares).

SOURCE: Worldwatch Institute, based on "The Extent of Human-Induced Soil Degradation," Annex 5 in L.R. Oldeman et al., *World Map of the Status of Human-Induced Soil Degradation* (Wageningen, Netherlands: United Nations Environment Programme and International Soil Reference and Information Centre, 1991).

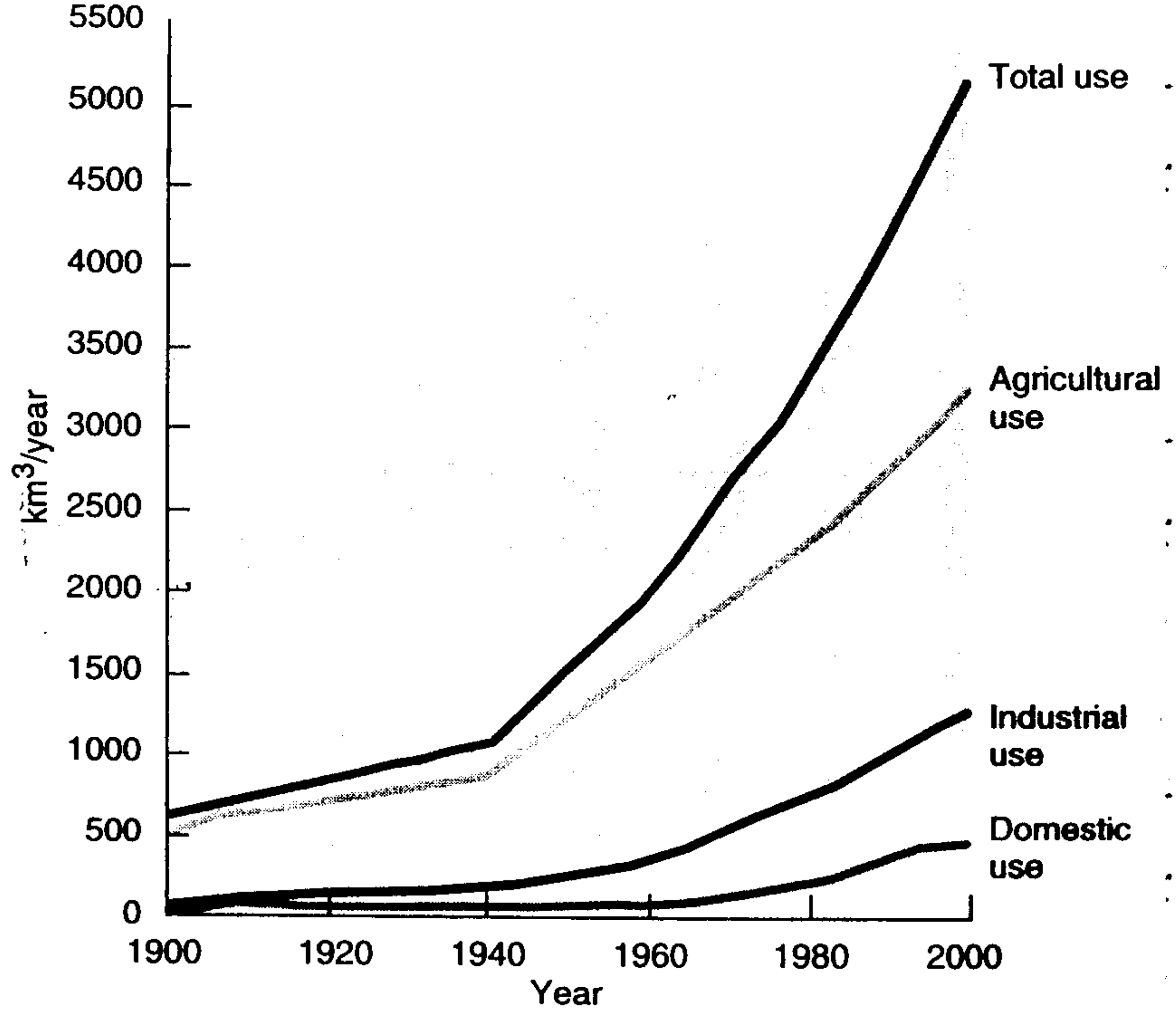
Table 1-4. Population Size and Availability of Renewable Resources, Circa 1990, With Projections for 2010

	Circa 1990	2010	Total Change	Per Capita Change
	(million)		(percent)	
Population	5,290	7,030	+33	–
Fish Catch (tons)[1]	85	102	+20	−10
Irrigated Land (hectares)	237	277	+17	−12
Cropland (hectares)	1,444	1,516	+5	−21
Rangeland and Pasture (hectares)	3,402	3,540	+4	−22
Forests (hectares)[2]	3,413	3,165	−7	−30

[1] Wild catch from fresh and marine waters; excludes aquaculture. [2] Includes plantations; excludes woodlands and shrublands.

SOURCES: Population figures from U.S. Bureau of the Census, Department of Commerce, *International Data Base*, unpublished printout, November 2, 1993; 1990 irrigated land, cropland, and rangeland from U.N. Food and Agriculture Organization (FAO), *Production Yearbook 1991* (Rome: 1992); fish catch from M. Perotti, chief, Statistics Branch, Fisheries Department, FAO, Rome, private communication, November 3, 1993; forests from FAO, *Forest Resources Assessment 1990* (Rome: 1992 and 1993) and other sources documented in endnote 30. For explanation of projections, see text.

Population 1.7 %
Water use 3.3 %



109 Growth of Global Water Use
Figure 19.7

Source: Data from L. A. Shiklomanov, "Global Water Resources" in *Nature and Resources*, vol. 26, pp. 34–43, UNESCO, Paris.

INDICATORS OF WATER STRESS

RESOURCE:

Water Tables ⇓
Availability of Surface Water ⇓
Rivers Drying up ⇑
Wetlands Disappearing ⇑
Number of Water-Scarce Nations ⇑
Rate of Desertification ⇑
Rate of Salinization ⇑
Pollution ⇑

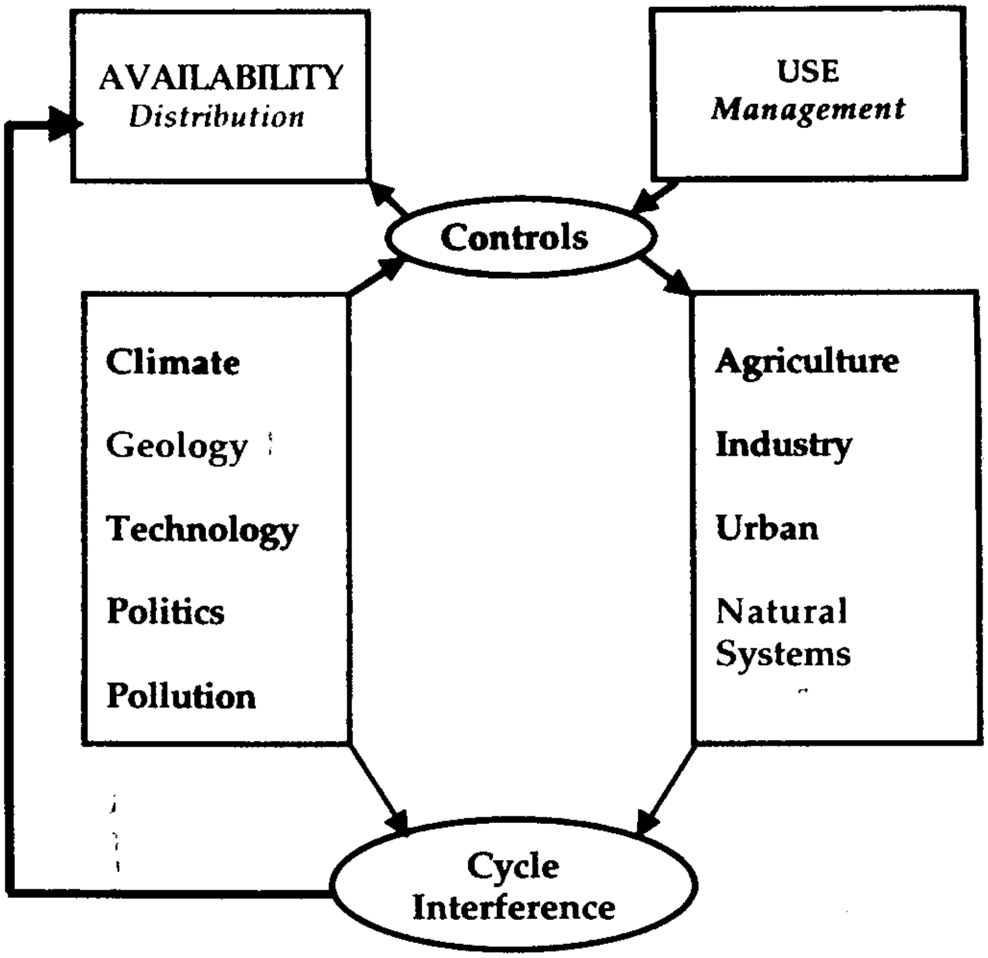
HEALTH:

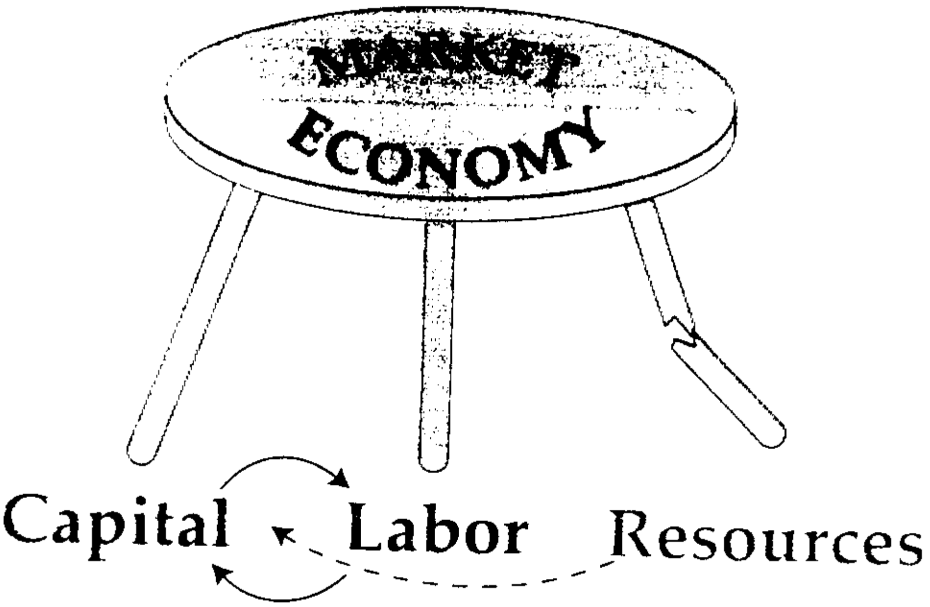
Children Dying for lack of Safe Water ⇑
Water-borne Infectious Diseases ⇑
Cost of Drinking Water Treatment ⇑
Cost and Consumption of Bottled Water ⇑
Need for better Waste Water Treatment ⇑
"No Swimming" Signs ⇑

NATURE:

Frequency of Floods & Droughts ⇑
Fresh-Water Species Extinctions ⇑
Delta and Coastal Subsidence ⇑
Erosion Sediment in Rivers ⇑
Eutrophication in Lakes and Estuaries ⇑
Aquatic Food-Webs Changes more Serious ⇑

WATER BREEDS CONFLICTS



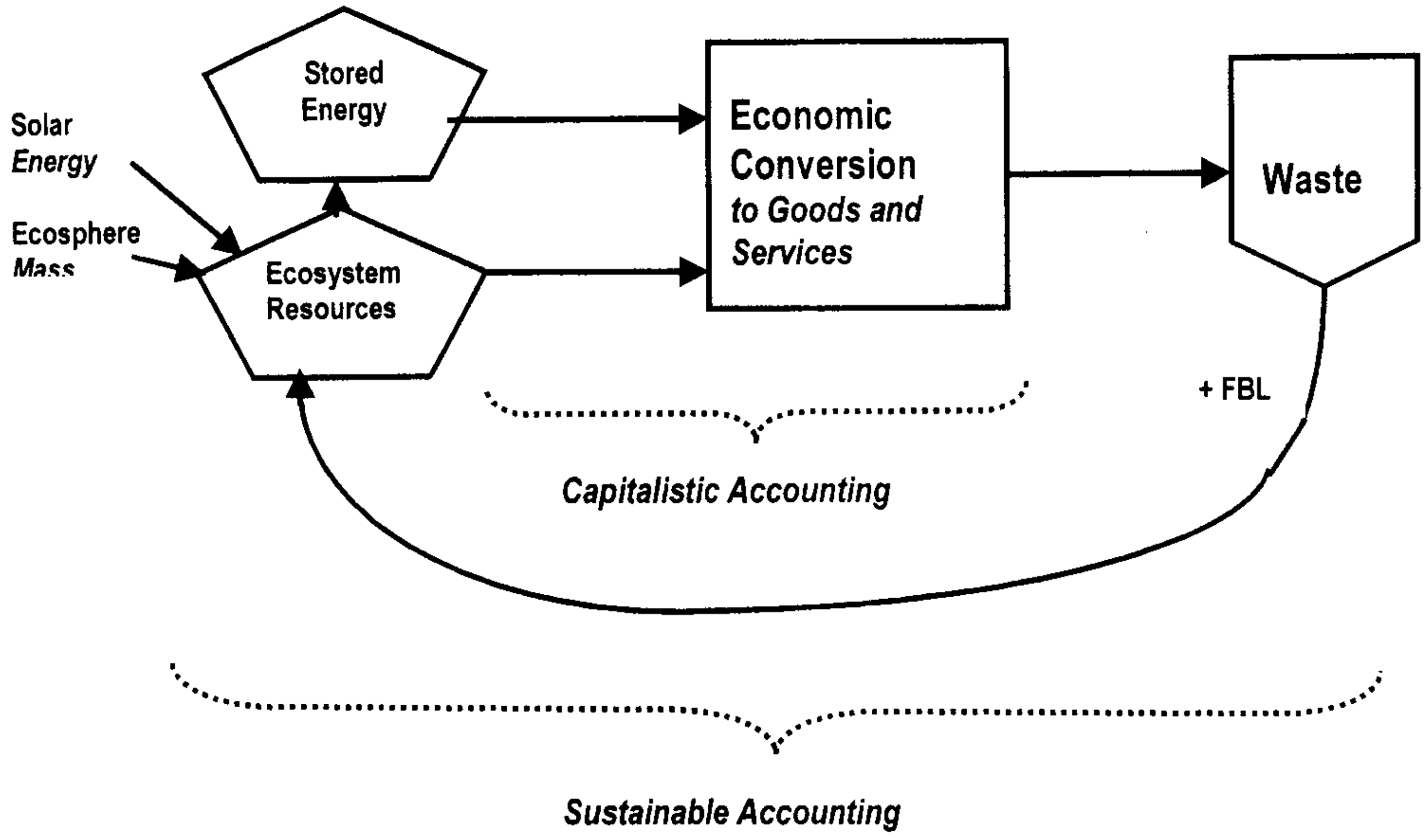


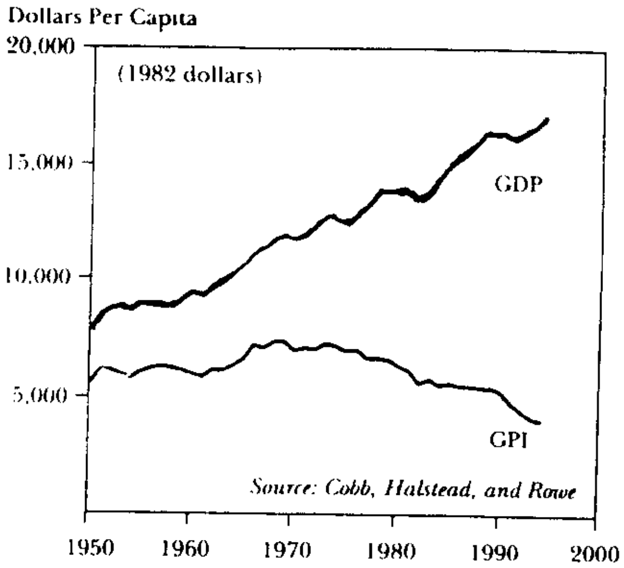
Interplay between capital and labor in converting resources to goods and services. Leads to privatized profit and resource degradation.

Costs of degradation, depletion and pollution of resources not included. Leads to communized costs in the form of clean-up, restoration and irreversible loss.

Consequence: Increasing instability of the economy as the resource base erodes and the decreasing probability of global economic prosperity.

Solution: Evaluation of costs of resource degradation and their proper insertion into the economic feedback loop in order that our resource base be sustained rather than exploited at the expense of future generations.


Solar Energy
Ecosphere Mass
Stored Energy
Ecosystem Resources
Economic Conversion to Goods and Services
Waste
+ FBL
Capitalistic Accounting
Sustainable Accounting



Source: Cobb, Halstead, and Rowe

Figure 6–1. Gross Domestic Product Versus Genuine Progress Indicator, United States, 1950–94

SOW '97

Gross Domestic Product (GDP)

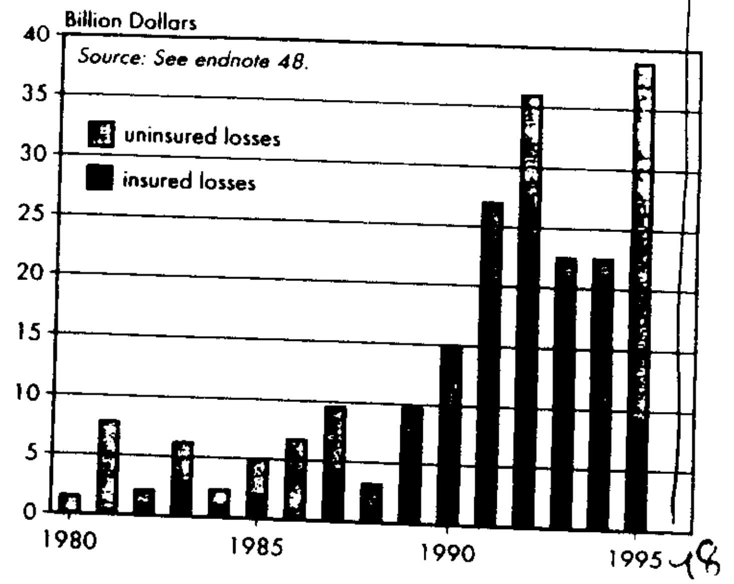
"The GDP makes no distinction between economic transactions that add to the well-being and those which diminish it.... As a result, the GDP masks the breakdown of social structure and natural habitat: and worse, it portrays this breakdown as economic gain."

Genuine Progress Indicator (GPI).

"The GPI counts the positive contributions of household and community work and subtracts for the depletion of natural habitat, pollution costs, income distribution, and crime."

[State of the World, 1997]

Economic Losses from Weather-related Natural Disasters Worldwide, 1980–95



Weather-related Disasters with Damages over Three Billion Dollars, 1990-1995

Disaster	Location	Year	Deaths	Estimated Damages (billion dollars)
Windstorm Daria	Europe	1990	-	4.6
Windstorm Vivian	Europe	1990	-	3.2
Cyclone	Bangladesh	1991	140,000	3.0
Flood	China	1991	3,074	15.0
Typhoon Mireille	Japan	1991	62	6.0
Hurricane Andrew	N. America	1992	74	30.0
Cyclone Iniki	N. America	1992	4	3.0
Winter storm	N. America	1993	246	5.0
Mississippi floods	N. America	1993	41	12.0
Winter storms	N. America	1994	170	4.0
Spring floods	China	1994	1,846	7.8
Flood	Italy	1994	64	9.3
Winter floods	Europe	1995	28	3.5
Flood	China	1995	1,390	6.7
Storm, flood	N. Korea	1995	68	15.0
Hurricane Opal	N. America	1995	28	3.0

WORLD INDUSTRIAL SYSTEM IN TRANSITION

will involve transition:

GROWTH ECONOMY ⇒	SUSTAINABLE ECONOMY
Degrades Resources	Sustains Resources
Ignores Waste	Recycles Waste
Destroys Biodiversity	Protects Biodiversity

why: GROWTH ECONOMY IS UNSTABLE

1. Violates two Fundamental Natural Laws

Maximum Power Law **through Inefficient Use of Energy**

Conservation of Mass **because it operates as an Open System**

2. Causes unsustainable waste stream: Resource →Production →Waste

3, Results in 'irreversible' reduction in Earth's Carrying Capacity

4. Does not distribute wealth.

5. Does not reward social benefit

how: INSERT into the ECONOMIC FEEDBACK LOOP

1. Natural Capital Accounting

2. Social & Existential Values

role of science:

more	*less*
Systems Evaluation	**Impact Descriptions, "End of Pipe"**
Coupling with Social Sector	**Information Burial in the Library**

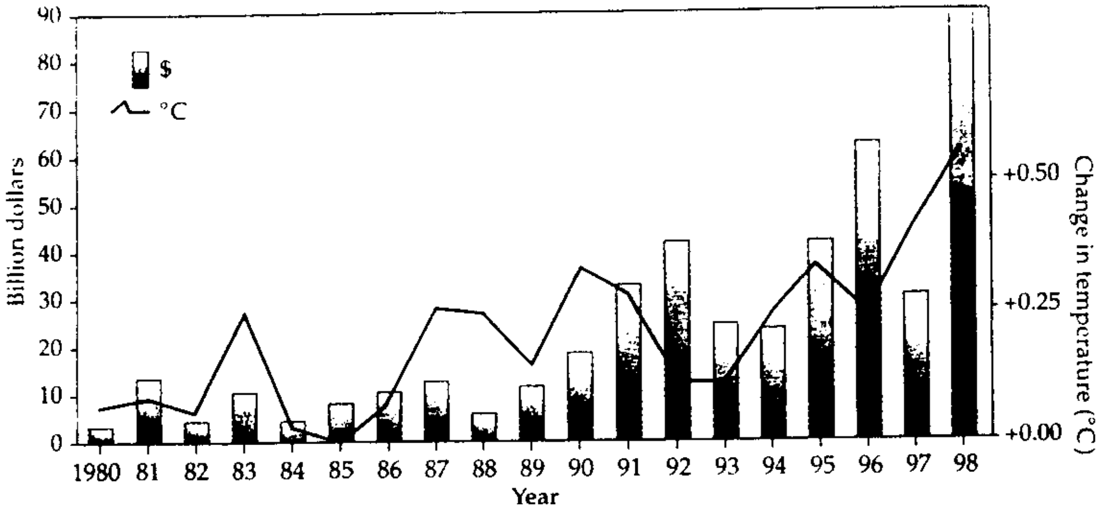


Figure 27.9 **Costs of natural disasters and global temperature change 1980–1998.** Disaster costs include infrastructure and crop losses, but do not include health costs, damage to natural resources, or long-term environmental damage. Global temperature change is expressed as deviations from the 1950–1980 mean temperature. (Data are from the Worldwatch Institute and the National Oceanic and Atmospheric Administration.)

Management Errors:

I Rejecting a true hypothesis - Global Warming

II Accepting a false hypothesis - Titanic

for which the cost/risk of being wrong >>> being right

Reasons for such behavior

I Invested interest

II Ignorance or denial of consequences

III Ignorance of alternative

If we choose to believe that all natural systems are renewable or restorable -> we have invested in a false hypothesis -

Prudence would have us monitor the entropic costs as we degrade a system - so as not to pass the point of no return -

Systems thinking would not condone isolating certain problems or components nor applying patchwork management solutions to component problems

studying only eutrophication
or
reducing only phosphorus discharges

ERRORS IN DECISION MAKING

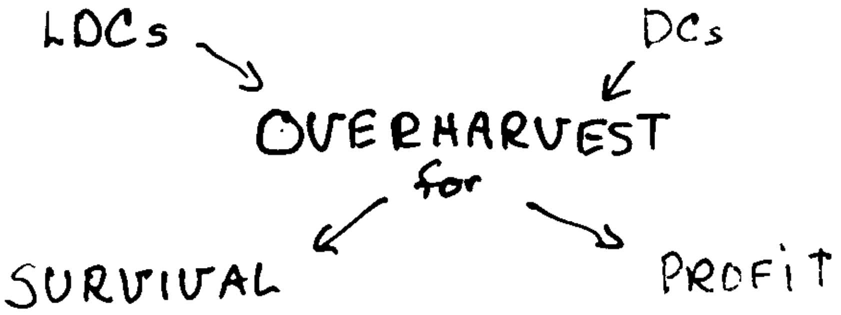
Type I:You reject a true hypothesis - *e.g. I'm not going to believe in Global Climate Change.*

Type II: You accept a false hypothesis - *e.g. The Titanic can't sink, Full speed ahead!*

Risk Assessment: One must multiply the probability of being wrong on these decisions with the cost involved in being wrong - *e.g. would you board an airplane that a pilot refused to fly?*

DEGRADATION CYCLES

Developing	Developed
more people	energy, mass subsidies
need more production	more agriculture potential
more deforestation	more potential market
more erosion	more marginal lands farmed
less grazing land	more intensive agriculture
less organics recycled	less ownership, more sell out
more soil degradation	more degradation
need more money/effort	more land – use conversion
less production	less production
production:person declines	production:person declines



POLICIES FOR SUSTAINABLE WATER USE

- Price Correctly for Auto-Regulation of Use
- Remove Subsidies (Agriculture & Industry)
- Stop Damming and begin Removing Dams
- Set a Depletion Tax on Aquifers
- Promote Efficient Irrigation Techniques
- Plan Correct Crops for Area
- Control Overuse of Fertilizers and Pesticides
- Improve Waste Treatment - Go Natural
- Separate Domestic & Industry Waste Streams
- Allow Urban Recharge Zones
- Build Urban Runoff Containment Ponds
- Stop Hazardous Waste Disposal
- Develop Recycle/Reuse Strategies for Industry
- Banned Toxic Substances – not in my drain
- Decrease Mining Wastes
- Protect Instream Ecosystems & Wiggly Life
- Protect Watersheds (Soil, Vegetation, & Wildlife)
- Conserve Water Use – don't water the street
- Sympathize with the Hydrocycle

DRINK H_2O

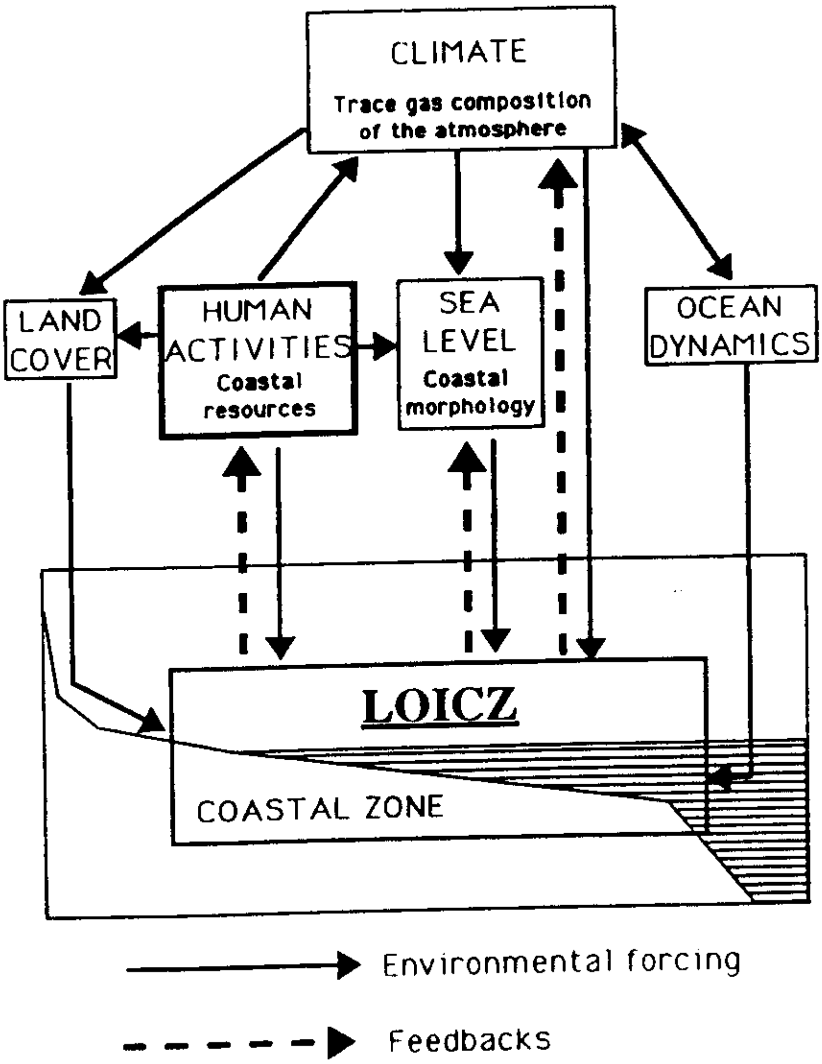


Fig. 6 Main effects of global change on the coastal zone, and of changes in the coastal zone on the global environment

SIMULATION of WATERSHEDS and COASTAL ZONES

NEED: TOOLS FOR ASSESSMENT OF 'NATURAL CAPITAL'

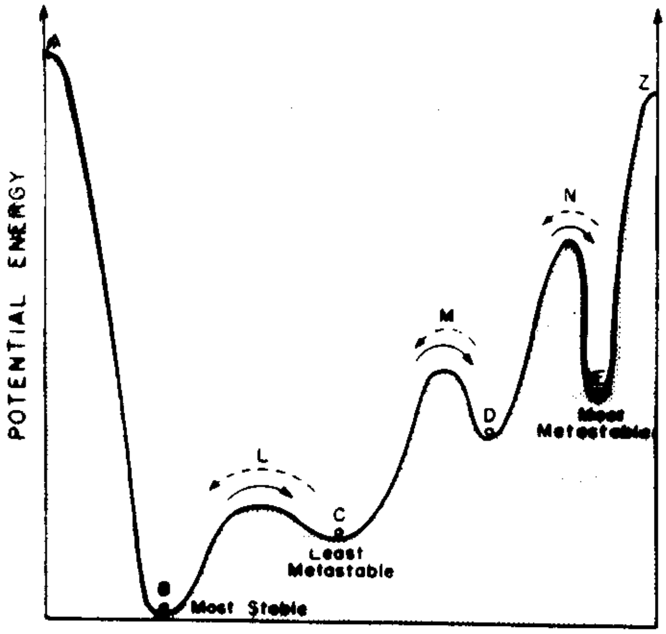
- **Evaluation of Costs of Land-Use Practices**
  riverine development, agriculture, buffer zones, point sources, etc.
- **System Resilience to Trends & Episodic Forcing Events**
  climate, sea level, land-use, nutrient & carbon loading, anoxia, etc. &
  storms, over-harvesting, habitat destruction, opportunistic invasions, etc.
- **Probability of Irreversible Degradation**
  groundwater contamination, water quality, system stability, fisheries, etc.
- **Options for Restoration of System Function**
  threshold conditions for stable, productive state

APPROACH: EARTH SYSTEMS SCIENCE

- **Holistic in Overview & Reductionist in Detail**
- **Multidisciplinary Teamwork & Transferable in Scope**
- **Links Forcing with Response through Process Space**
  by tracing the mass, energy and information flux through the system
- **Quantifies the System into a time-dependent Process Model**
  using non-linear Simulation Software)
- **Accounts for Spatial Variability**
  by using Virtual Components and coupling with gridded models
- **Optimizes Data Input Schemes**
  validation at selected 'choke points' and simulations with real-time data

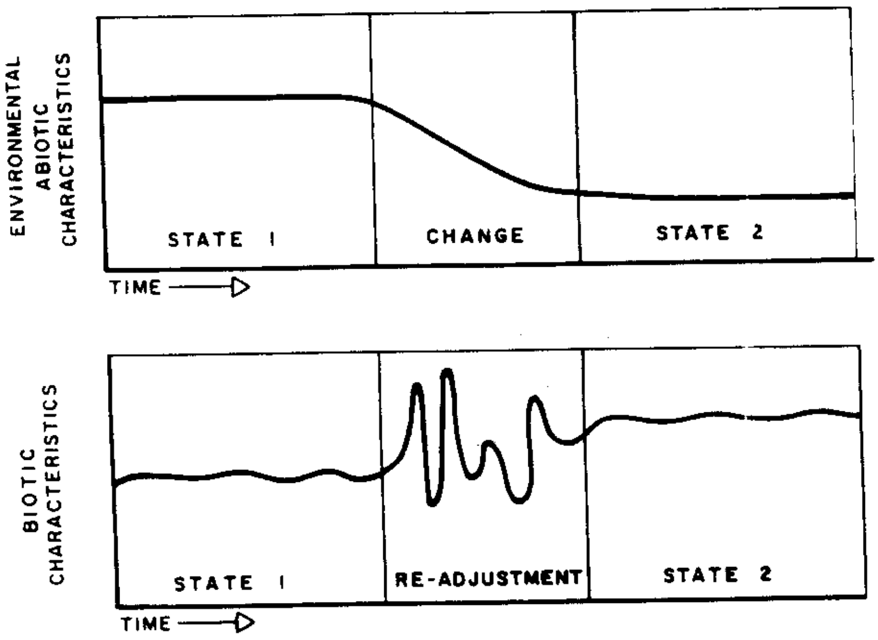
RESULTS: SIMULATION MODEL OF WATERSHED/COASTAL ZONE

- **Allows quantitative answers to Simulated Management Scenarios**
- **Couples of Scientific Output to Economic Indicators**
- **Provides Cost-optimization Resource Use & Planning**
- **Generates a framework for Monitoring, Process Studies & Modelling**



SCGP Fig. 3.37 [Mooney + Godron 1983]

Fig. 2. Stability states in terms of potential energy. Point *B* it the most stable. Points *C*, *D*, and *E* are metastable. Points *A*, *L*, *M*, *N*, and *Z* are unstable. The transitions from *B* to *C*, and to *E* are difficult, but increase the degree of metastability (such a progression corresponds to a series of successional stages which begins with the most stable state, moves rapidly to the least stable state, and thereafter gradually increases its metastability). The transitions from *E* to *D*, to *C* and to *B* are less difficult. (They correspond to a degradation in ecological systems)



SCGP Fig 3.38 [De Santo 1978]

Figure 3.1. There is virtually always an ecological response to an abiotic change in the biosphere. An ecological response is essentially a biotic change which results from the physiological readjustment of the living system to an altered environment. The rate and extension of these physiological and ecological readjustments often fluctuate irregularly until some relatively stable state is achieved when a stable abiotic environment is present.

Some Tenets of Systems Theory:

Science is approximate and subject to our method of questioning - - ***Heisenberg***

There are no objects nor individuals in the universe; every thing is a set of processes and interactions - - ***Bertalanffy***

There is not enough information within something to understand/predict its behavior; one must include its external interactions - - ***Godel***

Systems can not be taken apart and studied in the laboratory - - ***Bertalanffy***

Two Conditions on Natural Systems:

However, they may be studied in-situ and their behavior may be through simulation.

But accounting for mass and energy fluxes alone without information is limited.

EARTH SYSTEMS SCIENCE APPROACH

1. PROBLEM (System Dysfunction)
   Land-use practices and discharges in the watershed are impacting the resource capital of the Coastal Zone.

2. OBJECTIVE (Scientific Simulations)
   Scientifically defendable linkages between Forcing and Response that can assist policy decision making.

3. DEFINITION (Boundaries of System)
   Keep primary functionality within system to minimize coupling with adjacent systems and to include sufficient response ↦

   System: Watershed - River - Estuary/Delta/Coastal Zone
   Open Boundary: Coastal Ocean
   Vertical Boundary: Atmosphere, Sediments
   Internal Sources: Emissions, Discharges

4. FORMULATION (Optimize Information & Minimize Structure)
   Input Parameters
   Response Indicators
   Primary Processes
   System Information Parameters
   Process-Critical Parameters

5. INFORMATION BASE (Input & Validation Data, Monitoring)
   Input data
   Validation data
   Calibration/Hindcast
   Monitoring

5. SOLUTION (Models)
   Conceptual Models
   Definition of Subsystems
   Quantification of Processes
   Coupling of Processes & Subsystems
   Validation and Calibration

7. IMPLEMENTATION (Generation of Output)
   Sensitivity & Simulation
   Design Iteration
   Translation to Policy Language

SYSTEM OBJECTIVES

Quantitatively Connect Watershed Forcing with Coastal Zone Response

Provide a Framework for improving Process Research and System Monitoring

Implement the Simulation Models and an Information Exchange with Resource Management

SYSTEM DEFINITION

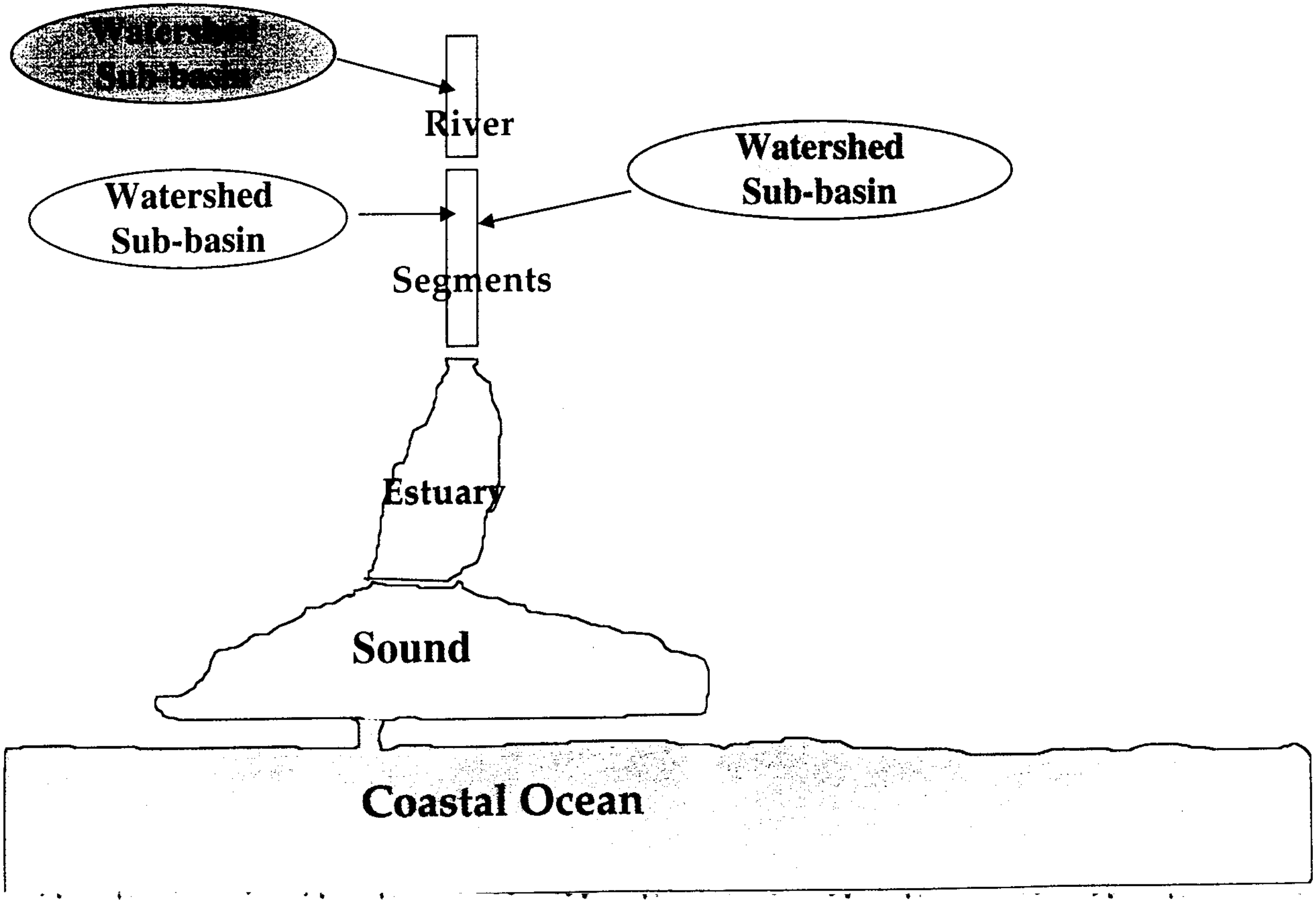
Determine the Boundaries of the System

The boundaries must include the primary functionality and its response within system in order to minimize the coupling with adjacent systems.

For example,

System: Watershed - River - Estuary - Coastal Zone
Open Boundary: Coastal Ocean
Vertical Boundaries: Atmosphere, Sediments
Internal Inputs: Waste produced and Discharged

Compartments of Watershed-River-Coastal System



INFORMATION BASE

The Construction Phase uses previous Scientific Results

The Simulation Phase uses support data:

- Input data from the external and internal sources
- Validation data from observations of the ‘choke points’ in the system
- Calibration/Hindcast data from previous observations
- Simulation data from in-situ monitoring or external models.

SYSTEM FORMULATION

Process Resolution must be Balanced throughout

Selection is critical to the design of the simulation model and its supporting observational data

The design is specified in reverse order to the mass flow, for example:

- **Output Indices required for the Economic Model**
- **Scientific Response Output**
- **Primary Processes**
- **System & Sub-System Variables**
- **Input Parameters**

MODEL SOLUTION

Procedure involves a sequence of steps:

- Conceptual Models
- Definition of Subsystems
- Formulation of Primary Processes
- Coupling of Submodels
- Validation and Calibration runs
- Simulation runs

Examples of Sub-Models would be:

- Regional scale Atmospheric Input
- Watershed
- Estuarine Circulation
- Primary Production
- Benthic Habitat
- Fish Response

Examples of Coupled Submodels would be:

- Estuarine Circulation and Pri.-Productivity
- Pri.-Productivity and Dissolved Oxygen
- Watershed and Sediment Deposition

a. A SPECTRUM OF FORMULATION STRATEGIES

Holistic	Reductionist
Often Simple	Complex
Linear	Nonlinear
Empirical	Theoretical
No Mechanisms	Component Mechanisms
Formulation: System Data	Component Data
Testing: System Data	System Data
Inexpensive	Costly

b. EXAMPLES OF FORMULATION STRATEGIES

Donor Controlled	Phenomenological	Physiological Mechanistic
Linear	Nonlinear	Highly Nonlinear
Advocate:	Advocate:	Advocates:
Bernard C. Patten	Howard T. Odum	Very numerous

Fig. 29. Various strategies of formulation, whereby the conceptual model is stated formally as mathematical equations, are proposed to fall along a continuum from holistic to reductionist (a). Examples of three strategies along this continuum are presented in detail (b).

Flux between Components is Linearly proportional to the upstream component

$\text{Flux} = k \cdot P$

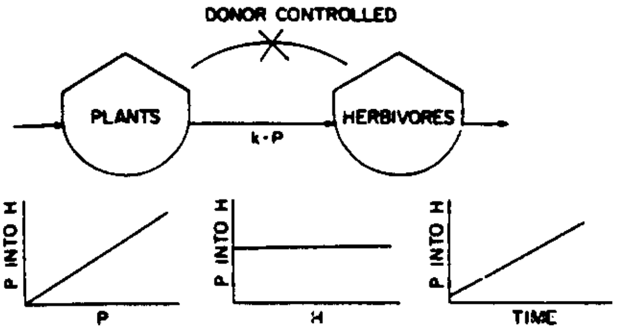


Fig. 30. Donor-controlled formulations assume that all fluxes are linearly dependent on a single compartment.

Flux between components is proportional To both components

$\text{Fux} = k \cdot P \cdot H$

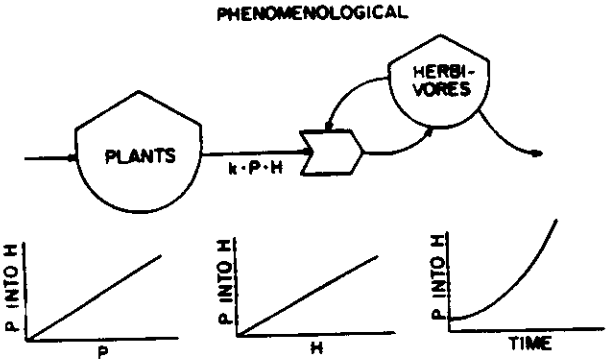


Fig. 31. Phenomenological Formulations express interactions that may take various linear or non-linear forms, based on asumptions about the forces driving each flux.

Flux between components is proportional to both components and external Control variables

$\text{Flux} = k \cdot f(P,H)$

$f(P) = f(N,L)$

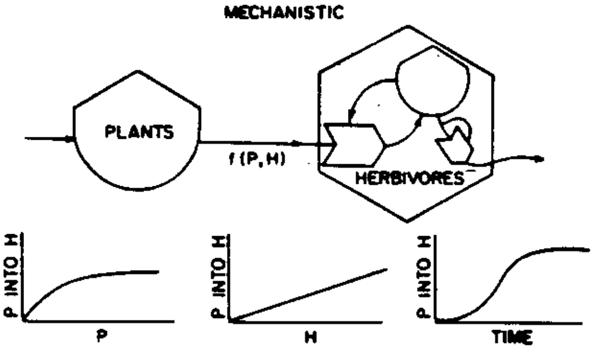


Fig. 32. Mechanistic Formulations express functional relationships between fluxes and the variables assumed to be important in determining the fluxes, based on controlled observations in the laboratory or in the field.

IMPLEMENTATION

The Phases of Implementation

Design: Convergence of model formulation and data acquisition needs

Construction: Process validation and calibration, Design iteration, Sensitivity and Coupling

Simulation: Simulation for scientific response, Translation to Economic Indices, Testing of Management Scenarios