Natural Systems
Natural Systems Functions
Natural Capital
Ecosystem Services
Interconnections
Natural Hazards
“A man’s relation to Nature must come very near to a personal one”

(Henry David Thoreau)
Humans are inclined to live in harmony with Nature - Sacredness

Humans easily develop an oppositional and manipulative stance
“Torture nature for her secrets”  F. Bacon

“This we know. The Earth does not belong to man; man belongs to the Earth. This we know. All things are connected...man did not weave the web of life; he is merely a strand in it. Whatever he does to the web, he does to himself”  (Chief Seattle, Spoken in 1854)
NON-NATURAL SYSTEMS
(Built Environment - Anthrosphere)

- Cartesian
- Somewhat predictable
- Designed as closed systems
- Built to last

NATURAL SYSTEMS
(Biosphere- Hydrosphere- Geosphere – Atmosphere)

- Non-Cartesian
- Non-linear
- Coupled
- Chaotic
- Diverse
- Open
- Dissipative
- Changing

VS.

Chaotic
Non-linear
Coupled
Chaotic
Change
Dissipative
Open
Closed
Diverse
Predictable
Designed
Built to last
Earth Systems

The Atmosphere
is the gaseous envelope that surrounds the Earth and consists of a mixture of gases composed primarily of nitrogen, oxygen, carbon dioxide, and water vapor.

The Biosphere
is the life zone of the Earth and includes all living organisms, including humans, and all organic matter that has not yet decomposed.

The Cryosphere
is the portion of the climatic system consisting of the world's ice masses and snow deposits. This includes ice sheets, ice shelves, ice caps, glaciers, sea ice, seasonal snow cover, lake and river ice, and seasonally frozen ground and permafrost.

The Geosphere
is the solid Earth that includes the continental and oceanic crust as well as the various layers of the Earth's interior.

The Hydrosphere
includes the water of the Earth, including surface lakes, streams, oceans, underground water, and water in the atmosphere.
- Geosphere: solid outer zone of the Earth
- Hydrosphere: zone of water
- Atmosphere: gaseous envelope around Earth
- Biosphere: living part of the Earth
- Anthrosphere: part of the environment made or modified by humans and used for their activities

Earth as a self-maintaining, living planet in/on which multiple physical and chemical processes of change take place. This is a $4.6 \times 10^9$ year old story…
What makes the anthrosphere?

- Structures used for dwellings
- Structures used for manufacturing, commerce, education, and other activities
- Utilities, including water, fuel, and electricity distribution systems and waste distribution systems, such as sewers
- Structures and facilities used for transportation, including roads, railroads, airports, and waterways constructed or modified for water transport
What makes the anthrosphere? (2)

- Structures and other parts of the environment modified for food production, such as fields used for growing crops and water systems used to irrigate the fields.
- Machines of various kinds, including automobiles, farm machinery, and airplanes.
- Structures and devices used for communications, such as telephone lines or radio transmitter towers.
- Structures associated with extractive industries.
Infrastructure

Infrastructure is that part of the anthroposphere composed of the utilities, facilities, and systems used in common by members of a society and upon which the society depends for its normal function.
Components of the Infrastructure

- Transportation systems, including railroads, highways, and air transport systems
- Energy generating and distribution systems
- Buildings
- Telecommunications systems
- Water supply and distribution systems
- Waste treatment and disposal systems, including those for municipal wastewater, municipal solid refuse, and industrial wastes
### 2001 REPORT CARD
America’s Infrastructure

<table>
<thead>
<tr>
<th>Category</th>
<th>Grade</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roads</td>
<td>D+</td>
</tr>
<tr>
<td>Bridges</td>
<td>C</td>
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<tr>
<td>Transit</td>
<td>C-</td>
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<tr>
<td>Aviation</td>
<td>D</td>
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<tr>
<td>Drinking Water</td>
<td>D</td>
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<td>Wastewater</td>
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<td>Dams</td>
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<td>Hazardous Waste</td>
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<tr>
<td>Energy</td>
<td>D+</td>
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</tbody>
</table>

America’s Infrastructure GPA: **D+**

**SOURCE:** Web-site of the American Society of Civil Engineers
FROM: Figure 1.1, Industrial Ecology, Environmental Chemistry and Hazardous Waste, Stanley E. Manahan
Earth Processes

Melting, Evaporation, Freezing, Condensation, Sublimation, Dissolution, Vaporization, Reaction, Decomposition, Dissociation, Chemical Precipitation, Photosynthesis, Respiration, Transpiration, Evolution

Nature has created a 3 billion year old success story of life on Earth. This success is reflected in the way that life is diversified and organized to make the best use of the resources available.
Moving Air in the Troposphere (0-18 km), From *Gaia* by James Lovelock (1991)
Plates and plate boundaries of the Earth (after West, 1995.)
Biogeochemical Cycles

Biogeochemical cycles refer to the transport and transformation of substances in the environment, through life, air, sea, land, and ice.

“The more fundamental conception is… the whole system (in the sense of physics) including not only the organism-complex, but also the whole complex of physical factors forming what we call the environment…

…We cannot separate them (the organisms) from their special environment with which they form one physical system…”

Hydrologic Cycle

From *Laboratory Manual in Physical Geology* by Busch et al., 1997.
Water Facts

- If Earth were the size of an egg, the total volume of water would be equivalent of one drop. Of this total, only about one-third of one percent is actually available to humans as fresh water for drinking and irrigating (water in lakes, rivers, and the accessible water table below ground).
- A human being can live several weeks without food, but without water, the longest one can expect to live is 10 days.
- More than 75% of the fresh water on the Earth's surface is frozen in the Antarctic ice cap.
- The Pacific Ocean is 25% larger than the entire land surface of the world combined.
Water Facts (2)

- Earth's total volume of water; some 1,360,000,000 km³, would cover the globe to a height of 2.7 km (1.6 miles) if spread evenly over its surface. But more than 97% is seawater, 2% is locked in ice caps and glaciers, and a large proportion of the remaining 1% lies too far underground to exploit.
- The Amazon, the largest river in the world, discharges 7,060,000 ft³ of water per second. Its volume nearly equals that of all the other large rivers combined.
- The average human has about 50 liters (50 quarts or 12.5 gallons) of water in his/her body. Most of this water is found between the cells, bathing and lubricating them. The wettest part of the body - blood – is 83% water; the driest - tooth enamel - is 2%.
Water Facts (3)

- The hydrologic cycle uses more energy in a day than humankind has generated throughout history.

- At any one time, only about 0.005% of the total water supply is moving through the hydrologic cycle. A drop of water spends about nine days passing through the air; once it falls as precipitation, it may remain in a glacier for 40 years, in a lake for 100 years, or in the ground from 200 to 10,000 years. A water molecule may remain in the ocean for 40,000 years before being cycled, but eventually, every drop of water on Earth is moved through the hydrologic cycle.
Geologic Cycle from Physical Geology, C. Plummer et al., 1996.
Mass of carbon in Gigatons of Carbon (Gt C) per year

Biogeochemical Cycles - Carbon

Atmosphere 745 ± 5

Vegetation 580 ± 30
Soil & Detritus 1390 ± 190
Decay

Surface Ocean 960 ± 60
Decay

Marine Biota 3 ± 0

Cycling with Deeper Waters

Intermediate & Deep Ocean 36,000 ± 2,000
 Decay

Sediment 150

CO₂ Exchange with Ocean

Changing Land Use

Primary Production & Respiration

Fresh, Feeding, Breeding
Biogeochemical Cycles - Carbon

- Carbon – it’s what all living creatures have in common!
- Pools: living creatures, atmosphere, underground, oceans
- Global, dynamic
- Intimately related to energy cycles
Biogeochemical Cycles- **Nitrogen**

- For amino acids (proteins) and nucleic acids
- Pools: atmosphere (80%)
- *Nitrogen-fixing bacteria* – vital to making $N_2$ available to plants
- Human impacts
Biogeochemical Cycles - Sulfur

- For amino acids
- Pools: atmosphere and sediment
- Enters atmosphere: combustion of fossil fuels, volcanoes, rock weathering, surface of ocean, decomposition
- Back to earth: in rainwater, as sulfuric acid
Biogeochemical Cycles - Phosphorous

- For nucleic acids, cell membranes, ATP
- Pool: rock, phosphate deposits
- Enters: weathering and erosion
- Form used: phosphate
- With acid or alkaline conditions, insoluble complexes form (unavailable to plants)
Figure 5.1. Climate and life are linked by a complex web of interconnected cycles. Life on earth depends on the cycling of nutrients through air, water, soil, and living things. The climate mediates the flow of materials through these global cycles. Solar energy degrades to heat at each stage of the cycling process and is eventually returned to space as infrared radiation. The composition of the earth's atmosphere regulates the radiative balance on earth between absorbed solar energy and emitted infrared energy, which, in turn, controls the climate.
Gaia as a single self-regulating, evolving, and living system (super-organism) “is concerned with the working of the whole system, not with the separate parts of a planet divided arbitrarily into the biosphere, the atmosphere, the lithosphere, and the hydrosphere.

There are no real divisions of the Earth, they are spheres of influence inhabited by academic scientists (and non-scientists and engineers)”

James Lovelock (1991)
(in “Gaia: the practical science of planetary medicine”
“The human body is a dynamic field of energy. It is constantly participating in exchange with the larger of field of energy that surrounds it…

- 98% of the atoms in your anatomy were not there a year ago..
- bones are re-created brand new every three months..
- a new liver every six weeks..
- skin is new every month..
- a new stomach lining every four days..
- surface cells that actually come in contact with digesting food are renewed every five minutes..
- Basically, your body completely re-creates itself down to the last atom over a period of four or five years”

(Deepak Chopra, 1995)
Capitalism

The economic system in which all or most of the means of production and distribution, as land, factories, railroads, etc., are privately owned and operated for profit, originally under fully competitive conditions; it has been generally characterized by a tendency toward concentration of wealth and, in its later phase, by the growth of great corporations, increased government control, etc.

(Webster’s New World Dictionary)
Types of Capital

- Human Capital
- Financial Capital
- Manufactured Capital
- Natural Capital

(Hawken et al., 1999)
What is Capital?

- **Wealth** in the form of money or property, owned, used, or accumulated in business by an individual, partnership or corporation.
- Any form of material **wealth** used or available for use in the production of more wealth.
- The remaining **assets** of a business after all liabilities have been deducted; net worth.
- The funds contributed to a business by the owners or stockholders.

(American Heritage Dictionary)
What represents Natural Capital?

Represents all the familiar natural resources used by mankind:
- water, air
- minerals, oil, coal..
- trees, plants
- animals
- rocks and soils
- etc.

About a 3.8 billion-year store of natural capital
Remarks

“Companies routinely disregard the social and environmental costs of their actions, an attitude that is sanctioned and indeed reinforced by the rules of the game. …

….the assumption that natural and social environments have no intrinsic value because no money change hands”

(Carl Frankel)
Remark

“A tree provides air-conditioning services no less than a window unit from Westinghouse. Open space provides relief from tension and noise no less than white noise machines and Prozac”

(Jonathan Rowe)
Remark

Humanity derives a wide array of crucial economic and critical life-support benefits from biodiversity and the natural ecosystems in which it exists. This is captured in the term “ecosystem services”.
Ecosystem Services

“Ecosystem services are the conditions and processes through which natural ecosystems, and the species that make them up, sustain and fulfill human life.”
- Maintain biodiversity
- Produce goods
- Provide life-support functions
- Provide Intangible aesthetic and cultural benefits

G. C. Daily 1997
Ecosystem Services

Critical services valued at trillions of dollars annually, provided at no cost by Nature such as:

- Purification of air
- Global oxygen production (photosynthesis)
- Maintenance of $O_2/ N_2$ gas concentrations for respiration
- Purification of water (wetlands, sediments, underground)
- Cycling of nutrients
- Pollination of crops and natural vegetation
Ecosystem Services (2)

- Generation and renewal of soil and soil fertility (nitrogen fixers and detritus)
- Mitigation of floods (vegetations, river shape) and droughts
- Production of soils, preservation of top soils
- Regulation of climate and oceans
- Moderation of temperature extremes and force of winds and waves
- Detoxification and decomposition of wastes
- Control of the majority of agricultural pests
- Dispersal of seeds & translocation of nutrients
- Support of human cultures
Ecosystem Services

- One square yard of pasture
  - 50,000 earthworms & relatives
  - 50,000 insects & mites
  - 12,000,000 round worms
- One gram of soil
  - 30,000 protozoa
  - 50,000 algae
  - 400,000 fungi
  - Billions of bacteria
Providing aesthetic beauty and intellectual stimulation that lift the human spirit

“If we have powers of imagination, these are activated by the magic display of color and sound, of form and movement, such as we observe in the clouds of the sky, the trees and bushes and flowers, the waters and the wind, the singing birds, and the movement of the great blue whale through the sea…

…If we lived on the moon….”

(Thomas Berry)
Ecosystem Services

“In general, human beings lack both the knowledge and the ability to substitute [technology & human designed systems] for the functions performed by [natural biological] cycles.”

Ehrlich & Mooney 1983
Ecosystem services yield ecosystem goods, such as seafood, wild game, forage, timber, biomass, fuels and natural fibers. They also underpin agricultural productivity, the pharmaceutical industry and many aspects of industrial production.
Some characteristics of natural ecosystems

- Biodiversity (genetic, habitat, species)
- Resiliency = sensitivity to perturbation
- Carrying Capacity
- Continuously Changing
- Interdependence / Interconnections
- Idiosyncratic
Organisms in a mature natural ecosystem

- Use waste as a resource
- Diversify and cooperate to fully use the habitat
- Gather and use energy efficiently
- Optimize rather than maximize
- Use materials sparingly
- Don’t foul their nests
- Don’t draw down resources
- Remain in balance with the biosphere
- Run on information
- Shop locally

(J. Benyus)
Ecosystem Services

Challenges:

- Identification
- Characterization
- Valuation
- Monitoring
- Safeguarding
On “Nature as Sacred” & “Interconnections”

Jan Christian Smuts (1870-1950) - South African statesman and scholar

“We are indeed one with Nature. Her genetic fibers run through all our being; our physical organs connect us with millions of years of her history; our minds are full of immemorial paths of pre-human experience.”
On “Nature as Sacred” & “Interconnections”

- Smuts challenged the mechanical viewpoint of science.
- He observed --the world is not made of substance but of flexible, changing patterns
- Patterns (arrangements) are the ultimate structure of the world- this leads to “the world consists of wholes.”
- Individual parts do not exist in nature, only wholes- and these form and shape each other.
Interconnections

- *Starfish experiment*— American biologist Robert Paine
- Removed one species of starfish (predator) from a tidal ecosystem containing 15 species (seen by naked eye)
- Within 1 year:
  - only 8 of the original 15 species were present
  - prey species numbers increased dramatically
  - competition for space – some moved, others died out
  - control area remained a complex community
- More than just a “collection of interconnected species” — they were a *whole*. 
Interconnections

In 1 teaspoon of water…

….up to 1 billion organisms can live…

How deep or widespread was the effect from removing just one predator species of starfish?…….
Natural Hazards

- Hazards with Earth materials
  (toxic minerals and gases)

- Hazards with Earth processes
  (earthquakes, volcanoes, landslides, avalanches, etc.)
<table>
<thead>
<tr>
<th>SOURCES of CASUALTIES</th>
<th>NUMBERS of CASUALTIES</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Wars versus Earthquakes</strong></td>
<td></td>
</tr>
<tr>
<td>U.S. Battle Deaths in World War II</td>
<td>292,131</td>
</tr>
<tr>
<td>Atomic Bomb, Hiroshima, Japan 1945</td>
<td>80,000 to 200,000</td>
</tr>
<tr>
<td>EARTHQUAKE, Tangshan, China, 1976</td>
<td>242,000</td>
</tr>
<tr>
<td><strong>U.S. Murders versus Single Volcanic Eruption</strong></td>
<td></td>
</tr>
<tr>
<td>Total murders U. S., 1990</td>
<td>20,045</td>
</tr>
<tr>
<td>VOLCANIC ERUPTION, Colombia, 1985</td>
<td>22,000</td>
</tr>
<tr>
<td><strong>AIDS Deaths in United States versus Single Landslide Event</strong></td>
<td></td>
</tr>
<tr>
<td>Total AIDS deaths U. S., through April, 1992</td>
<td>141,200</td>
</tr>
<tr>
<td>LANDSLIDES, Kansu, China, 1920</td>
<td>200,000</td>
</tr>
<tr>
<td><strong>Greatest Atrocity versus Greatest Flood Events</strong></td>
<td></td>
</tr>
<tr>
<td>The Holocaust, Europe, 1939-1945</td>
<td>6,000,000</td>
</tr>
<tr>
<td>FLOOD Yellow River, China, 1887</td>
<td>900,000 to 6,000,000</td>
</tr>
<tr>
<td>FLOOD Yangtze River, China, 1931</td>
<td>3,700,000</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>GEOLIC HAZARD</th>
<th>COST in 1990 Dollars*</th>
<th>SOURCE(S)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reactive Aggregates</td>
<td>No estimate</td>
<td></td>
</tr>
<tr>
<td>Acid Drainage</td>
<td>$365 million annually to control; $13 to 54 billion cumulative to repair</td>
<td>USBM, 1985, IC 9027; Senate Report, 1977, 95-128</td>
</tr>
<tr>
<td>Asbestos</td>
<td>$12 to 75 billion cumulative for remediation of rental &amp; commercial buildings; total well above $100 billion including litigation and enforcement</td>
<td>Croke and others, 1989, The Environmental Professional, v. 11, pp. 256-263. Malcolm Ross, USGS, 1993, personal communication. Costs depend on extent and kind of remediation done; removal is most expensive option.</td>
</tr>
<tr>
<td>Radon</td>
<td>$100 billion ultimately to bring levels to EPA recommended levels of 4 pCi/L</td>
<td>Estimate based on remediating about 1/3 of American homes at $2500 each plus costs for energy and public buildings.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>HAZARDS from PROCESSES</th>
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<tbody>
<tr>
<td>Subsidence 2 and Permafrost 3</td>
</tr>
<tr>
<td>Floods</td>
</tr>
</tbody>
</table>

*Costs from dates reported in "SOURCE(S)" column have been reported in terms of 1990 dollars. This neglects changes in population and land use practice since the original study was done but gives a reasonable comparative approximation between hazards. 1^Aggregates are substances such as sand, gravel or crushed stone that are commonly mixed with cement to make concrete. 2^Subsidence is local downward settling of land due to insufficient support in the subsurface. 3^Permafrost consists of normally frozen ground in polar or alpine regions that may thaw briefly due to warm seasons or human activities and flow. 4^Storm surge occurs when meteorological conditions cause a sudden local rise in sea level that results in water piling up along a coast, particularly when strong shoreward winds coincide with periods of high tide. Extensive flooding then occurs over low-lying riverine flood plains and coastal plains.
International Decade for Natural Disaster Reduction (IDNDR)

“The objective of the Decade is to reduce through concerted international action, especially in the developing countries, the loss of life, property damage, and social and economic disruption caused by natural disasters, such as earthquakes, wind storms, tsunamis, floods, landslides, volcanic eruptions, wildfires, grasshopper and locust infestations, drought and desertification and other calamities of natural origin.”
Hurricane Andrew: $27 Billion
Midwest floods of 93: $21 Billion
Northridge Earthquake of 94: $45 Billion