Introduction / Overview of Environmental Geology

I. The Topic Defined

A. Environmental Geology
1. application of geologic principles to "real-world" problems

B. Related Areas
1. Natural Hazards
a. flood hazards
b. landslide hazards
c. seismic hazards
d. volcanic hazards
2. Planning / Landuse Management
a. Logging
b. soil managment / erosion
c. agricultural management
3. Earth Materials / Energy Resources
a. Raw Materials Extraction
b. Fossil Fuels
4. Hydrologic Resources
a. Water quality and quantity

C. Critical Concept of Environmental Geology
1. The interaction of the biosphere (including humans) with geologic processes and landscape systems

II. Earth Systems Cycles
A. Tectonic Cycle
B. Rock Cycle
C. Biologic Cycles
1. carbon cycle
2. biogeochemical cycle
D. Hydrologic Cycle

III. Soil Systems
A. Soils as a Geologic Surface Material
1. weathered regolith / rock weathering
2. soil development over time
3. The basis of human food chain / agricultural production
B. Soil Issues
1. Soil Moisture / Plant Growth
2. Soil Fertility
3. Soil Erosion
a. soil loss
4. Soil Contamination

        a. contaminant transfer to water and plants
    5. Desertification

IV. Geologic Hazards Overview
  A. Hazard - the interaction of geologic process and humans
    1. loss of life and property
    2. economic / social system impacts

  B. Risk Assessment
    1. probability of occurrence
    2. recurrence interval
    3. hazard forecasting / warning
    4. hazard planning / mitigation
        a. engineering design and construction
    5. hazard insurance

  C. River Hazards
    1. flooding (loss of life and property)
    2. bank erosion / land loss

  D. Landslide hazards (mass wasting / slope failure)
    1. loss of life and property
    2. Landuse
        a. logging / clear cutting
        b. land development
        c. grazing
        d. urbanization / building
        e. landslide warning systems
        f. engineered solutions

  E. Seismic Hazards
    1. Ground shaking, liquefaction, tsunami
        a. property destruction / loss of life
    2. Earthquake Risk Analysis
        a. mapping / seismic hazards maps
        b. probability / recurrence intervals

  F. Volcanic Hazards
    1. lava flow, tephra fallout, lahar / debris flow
    2. atmospheric impacts
        a. air travel

  G. Coastal Hazards
    1. flooding, erosion, mass wasting, tsunami, habitat loss

V. Anthropogenic Influences / Interaction with Earth

A. Water Supply / Water Resources
B. Water Pollution / Contamination
C. Waste Management
    1. solid waste refuse
    2. municipal waste
    3. industrial waste / radioactive waste
D. Environmental Health
    1. asbestos issues
    2. heavy metals poisoning
    3. radioactive exposure / carcinogens

E. Mineral / Energy Resources
    1. mineral resources / raw materials
    2. fossil fuels
    3. hydroelectric power gneration
    4. geothermal energy

ENVIRONMENTAL GEOLOGY OVERVIEW

CLASSIC STUDY = "HAZARDS GEOLOGY" = CATASTROPHIC EVENTS, NATURAL DISASTERS, ENGINEERING GEOLOGY

"NATURAL HAZARDS"

EARTH QUAKES, SEISMICITY (DEATH AND DESTRUCTION)
INCLUDES TSUNAMIS

VOLCANIC ERUPTIONS (MORE DEATH AND DESTRUCTION)

INCLUDES: CLIMATIC IMPACTS ("DUST VEIL" EFFECT)
POST-VOLCANIC MASS WASTING, MUD SLIDES

FLUVIAL DYNAMICS

FLOODS, BANK EROSION

CATASTROPHIC MASS WASTING EVENTS

SLOPE INSTABILITY, LANDSLIDES, MUDFLOWS

DYNAMIC COASTAL EVOLUTION

COASTAL EROSION, WAVE EROSION, DUNE EROSION

"ANTHROPOGENIC" PHENOMENA

LAND DEVELOPMENT

URBANIZATION

DISRUPTION OF HYDROLOGIC CYCLE
RUNOFF-FLOODING
EROSION PROBLEMS
ECOSYSTEM DESTRUCTION
TOP SOIL LOSS
LOSS OF AGRICULTURAL LANDS/ARABLE LAND

SOIL AND WATER CONTAMINATION (SURFACE AND GROUND)

WASTE DISPOSAL PRACTICES

SOLID, LIQUID, RADIOACTIVE
COMMERCIAL/INDUSTRIAL

GROUND AND SURFACE WATER CONTAMINATION

CHEMICAL DISCHARGES
SALT WATER INTRUSION

- HYDROCARBON CONTAMINATION
    - STORAGE TANKS
    - OIL SPILLS
- SURFACE WATER DISCHARGES
    - INDUSTRIAL PROCESSING
    - RESIDENTIAL/SEWAGE
- AGRICULTURAL CONTAMINATION
    - PESTICIDES, HERBICIDES

AIR POLLUTION

- ACID RAIN
- PARTICULATES
- NOx, SOx, CO EMISSIONS
- GREEN HOUSE GASES

RESOURCE UTILIZATION

- MINERAL RESOURCES
    - OVER-EXTRACTION/SCARCITY
- GROUND-WATER MINING
    - OVER-EXTRACTION/SCARCITY
    - OVER-DEVELOPMENT
    - EXTRACTION-RELATED SUBSIDENCE
- DESERTIFICATION
    - DEFORESTATION
    - OVER-GRAZING

ENGINEERING DISASTERS

- DAM COLLAPSE (JOHNSTOWN FLOOD)
- POORLY PLANNED BUILDING SITES
    - UNSTABLE SURFICIAL MATERIALS
- MINE SUBSIDENCE

REGULATORY OVERVIEW

NATIONAL ENVIRONMENTAL POLICY ACT (NEPA) 1969-

FIRST ENVIRONMENTAL POLICY STATEMENT BY FEDERAL GOVERNMENT

STATUTES NOT ENFORCEABLE

ESTABLISHES POLITICAL FRAMEWORK FOR LATER ENVIRONMENTAL LEGISLATION

ESTABLISHED THAT ENVIRONMENTAL IMPACT STATEMENTS (EIS) REQUIRED FOR FEDERAL PROJECTS

FEDERAL WATER POLLUTION CONTROL ACT 1972
CLEAN WATER ACT (CWA) AMENDMENTS 1977

GUIDELINES FOR RESTORATION AND MAINTENANCE OF CHEMICAL, PHYSICAL, AND BIOLOGICAL INTEGRITY OF NATIONS WATER

"NPDES" PERMITS= NATION POLLUTANT DISCHARGE ELIMINATION SYSTEM SETS WATER QUALITY STANDARDS

SAFE DRINKING WATER ACT 1974

CONTROLS CONTAMINANT LEVELS ALLOWABLE IN SURFACE AND GROUND WATER

RESOURCE CONSERVATION AND RECOVERY ACT 1976 (RCRA)

FIRST ATTEMPT TO DEAL WITH HAZARDOUS WASTE

REGULATES HAZARDOUS AND RESIDUAL WASTE THROUGHOUT PROCESSING STREAM (PRODUCTION, CONVEYANCE, STORAGE AND DISPOSAL)

"SUBTITLE D": GOVERNS CONSTRUCTION AND OPERATION OF LANDFILLS

PERMIT PROCESS: ESTABLISHES SELF-CHECKING AND MONITORING PROCEDURES FOR GOVERNMENT AND INDUSTRY

GOVERNS KNOWN AND RESPONSIBLE OPERATORS

COMPREHENSIVE ENVIRONMENTAL RESPONSE, COMPENSATION AND LIABILITY ACT (CERCLA, 1980) = "SUPERFUND"

ESTABLISHED TO REMEDIATE AND CLEAN-UP KNOWN CONTAMINATION SITES (ORPHANED INDUSTRIAL SITES)

LITIGATION TO ESTABLISH POTENTIALLY RESPONSIBLE PARTIES (PRP'S)

GOVERNMENT DRIVEN CLEAN-UP, BILLING

SUPERFUND AMENDMENT REAUTHORIZATION ACT (1986)

- LIABILITY DECISIONS
- TAP INTO SUPERFUND ACCOUNT
- REAUTHORIZATION
  - CERCLA/SARA AREAS OF CONCERN
    - ESTABLISH CLEAN-UP/REMEDIATION STANDARDS
    - PERMANENT/LONG-TERM TREATMENT
    - FOLLOW-UP MONITORING
    - EPA ESTABLISHES "NPL" = NATIONAL PRIORITIES LIST
    - HEALTH ASSESSMENTS
      - RISK ANALYSIS
      - HOW CLEAN IS CLEAN?
    - HEALTH AND SAFETY OF HAZ WASTE WORKERS
      - HAZWOPER (40/8 HR TRAINING)
      - OSHA REGULATIONS
    - REMEDIAL INVESTIGATION/FEASIBILITY STUDIES (RI/FS)
      - 3-PHASE APPROACH
        - PHASE I- ANALYZE EXISTING DATABASE, SCOPE OF PROBLEMS
        - PHASE II-ACTIVE FIELD INVESTIGATION, SITE CHARACTERIZATION
        - PHASE III-DESIGN AND IMPLEMENTATION OF REMEDIAL ACTIVITIES
        - SITE CLOSURE AND FOLLOW-UP MONITORING

SURFACE MINING CONTROL AND RECLAMATION ACT (SMCRA)

- COVERS SURFACE AND UNDERGROUND MINING
- WATER SUPPLY REPLACEMENT BY MINING COMPANIES
- EROSION CONTROL
- AMD CONTROL

TOXIC SUBSTANCES CONTROL ACT (TOSCA)

- CONTROL OF CHEMICALS IN INDUSTRY, ACADEMIA AND GOV'T
- RISK ANALYSIS OF TOXIC POTENTIAL (TOXICOLOGY)

FEDERAL INSECTICIDE, FUNGICIDE, AND RODENTICIDE ACT (FIFRA)

- CONTROLS USE OF AGRICULTURAL CHEMICALS
  - MANUFACTURING, USE AND DISPOSAL
- USE RESTRICTIONS

CLEAN AIR ACT (1990)

PHASED IN OVER NEXT FEW YEARS
CONTROL OF GREENHOUSE GASES
CFC'S - OZONE DEPLETING GASES
INDUSTRIAL EMISSIONS

ACID RAIN
NO_x, SO_x, CO, PARTICULATES
STACK TESTING AND MONITORING
"SCRUBBERS"/EMISSIONS SYSTEMS
AUTOMOBILE EMISSIONS

SOURCES OF ANTHROPOGENIC CONTAMINATION

LAND DISPOSAL OF SOLID WASTES

RESIDENTIAL (SEWAGE, HOUSEHOLD CHEMICALS, HOUSEHOLD WASTE)
INDUSTRIAL (DISCHARGE, METALS, CHEMICALS, ORGANICS, ACIDS)
"LEACHATE" CONTROL

LAND APPLICATION OF SEWAGE

SEPTIC TANKS/CESS POOLS (29% OF US POPULATION)
MUNICIPAL SEWAGE TREATMENT
SEWAGE SLUDGE- LAND APPLICATION (NITROGEN/NITRATES)

AGRICULTURAL ACTIVITIES
SYNTHETIC/CHEMICAL FERTILIZERS, HERBICIDES, PESTICIDES

GOLF COURSES

PETROLEUM/HYDROCARBON LEAKS AND SPILLS

UST's, GAS STATIONS, TRANSFER STATIONS, STORAGE TANKS, REFINERIES, PRIVATE AND PUBLIC (MILITARY BASES)

INCLUDES: OIL, GASOLINE, KEROSENE (LNAPL'S = "LIGHT NON-AQUEOUS PHASE LIQUIDS = FLOATERS)

DNAPL's = DENSE NON-AQUEOUS PHASE LIQUIDS = SINKERS (HEAVY LIQUIDS, HALOGENATED HYDROCARBONS (CHLOROFORM, BROMOFORM), KREOSOTE)

INDUSTRIAL PROCESSING

CHEMICAL PLANTS, STEEL MILLS, PAPER MILLS, TEXTILES, FOOD PROCESSING, PLASTICS, ELECTRONICS

INDUSTRIAL WASTE LAGOONS

"DRY WELLS" OR DEEP WELL INJECTION

MINING ACTIVITIES

COAL, METALS, MINERALS

TAILINGS/SPOIL PILES
AMD = ACID MINE DRAINAGE, ACIDIFYING CONDITIONS
HEAVY METALS CONTAMINATION

RADIOACTIVE WASTES

U-MINING, NUCLEAR REACTORS, TAILINGS

PRIMARY COURSE TOPICS/READINGS

OVERVIEW OF ENVIRONMENTAL CONCERNS, REGULATORY HISTORY

COAL, COAL MINING, MINE-RELATED PROBLEMS

SOLID WASTE AND LANDFILL TECHNOLOGY

SYNTHETIC LINER SYSTEMS

UNDERGROUND STORAGE TANKS/ISSUES IN HYDROCARBON CONTAMINATION

ENVIRONMENTAL PROPERTY ASSESSMENTS

GROUNDWATER ISSUES

SOIL AND WATER REMEDIATION TECHNIQUES

FOCUS ON SPECIAL REGULATORY ASPECTS

BASICS OF FIELD AND ANALYTICAL TECHNIQUES

WETLANDS ISSUES: DELINEATION AND REGULATIONS

HEALTH AND SAFETY CONCERNS

CONSULTING PRACTICE AND BUSINESS

Physical Properties and Principles

I. Review of Fundamental Physics

A. Fundamental (Measurable) Physical Quantities

1. **Mass** - a measure of the amount of matter contained in a given quantity of material (measure of matter's resistance to motion or inertia; scalar quantity with magnitude only)
   a. mass units kg 1 kg = 1000 g; 1 g =1000 mg

2. **Length** - linear measure of distance (scalar quantity with magnitude only)
   a. length units m 1 m = 100 cm; 1 km = 1000 m

3. **Time** - passage of time measured in terms of motion or displacement of bodies in space
   a. time units sec 1 yr = 365 day; 1 day = 24 hr; 1 hr = 60 min, 1 min =60 sec

4. **Temperature** - measure of the amount of molecular kinetic energy ("heat") contained within a substance (i.e. > heat energy, >vibration rate of atoms / molecules, > temp.)

   a. temperature units degree celsius (C) degree Fahrenheit (F)

      (1) Conversion Factors:

         (a) From C to F: $F = 9/5C + 32^o$
         (b) From F to C: $C = 5/9(F - 32^o)$
            i) E.g. convert 40 C to F
               $F = 9/5(40) + 32 = 104^o$ F

5. **Force** - the push or pull action on an object. Force is required to start an object in motion from rest, or stop an object that is moving, or cause a moving object to speed up or slow down.

   a. force units N (newton) $1 N = 1 kg\text{-}m/s^2 = 1 kg\text{-}ms^{-2}$

B. Geometric (Measurable) Physical Quantities

1. **Angle** measured in degrees circle = 360^o
2. **Length** L units: m
3. **Area** $A = L^2$ units: m^2
4. **Volume** $Vol = L^3$ units: m^3

C. Kinematic (Measurable) Physical Quantities (kinematic = "in motion")

1. **Time** T units: sec
2. **Velocity** V = L / T units: m/sec (change in position over time)
3. **acceleration** a = V/T units: m/sec^2 (change in velocity over time)

   a. **g** - acceleration due to gravity = 9.8 m/sec^2

4. **Discharge** Q = Volume / T = L^3 /T units: m^3/sec (fluid flow rate)

D. Dynamic (Measurable) Physical Quantities (dynamic = "changeable")

1. **Force (weight)** F=mg units: $kg\text{-}m/sec^2$ = N

2. **Pressure** P = F/A (force per unit area)
   units: N/m^2 = Pa (paschal)

3. **Energy (work)** W = Fs (force x displacement) units: N-m
   1N-m = 1 kgm^2/sec^2 = 1 J (joule)

4. **Power** P = W/t (work per unit time) units: J/sec = watt (W)

5. **Momentum** M = mass x velocity units: kg-m/sec

6. **Mass Density** D = mass / volume units: kg/m^3

7. **Weight Density** Dw = weight / volume units: N/m^3

8. **Dynamic Viscosity** - resistance of a fluid to flow (due to intermolecular attractions)
   dimensional units: $N\text{-}sec/m^2$ = Pa-s

** dimensionless quantities are ones that have no units (e.g. a "dimensionless ratio" is a quantity in which all units "cancel out" **

II. Heat Energy and Thermodynamics (heat flow)

A. Heat - internal energy within a substance = kinetic molecular energy
   1. high heat substances = high degree of kinetic molecular energy
      a. i.e. the higher the heat the faster the vibration of atoms and molecules

   2. Temperature - measure of the average amount of heat energy in a substance - i.e. the average kinetic energy of a substance

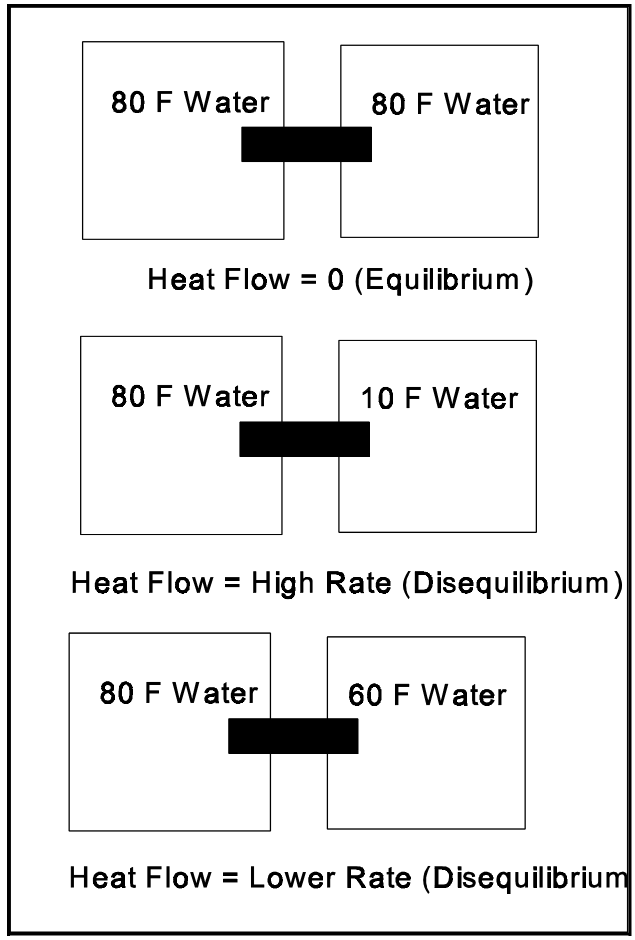
B. Heat Flow

   1. "Thermodynamics" = study of heat, heat flow and behavior of heat

2. Heat Flow : An Equilibrium Process
   a. Temperature Imbalance Causes Heat to Flow or Transfer
   b. Substances at Same Temperature = Temperature Equilibrium

3. Heat Flows from High Temperature Regions to Low Temperature Regions
   a. At temperature equilibrium: net heat flow = 0
   b. The higher the temperature differential, the faster the heat flow
   c. The lower the temperature differential, the slower the heat flow

Consider an experiment with two vessels of water, with variable heat-content. They are connected by a tube that allows heat to exchange between the two vessels.



   d. Specific Heat Capacity
      (1) Amount of heat required to raise the temperature of 1 gram of a substance, 1 degree C

      (2) E.g. Water has high heat capacity compared to rock
         (a) takes a higher amount of heat to raise the temperature of water, compared to rock
         (b) Result: water heats and cools more slowly than earth /rocks

C. Heat, Expansion, Contraction

1. Expansion of Hot Matter
    - a. Increase heat, increase temperature, increase vibrational kinetic energy of atoms / molecules
        - (1) atoms/molecules vibrate faster - move farther apart to make room
        - (2) Net Result: Expansion and Volume Increase

2. Contraction of Cold Matter
    - a. Opposite Relation: remove heat, < temperature ... volume decrease / contraction

3. Density Relations to Heat-Induced Volume Changes
    - a. Density = mass / volume
        - (1) assuming mass is constant, when volume decreases, density increases
        - (2) assuming mass is constant, when volume increases, density decreases
            - (a) i.e. an "inverse relationship" between density and volume

    - b. Heat Loss = Cooling = < kinetic energy = < volume = > density
    - c. Heat gain = Warming = >kinetic energy = > volume = < density

        - (1) e.g. Hot Air Balloon: Hot Air = volume increase = density decrease
            - (a) less dense hot air rises relative to more dense cold air

4. States of Matter vs. Volume Change / Density Change
    - a. Solids = decreased temperature = decreased kinetic energy = decreased volume = increased density
    - b. Gases = increased kinetic energy = increased volume = decreased density

5. Special Consideration: Water
    - a. Most substances are more dense in a solid state compared to a liquid state
    - b. Water is the opposite
        - (1) Density of Ice (solid water) = 0.92 gm/cm^3
        - (2) Density of Water (liquid) = ~1.0 gm/cm^3

            - (a) Result: Ice Floats in Water

        - (3) Why? Because the crystal structure of ice takes up more space (greater volume) than the structure of liquid water molecules

    - c. Importance: A good thing, otherwise oceans and lakes would freeze from the bottom - up... resulting in destruction of all aquatic life!!!

        - (1) Luckily: Lakes / oceans freeze with ice on the surface, and liquid water insulated from freezing at depth.

D. Heat Transfer

1. Mechanisms of Heat Transfer

a. Conduction: heat and vibrational kinetic energy is passed from molecule to molecule, without actual transfer of mass
   (1) heat transfer without mass transfer
   (2) e.g. heating an iron rod, the heat is transferred from one end to the other without transfer of mass

   (3) Examples
      (a) Good conductors of heat = iron / metal (rapidly transmit heat)
      (b) Poor conductors of heat = adobe / brick, fiber glass insulation
      (c) Poor conductor = "good insulator"

b. Convection - heat transferred via transfer of mass

   (1) e.g. "fluid currents" transfer heat

   (2) Convection cells common in ocean, atmosphere, and earth's interior
      (a) e.g. Warm air rises, cools, sinks
      (b) e.g. Warm ocean water rises, cools, sinks

c. Radiation - heat transfer via electromagnetic radiation
   (1) infrared radiation = "thermal radiation"
   (2) remember: infrared = wavelengths longer than visible spectrum

   (3) Emitters of radiant energy
      (a) Sun (hydrogen fusion)
      (b) Earth (radioactive decay of elements)

E. Temperature, Energy and Influence on Physical State

1. Three physical states of matter (water in this case) - dependent on amount of heat energy (vibrational kinetic energy) contained within matter
   a. solid (low energy)
      (1) crystalline atomic structure
   b. liquid (medium energy)
      (1) fluid - material changes shape easily
   c. gas (high energy)
      (1) fluid - material changes shape easily

2. Transformation Processes related to energy input and entropy of water: heating of water, > atomic activity of the water molecules, i.e. > vibrational energy of water atoms.

ICE ----------HEAT----- WATER-------HEAT -------WATER VAPOR
(<32 degrees) (32-212) (>212 degrees F)

3. Evaporation- process of transforming water from liquid to gaseous state (Heat Gain)

4. Freezing- process of transforming water from liquid to solid state (Heat Loss)

5. Condensation- transformation of water vapor to liquid form (Heat Loss)

6. Sublimation- process of transforming ice to water vapor directly through superheating, bypassing liquid form. (Heat Gain)

F. Thermal Budget and States

1. States of matter a function of amount of heat in system, which in turn influences the vibrational rates of molecules

a. gas - high rate of vibration, high heat condition

b. liquid- medium rate of vibration, medium heat system

c. solid- low rate of vibration, low heat system

2. Heat Energy

a. measured in calories

(1) amount of energy required to raise the temperature of 1 gram of water 1 degree C

3. Heat and State Transformation

a. Evaporation: water liquid to vapor = system must absorb 600 Cal of energy

(1) energy absorbed by molecules, > rate of vibration to allow phase change

(2) latent heat of vaporization = "stored heat" that is exchanged to cause phase change

b. Condensation: water vapor to liquid = system must lose 600 Cal of energy

(1) < vibratory motion

(2) latent heat of condensation

(3) Condensation/heat transfer

(a) drives storm systems

(b) affects climate

(c) transfers heat from equator to poles

(d) results in cloud phenomena

c. Melting: solid ice changed to liquid = system must gain 80 calories of energy

d. Freezing: liquid to solid = system must lose 80 calories of energy

(1) latent heat of fusion for water

e. Sublimation: solid to gas or gas to solid = system must gain 680 cal of energy or lose 680 cal of energy respectively for transformation to occur

(1) e.g. dry ice sublimates to gaseous carbon dioxide with no intervening liquid phase

G. Basic Laws of Classical Physics

1. Conservation of Mass - mass is neither created nor destroyed
2. Conservation of Energy - energy is neither created nor destroyed
3. Newton's Second Law of Motion: $F = ma$ (force is equal to mass x acceleration)

Example Conservation Equation in Hydrology

Total Water In = Total Water Out (for example in an aquifer or a watershed)

thus,

$$I - Q = \Delta S$$

where I = water into a system, Q = water flow out of a system, ΔS = change in storage of system

Example Problem: A reservoir is full to the brim and holds 10 km^3 of water. During the course of a given year, the reservoir receives 0.58 km^3 of water via rainfall. Meanwhile, a local city uses 2.3 km^3 of water, what is the net change in reservoir storage for the year?

Show all of your math work.

What is the absolute volume of water in storage at the reservoir after the year in question?

III. Physical Properties of Water

A. Can exist in all three physical states: liquid, solid (ice), and gas (water vapor)

B. Transformation Processes related to energy input and entropy of water: heating of water, > atomic activity of the water molecules, i.e. > vibrational energy of water atoms.

1. ICE ----------HEAT----- WATER-------HEAT -------WATER VAPOR
(<32 degrees) (32-212) (>212 degrees F)

C. Water is one of few earth substances that remains in a liquid state at the operating surface temperatures of the earth.

1. The liquidity of water makes it a dominant and pervasive component of all earth processes

D. Water has High Heat Capacity- it has a capacity to absorb and hold energy with only a small amount of temperature rise.

1. important for water-based organisms to regulate temperature
2. produces the moderating effects of oceans on climate
    a. oceans = warm residual heat in winter (warms air temp.)
    b. oceans = slow rate of heating in summer (cools air temp.)

E. Water expands in volume when it freezes/ becomes colder, in contrast to majority of substances (which contract when colder)

1. Result Density of ice < Density of water: thus ice floats on water

F. Water strongly influenced by the force of gravity, constantly driven downward, and can possess great erosive/ landscape carving force

G. Water has property of high surface tension, ability to have strong molecular attractive forces (sticks to itself and electrostatically attracts ionic forms of elements)

1. Capillarity- phenomena of water moving upward against the force of gravity, due to strong electrostatic adhesive forces, most notable in narrow, restricted pore spaces where surface to surface contact in high.

H. Water acts as a "universal solvent" and can dissolve most any substance over time. Water + carbon dioxide forms a mild carbonic acid solution naturally in hydrosphere, as an acid can result in cationic exchange with positive ionic species, and result in chemical breakdown of substances.

1. Bipolar Water Molecule H_2O

2. Covalent bonds between hydrogen and oxygen (strong bond, via sharing of electrons)
    a. Hydrogen: 1 valence electron (atomic no. of 1)
    b. Oxygen: 6 valence electrons (atomic no. of 8)

Introduction to Earth Systems Science

I. INTRODUCTION

A. **Initial Comment**: The earth is our home and habitat, without its abundant resources (air, water, heat) we would not be in existence today.

1. The Earth is approximately 4.6 billion years old,

2. Basic Earth-Resource Visualization

a. Solar Energy + Plants + Earth Soil (weathered rock) = FOOD!
b. clothing: synthetics/oil, natural/soil
c. building materials: plastics/oil, gypsum, cement, metals
d. energy: gas, electric/coal, fuel oil = fossil fuels from solar energy
e. transportation: gasoline, cars

B. **Earth System Science Defined**: Interdisciplinary study of the earth's naturally occurring phenomena, its processes and evolution.

1. Earth Science by necessity involves the marriage of a number of specialty sciences

a. **Astronomy**- Study of the origin, evolution and composition of the universe, solar system and planetary bodies.

(1) Cosmology: origin of the universe
(2) Astrogeology: comparison of extra-terrestrial planetary bodies with the earth
(3) Astrophysics: quantitative study of the physical nature of the universe

b. **Geology**- study of the earth, its composition, origin, evolution and processes.

(1) Mineralogy/Petrology: study of rocks and minerals
(2) Geophysics: study of earth physics and processes
(3) Volcanology: study of volcanoes
(4) Seismology: study of earthquakes and seismic waves
(5) Geomorphology: study of surface processes and landforms
(6) Paleontology/Historical Geology: study of past life and historical evolution of the earth through time
(7) Plate Tectonics

c. **Meteorology**: Study of atmospheric phenomena

(1) Climatology: study of geographic climate patterns: processes and causes

(a) Future Climate Prediction: Green House
(b) Paleoclimatology

(2) Weather studies and weather prediction
(a) Storm Prediction and Emergency Management

(3) Atmospheric Science: study of physics and chemistry of earth's atmosphere

(a) Environmental/Air Pollution Control

d. **Oceanography**: study of earth's ocean systems

(1) Earth's surface covered by 70% ocean water... hence the reference to the "Blue Planet".
(2) Study of ocean chemistry and circulation patterns
(3) Physical study of seafloor

C. Environmental Spheres of the Earth

1. the earth can be subdivided into spheres" of composition represented by the complex interface of four principal components of the environment: the lithosphere, atmosphere, hydrosphere, and biosphere.

a. The **Geosphere**: comprised of the solid, inorganic portion of the earth's framework including elements to form atoms to form minerals to form rocks (the very foundation of the planet)

(1) Lithosphere and Interior of the Solid Earth - The earth is comprised of a series of compositionally distinct shells of rock.

(a) inner core, a solid iron-rich zone with a radius of 1216 km
(b) outer core, a molten metallic layer 2270 km thick
(c) mantle, a solid rocky layer 2885 km thick
i) includes the upper portion of the mantle referred to as the aesthenosphere - a plastic, viscous zone that is capable of flowing

(d) Lithosphere/crust, the outer rocky skin of the earth, 4 - 40 km thick, designated to include the upper portion of the aesthenosphere and near surface crustal rocks, thicker over continents and thinner over oceans (continental crust vs. oceanic crust).

The earth is a dynamic organism, even though it is made of solid "rock" it is capable of global movements on the lithosphere

b. The **Atmosphere**: the gaseous envelope of air that surrounds the earth

(1) a thick envelope of air (100's of miles thick) that surrounds the earth's surface. Provides the air we breath, together coupled with the sun's energy, drives our climatic and weather systems.

(2) Troposphere-Stratosphere-Mesosphere-Thermosphere-Magnetosphere\

(3) Average composition of elemental gases in dry air
(a) Nitrogen (N_2)= 78%
(b) Oxygen (O_2)= 21%
(c) Argon (inert) = 0.93%
(d) Carbon Dioxide (CO_2) = 0.035%

i) Ability to absorb heat in atmosphere from energy radiated from earth's surface, helps keep the atmosphere warm

(e) All Others = trace (includes Water Vapor)

c. The **Hydrosphere**: the waters of the earth including ground water (beneath the surface), surface water (rivers, streams, lakes, oceans), and water locked up as ice in the form of glaciers.

(1) the water and liquid that is present on the earth's surface, in its atmosphere, and beneath its surface.

(2) Oceans cover 71% of the earth's surface and contain 97% of the earth's water.

(3) Water cycles from the ocean's to the air via evaporation, moves to land, precipitates as rain/snow, partially infiltrates the earth's surface, and eventually flows back to oceans via rivers.

Water and air uniquely combine on the earth's surface and make it habitable for life forms.

d. **Biosphere**: all living matter and cellular tissue on the earth, in the form of plant and animal, both microscopic and macroscopic.

(1) All life on the planet is contained within its uppermost layer of the earth, including its atmosphere.

(2) the vast majority of all earthly life inhabits a zone less than 3 miles thick, and the total vertical extent of the life zone is less than 20 miles.

These 4 environmental spheres are not discrete and separated but are interdependent and interwoven with one another.

E.g. soil- composed of mineral matter (lithosphere), contains life forms (biosphere), soil moisture (hydrosphere), and soil gas (atmosphere) in pore spaces.

D. Basic Earth Perspective

1. The Earth is our home

a. Seemingly infinite in its size and abundance relative to our personal lives, our Earth however is merely an infinitesimal speck floating in the vastness of space, the buffer of life between us as individuals and the hostile vacuum of space.

2. Earth Facts:

Radius = 4000 miles
Diameter = 8000 miles
Circumference = 24,900 miles
Distance to Moon = 230,000 miles
Distance to Sun = 93,000,000 miles
Distance to Next Nearest Star=2.5 x 10^{13} mi.
Highest Elevation = 30,000 ft AMSL
Lowest Elevation = 36,000 ft BMSL

a. Shape of Earth: almost a perfect sphere, but not quite, actually best termed an "oblate spheroid", i.e. the diameter of the earth at the poles is slightly less than the diameter at the equator

(1) Polar diameter = 7900 miles
Equatorial diameter = 7927 miles

Plus topographic irregularities and the concentration of the earth's continents in the northern hemisphere make it slightly less than a perfect blue ball.

E. The Scientific Method

Modern science believes that fundamental, organized laws exist in nature and that through detailed study these laws can be transcribed into human symbolism. Steps in scientific investigations:

1. Collection of scientific facts through careful observation.

a. Use of Earth "Sensing" Instruments for measurements of:
(1) Magnetism
(2) Seismic Waves
(3) Satellite Imagery
(4) Physical Atmospheric Properties

b. Quantification of Data

c. Pattern Recognition, Relationship Definition

2. The development of a working hypothesis to explain the existence of these relationships

a. Quantitative Model Development: Explanation

3. Construction of experiments to validate or reject the hypostheses
    a. Hypothesis Testing
    b. Repeatable results

4. The acceptance, modification, or rejection ofthe hypothesis basedon extensive testing
    a. Development of Scientific Theory/Paradigm: accepted as truth

II. Matter and Energy

A. Matter - all the material of the universe that has mass and exists
    1. Mass - measured typically in grams and kilograms
    2. Matter is comprised of: atoms of elements

B. Energy - ability to do work

    1. work in physics = force and motion
    2. Examples of Energy
        a. Kinetic Energy - energy of motion
            (1) e.g. falling rock
        b. Potential Energy - energy of position, related to gravitational force
            (1) e.g. rock perched on a cliff
        c. Thermal or Heat Energy
            (1) kinetic energy of atoms in a system
            (2) e.g. air temperature = how fast air atoms are moving and vibrating
        d. Electrical Energy
            (1) free flow of electrons
        e. Sound Energy
        f. Mechanical Energy

C. Law of Conservation of Energy - the total energy of the universe is finite, it is neither created nor destroyed, but may be transformed from one type to another
    1. e.g. transfer from potential energy (perched rock on cliff) to kinetic energy (falling rock)

D. Einstein said: Mass (material) and Energy are Interchangeable

    1. $E = mC^2$ - Energy may be converted to mass, and mass to energy

    e.g. solar energy + tree = wood (energy to mass)
        heat + oxygen + wood = fire (mass to energy)

III. Systems and Models
A. System - isolated portion of Universe selected for purposes of observation and measurement

    1. Hierarchy: Universe --- System ---- System Components

2. Scale Examples
    a. Solar System (Sun + Planets)
    b. Earth System (Geosphere + Atmosphere + Hydrosphere + Biosphere)
    c. Classroom-Scale System:

        Question - What are the essential components of our classroom system??

    d. Bench-Top System
        (1) e.g. a beaker half-filled with air and water

B. Boundary Conditions of System
    1. Boundary -limits interaction between system components
        a. Open Boundaries vs. Closed Boundaries

    2. Open System - boundary conditions are such that matter and energy can enter or exit the system freely

        a. Example - this classroom!

    3. Isolated System - boundary conditions are such that matter and energy are contained, neither may enter or leave the system.

        a. Does this exist - can you think of an example?

    4. Closed System - boundary conditions are such that matter can not exit or enter the system, but energy can exchange freely.

        a. Earth = approximates a closed system
            (1) Neglects meteorite impacts to Earth surface or influx of cosmic atomic material (matter addition)
            (2) Energy freely transferable into and out of the system
                (a) Atmospheric heat loss to space
                (b) Solar Energy influx
            (3) Material Resources of Earth are Finite
            (4) Components of the System Interact with One Another
                (a) e.g. Global Warming model
                    i) Biosphere + Hydrosphere + Geosphere regulate carbon dioxide content of atmosphere
                    ii) Carbon dioxide content contributes to regulation of atmospheric temperatures

C. Systems Interactions
    1. Transfer of Energy ("Energy Flux")
        a. e.g. Atmospheric Processes
    2. Transfer of Mass / Matter ("Mass Flux")
        a. e.g. Tectonic Processes

3. Cycling of Mass and Energy
   a. Repetitive flow / transfer of matter/energy between system components
      (1) e.g. oceanic evaporation / atmospheric precipitation
   b. Rates of Change= amount of transfer / change per unit time
      (1) e.g. discharge in a river = gallons / minute

4. System Response Functions

   a. system feedback - response of the system to changes in system components
   b. Negative Feedback - the system response is in the opposite direction of output from a specific function

      (1) Book Example - thermostat control on home heating system

      thermostat - metal electrical connection: heating expands the metal, cooling contracts the metal

      cooling room air = thermostat contraction = electrical connection = furnace on = heating of room

      the net result of room heating is opposite of the initial system condition of room cooling - this is a negative feedback

      (2) Earth Example of Negative Feedback
      Consider Landslides on Steep Mountain Slopes:
      - steep mountain slopes are subject to gravity-driven landslides

      -landslides result in erosion of mountain slopes

      -erosion of mountain slopes reduces the slope angle

      -reduced slope angles do NOT promote gravity-driven landslides

   c. Positive Feedback - the system response is in the same direction as output from a specific function

      (1) Book Example - fire and wet wood

      wet wood does not burn easily

      once fire is started, the heat dries out the wood, and promotes further burning

      ** the net result of wet wood burning is in the same direction asa the initial condition of fire burning ** - this is a positive feedback

(2) Earth System Example of Positive Feedback
Assume Global Warming is Happening...

-Carbon Dioxide Buildup in the Atmosphere Results in Global Warming

-Global Warming results in higher air temperatures

-Higher air temperatures result in drying of forests

-Dry Forests are subject to forest fire

- Forest fire releases more carbon dioxide into atomosphere

-Increased atmospheric carbon dioxide leads to more global warming

IV. Examples of Primary Cycling Functions in the Earth System

A. Energy Cycle

1. Basic Rules of Energy (laws of thermodynamics)

a. Energy is neither created nor destroyed, but it may be changed from one form to another ("Law of Conservation of Energy")

b. Energy will naturally transfer from a more organized state to a more disorganized state

(1) Entropy - measure of disorganization in a system

(a) example- a clean room easily transforms into a messy room, but a messy room does NOT easily transform into a clean room

2. Earth's Energy Budget

a. Solar Energy (electromagnetic radiation)

(1) Source of Solar Energy - hydrogen fusion / hydrogen fuel

(2) Electromagnetic Radiation Products from Sun

(a) visible light (colors of rainbow - ROYGBV)
(b) infrared radiation ("heat")
(c) ultraviolet radiation (sun burn material)

(3) Earth System Response to Solar Energy

(a) Plant Photosynthesis - the basis of Earth life
(b) Atmospheric Processes

i) wind, evaporation / condensation, storms

(c) Oceanic Processes
i) wind/waves, ocean currents

b. Geothermal Energy (internal heat of Earth)

(1) Evidence that the Earth is hot on the inside:
(a) hotsprings, geysers
(b) volcanic eruptions
(c) deep mine shafts / wells

(2) Source of Geothermal Energy
(a) Decay of radioactive elements with heat as a by-product
i) e.g. Uranium

(3) Earth System Response to Geothermal Energy
(a) volcanic eruptions
(b) plate tectonic motion
(c) mountain building
(d) earthquakes

c. Tidal Energy in Oceans

(1) Tides - driven by force of gravity
(a) gravitational pull of ocean water by moon and sun

3. Energy Transformation by Earth System

a. Atmospheric reflection of incoming solar radiation

(1) ~40% of incoming solar radiation is reflected by into space

(2) albedo - measure of the degree of reflectiveness of the Earth's surface

b. Absorption of incoming solar radiation at Earth's surface

(1) heat transfer to atmosphere, plants, oceans

c. Geothermal energy transfer
(1) internal heat loss via
(a) volcanic eruptions
(b) transfer to mechanical energy
i) earthquakes
ii) plate tectonic motion

B. Hydrologic Cycle (include basic chemical composition of sea water)

1. Significance of Water

a. Essential for animal and plant life to exist, forms the medium in which biochemistry can take place.
b. Water solutions transport nutrients and elements to organic tissues, nourishing them. Carries waste products out of tissues.
    (1) Mass of living organisms comprised of water ranges from 65-95%
c. Surface water covers more than 70% of the earth's surface

2. Hydrologic Cycle

a. Closed System

    (1) Water is neither created nor destroyed, the hydrosphere is essentially a closed system,
    (2) BUT water may be transformed from one form to another, and moved from one place to another.

    (3) The Hydrologic Cycle: a circuit of water movement, with storage areas interconnected by various transfer processes... water moves not only geographically, but through physical states as well.

b. Basic Model: Ocean Water----sun's energy---- evaporation -----atmospheric moisture----- condensation/precipitation------land/continental waters-----downgradient flow due to gravity------ back to ocean------and cycling through.

c. Surface to Air: Evaporation prime mechanism for transfer to atmospheric moisture.

    (1) Ocean Evaporation- heat and wind operate on oceans and result in evaporation of water from liquid to vapor form (especially effective in lower latitudes, areas with most direct heating from sun's rays)

    (2) Land Evapotranspiration- water is not only release to the atmosphere on land through evaporation, but also through transpiration of water vapor from plants/trees to the atmosphere.

    (3) Water Vapor Movement:

        (a) Convection- vertical movement of moisturelaiden air masses through heat transferprocess
        (b) Advection - horizontal transport of airmasses by wind

d. Air to Surface: atmospheric water vapor is eventually condensed into liquid or sublimated into ice to form cloud particles = precipitation

e. Surface and Ground Waters: precipitation on land can run several possible courses:

(1) accumulation/ponding on the continental surfaces (will subsequently be subject to high rates of evaporation).
(2) surface runoff: in form of streams and rivers, eventually being subject to partial evaporation and final emptying back to sea.
(3) Infiltration into the ground and uppermost strata comprising the lithosphere; forming "ground water"

(4) Vegetative interception: the interception of precipitation by the vegetative canopy of the biosphere, may be subject to evaporation or eventually fall to ground.

f. Duration of Cycle: water may become temporarily stored and removed from the cycle from hours to days, to years to 100's of thousands of years...depending on the geohydrologic circumstance.

3. Moisture Inventory:

a. Oceans: contain 97% of earth's water
b. Glaciers: 2% of all moisture, comprising 75% of worlds fresh water
c. Ground water: 0.5% of total
d. Surface Water: 0.2%
e. Soil Moisture: 0.1%
f. Atmospheric Moisture: 0.0001%
g. Biological Water: negligible

C. Ultimate Controlling Mechanisms of Earth System Processes
1. Solar Energy (hydrogen fusion)
2. Geothermal Energy (internal radioactive decay)
3. Gravity (driving force of pull)

V. Deep Geologic Time and the Age of the Earth

A. Age of the Earth

1. Archbishop Ussher in 1658 provided first attempt at dating the Earth based on the Bible and Genesis

a. Result: Earth created on October 23, 4004 BC
b. Age of Earth according to biblical reconstruction ~ 6000 years old

2. Modern Chronology Based on Astronomy, Physics, Geochemistry, Paleontology, and Archeology

a. 15-20 billion years ago - Big Bang: beginning of present Universe
b. 5-10 billion years ago - Earth solar system begins developing
c. 4.6 billion years ago - Planet Earth assembled with basic geologic structure
d. 4.0 billion years - first simple cells of life formed
e. 3.5 billion years - oldest known fossils (soft, single cell)
f. ~3.0 billion years - primitive photosynthetic plant cells
g. 600 million years - first multicellular organisms
h. 600-400 million years - invertebrate ocean critters
i. 400 million years - vertebrate / fishes evolve
j. 300- 400 million years ago - plants evolve, amphibians
k. 200 million years - primitive mammals, reptiles / dinosaurs dominate
l. 65 million years - land mammals dominate, extinction of dinosaurs
m. 2 million years - human-like critters evolve
n. 18,000-20,000 years ago - Last major glacial cover on North America (Seattle was under a 1000 ft of ice!)
o. 15,000 years ago - earliest archeological evidence for modern man in North America
p. 500 years ago - Spanish explorers to "New World"
q. 15-20 years ago - MTV evolves
r. 5 years ago - the internet takes off
s. today - You and I are here thinking about it....

B. Geologic Rock Record:

1. Rocks - record of Earth history

   a. Analogous to a tape recording in which some historical events are preserved and recorded, others have been erased, and still others were not taped at all

2. Types of Records Preserved in Rocks
   a. Past Life (fossils)
   b. Past Climate Conditions
      (1) e.g. "Glacial Ages"
   c. Past Geographic Organization
   d. Past Oceanic Conditions
   e. Past Magnetic Field Conditions

C. Basic Principles
1. Principle of Uniformitarianism
   a. "The present is the key to the past".

   b. Natural laws that are presently observable, have been operating throughout Earth history

   c. Very slow, incremental geologic processes have occurred over immense amounts of time, to result in large scale changes of the earth.

2. Principle of Catastrophism

a. Catastrophist View: large-scale catastrophic processes are responsible for most of the changes and evolution of the earth (floods, earthquakes, volcanic eruptions, storms)

(1) Short bursts of violent (high energy) processes, followed by slow process cycles

b. Original Premise - Church / biblical view of Earth history
(1) Phase 1 - all time since creation before Noah's Flood
(2) Phase 2 - all time since Noah's Flood to the present
(3) Noah's Flood
(a) used to explain most geologic phenomena originally

D. Methods of Determing Ages of Rock Materials

1. Relative Dating
a. Earth history placed in the context of relative sequences of geologic events.
b. Example - Law of superposition- in an undisturbed sequence of sedimentary rocks, the lowermost rock layers are the oldest, and the uppermost rock layers the youngest.

2. Absolute / Numeric Geochemical Dating

a. Chemical Technique - uses radioactive elements contained within minerals and rocks chemically and quantitatively determine the absolute age of that rock within the framework of statistical and/or experimental error.
b. Precise dating of geologic events from the rock record
c. Example: Uranium decays into lead at a known, constant rate
(1) measure the amount of lead and uranium in a mineral, can determine it's age since formation