G473 Environmental Geology - Rivers and Floods

I. Hydrologic Cycle

A. 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.

1. 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.

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

a. 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)

b. 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.

c. Water Vapor Movement:

(1) Convection- vertical movement of moisture laden air masses through heat transfer process

(2) Advection - horizontal transport of air masses by wind currents.

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

a. accumulation/ponding on the continental surfaces (will subsequently be subject to high rates of evaporation).

b. surface runoff: in form of streams and rivers, eventually being subject to partial evaporation and final emptying back to sea.

c. Infiltration into the ground and uppermost strata comprising the lithosphere; forming "ground water"

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

B. Moisture Inventory:

1. Oceans: contain 97% of earth's water
2. Glaciers: 2% of all moisture, comprising 75% of worlds fresh water
3. Ground water: 0.5% of total
4. Surface Water: 0.2%
5. Soil Moisture: 0.1%
6. Atmospheric Moisture: 0.0001%
7. Biological Water: negligible

C. WATER BUDGET

1. Input Mechanism into surface water process = atmospheric precipitation
   - a. Precipitation = runoff + interception + storage
     - (1) Interception = evapotranspiration + evaporation + infiltration
     - (2) Storage = groundwater and/or snow pack and ice

2. Precipitation: atmospheric moisture release (rain/snow fall)
   - a. Regional climatic and seasonal control on amount in any given region
     - (1) Storm/precipitation cycles
       - (a) Intensity: volume precip/unit time (> volume/time > intensity)
         - i) rainfall volume measured in inches of rain
         - ii) may graph time vs. inches of rain
       - (b) Recurrence Interval = statistical chance of a storm of a given intensity occurring within a prescribed time period
         - i) $RI = \frac{\text{Total No. of Years of Record}}{\text{No. Storms > Given Intensity}}$
           - a) e.g. 20 RI over 100 years observation = 5 occurrences
           - b) Generally the larger the event, the greater the recurrence interval
       - (c) Duration: length of storm occurrence
         - i) Intensity inversely proportional to duration and RI
           - a) High intensity, long duration storms will produce the greatest amount of geomorphic change to the landscape

3. Interception
   - a. interception of rainfall by plants, leaves, groundcover prior to reaching the ground
     - (1) Interception = "energy dissipator" in terms of rain fall impact on landscape (reduces erosion rates)
   - b. Evapotranspiration: atmospheric evaporation of moisture directly from plant tissue and/or in-take of moisture into plant system
     - (1) Foliage Evaporation = function of air temp. and humidity

c. Amount of interception = function of:
   (1) type and species of plant cover
   (2) density of foliage/plant cover

d. Approximating Regional Interception
   (1) Measure total precipitation for drainage basin
   (2) Measure total stream discharge at mouth of basin
      (a) difference ~= interception + infiltration
      (b) generally difficult variable to measure

4. Infiltration
   a. water/precipitation that seeps into soil/subsurface rock
   b. Infiltration function of:
      (1) vegetative cover
      (2) soil permeability/porosity
      (3) slope grade
      (4) moisture content of soil dissolution.

   c. Soil Moisture Content
      (1) Soil Water Balance; soil water budget: input via precipitation and surface infiltration (capillary action to lesser extent); output via evapotranspiration. Soil water balance influenced by soil structure, vegetative characteristics, and climate

5. Runoff = free water flowing on continental surfaces of earth (free flowing water not tied up as infiltration or evapotranspiration)

II. Watershed and River Analysis

A. Measuring Channelized Runoff
   (1) Discharge: volume of flow/unit time (continuity equation):

      (a) Q = VA; V = L/T; A = wd where,

Q = discharge (L^3/T) V = average velocity (L/T) A = cross-sectional area (L^2)
w = channel width d = channel depth

      (b) As Q>, V> in channelized flow, i.e. stream flow is faster during flood periods

   (2) Wetted Perimeter = wetted portion of channel base and sides

      (a) P = 2d + w
      (b) wetted perimeter = zone of friction interface between flowing water and channel boundaries
         i) water velocity lowest around margins of channel (due to friction), highest in central portion of channel

(c) Hydraulic Radius of Channel: R

i) R = A/P (L)

(d) Manning Equation

i) $v = (R^{0.66}S^{0.5})/n$

where v = mean velocity, n = coefficient of roughness R = hydraulic radius S = slope

1. Stream Discharge and Flooding

a. Gaging stations: measure discharge of stream/river over period of time (daily, monthly, annually)

(1) RI = Recurrence Interval of Discharge Data =

$$\frac{\text{Total No. of Years of Record}}{\text{No. of Discharge Occurrences > Given Value}}$$

(a) Discharge Observations (Y axis) vs. Recurrence Interval (X axis)

b. Flood periodicities and frequencies of occurrences are important calculations for watershed planning, land use analysis, and emergency management operations

B. Morphologic Features of Drainage Systems

1. Drainage Basin: spatially restricted network of branching surface streams/rivers. aka a "watershed"- an area that contributes overland flow and groundwater to a specific stream network.

a. Drainage Divide: upland flow separation between runoff that descends in the direction of the drainage basin in question and that which goes toward and adjacent basin.

b. Drainage Net: the complex of streams within a drainage basin.

c. Nested drainage basins based on scale (e.g. Sewickly Creek flows past WCCC, makes its way to Yough River, which makes its way to Mon, and on to Ohio, and on t Mississippi. At each level of scale, a drainage basin can be defined).

2. Topographic Considerations

a. Valley- lowlying area that is totally or partially occupied by a stream channel

Includes: stream channel, adjacent floodplain, and valley sides. Valley bottoms may be narrow or extensively wide Valley sides may be gentle or very steep.

b. Interfluve- the high land above valley sides that separates adjacent valleys ("between rivers"). May be sharp and well defined or broad and diffuse upland drainage divides.

3. Stream Order Hierarchy: organization of drainage basin tributaries according to relative size (Horton, 1945; Strahler, 1952)

a. Stream Orders: hierarchical ranking of stream size within a drainage basin

(1) First order- smallest unit in system, represents a single tributary in a net.
(a) small scale tributaries in headland region of basin
(2) Second order- a stream formed by two first order streams coming together

(a) Medium scale tributary
(3) Third order- a stream formed by confluence of two second order streams
(4) Fourth Order: larger scale drainage basin

b. Drainage Basin Classification: based on largest order trunk stream draining basin

(1) e.g. 5th order Basin = drained by 5th order trunk stream, etc.

c. General Relationships: as Stream order >: stream length >, no. of streams of given order <, drainage area >, Discharge >, gradient <

C. River Morphology
1. River Parts
a. Channel
b. Floodplain
(1) Floodplain Formation
(a) Lateral Erosion
(b) Vertical Deposition
c. Levee
2. River Shapes
a. Meandering
b. Braided
c. Straight
3. Controlling Factors on Discharge
a. Precipitation / Runoff
(1) Season
(2) Vegetative Cover
b. Drainage Area
c. Number of Tributaries
d. Channel Shape
(1) Wide / Shallow
(2) Narrow / Deep

III. Flooding

A. river stage = water surface elevation
   1. height of surface above datum (e.g. sea level)
   2. flood stage
      a. height of river surface during overbank conditions
   3. Bankfull stage - height of river at which channel is completely full

B. Gaging stations - measure height of river stage
   1. stage rating curve:
      a. relates river stage to discharge
      b. Bankfull discharge
      c. flood discharge

C. Flood - overbank flow (out-of-channel flow)
   1. Flood Stage
      a. Elevation of water surface associated with out-of-channel flow
   2. Flood Discharge
      a. Discharge associated with overbank flow

D. Driving Mechanisms
   1. Seasonal Precipitation
   2. Storm Events
   3. Rain-on-snow Events
   4. Dam Burst
      a. Natural
         (1) Volcanic Dams
         (2) Glacial Dams
      b. Man-made
         (1) e.g. Buffalo Creek, WV
   5. Backwater Flood Effects (local damming by obstructions)
      a. Bridges
      b. Culverts
      c. Ice Jams
      d. Woody Debris Dams

E. Special Case: Coastal Flooding
   1. Affected Areas: Tidal Channels, Estuaries and Coastal Rivers
   2. Driving Mechanisms
      a. High Discharge from River
      b. Ocean Storms
         (1) Storm Surge / High Wave Activity
      c. Tsunami (seismic sea waves)
      d. Tidal / Gravitational Effects
      e. Global Warming / Ice Cap Melting

   3. Coastal Development and Erosion Issues

IV. Floodplain Delineation / Flood Hazards Analysis

A. Intensity-Duration-Frequency Analysis of Point Rainfall
  1. Considerations
    a. Economics: must design structures to accommodate reasonably large-size event within economic constraints
    b. Geomorphic Work
      (1) work done during extreme events
        (a) although less than mid-size events
    c. Recurrence interval and maximum events
      (1) is it worth planning/$$ for 500 yr event?
    d. Basic Pattern
      (1) short duration: high intensity
      (2) long duration: low intensity

  2. Data for Intensity-Duration-Frequency Analysis for Storms
    a. Intensities calculated at varying time intervals (5 min, 1 hr, 2 hr, 6 hr 24 hr, etc)
    b. Freqeuncy analysis
      (1) Recurrence Interval = "return period"
        (a) $T = 1/p = (n+1)/m$
          i) where T = recurrence interval in yrs, p = probability of equal or exceeding given intensity

      (2) Data for highest and lowest values sparse, and must be extrapolated
        (a) paleoflood analysis used to push limits of extrapolation
      (3) Authors give some graphical techniques for analysis

B. Magnitude-Frequency Relations for Stream Discharge
  1. similar to rainfall intensity above, only using stream discharge

C. Flood Hydrograph
  1. x-axis = time (days)
  2. y-axis = dicharge

V. Flood Hazards and Social Costs
A. Controlling Factors
  1. Land-use on Floodplain
  2. Magnitude
  3. Duration
  4. Season
  5. Forecasting / warning

B. Damage
  1. Erosion / sedimentation
  2. Building Destruction
  3. Crop / Animal Loss
  4. Death / Drowning
  5. Property Loss / Loss of Infrastructure

C. Social Aspects
  1. short memory by public
  2. Federal insurance programs promote re-building / continued development
  3. Rivers and Floodplains Heavily Populated
    a. Water necessary for life
    b. River valleys prime for agricultural Production

D. Human Habitation
  1. flood plains attractive for habitation
    a. level ground
    b. transportation corridors
    c. soils fertile
    d. water source for infrastructure

  2. problem: flood prone, damage, destruction
    a. psychology of habitation
    b. land developers

  3. Flood Damage Estimates
    a. large diffs. in flood damage estimates around US
      (1) f(economy, hydrology, topography, population)
      (2) quality of reports, records
    b. illusion: "flood control"
    c. Crop loss, livestock, scouring of topsoil (often left out of flood damage estimates)
    d. business interuptions, commercial property loss
    e. residential: water damage, structural damage

E. Case Histories

  1. 1972 - Buffalo Creek, Logan County, WV
    a. Collapse and failure of coal-waste impoundment
      (1) narrow, steep mountain valleys
      (2) 132 million gallons of water released instantaneously
      (3) 125 dead, 4000-5000 homeless
      (4) catastrophic outburst flood

        (a) discharge increased to 50000 cfs within minutes
        (b) flash flood / wall of water
        (c) flood depths of 3-5 m (up to 20 ft)

    b. Heavy rainfall resulted in dam failure

2. Large-Scale Regional Flooding - Hurricane Agnes, June 1972
   a. Hurricane tracked from Gulf up the eastern sea board
   b. High intensity rainfall
      (1) PA, NY hardest hit with flooding
         (a) 117 deaths, $3 billion in damage
         (b) Susquehanna River 15-20 ft above flood stage
         (c) >200 yr flood

VI. Flood Hazard Mitigation
A. Prevention
   1. Levees and flood walls
   2. Flood-control Reservoirs
   3. Storm-water Retention basins
   4. Channel Diversions
   5. Lock and Dam System
   6. Channelization
      a. Channel Deepening / Dredging
      b. Drainage of Wetlands (> storage capacity on floodplain)
   7. Erosion Control
      a. Rip-Rap
      b. Concrete Linings

B. Floodplain Regulation
   1. Restricted floodplain development
   2. Sustainable floodplain design
   3. floodplain zoning

C. Flood Hazard Mapping
   1. Critical Questions
      a. Area of inunundation vs. flood size (discharge and stage)?
      b. Flood stage predicted?
      c. Flood discharge / stream power predicted?
   2. Data Sources
      a. Historical Flood Records / Recurrence Interval
      b. Gage Station Data / Flow Data
      c. Stream Numbers and Drainage Density
      d. Remote Sensing / Aerial Photos / Geomorphic Mapping
         (1) Soils, Vegetation, Rock Geology
         (2) Geobotanical I.D. of Flood-Impacted Zones
         (3) Paleoflood Hydrology
   3. GIS Analysis / Spatial Analysis
      a. Floodplain Modelling
      b. Discharge / Stage Modelling
         (1) Channel Geometry
         (2) Valley Geometry
         (3) Discharge Calculation
         (4) Stage Calculation
         (5) Prediction of Flood-Impacted Zones

4. Products Available
    a. Flood-Hazard Maps (U.S. Geological Survey)
    b. Flood Hazard Maps (FEMA)
    c. Floodplain Maps (RI=100 yr, U.S. Army Corps of Engineers)
    d. Flood Insurance Maps (National Flood Insurance Program)

D. Hydrologic Information for Flood Damage Reduction

1. Data utilized for planning and mitigation
    a. rainfall/snowmelt runoff data
    b. weather station meteorological data
    c. help modelling/water budgets
        (1) basic water conveyance, engineering design data
    d. Flood records, geomorph investigation to characterize size of known floods
        (1) paleoflood analysis
        (2) site evaluations following floods
        (3) air photos/records
        (4) historical records, papers, interviews
        (5) gauge records
        (6) alluvial geometries, terraces, soils types
        (7) use of vegetation in recognizing flood-prone areas
            (a) weird events to think about when planning
                i) glacial outbursts
                ii) tsunamis

E. Floodplain Zoning
1. 100 Year Floodplain
2. Flood Hazard Area
    a. Floodway District
        (1) Zone that permits passage of 100 year flood discharge without increasing the elevation of the flood stage by more than 0.3 m
            (a) farming, agriculture, open facilities such as parking lots
    b. Floodway Fringe
        (1) Zone of elevation between Floodway District and maximum elevation of 100 year flood in a region

F. Risk Assessment of Flood Hazards
1. Flood Prediction
    a. Statistical Probabilities
    b. Flood Frequency Analysis
        (1) Recurrence Interval

2. Flood Forecasting / Modelling
    a. Data
        (1) Channel Morphology
            (a) Width / Depth / Slope
            (b) Valley Morphology
        (2) Catchment Area
        (3) Infiltration / Runoff Estimates

                (a) Soils
                (b) Vegetation
                (c) Bedrock
                (d) Antecedent Moisture
            (4) Precipitation Volume
                (a) Rainfall
                (b) Rain-on-Snow Modelling
            (5) Flood Hydrographs
                (a) Peak Discharge / Peak Stage Modelling

VII. Effects of Urbanization
- A. Urbanization
    - 1. < vegetative cover
    - 2. floodplain development
        - a. pavement < infiltration, > flashy runoff
    - 3. storm-water management

- B. Effects of Urbanization (> Runoff)
    - 1. < in lag time to peak discharge (flashy discharge)
    - 2. > magnitude of peak discharge from a given storm
    - 3. > total discharge from a given storm

- C. Agriculture and Forest Practices
    - 1. Clear-cutting
    - 2. Loss of agricultural areas to urbanization

- D. Planning/Engineering Solutions for Mitigation in Urban Areas
    - 1. stormwater management
        - a. detention in small volumes near source
            - (1) allowing short term retention of water on roof tops and parking lots
            - (2) underground storage tanks
            - (3) diversion of stormwater to permeable subsurface environment
                - (a) infiltration wells, porous pavement
                - (b) problem: stormwater contamination
            - (4) surface detention ponds, culverts
                - (a) nonpoint source contamination
            - (5) Flood storage in natural landscape