Drainage Basins
Overview of Surface
Hydrology

Section 1. The Drainage Basin

I. Introduction
- A. Terminology
  - 1. drainage basin or watershed: network of surface water collection tributaires
    - a. delivery of sediment and water from system
  - 2. divide or interfluve - upland areas that separate drainage basins
  - 3. Trunk channels vs. tributaries
    - a. Sediment removal mechanism
    - b. landscape degradation

- B. System
  - 1. External Inputs
    - a. Geology
    - b. Tectonics
    - c. Climate
    - d. Landuse

  - 2. Internal System
    - a. Basin collection
    - b. Channel transport
    - c. Delta deposition
    - d. Fluvial Mechanics
      - (1) sediment supply vs. water discharge
      - (2) mechanical adjustments as needed
        - (a) aggradation
        - (b) degradation

II. Slope Hydrology and Runoff Generation

- A. Water Budget

  - 1. Precipitation: source of drainage
    - a. primary flux of water in any drainage system
    - b. water transport pathways
  - 2. Interception: vegetal interception
    - a. catchment of rainfall by leaves, trunks and other vegetal matter
    - b. < erosive force of raindrop
    - c. 10-20% interception in grass area, up to 50% in forest canopy
  - 3. Evapotranspiration: rain that does not reach ground, vegetal consumption, leaf evaporation
  - 4. Infiltration vs. Runoff

    - a. storm of surface runoff: direct surface flow following precipitation event
    - b. Infiltration: soil percolation, vadose zone hydrology

(1) Infiltration Capacity: rate of percolation based on soil conditions (in mm/hr)

(a) f(soil thickness, texture, structure, vegetation, pre-existing soil moisture)
(b) control:
i) absorption to soil
ii) storage of water in pore spaces
iii) downward conveyence through soil

(2) Infiltration vs. Runoff controlled by geology
(a) lithology and related soils controlled by inherent permeability of earth materials

(3) Infiltration with time
(a) high rate, exponentially decays with time as available pore spaces fill

c. Hortonian Overland Flow

(1) precipitation > infiltration capacity = runoff down slope surface
(2) instantaneous supply to channels as sheet flow
(3) where precipitation < infiltration capacity = water infiltrates, transport to water table, then to channels

(a) result: delay in peak flow of streams from ppt to discharge, because of groundwater lag.

(4) Overland flow
(a) sheetflow
(b) rill- flow

5. Subsurface Stormflow and Saturated Overland Flow

a. Vadose zone transport
(1) lateral = through-flow or interflow
(2) vertical percolation
(a) =f(anisotropy, permeability)
(3) Variations on Theme
(a) Macropore piping
i) preferred flow along root channels or borrows
ii) textural variables
(4) Saturated Overland Flow
(a) all vadose zone fully saturated
(b) direct surface runoff only possible

B. Stream Hydrograph and Basin Character

1. Basic Question: how much runoff? how quickly discharged to channels? Probability and prediction of flood?

2. Flood Hydrographs
   a. data collection of stream discharge vs. time
      (1) direct runoff (surface response)
      (2) baseflow (groundwater discharge to stream system over time)
         (a) sole source feeding stream flow during dry seasons
   b. Data Character
      (1) precipitation---- rising limb of graph --- peak flow --- recessional limb of graph
         (a) lag time common: between peak storm discharge and peak flow to stream
            i) owing to transport (surface and subsurface)
            ii) "basin lag"- time diff. between centroid of rainfall event and centroid of max. Q at measuring points
            iii) > lag time with > basin size
               a) f(floodplain storage potential)

C. Effect of Physical Basin Characteristics

1. Controls on Hydrograph
   a. temporal and spatial distribution of rainfall/precipitation
   b. basin characteristics
      (1) area, channel density, geometry, soils, vegetation, land use
   c. "unit hydrograph" = type hydrograph for a given basin

III. Initiation of Channels and Drainage Networks

A. Basic Principles

1. Hortonian Principle
   a. rainfall intensity > infiltration capacity = overland flow = erosion
      (1) shear force of flowing water on slope material
         (a) as Force > Resistance = erosion
            i) Threshold process F>R

      (2) Resisting Factors
         (a) soil cohesion
         (b) vegetative cover (type and density)
         (c) pre-existing moisture

   b. Tractive or Shear Force

$$\tau_o = (\gamma_f)D(\theta_c)$$

where τ_o = shear or tractive force on sediment, γ_f= specific weight of fluid, D is flow depth, θ_c = gradient

c. Hillslope Erosion Processes

(1) Erosive process: rills to gullies to channels
(a) Horton's critical length = distance from drainage divide to point downslope where erosion/rilling will begin
(b) f(rainfall intensity, slope, veg. cover)

(2) Rill Process
(a) micropiracy and "cross-grading"
i) rills pirate into primary rill channel
ii) rills necessary forerunner of stream channels

(3) Channel Bifurcation
(a) division of single channels into two
i) headward erosion

(4) Groundwater Sapping
(a) gw seepage zones, with flow convergence on hillslopes
(b) hillslope erosion at point of emergence, spring discharge

B. Basin Morphometry

1. General
a. Basin Morphometry: geometric characterization of drainage basin
(1) predict flood peaks, sediment yield, estimate erosion rates
b. Strahler (1952) Stream Ordering Technique
(1) 1 = smallest trib. with no other tribs.
(2) 1+1 =2, 2+2 = 3, 3+3 =4, etc.
c. Quantification and Characterization
(1) Linear scale (with units) measurements
(2) Dimensionless Ratios

2. Types of Relations
a. Linear
(1) relates basin character to stream order
(2) Examples
(a) Bifurcation ratio: ratio of no. of streams of given order to next highest order
i) rapid estimate of frequency of orders
ii) Rb avg. 3 - 5

(b) Length Ratio: ratio of avg. length of streams of a given oder to those of next highest order.
b. Areal
(1) Ao = area of any basin of given order (basic unit)
(2) Drainage density D = avg. length of streams per unit area
(a) f(geolog yand climate)

c. Relief: characterizes vertical dimension of basin
  (1) includes factors of gradient and elevation
  (2) examples
    (a) max. basin relief: high el. on divide - lowest el. at mouth of trunk stream
    (b) relief ratio: max. basin relief/dist. parallel to trunk basin drainage
    (c) Hypsometric analysis: relates elevation and basin area

3. Summary Common Morphometric Relationships

(common abbreviations in formulas: s = order of master stream, o = given stream order, H = basin Relief, P = Basin parameter)

a. Linear Morphometry

Stream Nos. in Order $N_o = R_b^{s-o}$

Total Stream Nos. in Basin $N = \dfrac{R_b^s - 1}{R_b - 1}$

Avg. Stream Length $(\text{Avg } L_o) = (\text{Avg } L_1) R_L^{0-1}$

Total Stream Length: $L_o = (\text{Avg } L_1) R_b^{s-1}((u^s - 1)/(u-1))$ where u = RL/RB

Bifurcation Ratio $R_b = N_o / N_{o+1}$

Lenght Ratio $R_L = (\text{Avg } L_o)/(\text{Avg} L_{o+1})$

Length of Overland Flow $l_o = 1/(2D)$

b. Areal Morphometry

Stream Areas in Each Order:

$$\text{Avg } A_o = (\text{Avg } A_1) R_a^{o-1}$$

Length Area $L = 1.4A^{0.6}$
Basin Shape $R_f = A_o / L_b^2$
Drainage Density $D = (\text{Sum } L)/A$
Stream Frequency $F_s = N/A$
Constant of Channel Maintenance $C = 1/D$

c. Relief Morphometry

Relief Ratio $R_h = H/L_o$
Relative relief $R_{hp} = H/P$
Relative Basin Height $y = h/H$
Relative Basin Area $x = a/A$
Ruggedness No. $R = DH$

C. Basin Morphometry and Flood Hydrograph
1. Hazards mitigation: led to prediction of flood occurrence by use of morphometric relationships
a. flood hydrograph ideally will be characterized by basin morphometry as it catches precip.
b. controls
(1) drainage density and peak flood
(2) floodplain storage capacity

IV. Basin Hydrology

A. Hydrologic Budget
1. water input - output = Storage
a. inputs = rain and snow
b. outputs =
(1) streamflow
(2) evapotanspiration
(3) infiltration

B. Subsurface Water

1. Hydrogeology - groundwater geology
2. Groundwater Profile
a. vadose/soil moisture
b. capillary fringe
c. water table
d. phreatic zone
3. Movement of Groundwater
a. gravity
b. head potential
c. hydraulic conductivity
d. hydraulic gradient
e. Darcy's Law: V = K (h1-h2)/L; Q = KIA
4. Aquifers, wells, etc.
a. unconfined,
b. confined
c. water table vs. potentiometric surface
d. artesian flow
e. cone of depression

C. Surface Water
1. Basic Principles
a. Discharge: Q =wdv = Av
(1) velocity is difficult to measure across channel be cause it is variable
b. Gaging Stations
(1) discharge measurements along streams/rivers
(a) mean daily discharge
(b) mean annual discharge

(2) River stage = height above ref. point
    (a) rating curve: relates stage to Q for ease of extrapolation

2. Flood Frequency
   a. What is the frequency and magnitude of floods in a given system?
   b. flood duration curve
      (1) semi-log plot of discharge (y-log) vs. percent of time flow equaled or exceeded discharge (x-arith)
      (2) used in flood mitigation/planning
   c. flood recurrence interval
      (1) Weibull method: R =(n+1)/m where R = recurrence in years, n = no. of years in annual series, m = magnitude rank of a given flood.
      (2) plotted on prob. paper to give estimate of mag. of flood that can be expected in a given time period.
      (3) Probability of a given flood occurrring P = 1/R

3. Paleoflood hydrology
   a. extending flood record back beyond historical records
      (1) in U.S. gage histories back to about 100 yrs.
   b. Paleoflood analysis a la Vic Baker and colleagues
      (1) tree scars/ring analysis of trees on floodplains
      (2) flood magnitude reconstruction from deposits and other markers
      (3) Stratigraphy of slack water deposits
          (a) fine grained seds. dep. in areas of backflow or flow separation from main current
              i) suspension deposition
          (b) sites
              i) narrow bedrock reaches
              ii) caves that are flooded
          (c) provides estimates of highest or terminal elevation of water up tributaries of channels
              i) i.d. highest el. of slack water seds. in distal reaches
              ii) date by radio carbon, or alternatively pmag. (if old enough).
          (d) Have extended flood frequency curves back 2000 to 10000 years
      (4) Paleoflood data used to reconstruct effects of Quaternary climate change on geomorphic systems

Section 2 Flood Climatology

I. Introduction

A. U.S. Climatic Regimes
1. humid coastal plains
2. arid desert basins
3. temperate woodlands
4. semiarid grasslands
5. tropical islands
6. subarctic interiors
7. complex microenvironments in mountainscapes

B. Flooding in U.S.
1. climate driven: more rain than drainage basin can store... flooding
2. Types of weather conditions that cause flooding
   a. convective thunderstorms
   b. tropical storms/hurricanes
   c. extratropical cyclones
   d. frontal systems
   e. rapid snowmelt
3. Large-scale climate framework
   a. seasonal availability and large-scale delivery pathways of atm. moisture
   b. seasonal frequency, localtions, and degree of persistence of weather/ppt events
   c. seasonal variation of climate, land surface conditions that effect runoff (antecedent soil moisture, snow cover)

II. Moisture in Atmosphere

A. General
1. Primary source = oceans
   a. evaporation
   b. moisture transport
   c. general atmospheric circulation/diff. heating
2. Precipitation process
   a. warm air > moisture capacity
      (1) moist air masses = warm, tropical ocean locals
      (2) cold dry air masses = polar continental

   b. Most precipitable moisture held in lower, warmer parts of the troposphere
      (1) max moisture content in warm oceanic areas
      (2) min moisture content in mountainous regions of western U.S.

3. Seasonal Flux in U.S.
    a. Summer/July = max. ppt/water vapor on avg.
        (1) concentrated in Gulf states

B. Large-scale, moisture delivery pathways
    1. General
        a. Moisture pathways in air determined seasonally by direction of surface winds
            (1) January
                (a) Northwesterly jetstream dips down into south central states
                (b) moisture delivery from Gulf and southern Atlantic in southern states; delivery to NE along appalachians (winter storms in NE)

            (2) April
                (a) Moisture from Gulf/Atlantic pushes northward in east, se
                (b) moisture from Pacific in West

            (3) July: heavy rainfall month
                (a) Pacific to west coast
                (b) Atlantic to Gulf on east U.S./central U.S.

            (4) October
                (a) Gulf air shifts back to south as jet stream from NW begins to shift southward

        b. Air Pathways shift seasonally
            (1) determine montly precipitation patterns
            (2) control tendency for regional flooding
                (a) via intense/prolonged storms

        c. Air mass source of moisture (regionally)
            (1) Pacific Ocean
                (a) seasonally shifts with seasons, from 60 to 35 N lat.
                (b) westerly winds, moisture to west coast
                (c) stabilizing effect to prevent extensive moisture from Pacific...
                    i) North Pacific anticyclone (high press)
                    ii) cold California current
                        a) especially in summer, with dry area along west coast
                (d) Orographic effect with Cascades/Sierras
                (e) Winter chinooks: modified dry Pacific air passes into western interior, with warm dry air, causing snow melt

            (2) Atlantic Ocean-Gulf of Mexico
                (a) dominant process of ppt delivery in east and central states
                (b) Summer months

i) subtropical high pressure of N. Atlantic shifts north and west allowing maritime tropical air masses to move onto continent
ii) spring and summer rain in central/east U.S.

(c) Gulf air to southwest occasionally

(3) Arctic Region
(a) cold, relatively dry arctic air pushes south into U.S.
i) frontal system dynamics
a) cold air on bottom
b) collision with warm moisture laiden air on top
c) unstable, cyclonic frontal systems

III. Atmospheric Processes that Release Moisture

A. General

1. Process of moisture release from atmosphere

a. controlled by uplift mechanisms that cool and condense layers of moist air leading to
(1) clouds development
(2) precipitation
(3) possible flooding

b. Air Uplift Mechanisms
(1) Thermal convection of moist, unstable air
(a) limited spatial distribution
(b) high intensity storms
(2) large-scale frontal convergence
(a) extensive spatial distribution
(b) low to mod. intensity
(3) forced vertical motions via perterbations in upper atmosphere
(a) local or widespread effects
(4) orographic lifting
(a) local or widespread effects depending on topographic extent and configuration

B. Convectional Processes

1. General

a. several mechanisms stimulated by convection
(1) air mass homogeneous throughout
(a) warm, wet

b. may act simultaneous with frontal or orographic conditions

c. process: thunderheads, cumulonimbus storm clouds
(1) high intensity, short duration storms
(2) flash flooding
(3) localized occurrence

2. Thunderstorm Activity
    a. Character
        (1) flashy, intense pppt
        (2) regional variation in occurrence in U.S.
            (a) Fla/ Gulf, highest occurrence in US
        (3) warm, moist unstable air
        (4) may form locally, or in concert with frontal systems

    b. Flood generation
        (1) usually storms don't produce enough ppt for flooding
        (2) multicell clusters of prolongued duration can delivery hugh amts of ppt/flooding though

3. Mesoscale Convective Complexes and Systems

    a. "MCC's" and MCS's

        (1) huge, multiple celled, highly organized thunderstorm complexes
        (2) can last for prolongued periods of time: 6-36 hours
        (3) multiple, supercelled T storms
            (a) tornadoes, lightening, locally intense ppt
        (4) Common in spring and summer in Great Plains and Midwest
        (5) e.g. Big Thompson Canyon flood in CO in 1972

4. Tropical Cyclones

    a. largest atmospheric features produced by convective processes
        (1) tropical low press. systems
        (2) diamters = 60-600 miles
        (3) sources: wester N.Atlantic, Gulf, Caribbean
        (4) critical temps of sea-surface: >79 F
        (5) late summer, early fall

    b. Flood history
        (1) commonly affect Eastern US
        (2) have resulted in largest floods of record
            (a) common to generate > 100 yr floods

        (3) Tropical cyclones and flood processes
            (a) coastal area storm surges
            (b) hits land delivering much moisture

C. Large-Scale Atmospheric Convergence
1. General
    a. collision of heterogeneous air masses
        (1) ppt of > geographic extent
        (2) long duration
        (3) < intensity

(4) localized instability
(a) secondary convective storms
i) T storms near front line

b. Regional/U.S.
(1) cold polar air masses collide with warm tropical air masses
(a) shifts seasonally

2. Extratropical Cyclones and Their Associated Fronts
a. Cyclone tracks as westerlies across U.S./Midwest
(1) winter: shift with southerly dip
(2) summer: maintained in northern lat.

b. Variations
(1) Great Lakes: local lake effect, snow squalls
(2) most active in spring

3. Precipitation-Enhancing, Upper Atmospheric Air Patterns

a. Modification to cyclonic systems
(1) jetstreams in upper atmosphere
(a) U.S. jetstream: west to east
(b) sinuous air flow patterns
(c) variability can control lower atmosphere cyclones, moving or stalling systems

D. Orographic Lifting

1. Process and Products
a. lifting of air masses over topography, mountains
(1) cooling air, moisture release
(2) wet cloudy windward slopes
(3) dry lee slopes

2. Regional / US
a. moderate orographic effect with Gulf/Atlantic air over Appalachians
b. west: Oregon, WA, Calif.
c. local flash flooding
(1) > flood prone areas, as soil moisture maintained at or near saturation
(2) additional processes can easily max. out system

IV. Antecedent Land-Surface Conditions

A. General
1. Precipitation may not cause flooding, also controlled by ground conditions
a. urban areas, impervious mateiral
b. vegetative cover/ evapotransp.
c. soil moisture

d. geology, soils, permeability
e. snow cover, frozen ground

B. Soil Moisture

1. soil mosture content
   a. pre-existing soil moisture
   b. seasonal: evapotranspiration factor
      (1) summer > Evapotranspiration, < flood potential, < soil moisture
      (2) soil moisture in general > late winter, spring
   c. soil moisture determines storage ability of hillslopes

C. Snow Cover, Frozen Ground and Snowmelt
1. Frozen ground = impervious surface; > flood potential
   a. < temps, > frozen ground
   b. snow pack conditions, thickness
   c. largest snowfall recorded, Mt. Rainier 1971-72: 1120 inches (wow!!!)
   d. nice maps of average duration of frozen ground in US
2. spring rain on snow, + snow melt = flood

Section 3. Precipitation Analysis

I. Introduction
    A. Precipitation = major source of hydrologic input for region
        1. affects ecology, geogrphy and land use

        2. Planning/land use data
            a. amounts of rain and snow
            b. seasonality
            c. sizes and intensities of storm

II. Precipitation Data Analysis
    A. Measurement of Precipitation at a Point
        1. rain guage

    B. Measurement of Precipitation over an Area
        1. Errors with point measurement of precipitation
            a. several% for single storm
            b. up to 30% with strong winds
            c. local obstructions like trees
            d. changes in instrumentation

        2. Need for areal distribution of data collection points
            a. collection at no. of pt. locations throughout area

            b. areal averaging of rainfall (techniques)
                (1) arithmetic average of all pt. data
                (2) Thiessen-weighted average
                (3) isohyetal (contouring) method

            c. Data collection factors
                (1) density of pt. source measuring devices
                    (a) variable intensity sites
                        i) arid areas
                        ii) mountainous area
                    (b) sparse network of collection guages will underestimate rainfall intensity

    C. Analysis of Rainfall Data
        1. Types of Data
            a. daily total ppt
            b. individual storm ppt
            c. seasonal totals
            d. frequency of small amt.s of ppt
            e. intensity of rainfall events
            f. duration of event
            g. aerial extent of event

D. Estimating Missing Data
  1. sources of gaps in rainfall data
    a. gauging installed at wrong time period
    b. malfunctions

  2. Extrapolations and corrections
    a. regression analysis
      (1) time regression
      (2) spatial regression
    b. weighted averaging of surrounding gauges about a gauge with missing data

  3. Extrapolation works well in cyclonic-regional weather patterns, but will be associated with error in flashy areas such as arid/mountain regions

E. Analysis of Total Rainfall Within Specific Measurement Periods
  1. aritmetic mean of annual totals of precipitation
  2. standard deviation: variability of individual years about the mean for all years
    a. normal distributions
      (1) 68% of all occurrences fall within 1 S.D. above or below mean
  3. Cumulative Frequency Analysis
    a. measured values of annual ppt vs. percentage of all events less than or equal to that event
      (1) shows graphical, aritmetic techniques
      (2) gives some examples of techniques

III. Characteristics of Individual Storms
  A. Storm intensity data
    1. useful in calculations of storm runoff/management
      a. design of sewers/flood control structures
      b. calculating hydrologic budgets
    2. Recording Rain Gauges
      a. timing of storms
      b. intensity of storms (amt/time)
      c. storm durations

IV. Total Storm Rainfall
  A. total amt. of ppt/storm event
    1. duration (time)
    2. amount of precipitation (mm)
    3. intensity = mm/hr (amt/time)

V. Intensity-Duration 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
   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

VI. Storms and Precipitation

A. Temporal Distribution of Rainfall During a Storm
   1. analyzing changes in rainfall intensity with time during a given event

B. Spatial Characteristics of Storm Rainfall
   1. analyzing spatial changes in intensity during a given event

C. Probable Maximum Precipitation
   1. statistically estimating the probability of max. ppt. over a given time

D. Long-Term Variations of Precipitation
   1. short and long term climate change prediction??
   2. climate modeling??

E. Sources of Precipitation Data
   1. National weather service

Section 4 - Calculation of Flood Hazard

- I. Introduction
  - A. Flood Significance
    - 1. annual $ loss; very high
      - a. flood control/mitigation
    - 2. large floods
      - a. Asia
  - B. Planning Perspectives
    - 1. planners should use hydrologic approach
    - 2. design to mitigate flood problems
    - 3. familiarize with hydrologic problems

- II. Storage and Transmission of Floodwater
  - A. Surface runoff
    - 1. drained to channels, runoff > channel capacity = flood
      - a. climate/rainfall events
      - b. dam failure
      - c. glacial outburst (high meltwater)

  - B. Flood Process
    - 1. flood wave
      - a. > Q, < Q as wave down channel
      - b. progressive flow: floodwave downstream w/o losing shape of slug of water
      - c. Reservoir action or pondage: wave is attenuated by storage in channel/valley bottom
        - (1) e.g. drainage reservoir: flow in > flow out (at spillway) as f(reservoir capacity)
    - 2. channel system
      - a. natural reservoir/storage capacity of flood plain-channel system
        - (1) natural flood attenuation characteristics
      - b. hydrograph analysis and case studies of natural flood wave attenuation
        - (1) with > drainage area, max. flood discharge < as a function of reservoir capacity of basin, floodplain

- III. Flood Prediction

  - A. Predicting occurrence of floods; necessary considerations

    - 1. volume of storm runoff
    - 2. peak flood discharge
    - 3. flood height or stage
    - 4. time distribution from hydrographs (Q vs. time)
    - 5. area inundated (flood prone areas)
    - 6. velocities fo flow across valley bottom

IV. Flood Records

A. past records are key to future prediction
   1. river guaging stations (US corps of engineers)
      a. most stations on large-mod. rivers
      b. little data on small drainages
   2. local news/historical records
   3. USGS water supply papers
   4. Soil/Ag cons. service
      a. small watershed stations
   5. forest service experimental stations

V. Hydrograph Separation

A. Hydrograph of stream
   1. Q vs. time (x-axis)
   2. flood character
      a. rising limb
      b. peak
      c. falling limb
   3. Hydrograph = stormflow + baseflow
      a. how to separate?

B. Separating storm from base flow
   1. hydrograph separation techniques
   2. shows graphical methods for differentiating hydrograph data

VI. Estimation of Storm Runoff Volume

A. Estimating Storm runoff volumes
   1. important for engineering design, capacity and conveyance mechanisms

B. Prediction Techniques
   1. correlation of rainfall ppt and Q
      a. regression/prediction stats.
      b. antecedent ppt index: estimation of pre-existing soil moisture, and infiltration/storage potential

   2. Water Budget Analysis
      a. est. infiltration, interception and storage

   3. US Soil Conservation Service
      a. runoff vs. soil/land use conditions
         (1) generate rating curve for catchments
         (2) lists numerous tables of hydrologic estimate parameters

VII. Calculating Flood Peak Discharges

A. Introduction

1. Peak discharges from streams must be calculated for planning purposes
    a. problem: variable data set, some streams gauged, some ungauged
        (1) statistical prediction techniques
        (2) field checking and data analysis

B. The Rational Method

1. Rational Runoff Method: predicts peak runoff rates from data on rainfall intensity and drainage-basin characteristics
    a. ideal: catchments < 200 ac
    b. widely used for sewer design

2. Assumptions
    a. uniform rain intensity over entire basin
    b. runoff > downbasin
    c. Q will approach constant max. as steady state is reached

3. Technique
    a. time of concentration: time lapse required for steady Qmax for basin to be attained; at time of concentration:

        (1) Q=CIA

where Q = peak runoff, C = runoff coefficient, I = rainfall intensity, A = drainage area (english units of cu. ft/sec, in/hr and acres)

            (a) c = f(soil, topo, roughness, vegetation, land use); taken from table estimates (range 0.4-0.95)

    b. Estimating time of concentration

        (1) $tc = L^{1.15} / (7700H^{0.38})$

where tc = time of conc., L = length of catchment, H = vertical diff of el. at divide and el. at mouth of catchment.

    c. Rational method critique
        (1) does not meet assumptions ideally, but is consistent enough in results
        (2) works best for urban storm runoff prediction

C. Probability Analysis of Flood Records

1. Concept: i.d. probability of floods occurring greater than certain limits
    a. for use in planning, insurance, etc.

2. Techniques and ideas
   a. use momentary peak Q rather than avg. daily Q
   b. fit probability distribution to data, then use to predict average recurrence intervals of floods of given magnitudes

   c. Probability distributions that have been used
      (1) Lognormal distribution
      (2) Gumbel type I distribution
      (3) Gumbel Type III distribution

         (a) Gumbel distributions

specially designed graph paper for plotting Q vs. Recurrence interval
            i) data plots as straight line if it fits the distribution

      (4) Pearson Type III distribution
         (a) widely used by US feds
         (b) sl. more complicated to use

   d. Examples of Technique
      (1) Recurrence interval: T = (n +1)/m

T = recurrence interval in years, n = total number of years of record, m = rank of peak discharge event for given year

      (2) plot of prob. graph
         (a) i.d. outliers and make decision to use or not
         (b) extrapolate to low and high Recurrence interval

D. Stage-Frequency Curves for a Station

1. Using stage data as opposed to discharge data

   a. discharge rating curves: calibrating river stage to Q estimates

      (1) problem change in channel morphology over time will affect relationship between stage and Q

      (2) needed: error estimation and rating curve updates

E. Maximum Probable Flood

1. Estimation of possibility of maximum flood

2. controlling factors to be considered

   a. max. prob. rainfall intensity
   b. snowmelt + rain storms

c. ice jams
d. antecedent moisture
e. dam bursts

F. Regional Flood Frequency Curves

1. problem: single gauging station data may be subject to large errors in probability estimates

a. short records, missing data, etc.

2. Regional Flood Frequency curves

a. estimating Q max for basin as a whole based on probability distributions

b. Gives example for Vermont experimental watershed
(1) average recurrence intervals for a no. of stations in basin, then average for basin as a whole

3. Uses

a. extrapolating Q flood frequency from known to unknown areas for planning
(1) developing regional flood freq. curves for use
(2) USGS has developed these

(a) minimum basin area of 10 sq. miles
(b) must extrapolate to smaller basins
i) apply to areas of uniform physiography, vege., etc.

G. Flood-frequency Curves for Large Rivers

1. Problem: large rivers collect drainage from several watersheds
a. may not fit pattern of regional curves
b. modification and adjustment in order

VIII. Use of Flood Frequency analysis in Urban Catchments

A. urbanization generally > size of flood Q to basin

1. studies to characterize effect of urbanization with respect to Q over time as urbanization advances

IX. Flood Routing
A. general
1. design problems for conveyance and management of storm Q
a. dams, spillways, levee systems

B. Reservoir Routing (using reservoirs to manange flood Q)

C. Channel Routing (channel design and modification to manage flood Q)