CE 3354 Engineering Hydrology

Lecture 5: Discrete Data Analysis; Risk-Based Design; Regression Equations

OUTLINE

- Discrete Data Preparation and Analysis
- Hydrologic Cycle; Risk Based Design
- Regression Equation

DATA ANALYSIS

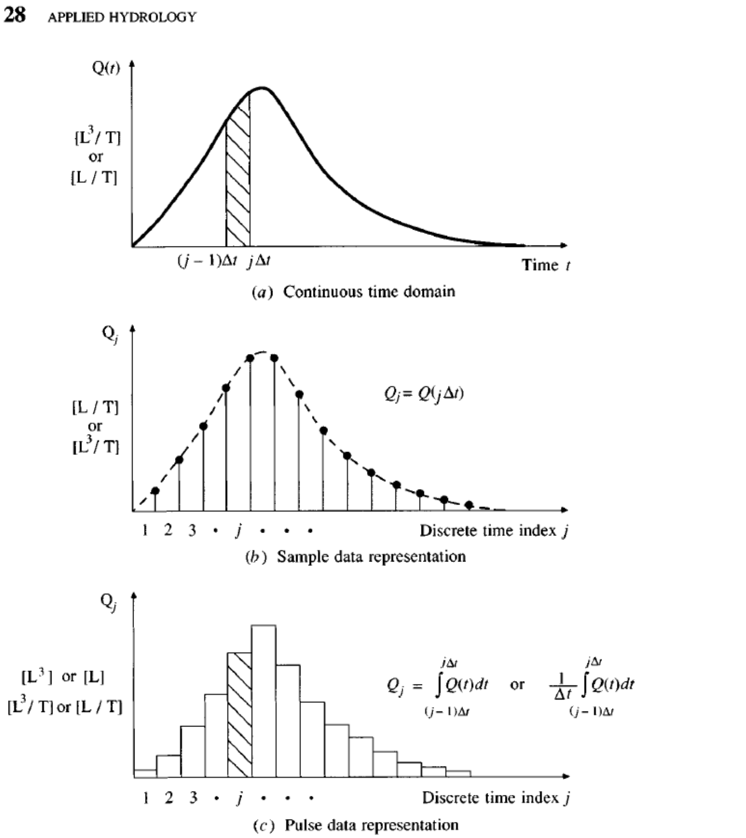


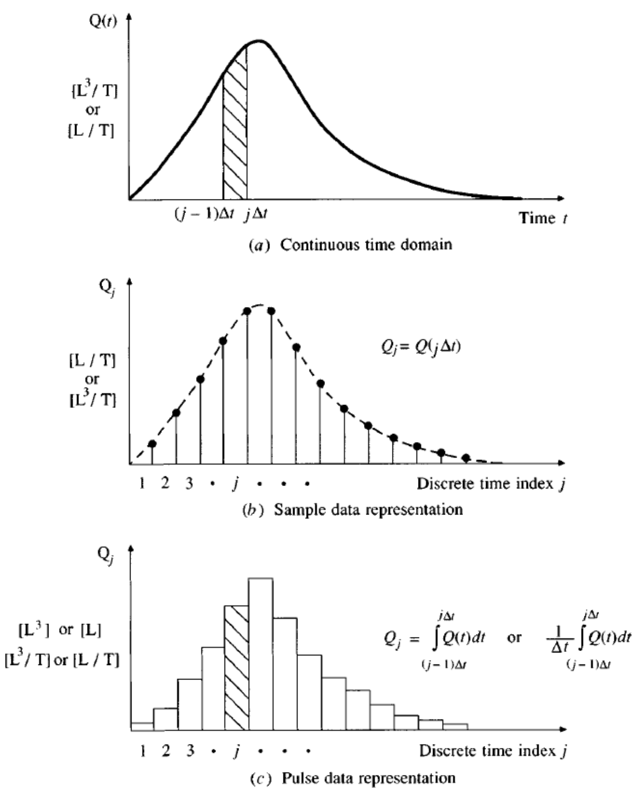
FIGURE 2.3.1
A continuous time function $Q(t)$, (a), can be defined on a discrete time domain either by a sampled data system (b), in which instantaneous values of the continuous time function are used, or by a pulse data system (c), in which the integral or average value of the function over the interval is used.

$$Q_j = \int_{(j-1)\Delta t}^{j\Delta t} Q(t)\,dt \quad \text{or} \quad \frac{1}{\Delta t}\int_{(j-1)\Delta t}^{j\Delta t} Q(t)\,dt$$

- Representations of real data are always some kind of discrete sample (2nd panel)
- The "pulse" type is typical – and is called incremental data.
- For instance, incremental rainfall would be the catch over some time interval (Δt in the figure)

DATA ANALYSIS

28 APPLIED HYDROLOGY



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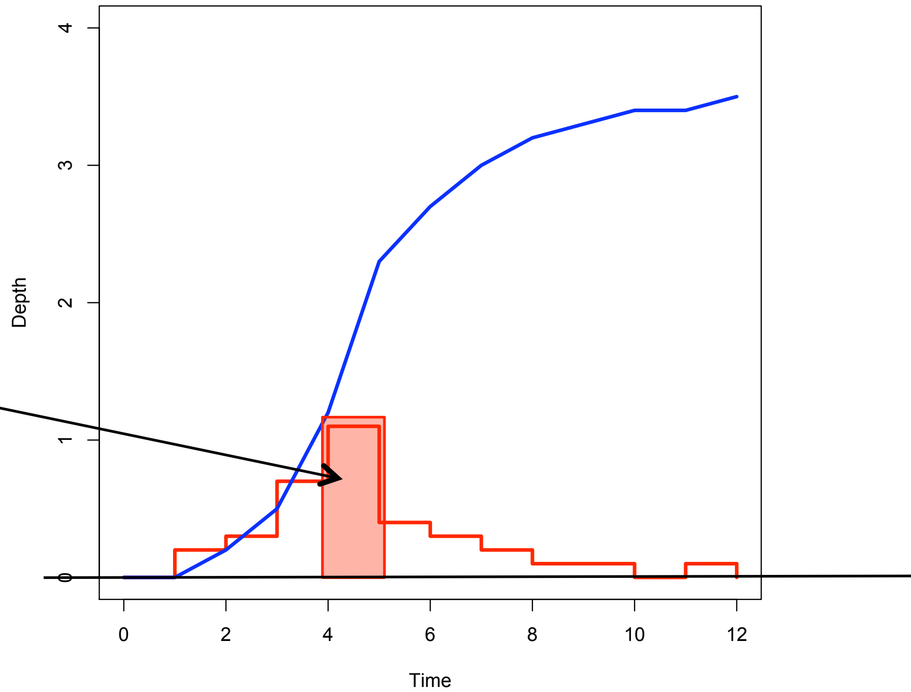
- For instance, incremental rainfall would be the catch over some time interval (Δt in the figure)
- An alternative way to represent the data is with a cumulative representation (which is the running sum of the incremental

DATA ANALYSIS

- Each "block" represents the amount of rainfall for the time interval
- The diagram is called "incremental" rainfall (red)
- The running sum of the blocks is the cumulative distribution (blue)



DATA ANALYSIS

- Accumulating (running sum) the incremental is "aggregation" (or just plain numerical integration)
- Differencing the cumulative is "disaggregation"
  - Often handy to zero pad the leading and trailing edges so don't have to worry too much about forward/backward differencing issues

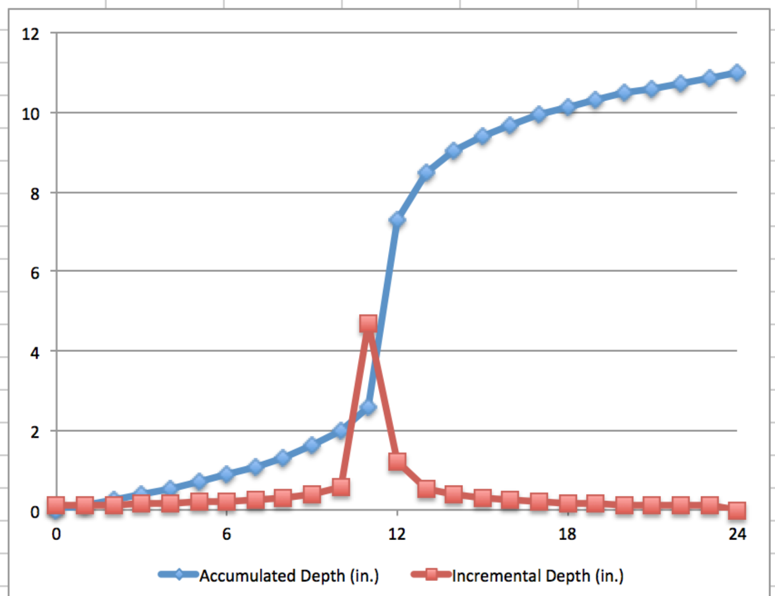
DIFFERENCING

L22

Example of Differencing of Cumulative to Obtain Incremental

Time (hours)	Accumulated Depth (in.)	Incremental Depth (in.)	
0	0	0.121	Rate during hour 1 (i.e. 0.121 per hour, for 1 hour = 0.121 at end of that hour
1	0.121	0.121	
2	0.242	0.132	
3	0.374	0.154	
4	0.528	0.165	
5	0.693	0.187	
6	0.88	0.198	
7	1.078	0.242	
8	1.32	0.297	
9	1.617	0.374	
10	1.991	0.594	
11	2.585	4.708	
12	7.293	1.199	
13	8.492	0.528	
14	9.02	0.374	
15	9.394	0.286	
16	9.68	0.253	
17	9.933	0.209	
18	10.142	0.176	
19	10.318	0.154	
20	10.472	0.132	
21	10.604	0.132	
22	10.736	0.132	
23	10.868	0.132	
24	11	0	Rate during hour 25 (i.e. 0.000 per hour, for 1 hour = 0.000 at end of that hour

=(B6-B5)/(A6-A5)



ACCUMULATING

K18

Example of Accumulating Incremental to Obtain Cumulative

Time (hours)	Incremental Depth (in.)	Accumulated Depth (in.)
0	0.121	0
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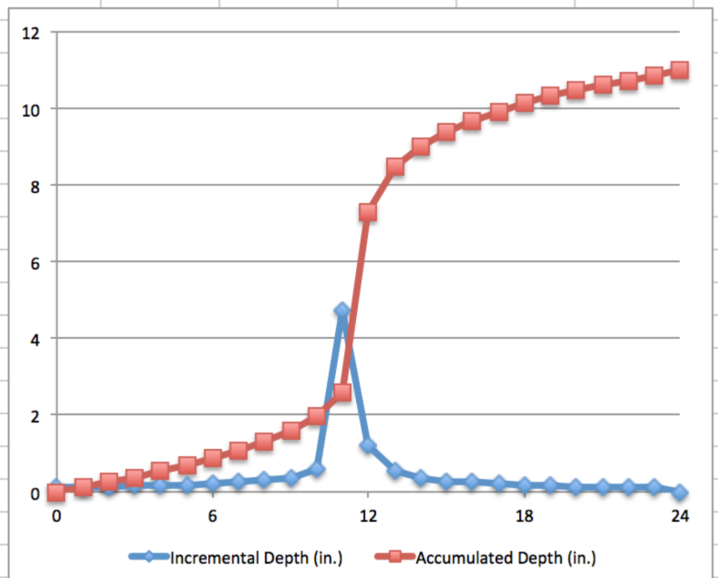
24	0	11

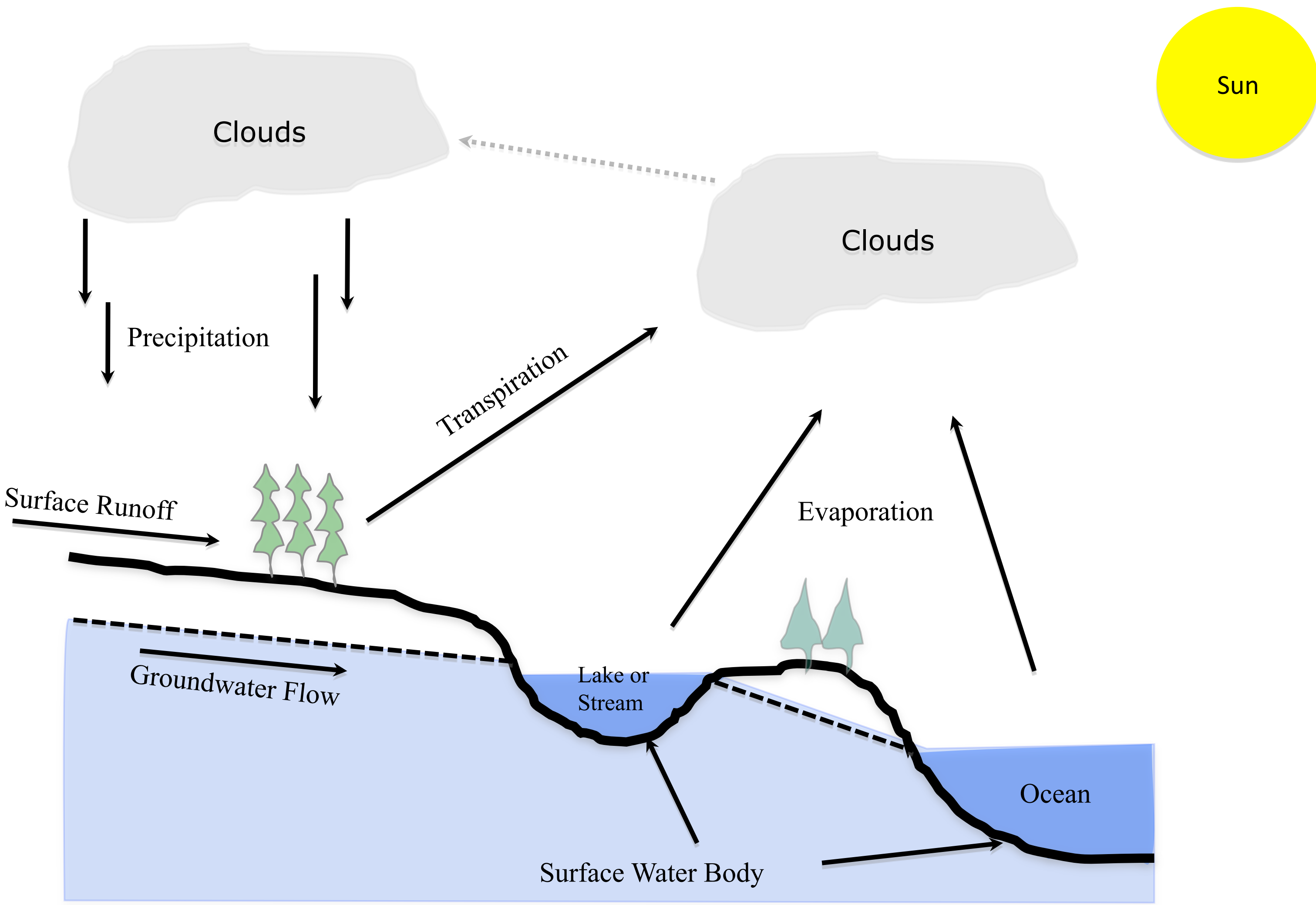
Rate during hour 1 (i.e. 0.121 per hour, for 1 hour = 0.121 at end of that hour

=B4*(A5-A4)+C4



Rate during hour 25 (i.e. 0.000 per hour, for 1 hour = 0.000 at end of that hour

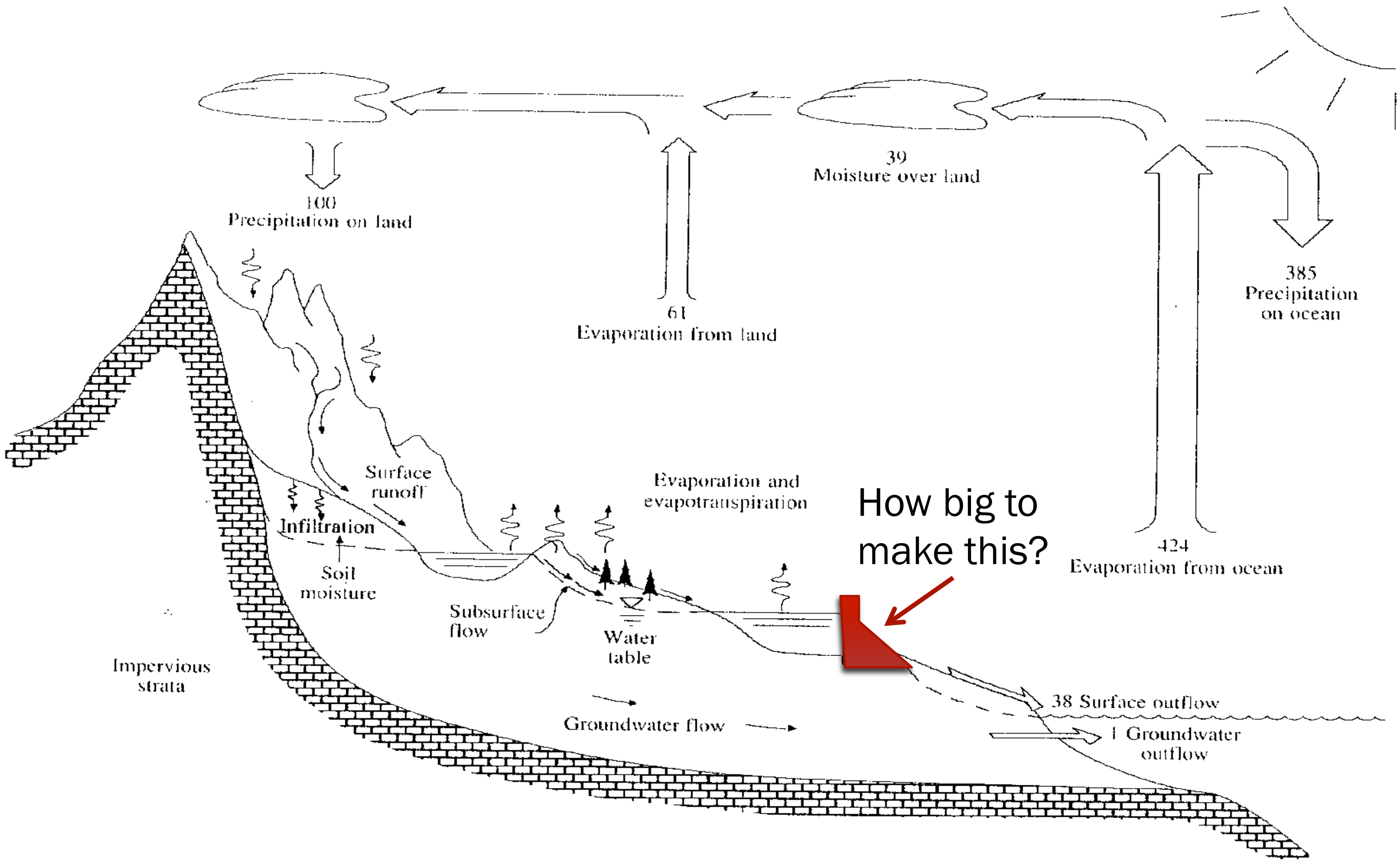
THE HYDROLOGIC CYCLE



HYDROLOGIC PROCESSES

- Fundamental Processes:
  - Precipitation
  - Evaporation
  - Infiltration
  - Storage
  - Runoff

DESIGN AND THE WATER CYCLE



PROBABILITY/RISK-BASED DESIGN

- Hazard is a situation (driving through deep water) that is likely to cause harm (loss) in the absence of its control.
- Loss is the dollar value caused by a hazard that manifests itself
- Risk is the probability that a particular criterion is exceeded

PROBABILITY/RISK-BASED DESIGN

- In many Civil Engineering contexts, risk is the consequence associated with the probability of flooding attributable to a project
- Assessing hazards, risk, and loss are done in both a qualitative and quantitative manner
- Hazards are mitigated (losses reduced) by:
  - Insurance (financial loss)
  - Education/barricades (DOS during the hazard)
  - Structural measures to lower the probability

ANNUAL EXCEEDANCE PROBABILTIY (AEP)

- In Civil Engineering contexts the probability is:
  - Annual Exceedence Probability (AEP)
  - Expressed at “percent chance”

  - Older terminology is 1/AEP = T-year event

PROBABILITY AND MAGNITUDE

- The magnitude of a hydrologic response is associated with a probability
- If discharge, then expressed as a Flood Frequency curve (FF-curve)
- If precipitation, then expressed as an Intensity-Duration-Frequency curve (IDF-curve)

PROBABILITY AND MAGNITUDE

- These probabilities and magnitudes are used in hydrologic models to estimate discharge
- The discharge is used to design hydraulic structures (culverts, bridges, ponds)

REGIONAL REGRESSION

- Regional regression refers to the construction of regression equations for a region by analyzing historical measured discharges on many streams within that region.
- These equations are statistical models of discharge based on certain explanatory variables, typically

AREA; SLOPE; SHAPE INDICES; CLIMATE INDICES

WATERSHED CHARACTERISTICS

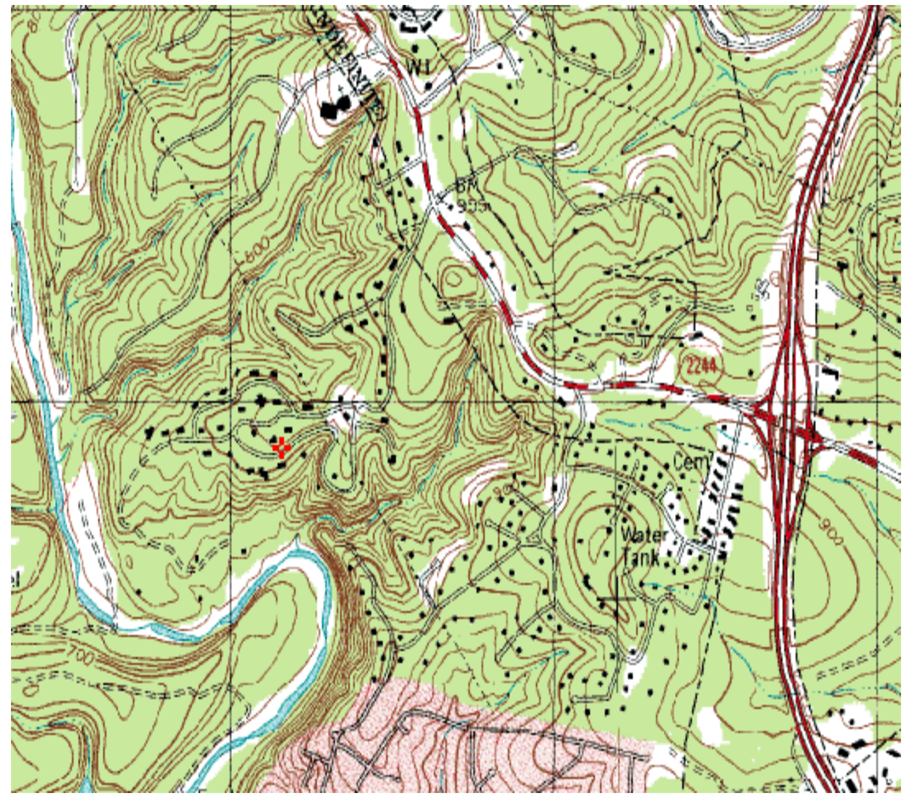
- What characteristics influence runoff?
  - Where you are
  - How large an area
  - Gradient

WATERSHED CHARACTERISTICS

- What characteristics influence runoff?
  - Width, shape
  - Elevation: minimum, maximum + slope
  - Roughness: Channels, overbanks
  - Geology and soils
  - Climate
  - Vegetation
  - Land use, including urbanization and imperviousness
  - Controls: Dams, gates, diversions, channel rectification

WATERSHED DELINEATING

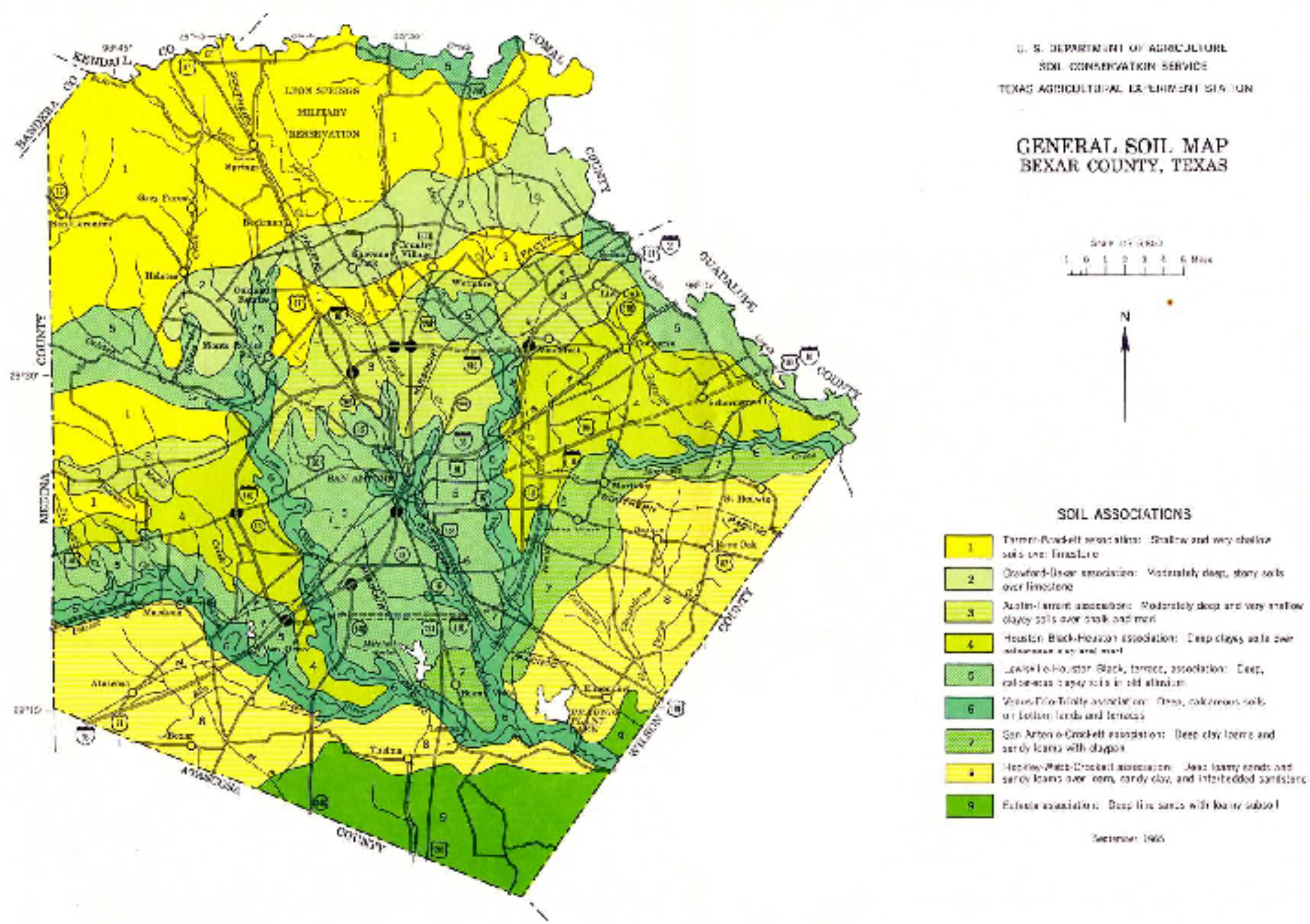
- Topographic maps
  - Hands-on methods
    - Marking directly on map
    - Tracing using light table
  - Computerized methods
    - DEMs
    - GIS software
    - Semi-automated delineation
    - Fully automated delineation



INFORMATION SOURCES

- USGS quadrangle maps
- Aerial photos
- Satellite imagery
- NRCS soil surveys
- Field surveys
- Previous investigations

NRCS COUNTY SOILS SURVEYS



REGIONAL REGRESSION ANALYSIS

- The equations are constructed by first fitting an appropriate probability distribution to observations at a gaged location (station flood frequency).
- Then the station flood frequency curves are used as surrogate observations (at a specified AEP) to relate discharge to select geomorphic variables

$$(\vec{Q}_{AEP} - \beta_0 - \beta_1 \vec{A} - \beta_2 \vec{S}_0 \cdots)^2 = \vec{\varepsilon}$$

- The "betas" are obtained by trying to make "epsilon" small, the AREA, SLOPE, and other watershed characteristics are the explanatory variables.

GENERAL FORMS OF REGIONAL EQUATIONS

- The resulting equations are typically expressed in a power-law form for actual application

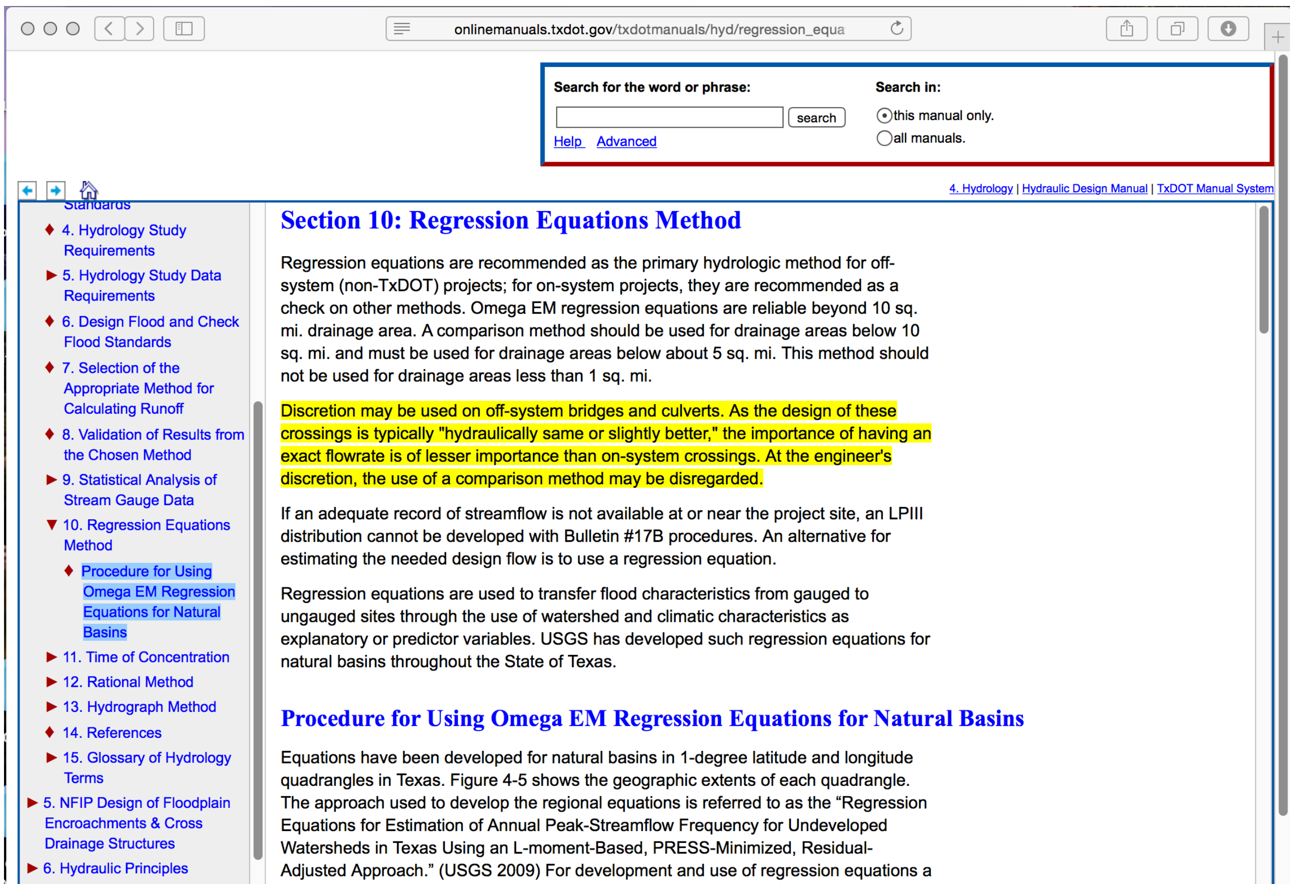
$$Q_{AEP,Estimate} = \beta_0 (AREA)^{\beta_1} (SLOPE)^{\beta_2} (MAP)^{\beta_3}$$

REGRESSION EQUATIONS IN TEXAS

- 2009 Asquith and Roussel
  - Documented in HDM
  - 7 Equations for different AEP
  - Mean annual precipitation to account for climatic variability
  - OmegaM used to account for location (mapped value)
  - Area and Slope
- Current (2011) Suggested Method

TXDOT HYDRAULIC DESIGN MANUAL

- Texas Regression Equations



onlinemanuals.txdot.gov/txdotmanuals/hyd/regression_equa

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4. Hydrology | Hydraulic Design Manual | TxDOT Manual System

Section 10: Regression Equations Method

Regression equations are recommended as the primary hydrologic method for off-system (non-TxDOT) projects; for on-system projects, they are recommended as a check on other methods. Omega EM regression equations are reliable beyond 10 sq. mi. drainage area. A comparison method should be used for drainage areas below 10 sq. mi. and must be used for drainage areas below about 5 sq. mi. This method should not be used for drainage areas less than 1 sq. mi.

Discretion may be used on off-system bridges and culverts. As the design of these crossings is typically "hydraulically same or slightly better," the importance of having an exact flowrate is of lesser importance than on-system crossings. At the engineer's discretion, the use of a comparison method may be disregarded.

If an adequate record of streamflow is not available at or near the project site, an LPIII distribution cannot be developed with Bulletin #17B procedures. An alternative for estimating the needed design flow is to use a regression equation.

Regression equations are used to transfer flood characteristics from gauged to ungauged sites through the use of watershed and climatic characteristics as explanatory or predictor variables. USGS has developed such regression equations for natural basins throughout the State of Texas.

Procedure for Using Omega EM Regression Equations for Natural Basins

Equations have been developed for natural basins in 1-degree latitude and longitude quadrangles in Texas. Figure 4-5 shows the geographic extents of each quadrangle. The approach used to develop the regional equations is referred to as the "Regression Equations for Estimation of Annual Peak-Streamflow Frequency for Undeveloped Watersheds in Texas Using an L-moment-Based, PRESS-Minimized, Residual-Adjusted Approach." (USGS 2009) For development and use of regression equations a natural basin is defined as having less than 10 percent impervious cover, less than 10

MEAN ANNUAL PRECIPITATION

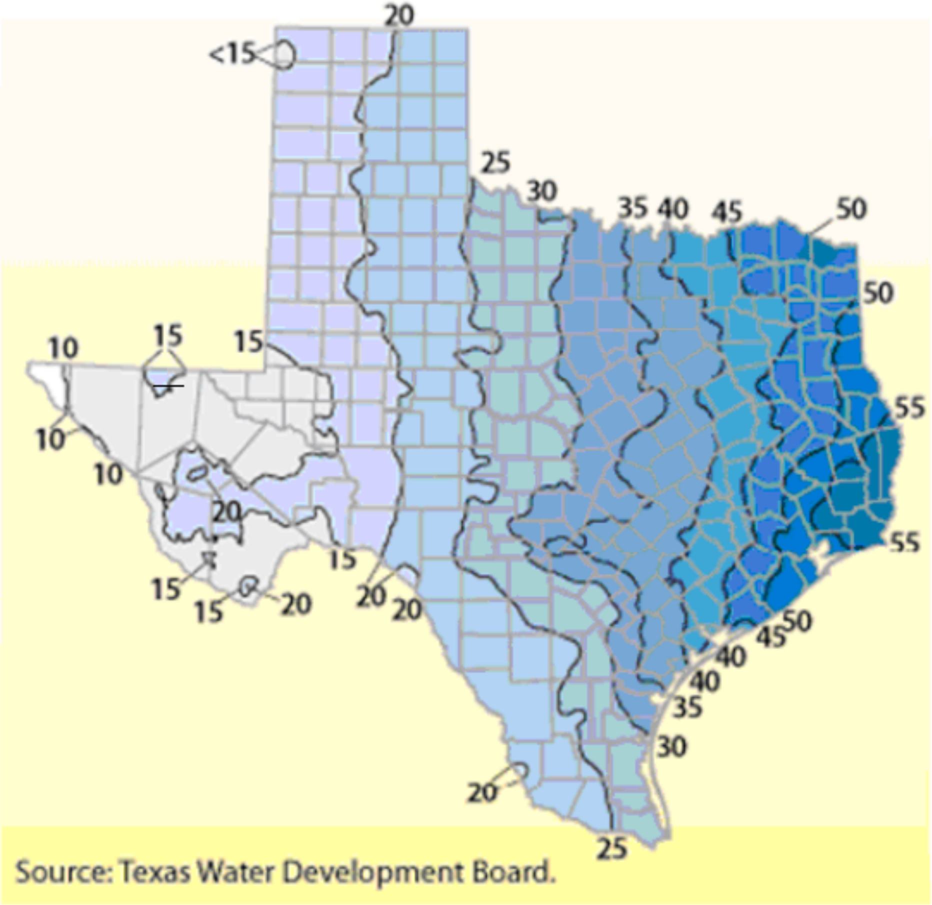
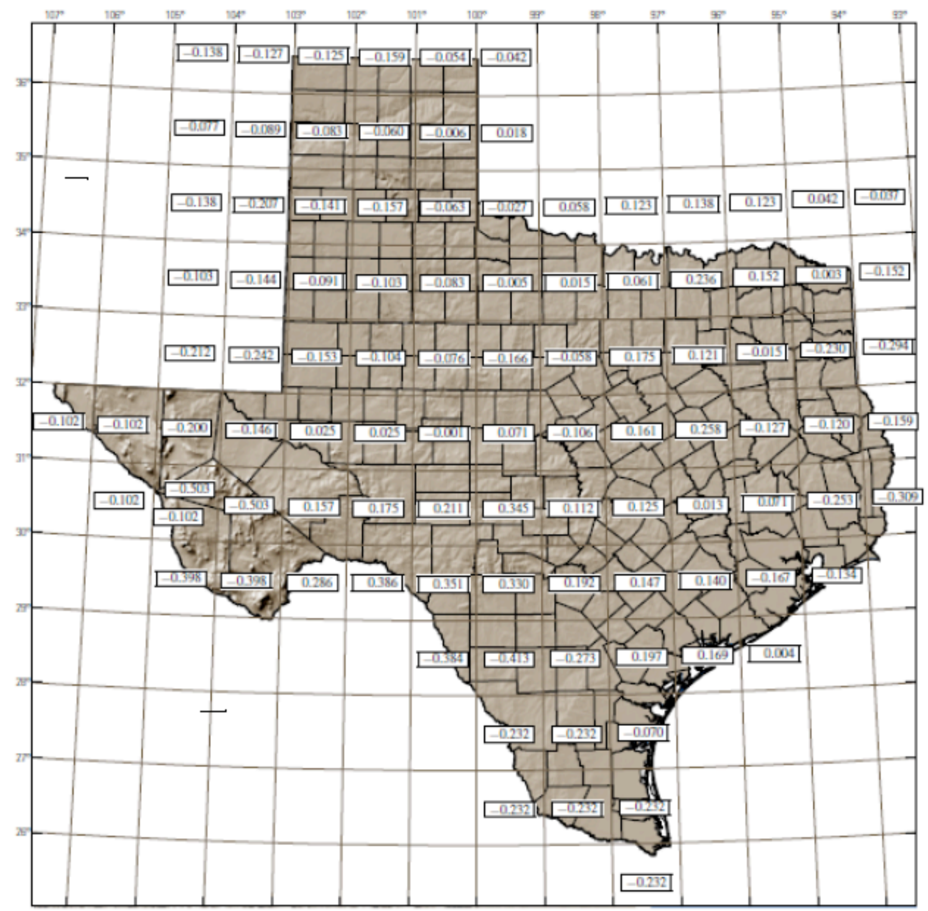


Figure 4-6. Mean annual precipitation, in inches

Omega EM



Base from Texas Natural Resources Information System digital data
Scale 1:7,920,000
Albers equal-area projection, datum NAD 83
Standard parallels 27°30' and 35°00', latitude of origin 31°00', central meridian -100°00'
Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

0 125 250 MILES
0 200 400 KILOMETERS

Texas Regression Equations

Table 4-4: Regression Equations

Regression Equations	RSE	Adj. R-squared	AIC statistic	PRESS statistic
$Q_2 = P^{1.398} S^{0.270} \times 10^{[0.776\Omega + 50.98 - 50.30A^{-0.0058}]}$	0.29	0.84	273	64.6
$Q_5 = P^{1.308} S^{0.372} \times 10^{[0.885\Omega + 16.62 - 15.32A^{-0.0215}]}$	0.26	0.88	122	49.1
$Q_{10} = P^{1.203} S^{0.403} \times 10^{[0.918\Omega + 13.62 - 11.97A^{-0.0289}]}$	0.25	0.89	86.5	46.6
$Q_{25} = P^{1.140} S^{0.446} \times 10^{[0.945\Omega + 11.79 - 9.819A^{-0.0374}]}$	0.26	0.89	140	49.5
$Q_{50} = P^{1.105} S^{0.476} \times 10^{[0.961\Omega + 11.17 - 8.997A^{-0.0424}]}$	0.28	0.87	220	55.6
$Q_{100} = P^{1.071} S^{0.507} \times 10^{[0.969\Omega + 10.82 - 8.448A^{-0.0467}]}$	0.30	0.86	320	64.8
$Q_{500} = P^{0.988} S^{0.569} \times 10^{[0.976\Omega + 10.40 - 7.605A^{-0.0554}]}$	0.37	0.81	591	98.7

EXAMPLE

- Apply the Regression Equations for the Hardin Branch Watershed – provide a comparative estimate to help guide the project
  - AREA = 17 sq. mi.
  - Mean Annual Precipitation = 23 inches/year
  - Omega EM = 0.345
  - Slope = 0.0048

EXAMPLE

- Regression Equations for the Hardin Branch

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	Purpose:	Spreadsheet Tool to Implement Texas Regional Regression Equations												
2	Reference:	http://onlinemanuals.txdot.gov/txdotmanuals/hyd/regression_equations_method.htm												
6	Input							Coefficients						
7	AREA	17	Square Miles				Variable	2yr	5yr	10yr	25yr	50yr	100yr	500yr
8	MAP	23	Mean Annual Precipitation (Inches) (from Map)				P	1.398	1.308	1.203	1.14	1.105	1.071	0.988
9	SLOPE	0.0048	Main Channel Slope				S	0.27	0.372	0.403	0.446	0.476	0.507	0.569
10	OmegaEM	0.345	Omega-EM (from Map)				OmegaEM	0.776	0.885	0.918	0.945	0.961	0.969	0.976
11							A	-50.3	-15.32	-11.97	-9.819	-8.997	-8.448	-7.605
12							A(exponent)	-0.0058	-0.0215	-0.0289	-0.0374	-0.0424	-0.0467	-0.0554
13							Constant	50.98	16.62	13.62	11.79	11.17	10.82	10.4
15	Estimate	Discharge (CFS)												
16	Q2	1,110												
17	Q5	2,687												
18	Q10	4,088												
19	Q25	6,345												
20	Q50	8,393												
21	Q100	10,866												
22	Q500	18,300												

NEXT TIME

- Flood Frequency Concepts
- Probability Estimation Modeling