A Comparison of Stream Flow Prediction Methods

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REGIONAL PLANNING

Learning Objectives

Discussion of the primary methods of estimating stream flow, namely:

- Stream Gauges
- Regression equations
- Rainfall-runoff calculations

We will also take intellectual detours into:

- The benefits and pitfalls of statistical extrapolation.
- The relationship between rainfall intensity and drainage area.


Why are we doing this?

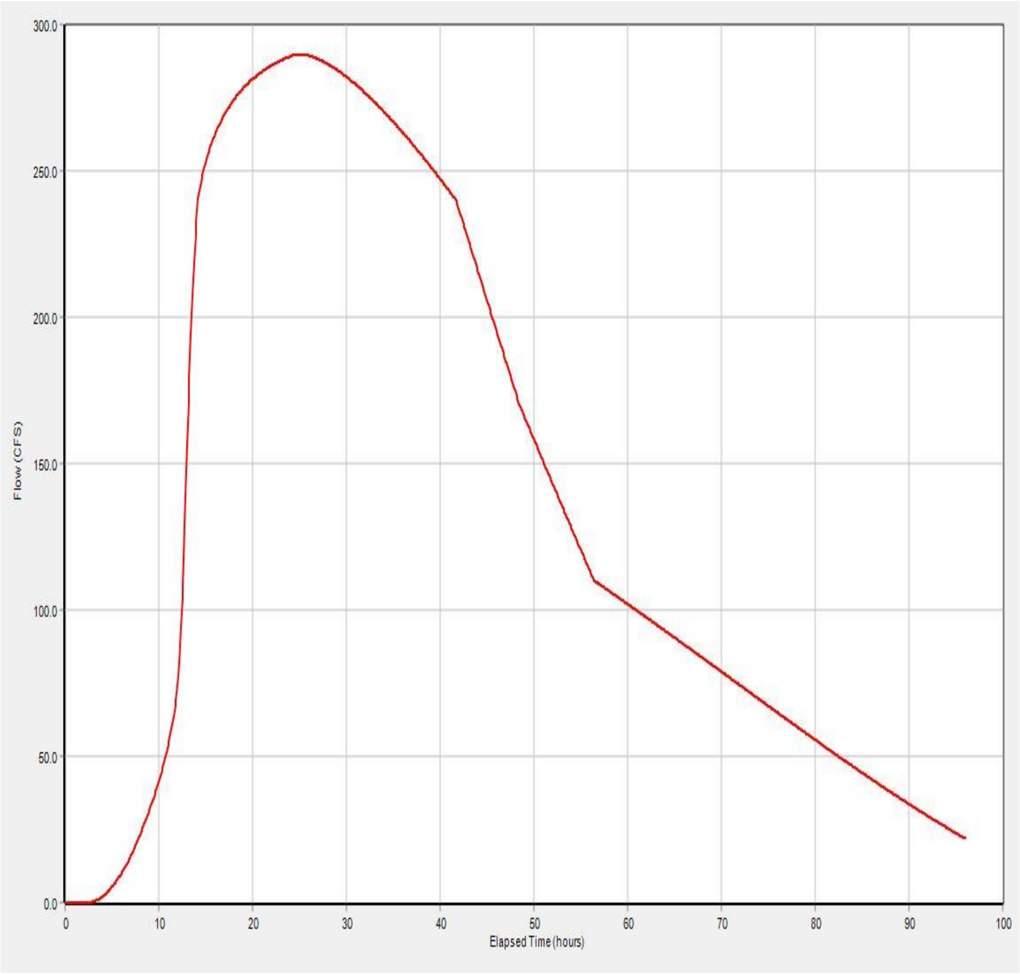
Predicting stream flow is critical to the design of:

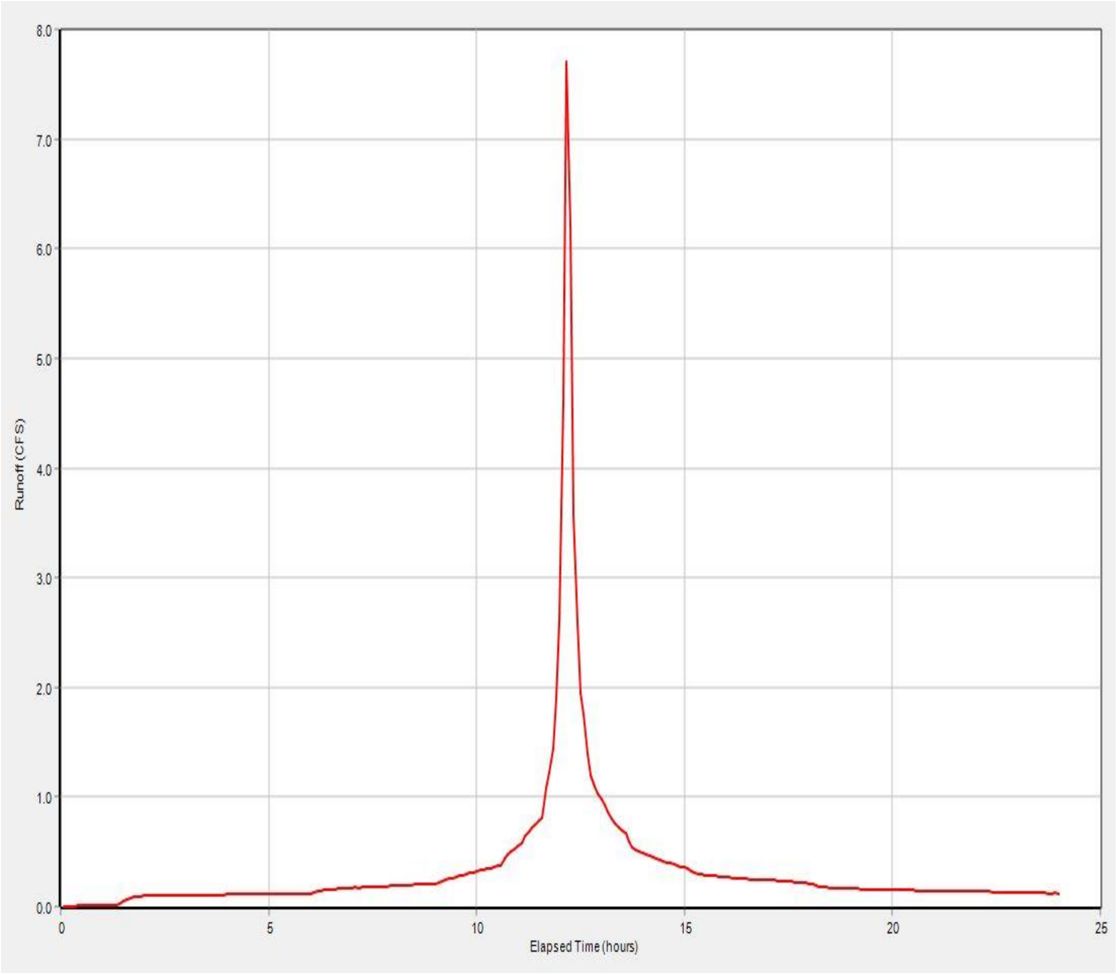

Why are we doing this?

Predicting stream flow is critical to the design of:

Introduction

Peak Flow vs. Full Hydrograph





Introduction

Peak Flow vs. Full Hydrograph

Peak Flow Only

- Design of simple hydraulic structures (culverts, bridges)
- Floodplain and floodway mapping
- Base flood elevation calculations
- Simple scour calculations

Full Hydrograph

- Design of stormwater management basins
- Design of reservoirs and dams
- Dam break inundation mapping
- Analysis of hydraulically complex systems
- Complex scour and sediment transport calculations

Introduction

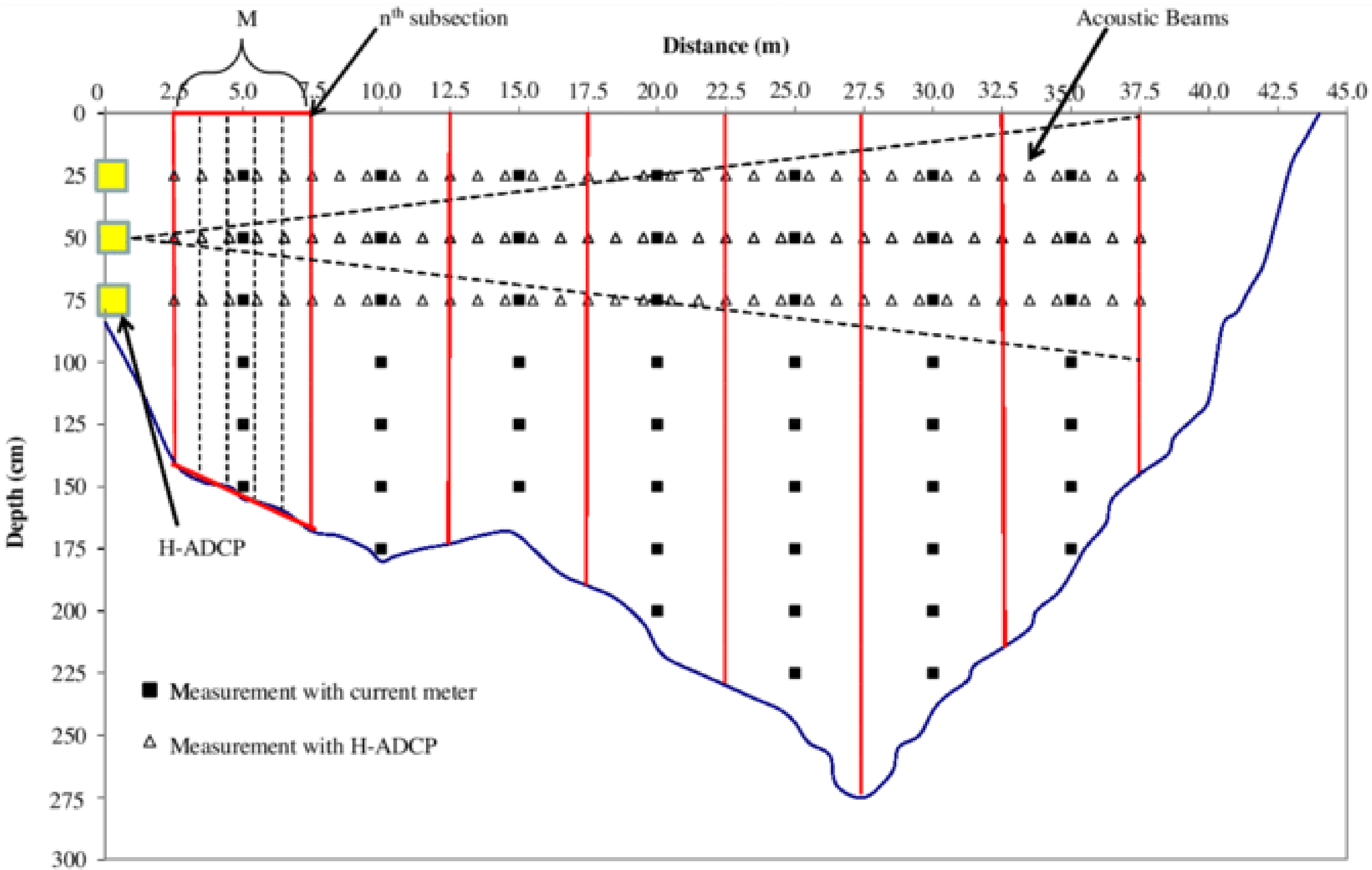
3 Broad Approaches

- Stream Gauge Data
- Regression Equations
- Rainfall-Runoff Calculations

Stream Gauge Data

Stream Gauge Data

How to Measure Stream Flow?



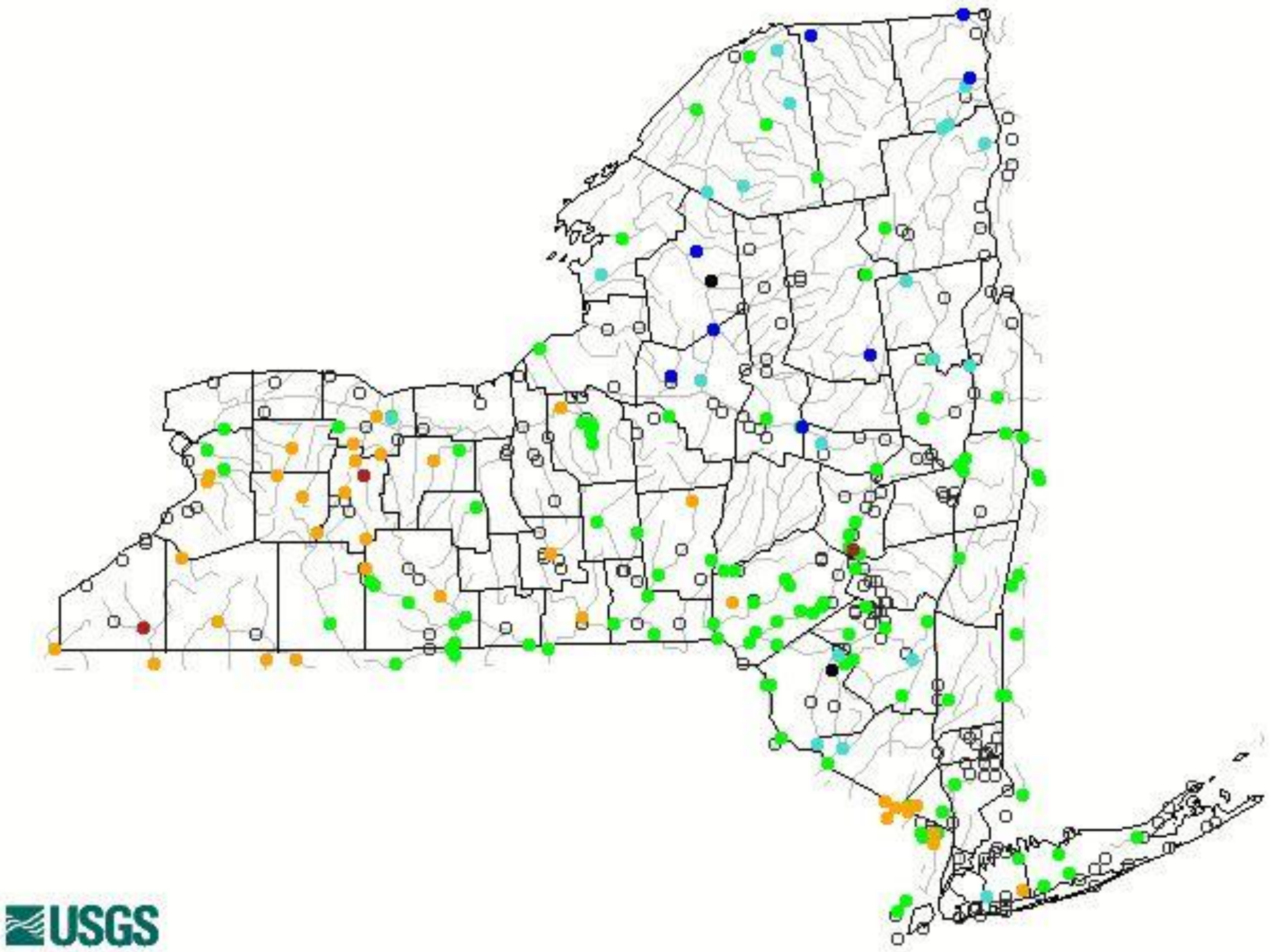
Stream Gauge Data

Measuring Stream Flow is Difficult!

- Time consuming
- Labor intensive
- Not scalable over time
- Dangerous during high-flow events

Stream Gauge Data

Look at all those stream gages!



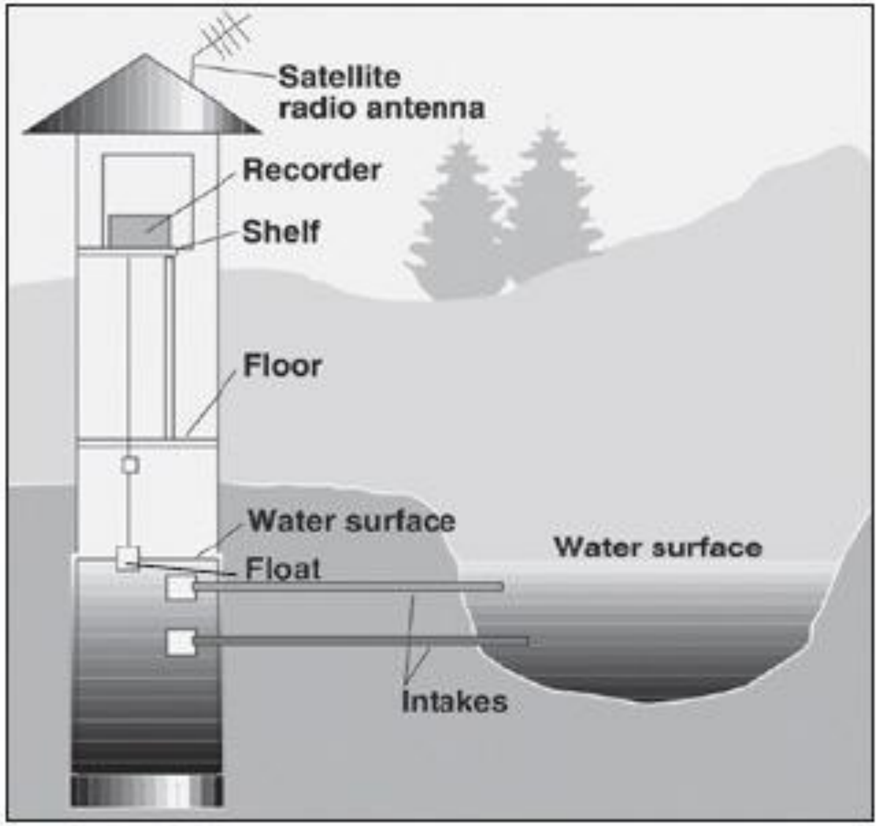
Is someone out there measuring stream flow at each one of these gauges every day?

Stream Gauge Data

Let's Measure Depth Instead!

- Depth is easy to measure
- Can use either float or pressure system
- Can be fully automated
- Depth = flooding so we want this data anyway

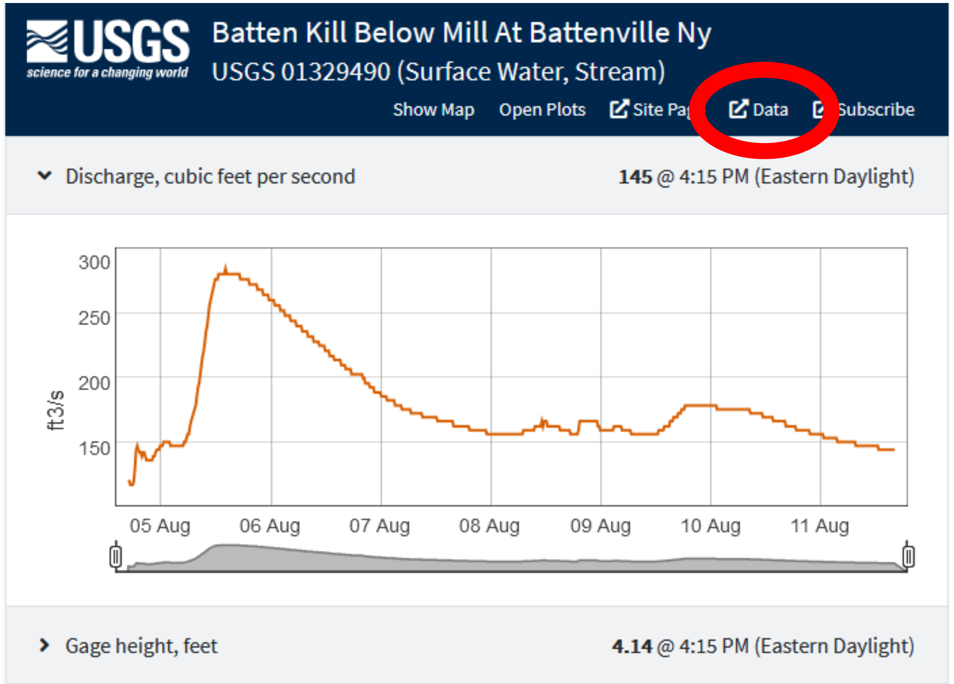
- MAJOR DRAWBACK:
  Calculating flow based on depth in a natural channel is not an exact science…

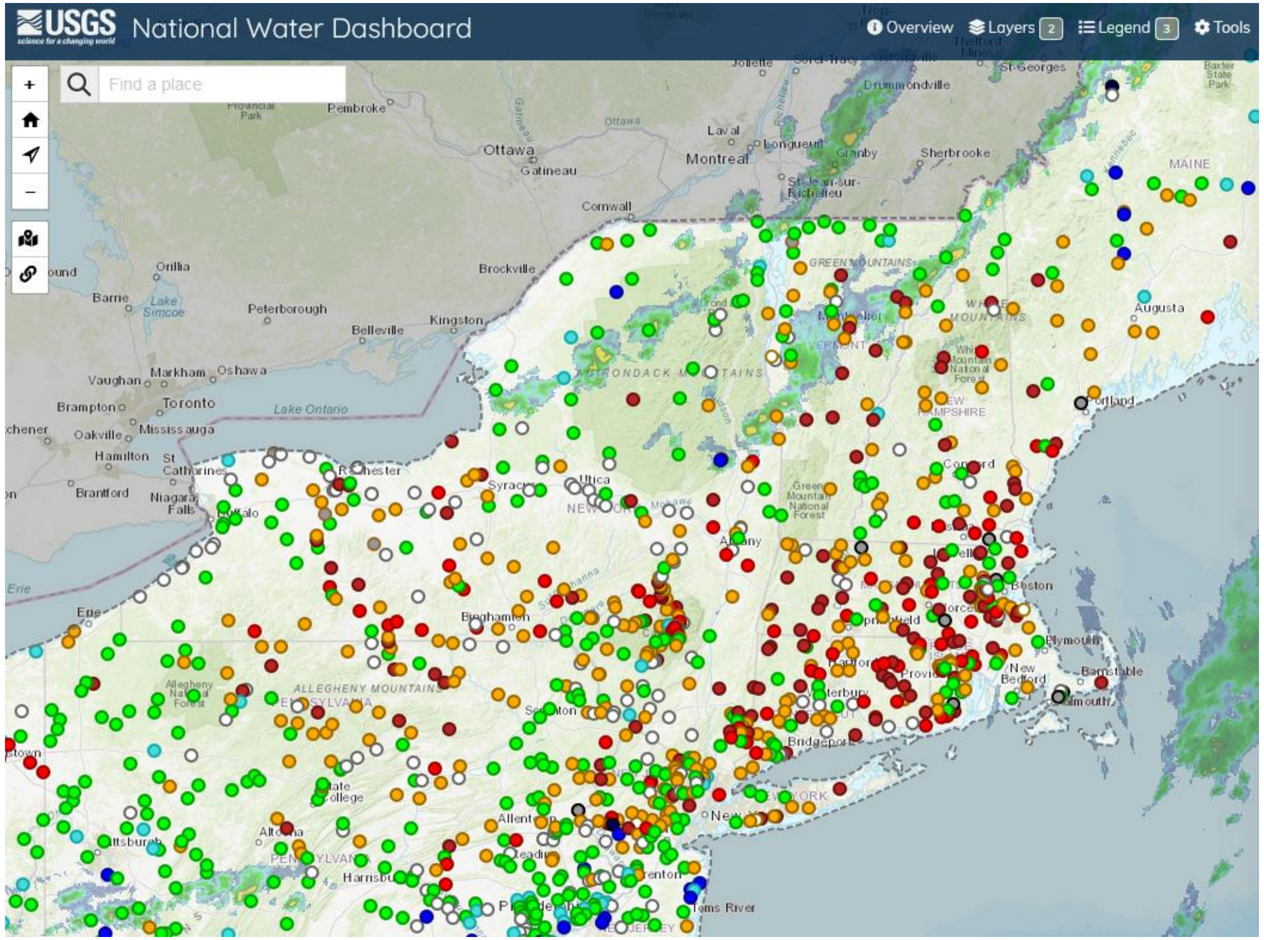


Stream Gauge Data

How It Works: Step 1

- Select the nearest gauge on the “National Water Dashboard” site, and pick “Data”.

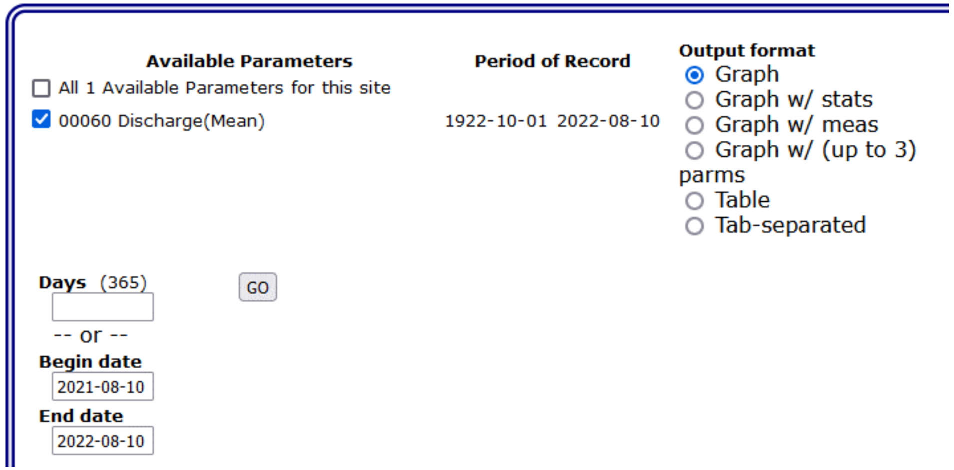


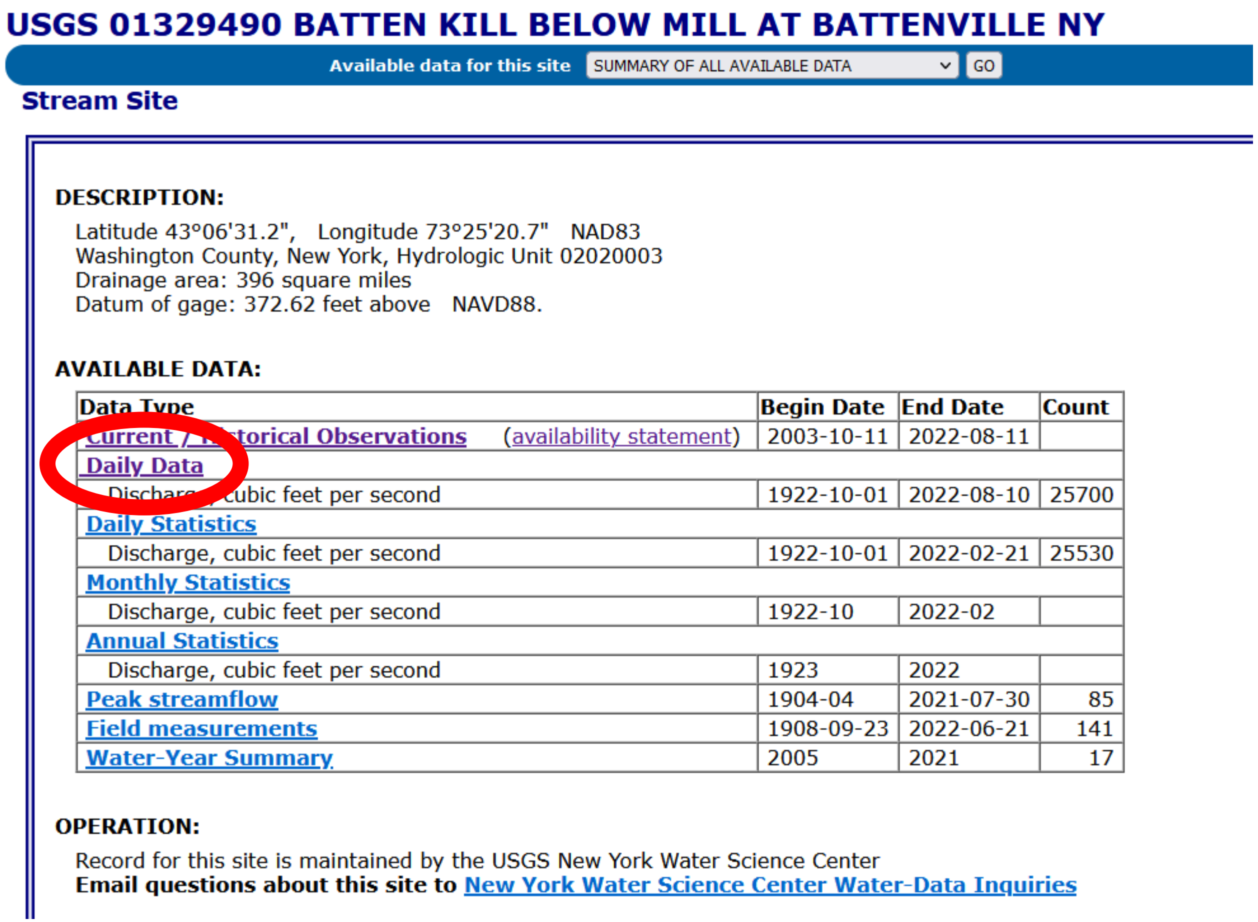


Stream Gauge Data

How It Works: Step 2

- Select “Daily Data”.
- Pick a date range and an output format.





USGS 01329490 BATTEN KILL BELOW MILL AT BATTENVILLE NY

Available data for this site SUMMARY OF ALL AVAILABLE DATA GO

Stream Site

DESCRIPTION:

Latitude 43°06'31.2", Longitude 73°25'20.7" NAD83
Washington County, New York, Hydrologic Unit 02020003
Drainage area: 396 square miles
Datum of gage: 372.62 feet above NAVD88.

AVAILABLE DATA:

Data Type	Begin Date	End Date	Count
Current / Historical Observations (availability statement)	2003-10-11	2022-08-11	
Daily Data			
Discharge, cubic feet per second	1922-10-01	2022-08-10	25700
Daily Statistics			
Discharge, cubic feet per second	1922-10-01	2022-02-21	25530
Monthly Statistics			
Discharge, cubic feet per second	1922-10	2022-02	
Annual Statistics			
Discharge, cubic feet per second	1923	2022	
Peak streamflow	1904-04	2021-07-30	85
Field measurements	1908-09-23	2022-06-21	141
Water-Year Summary	2005	2021	17

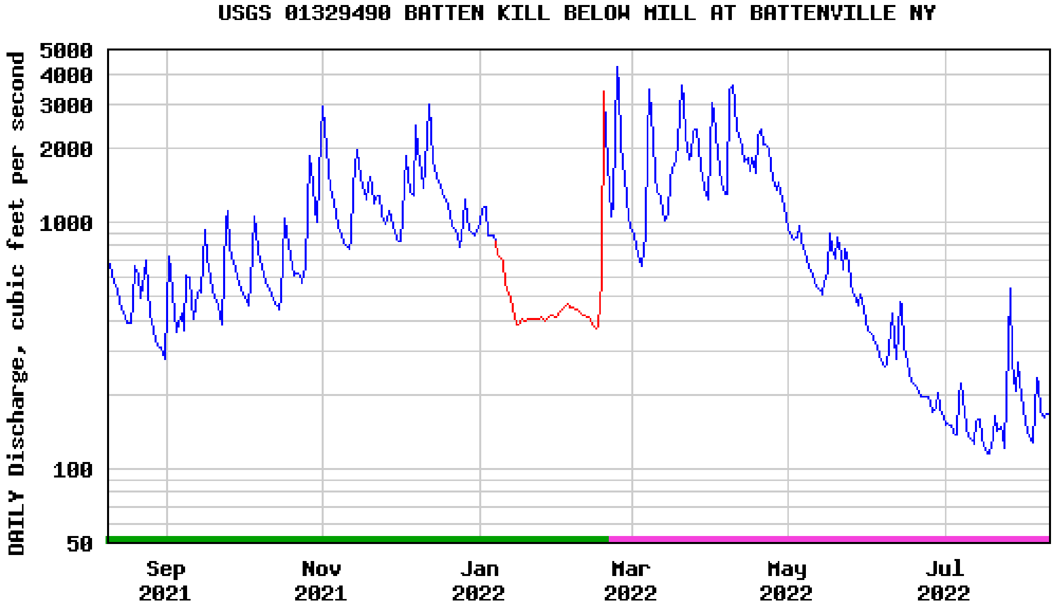
OPERATION:

Record for this site is maintained by the USGS New York Water Science Center
Email questions about this site to New York Water Science Center Water-Data Inquiries

Stream Gauge Data

How It Works: Step 3

- Get your daily peak flow results!



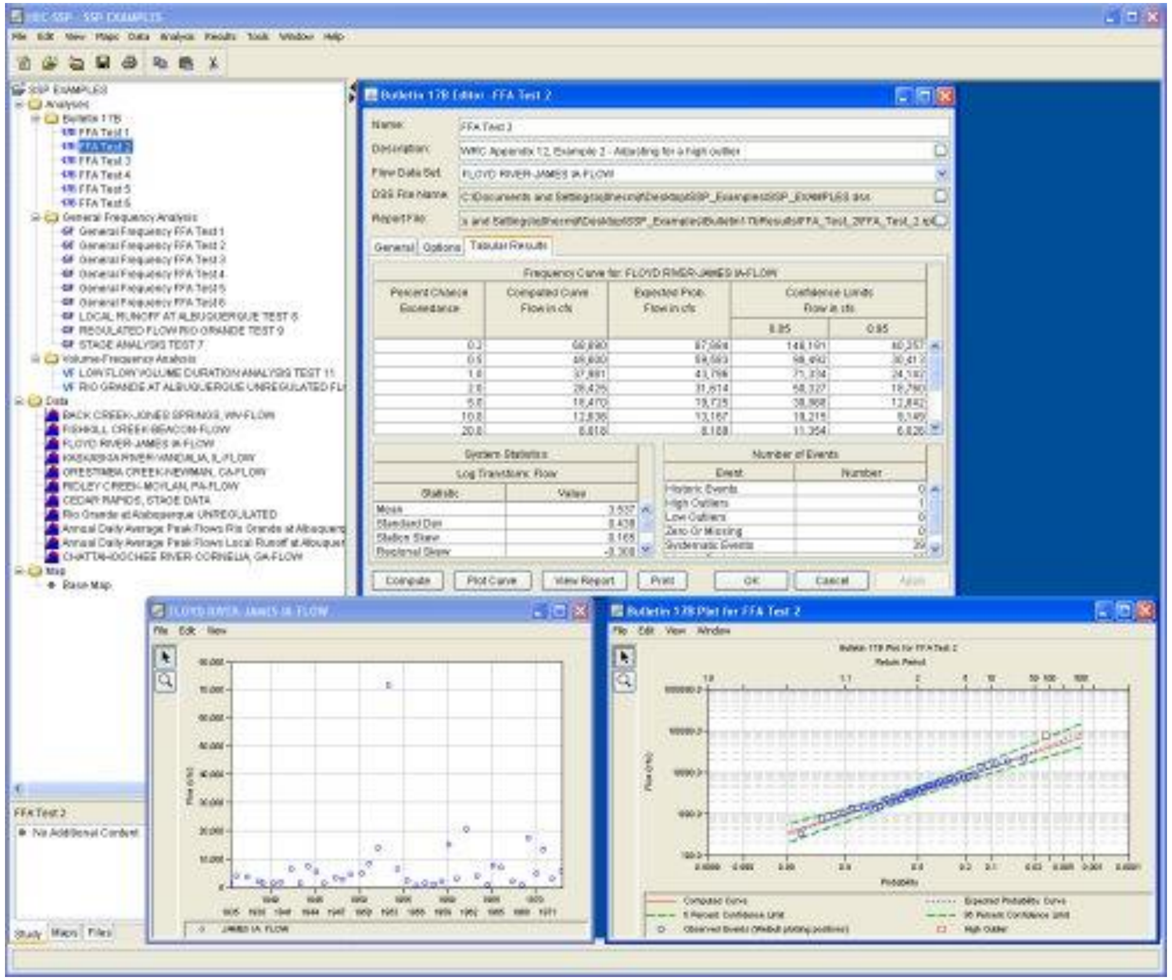
Daily Mean Discharge, cubic feet per second

DATE	Aug 2021	Sep 2021	Oct 2021	Nov 2021	Dec 2021	Jan 2022	Feb 2022	Mar 2022	Apr 2022	May 2022	Jun 2022	Jul 2022	Aug 2022
1		279[A]	508[A]	2,920[A]	836[A]	980[A]	432[A] e	911[P]	3,040[P]	943[P]	362[P]	151[P]	154[P]
2		727[A]	478[A]	2,010[A]	1,050[A]	1,130[A]	440[A] e	880[P]	2,770[P]	868[P]	350[P]	152[P]	140[P]
3		628[A]	460[A]	1,610[A]	1,860[A]	1,150[A]	454[A] e	794[P]	1,890[P]	856[P]	336[P]	151[P]	129[P]
4		427[A]	570[A]	1,370[A]	1,540[A]	888[A]	462[A] e	686[P]	1,650[P]	871[P]	311[P]	139[P]	127[P]
5		358[A]	1,050[A]	1,200[A]	1,320[A]	884[A]	448[A] e	666[P]	1,450[P]	967[P]	290[P]	138[P]	232[P]
6		392[A]	935[A]	1,070[A]	1,280[A]	879[A]	447[A] e	903[P]	1,310[P]	837[P]	272[P]	197[P]	220[P]
7		429[A]	753[A]	957[A]	2,450[A]	830[A]	444[A] e	2,150[P]	1,300[P]	756[P]	260[P]	221[P]	169[P]
8		361[A]	668[A]	880[A]	1,960[A]	743[A] e	439[A] e	3,450[P]	3,450[P]	702[P]	265[P]	171[P]	161[P]
9		603[A]	605[A]	819[A]	1,600[A]	713[A] e	425[A] e	2,170[P]	3,580[P]	654[P]	308[P]	147[P]	167[P]
10	677[A]	601[A]	567[A]	801[A]	1,380[A]	691[A] e	422[A] e	1,520[P]	3,010[P]	611[P]	426[P]	135[P]	168[P]
11	608[A]	467[A]	534[A]	778[A]	1,670[A]	562[A] e	417[A] e	1,330[P]	2,370[P]	575[P]	333[P]	129[P]	
12	563[A]	401[A]	503[A]	845[A]	3,000[A]	509[A] e	410[A] e	1,270[P]	2,140[P]	547[P]	280[P]	125[P]	
13	526[A]	516[A]	479[A]	1,380[A]	2,340[A]	495[A] e	396[A] e	1,090[P]	1,980[P]	524[P]	470[P]	154[P]	
14	481[A]	530[A]	460[A]	1,960[A]	1,800[A]	446[A] e	380[A] e	1,010[P]	1,760[P]	505[P]	456[P]	158[P]	
15	444[A]	517[A]	442[A]	1,720[A]	1,540[A]	383[A] e	372[A] e	1,070[P]	1,810[P]	567[P]	316[P]	134[P]	
16	409[A]	935[A]	491[A]	1,510[A]	1,460[A]	380[A] e	377[A] e	1,510[P]	1,620[P]	625[P]	267[P]	123[P]	
17	387[A]	714[A]	1,040[A]	1,320[A]	1,400[A]	401[A] e	575[A] e	1,640[P]	1,830[P]	905[P]	245[P]	115[P]	
18	390[A]	593[A]	904[A]	1,230[A]	1,250[A]	395[A] e	3,380[A]	1,750[P]	1,580[P]	781[P]	226[P]	114[P]	

Stream Gauge Data

How It Works: Step 4

- So we have historical data… How to predict the 100-year flood?
- Temporal extrapolation of flows at gauge location
  - Perform log-Pearson Type III distribution analysis (Reference USGS Bulletin 17C)
  - In practice use HEC-SSP

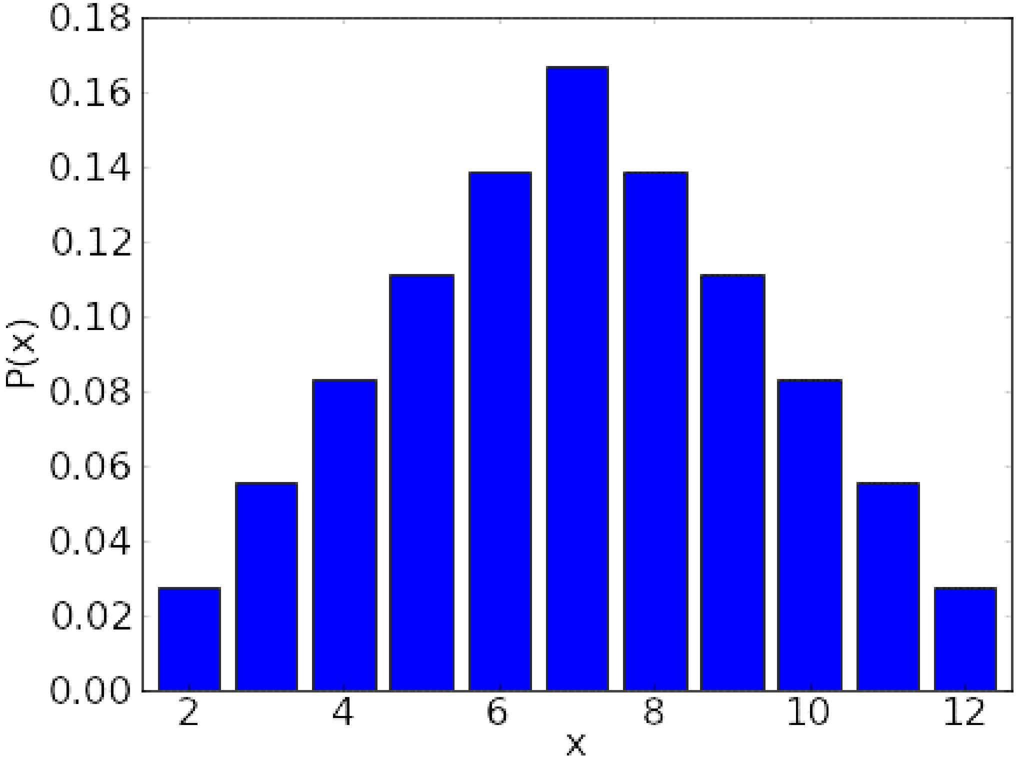


Stream Gauge Data

Quick Aside: Statistical Extrapolation

EXAMPLE:

- 2 dice
- 36 possible combinations

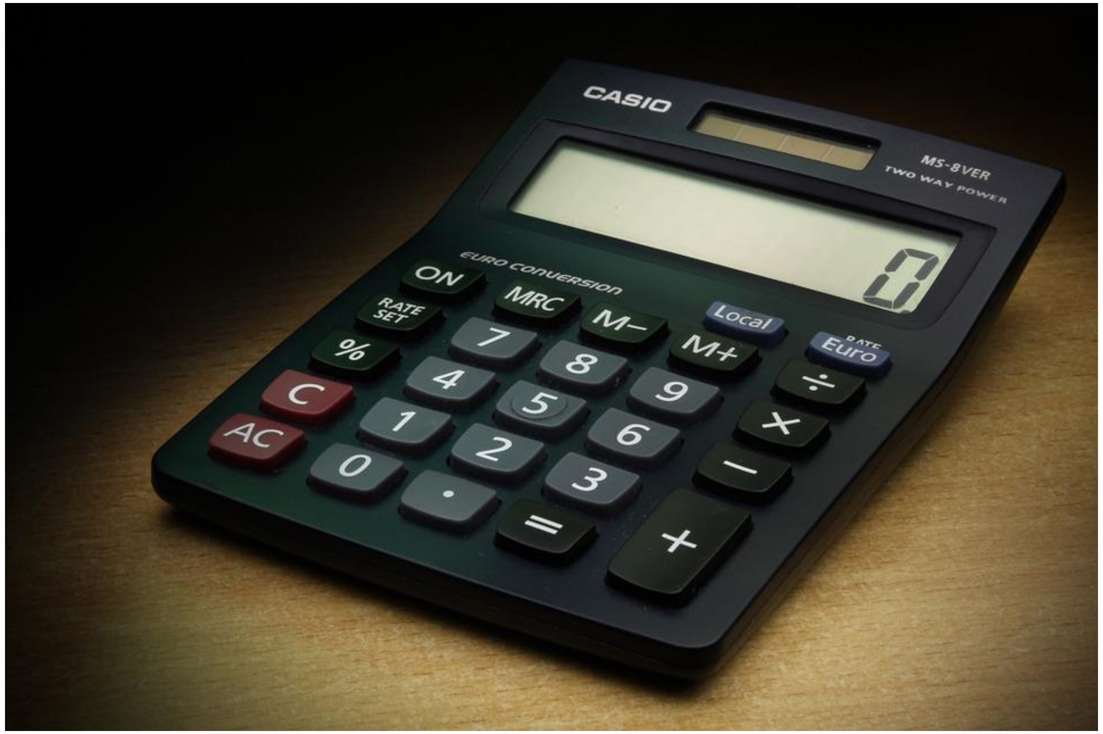


Stream Gauge Data

How It Works: Step 5

Spatial extrapolation to other locations on the same stream

$$\frac{DA_{gauge}}{DA_{site}} \sim \frac{Q_{gauge}}{Q_{site}}$$



Stream Gauge Data

Summary

- Only applicable if gauge data is available for your stream
- Gauges tend to be located on larger streams and rivers
- Provides peak flow only

- Keeping Score: we are now 3 steps removed from reality!
    1. Not measuring flow directly
    2. Temporal extrapolation because limited data history
    3. Spatial extrapolation from gauge site to project site

Stream Gauge Data
Quiz

Fill in the blank:

Measuring flow directly is difficult. Most stream gauges therefore measure _______ and estimate flow based on that.

a) Water temperature
b) Flow velocity
c) Flow depth
d) Rainfall

Regression Equations

Regression Equations

How to Apply Gauge Data to Other Streams?

- We have gauge flow data
- We have geospatial data about the gauged watershed
  - Slope
  - Vegetation
  - Impervious cover
  - Etc.

➢Let’s look for patterns…

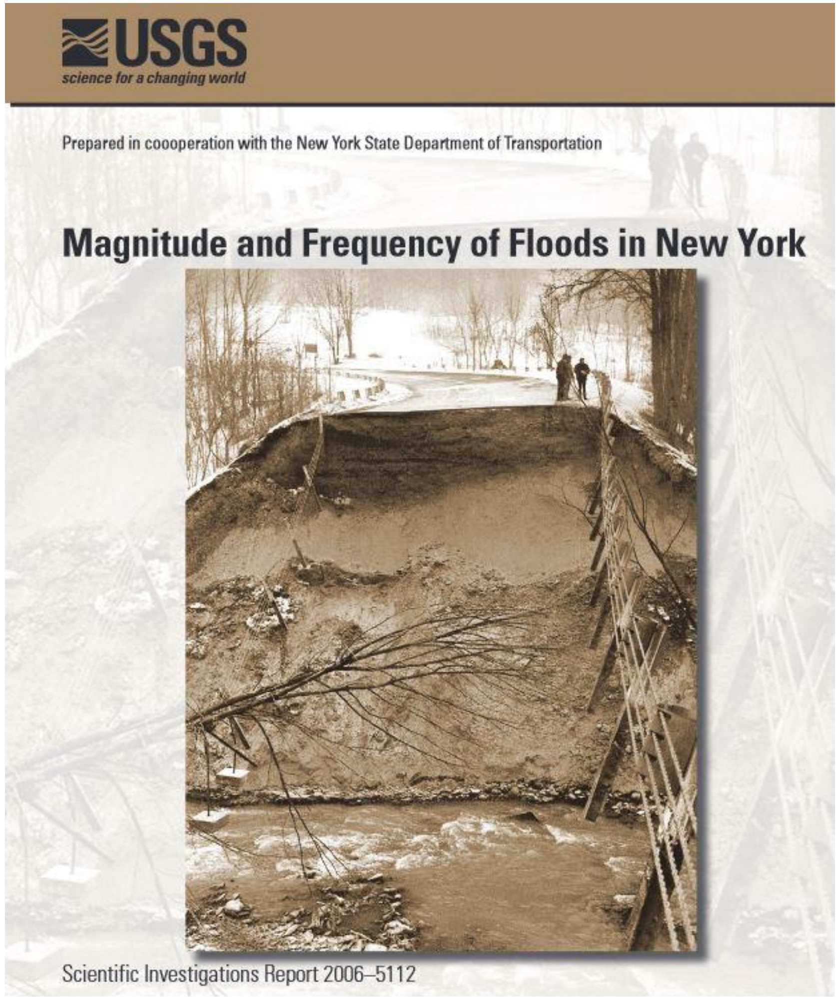
Regression Equations

More Spatial Interpolation

- Thank you USGS!

[A, drainage area, in square miles; ST, basin storage, in percent; P, mean annual precipitation, in inches; LAG, basin lag factor; FOR, basin forested area, in percent; RUNF, mean annual runoff, in inches; MXSNO, seasonal maximum snow depth, 50th percentile, in inches; SR, slope ratio; SL, main channel slope, in feet per mile; EL12, percent of basin above 1,200 feet; Q, flow. subscript is recurrence interval; thus, Q_2 refers to discharge with 2-year recurrence interval]

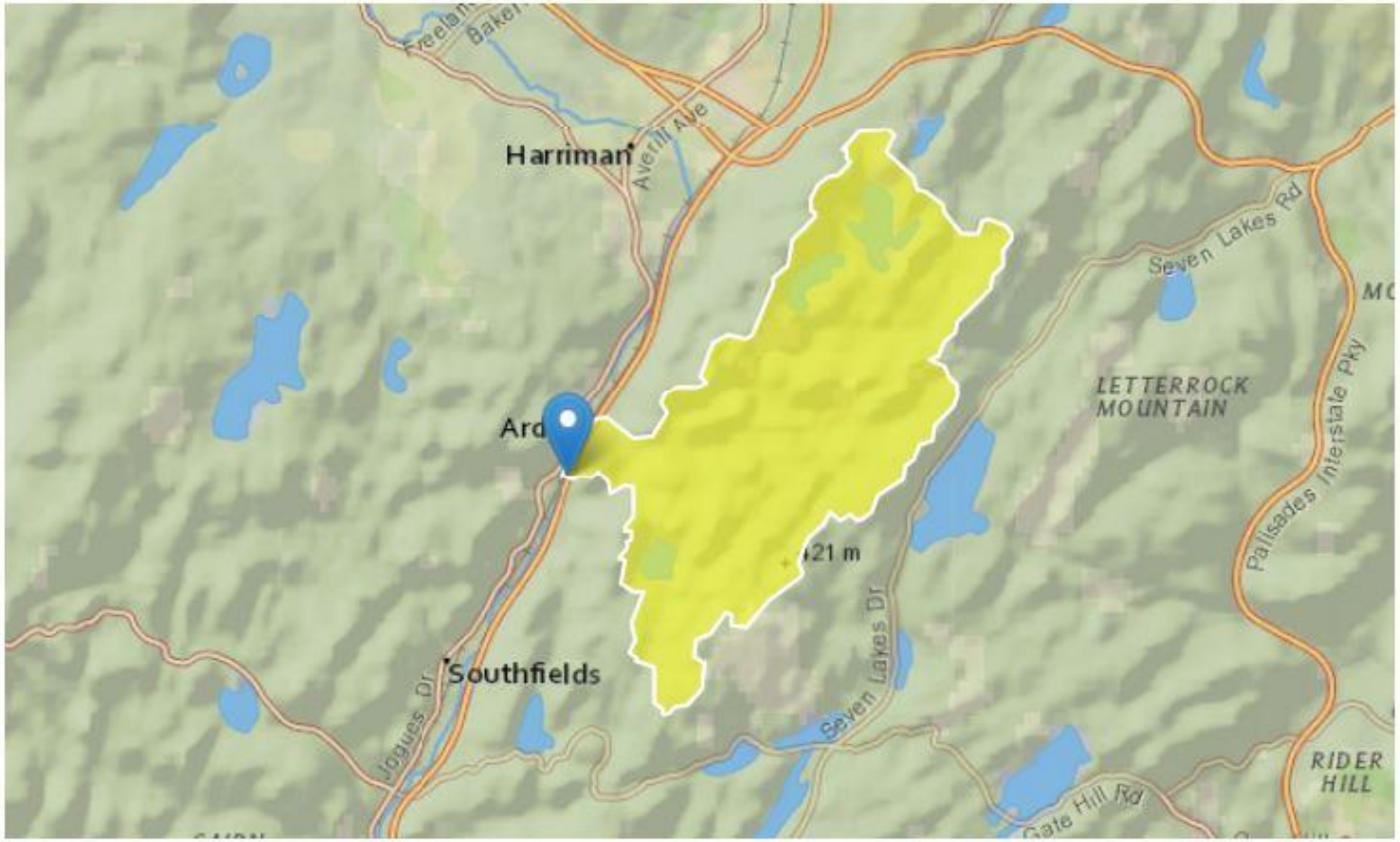
Recurrence interval (years)		Full-regression equation *
Region 1		
$Q_{1.25}$	=	$69.0\,(A)^{0.972}\,(ST+1)^{-0.160}\,(P)^{1.859}\,(LAG+1)^{-0.355}\,(FOR+80)^{-1.514}$
$Q_{1.5}$	=	$144\,(A)^{0.973}\,(ST+1)^{-0.164}\,(P)^{1.718}\,(LAG+1)^{-0.383}\,(FOR+80)^{-1.519}$
Q_{2}	=	$299\,(A)^{0.972}\,(ST+1)^{-0.169}\,(P)^{1.576}\,(LAG+1)^{-0.411}\,(FOR+80)^{-1.518}$
Q_{5}	=	$1180\,(A)^{0.970}\,(ST+1)^{-0.178}\,(P)^{1.335}\,(LAG+1)^{-0.460}\,(FOR+80)^{-1.530}$
Q_{10}	=	$2310\,(A)^{0.968}\,(ST+1)^{-0.184}\,(P)^{1.241}\,(LAG+1)^{-0.482}\,(FOR+80)^{-1.549}$
Q_{25}	=	$4580\,(A)^{0.965}\,(ST+1)^{-0.192}\,(P)^{1.167}\,(LAG+1)^{-0.500}\,(FOR+80)^{-1.582}$
Q_{50}	=	$7030\,(A)^{0.963}\,(ST+1)^{-0.197}\,(P)^{1.131}\,(LAG+1)^{-0.511}\,(FOR+80)^{-1.610}$
Q_{100}	=	$10300\,(A)^{0.962}\,(ST+1)^{-0.202}\,(P)^{1.106}\,(LAG+1)^{-0.520}\,(FOR+80)^{-1.638}$
Q_{200}	=	$14500\,(A)^{0.960}\,(ST+1)^{-0.206}\,(P)^{1.086}\,(LAG+1)^{-0.528}\,(FOR+80)^{-1.667}$
Q_{500}	=	$22000\,(A)^{0.959}\,(ST+1)^{-0.210}\,(P)^{1.067}\,(LAG+1)^{-0.539}\,(FOR+80)^{-1.704}$



Regression Equations

In Practice: Use StreamStats!

- StreamStats web application makes this too easy!



Regression Equations

Results and Limitations

- Peak Flows Only
- Beware the parameter range limitations!
- Must be modified for use in heavily urbanized areas (USGS Water Supply Paper 2207)

Parameter Code	Parameter Name	Value	Units	Min Limit	Max Limit
DRNAREA	Drainage Area	7.61	square miles	1.93	996
LAGFACTOR	Lag Factor	0.0498	dimensionless	0.014	6.997
STORAGE	Percent Storage	10.1	percent	0	11.88
MAR	Mean Annual Runoff in inches	28.6	inches	16.03	33.95

Peak-Flow Statistics Flow Report [2006 Full Region 2]

PII: Prediction Interval-Lower, Plu: Prediction Interval-Upper, SEp: Standard Error of Prediction, SE: Standard Error (other -- see report)

Statistic	Value	Unit	SE	SEp	Equiv. Yrs.
1.25 Year Peak Flood	119	ft^3/s	25.5	25.5	4.8
1.5 Year Peak Flood	150	ft^3/s	25.6	25.6	4.3
2 Year Peak Flood	194	ft^3/s	25.8	25.8	4.4
5 Year Peak Flood	339	ft^3/s	27	27	7.3
10 Year Peak Flood	468	ft^3/s	28.2	28.2	10.1
25 Year Peak Flood	669	ft^3/s	29.9	29.9	13.6
50 Year Peak Flood	852	ft^3/s	31.5	31.5	15.8
100 Year Peak Flood	1070	ft^3/s	33.3	33.3	17.6
200 Year Peak Flood	1320	ft^3/s	35.3	35.3	18.9
500 Year Peak Flood	1720	ft^3/s	38.4	38.4	20.1

Regression Equations

Summary

- Very easy to use thanks to StreamStats
- Beware applicability limitations
- Provides peak flow only

- Keeping Score: we are now 4 steps removed from reality!

    4. More spatial extrapolation, to other streams

Regression Equations

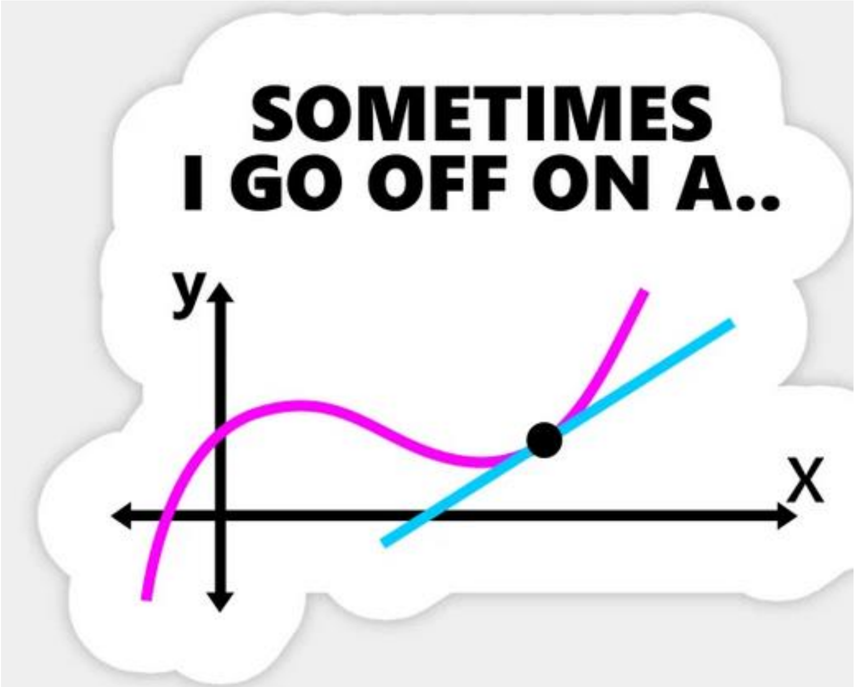
Quiz

Fill in the blank:

The easiest way to use the USGS regression equations is the ________ web application.

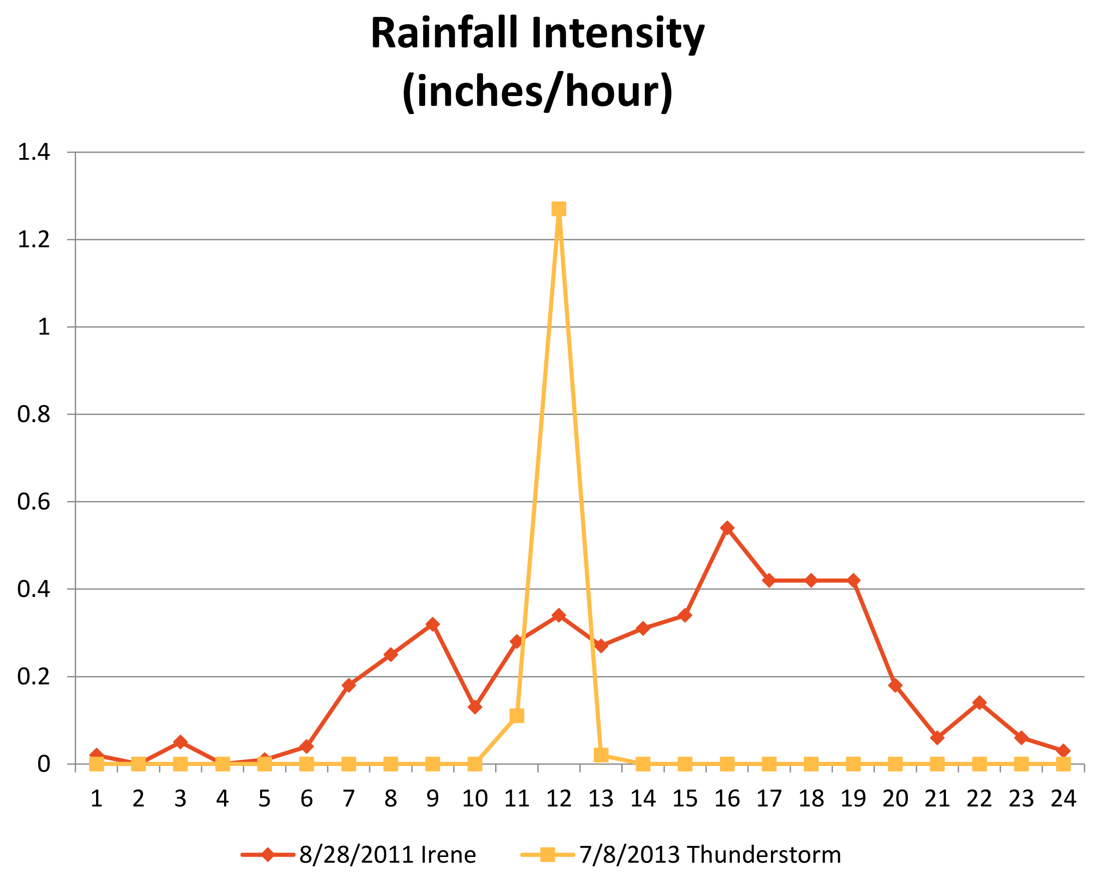
a) FlowFinder
b) StreamStats
c) RiverRun
d) WaterWatch

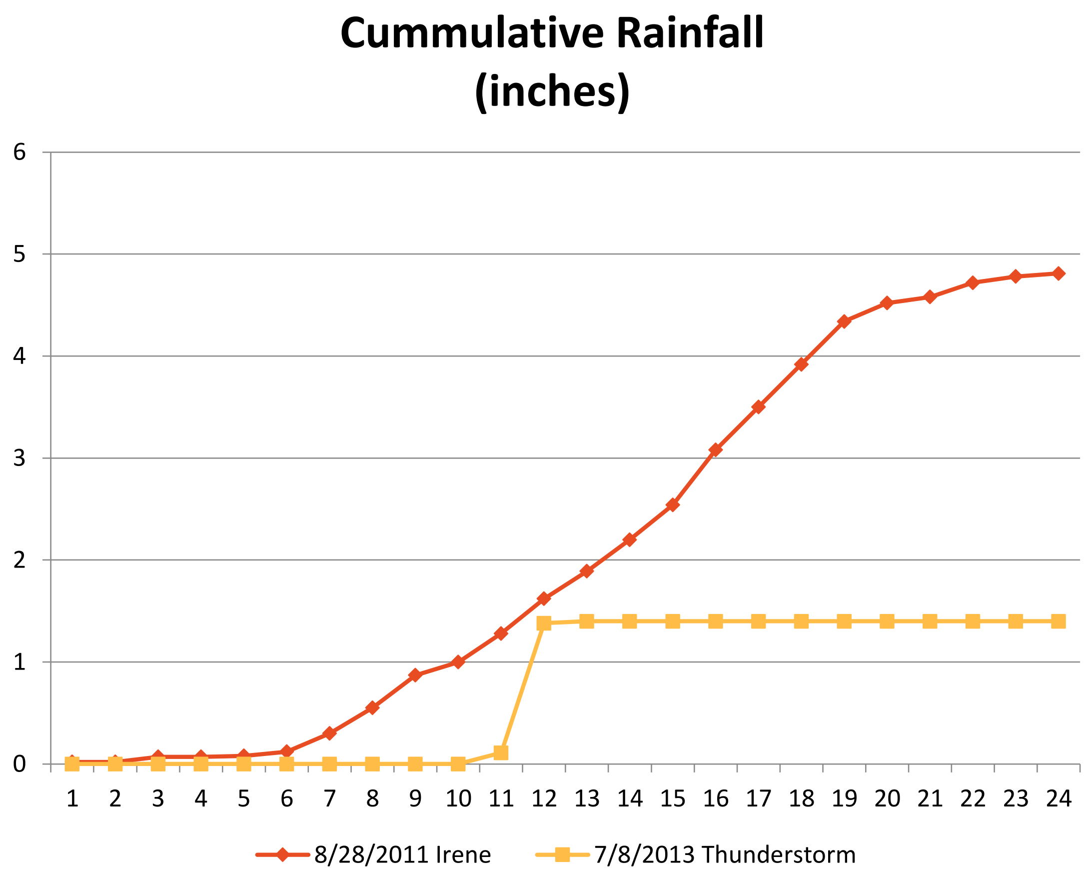
Tangent: Rainfall Patterns and Synthetic Rainfall Hydrographs



Tangent: Rainfall Patterns and Synthetic Rainfall Hydrographs

Example Natural Rainfall Hydrographs





Tangent: Rainfall Patterns and Synthetic Rainfall Hydrographs

Which one was the more severe storm?

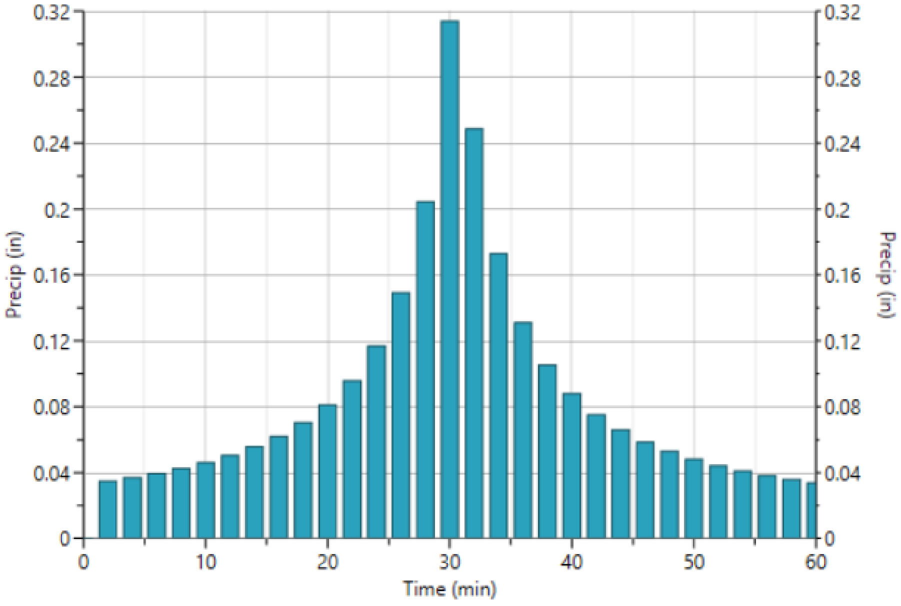
- The thunderstorm flooded portions of the local mall parking lot 2 feet deep. The Schoharie river was fine.
- The hurricane caused massive floods on the Schoharie (and many other rivers). The mall parking lot was fine.

➢ Differences in temporal and geographic distribution.

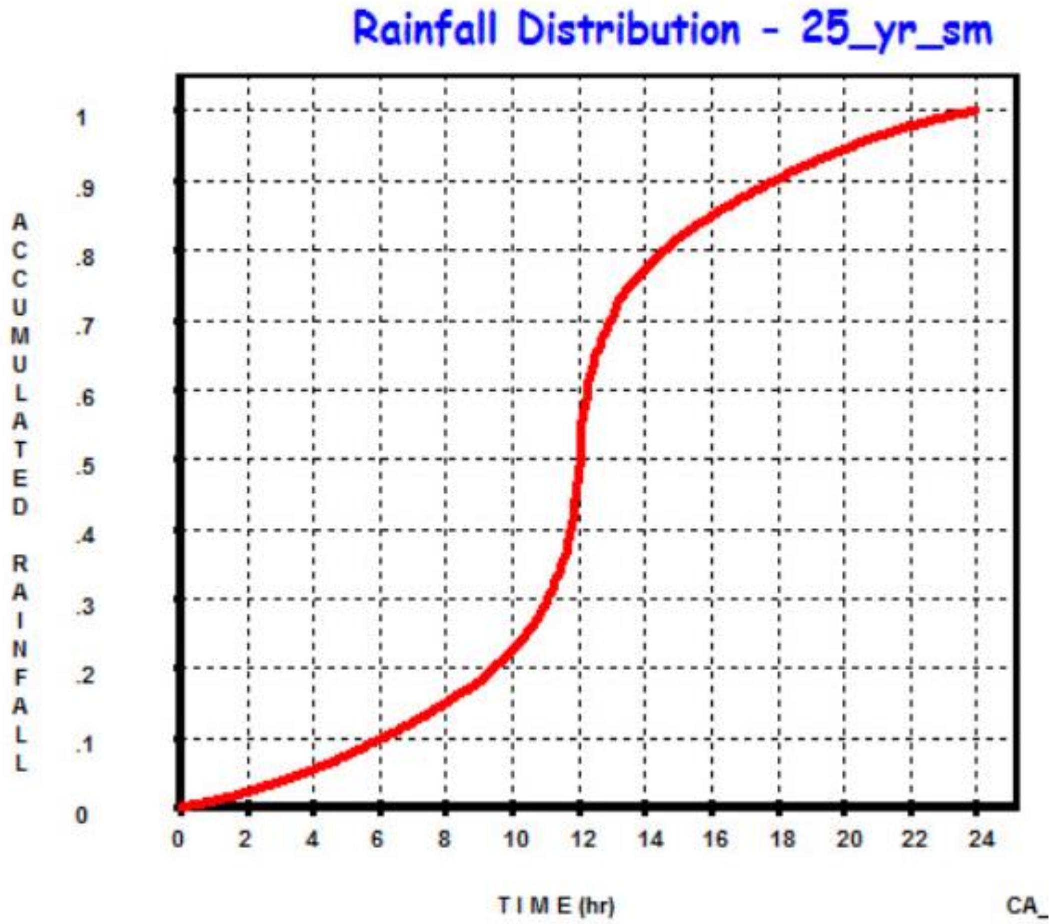
➢ The size of the watershed matters when you are considering what storm event to be concerned about!

Tangent: Rainfall Patterns and Synthetic Rainfall Hydrographs

Synthetic Rainfall Hydrographs



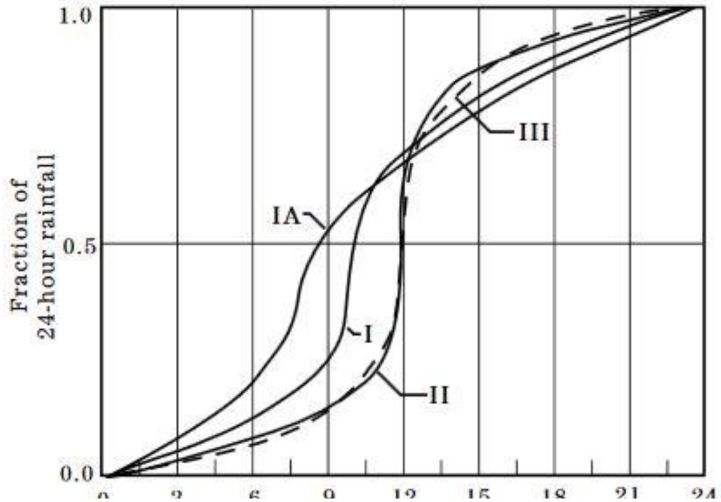
Extremely powerful design tool: Allows a single synthetic storm to return the maximum runoff rate for watersheds of any size.

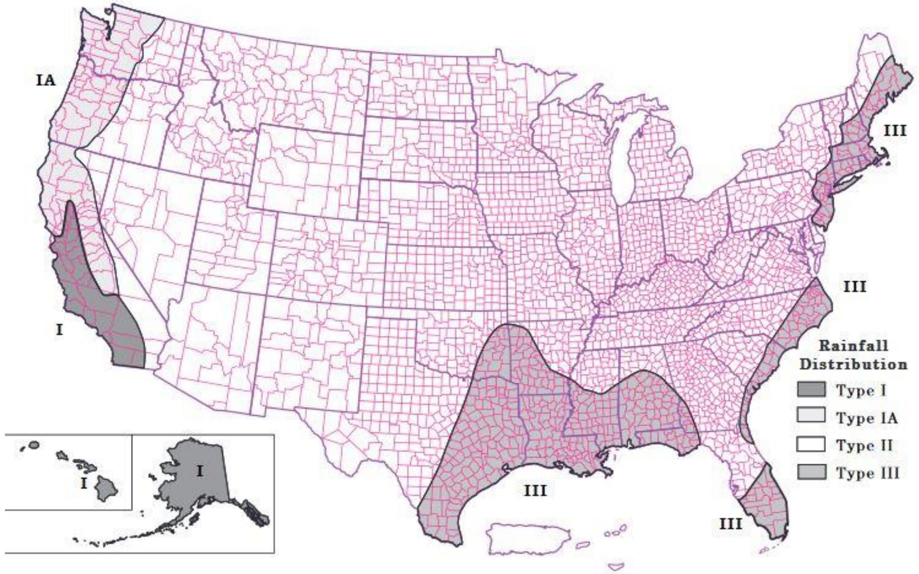


Tangent: Rainfall Patterns and Synthetic Rainfall Hydrographs

How does it work in practice?

- Need a unit hydrograph and a depth
- Unit hydrographs available from:
  - Natural Resources Conservation Service (NRCS)
  - Northeast Regional Climate Center (NRCC)
- Depths available from:
  - NRCS TR-55
  - NRCC
  - NOAA Atlas 14





Tangent: Rainfall Patterns and Synthetic Rainfall Hydrographs

Quiz

Fill in the blanks:

A thunderstorm will typically have a _______ intensity and _______ total rainfall depth than a hurricane.

a) Lower / Lower
b) Higher / Higher
c) Lower / Higher
d) Higher / Lower

Rainfall-Runoff Calculations

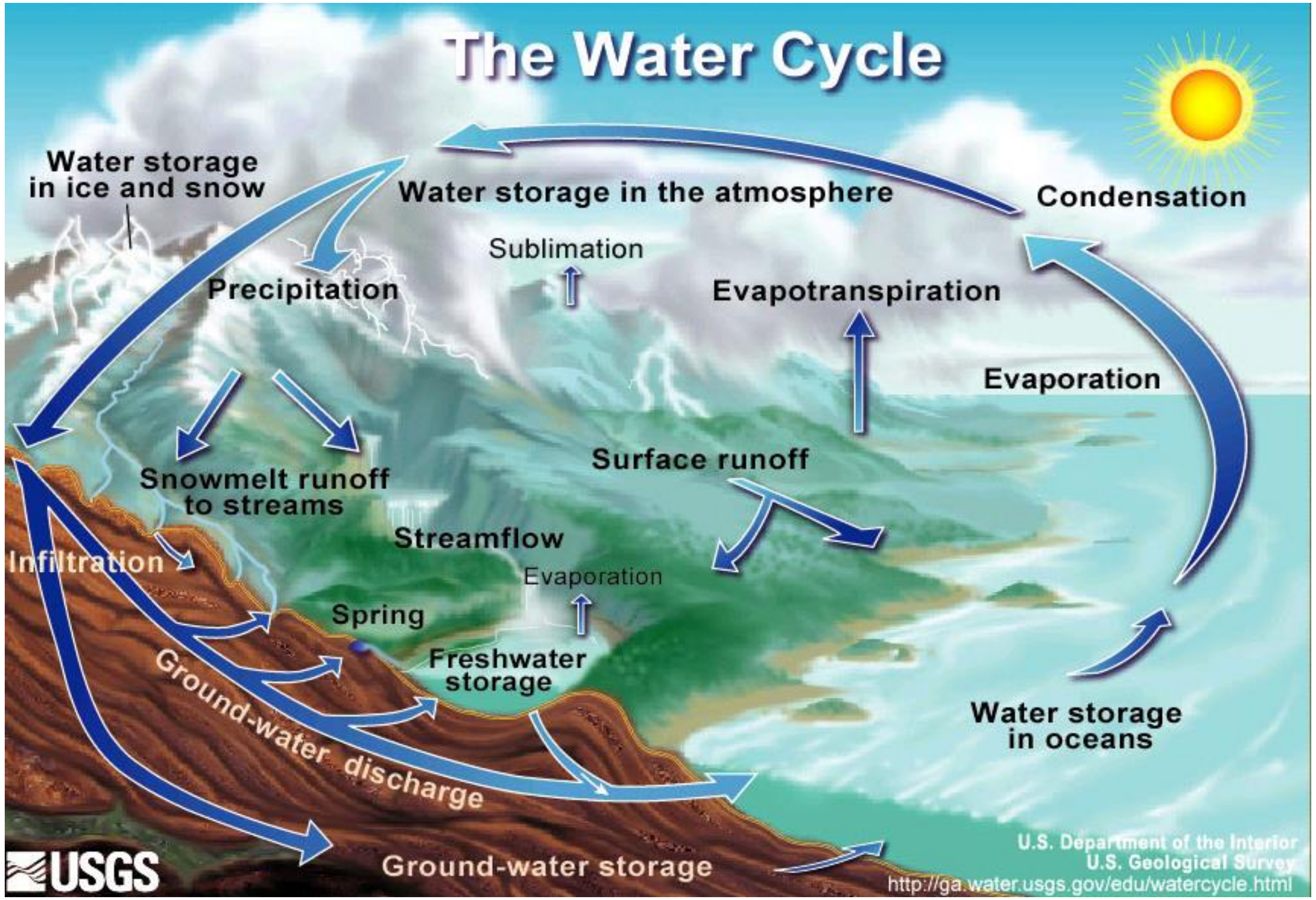
Rainfall-Runoff Calculations
Overview

GIVEN:

- Rainfall hydrograph
- Watershed characteristics

CALCULATE:

- Runoff hydrograph

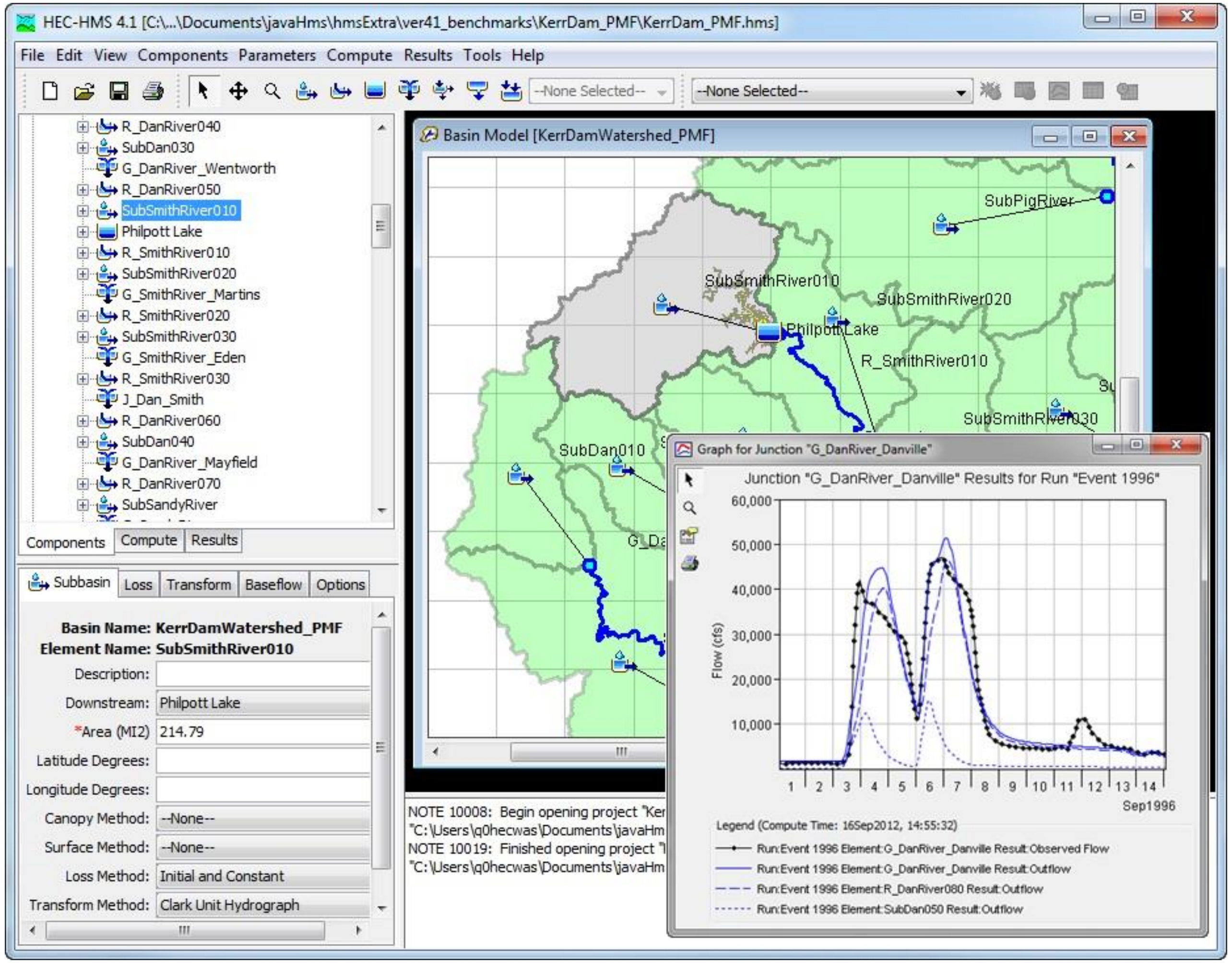


Rainfall-Runoff Calculations

Curve Number Method

Watershed characteristics:

- Area
- Curve Number
- Time of Concentration/lag time



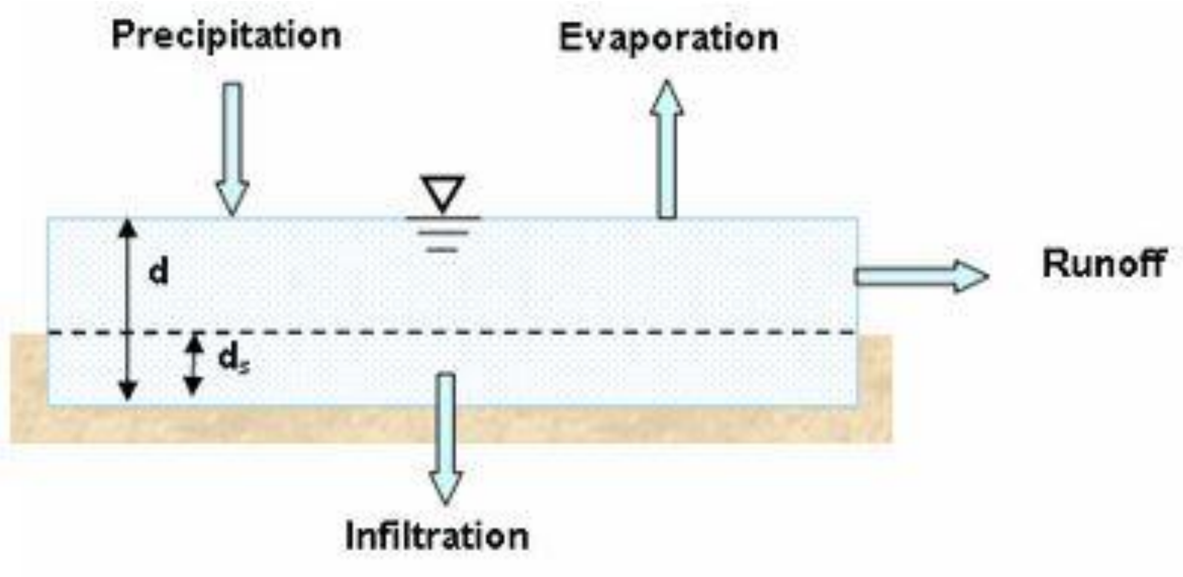
Software examples:

- HEC-HMS
- HydroCAD

Rainfall-Runoff Calculations
SWMM Method

Watershed characteristics:

- Area
- Width
- Slope
- Depth of storage
- Roughness coefficient
- Infiltration factor



Software example:

- EPA SWMM

Rainfall-Runoff Calculations

Limitation #1: Synthetic Rainfall Hydrographs

- By design gives the worst-case rainfall intensity for every watershed.
- Does not account for temporal storm distribution.
- Does not account for spatial storm distribution.

➢ These issues are amplified as the watershed gets larger.

Rainfall-Runoff Calculations

Limitation #2: Real Watersheds are not Homogeneous

- Variations in:
  - Slope
  - Land cover
  - Hydrologic soil group

- The larger the watershed, the less homogeneous

Rainfall-Runoff Calculations

Limitation #3: Runoff ≠ Stream Flow

- Un-designed micro-detention (a.k.a. puddles)

Puddle storage is:

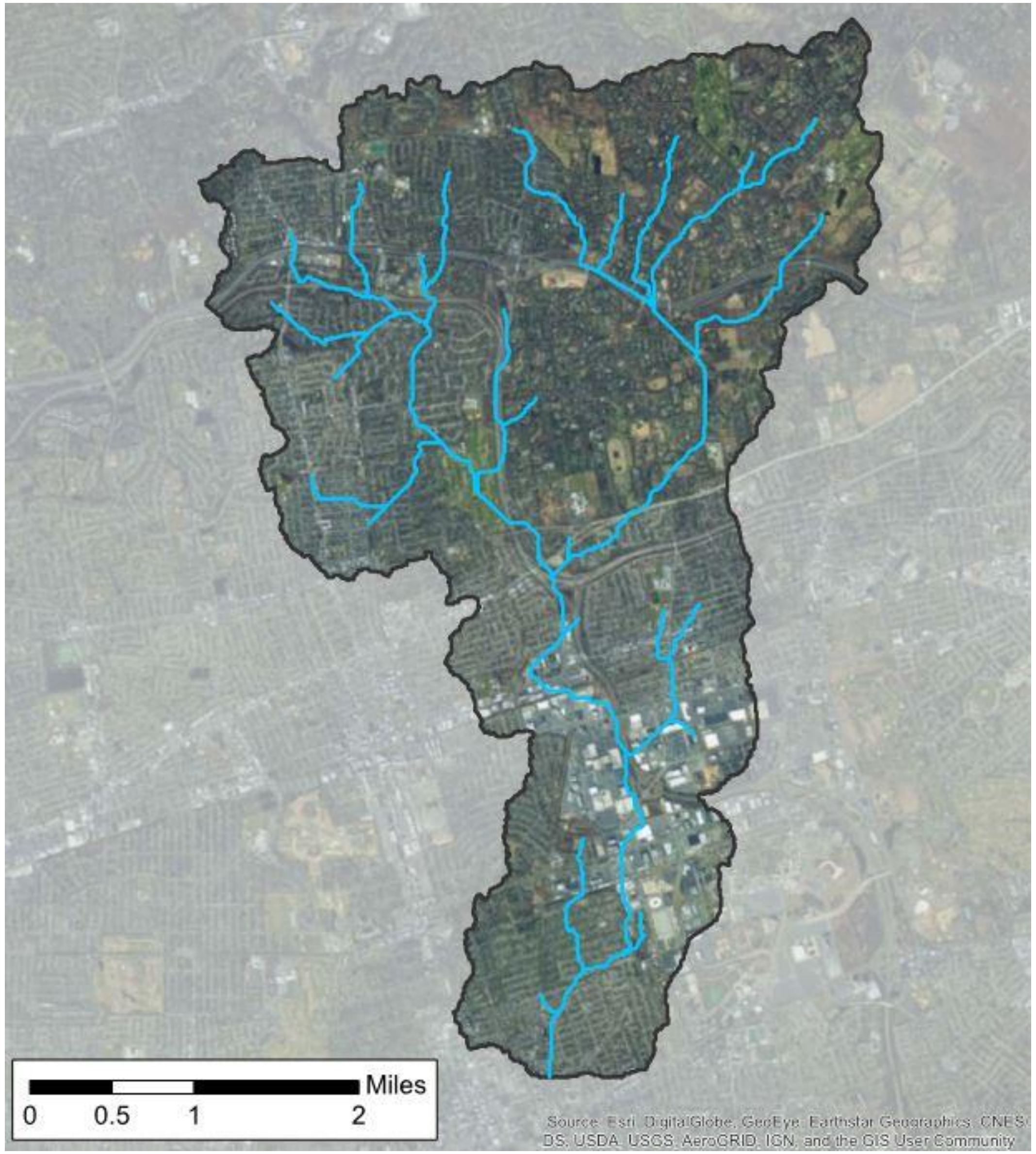
- Directly proportional to wildness
- Inversely proportional to slope

Rainfall-Runoff Calculations

Limitation: Example

- Unnamed Stream on Long Island
- Heavily urbanized watershed
- Watershed Area = 13.5 square miles (8,640 acres)

	Gauge Data	Regression Equations	SWMM Method	Curve Number Method
100-yr Q (cfs)	370	2,700	9,400	10,400



Rainfall-Runoff Calculations

Mitigating for Stream Flow Over-Estimation

- NYSDOT Highway Design Manual recommends max drainage area = 640 acres (1 square mile)
- Break up watershed into smaller subcatchments
- Explicitly model surface storage where possible
- Sanity check results against Streamstats or gauge data
- Calibrate to real-world data
- Use common sense!

Rainfall-Runoff Calculations

Quiz

Which of the following watershed characteristics does the Curve Number method rely on:

a) Area
b) Curve Number
c) Time of concentration
d) All of the above

Conclusion

Conclusion

Summary of Methods

	Gauge Data	Regression Equations	Rainfall-Runoff Calculations
Output Type	Peak flow only	Peak flow only	Full hydrograph
Applicability	Very limited (gauged streams only)	Theoretically universal (within published limitations)	Theoretically universal
Drainage Area	Larger streams and rivers Typically >10 square miles	Varies by region Typically 1 to 30 square miles	Beware if greater than 0.5 square miles!
Land Use	Any	Generally limited to less urbanized areas	Any
Effort Required	Moderate (Need to know where to look and how to interpret data)	Very easy with StreamStats (Maybe too easy!)	Specialized knowledge and software required

Conclusion

Thank you for Your Time!

Contact Info:

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Glens Falls, NY 12801
pguillet@labellapc.com

Please enjoy the rest of the conference ☺