THE ANTHROPOGENIC AND CLIMATIC EFFECTS ON THE SCALING OF DISCHARGE AND DRAINAGE AREA FOR MULTIPLE WATERSHEDS FROM USGS DISCHARGE RECORDS

Paper #85-7

Joshua C. Galster, Joshua.Galster@montclair.edu, Dept. of Earth & Environmental Studies, Montclair State University, Upper Montclair, NJ 07043

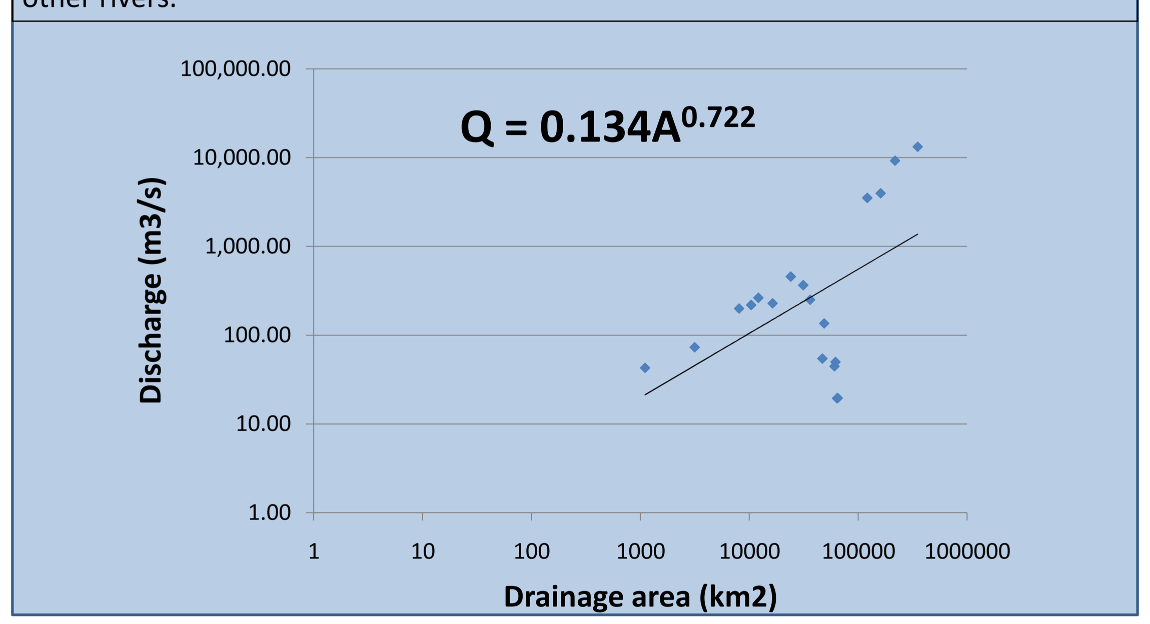
ABSTRACT

River discharge is the fundamental process operating in a fluvial system, with the surrounding drainage area contributing this discharge. The increase in discharge and drainage area downstream is intuitive but datasets describing this increase within individual watersheds are not common. The scaling of discharge and drainage area can be described as: $Q = kA^c$, where "Q" is river discharge, "A" is drainage area, and "k" and "c" are scaling constants. While "k" is not often illustrative of watershed processes, the constant "c" represents the rate at which discharge (Q) increases downstream when compared to drainage area (A). This study compiles the annual peak discharge records of rivers from USGS gauges to analyze the rate at which discharge and drainage increase downstream. Peak discharges are effective geomorphic agents and can pose flooding hazards. The peak annual discharge records were selected to represent a variety of watersheds across multiple climatic and geographic settings as well as to illustrate the effects of anthropogenic land-use change and water management changes over the length of the records. Peak annual discharges were plotted versus drainage area at the gauging station. It is often assumed that the scaling between discharge and drainage area is linear, several of these watersheds exhibit this behavior over the length of their record. However, multiple rivers also show nonlinear behavior, as the discharge scaling values (*c*) are less than linear with the amount of discharge generated per unit drainage area decreasing in the downstream areas of the watershed. Variables such as slope, evapotranspiration, runoff generation, and winter snowpack contribution to peak annual discharges may be spatially inconsistent in a watershed, creating the nonlinear behavior in the scaling of discharge.

Gauge name	Year	Discharge (m³/s)	Drainage area (km²)
Granite	1945	43	1106
Salida	1945	73	3155
Canon City	1945	199	8073
Portland	1945	218	10422
Pueblo	1945	263	12137
Avondale	1945	228	16387
Near Nepesta	1945	456	24064
La Junta	1945	365	31326
Las Animas	1945	250	36198
John Martin	1945	54	46957
Lamar	1945	135	48770
Holly	1945	44	60671
Syracuse	1945	50	61917
Garden City	1945	19	63981
Dodge City	1945	20	64794
Ralston	1945	3512	121342
Tulsa	1945	3965	160772
Muskogee	1945	9232	217904
Little Rock	1945	13225	351849

C calculation example: Arkansas River

Below are the peak discharges recorded on the Arkansas River in 1945 by the United States Geological Survey (USGS). The discharges and upstream drainage areas were converted to metric units. For linear regression the logarithm of drainage area and discharge were calculated and input into SPSS. The value of the linear regression is the constant *c* from the equation $Q = kA^c$. This value is then plotted (along with the 95% confidence interval) onto the graph to the right. This is repeated for each year that had at least three stations recorded discharge. The same method was repeated for the other rivers.



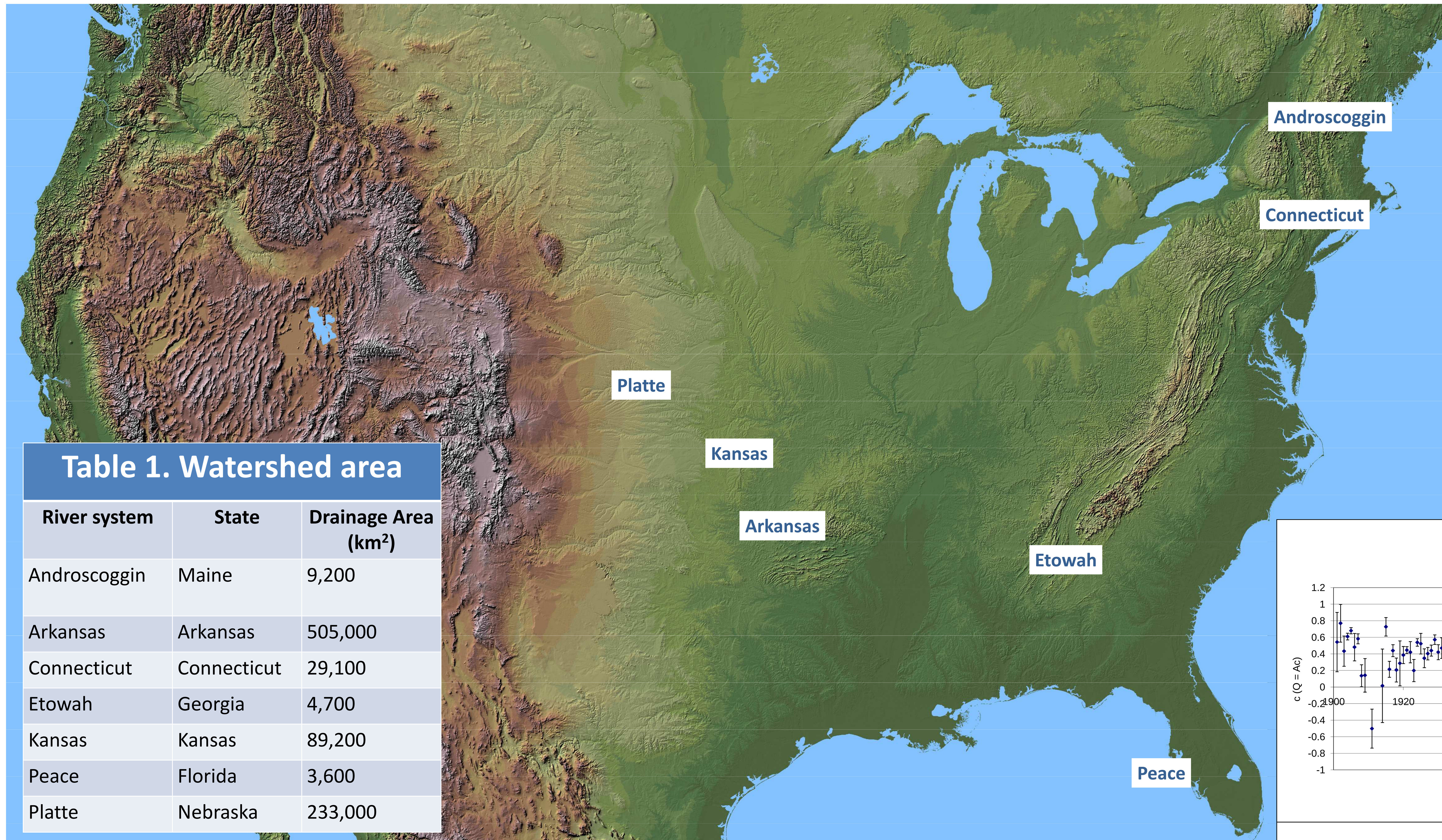
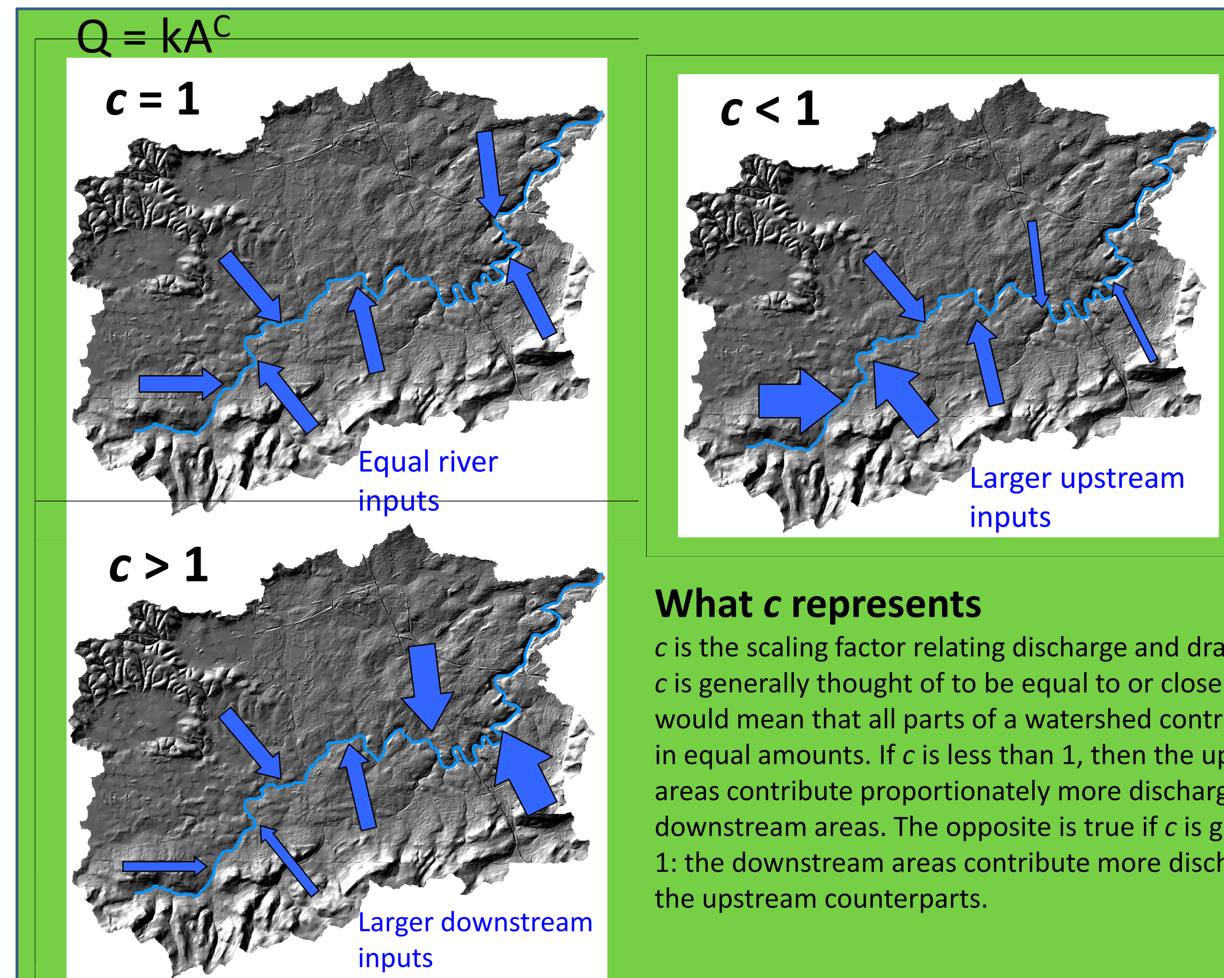


Table 1. Watershed area

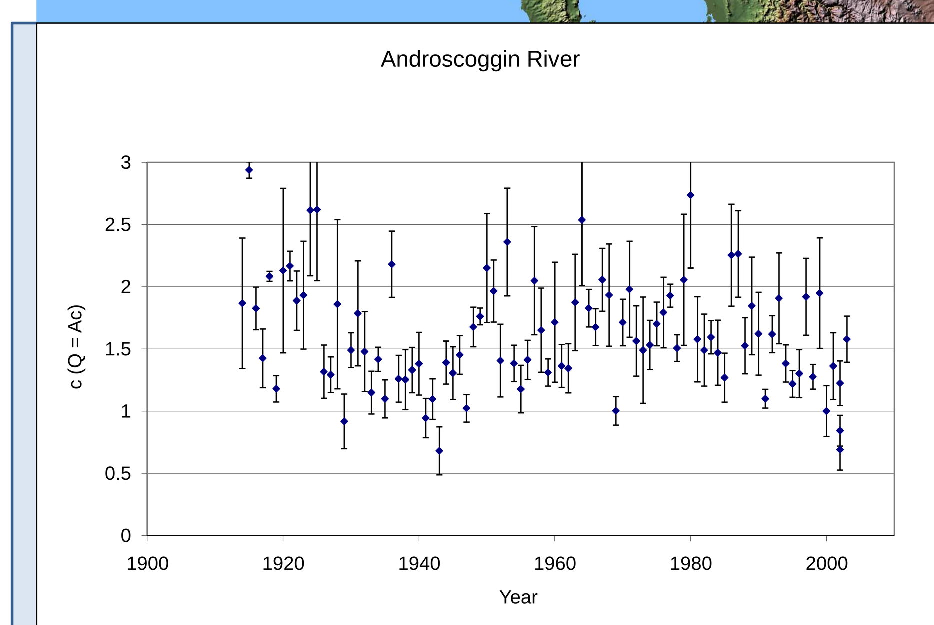
River system	State	Drainage Area (km²)
Androscoggin	Maine	9,200
Arkansas	Arkansas	505,000
Connecticut	Connecticut	29,100
Etowah	Georgia	4,700
Kansas	Kansas	89,200
Peace	Florida	3,600
Platte	Nebraska	233,000

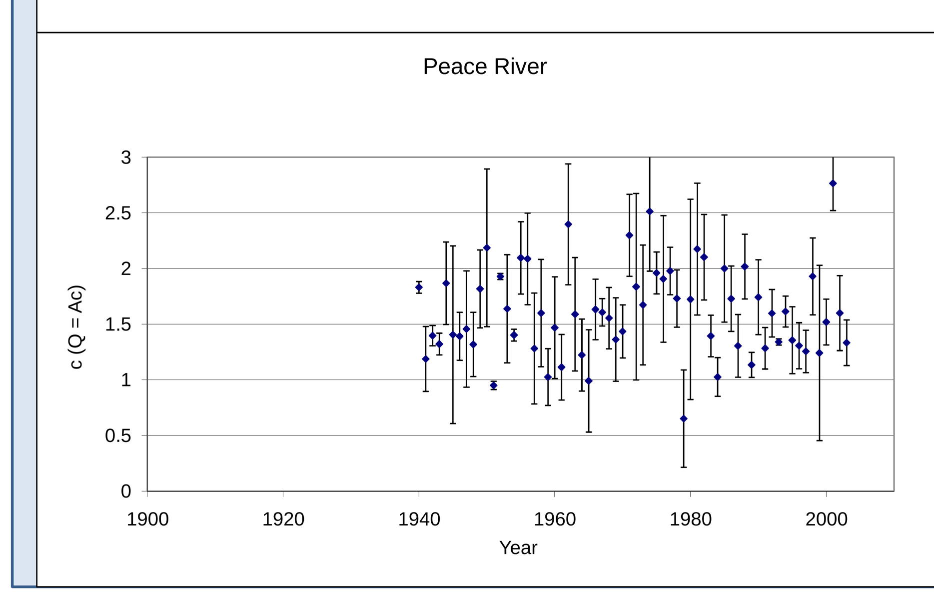
$Q = kA^C$



What *c* represents

c is the scaling factor relating discharge and drainage area. *c* is generally thought of to be equal to or close to 1, which would mean that all parts of a watershed contribute runoff in equal amounts. If *c* is less than 1, then the upstream areas contribute proportionately more discharge than the downstream areas. The opposite is true if *c* is greater than 1: the downstream areas contribute more discharge than the upstream counterparts.



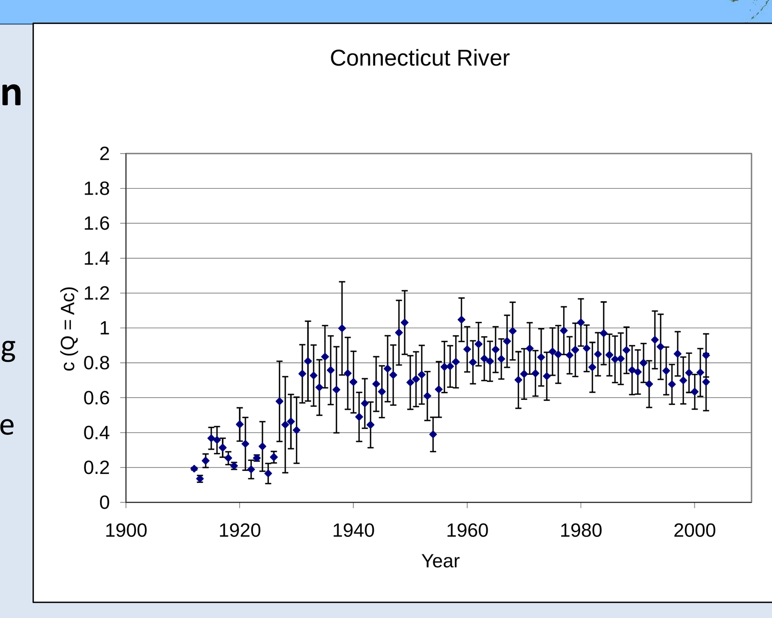


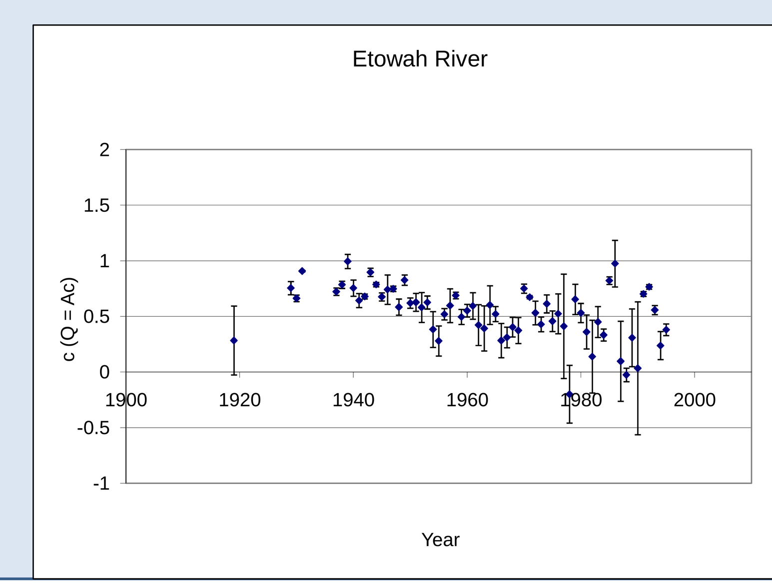
Two rivers, two different settings, similar outcome

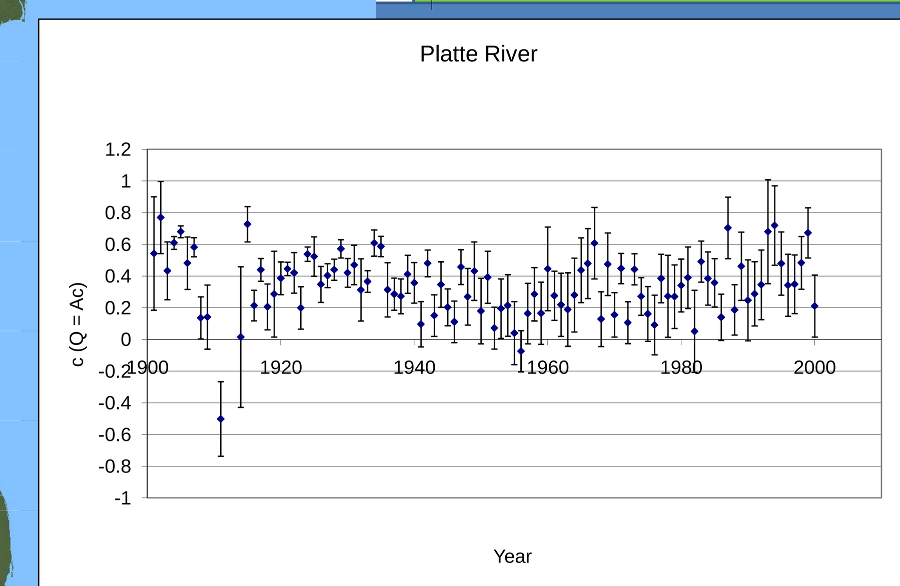
The Androscoggin River in Maine and the Peace River in Florida have different watershed conditions but have similar *c* values over the last 60 years. The Androscoggin flows over metamorphic and igneous rock and over steeper terrain than the Peace River in Florida, whose bedrock is mostly carbonates and other sediments. It is notable that both rivers have *c* values higher than the assumed 1 for much of their record. The larger *c* values represents more discharge being generated in the downstream area of the watershed.

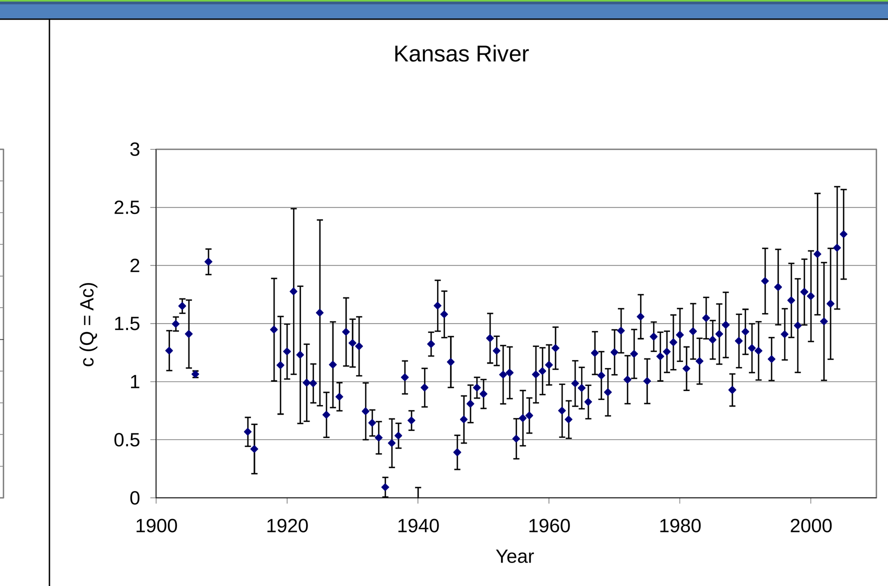
Secular changes in *c* values

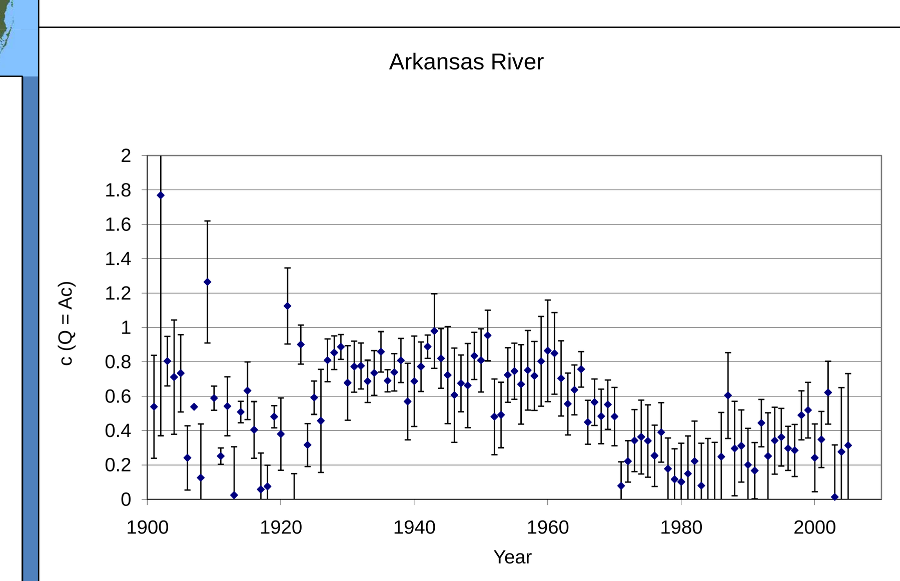
The Connecticut River and the Etowah River (located in Connecticut and Georgia) show evidence for there being a driving force that has been changing the value of *c* over time. This external force may be natural (climate, precipitation, vegetation), anthropogenic (flood-control dams, groundwater usage, land-use change) or some combination of the two.

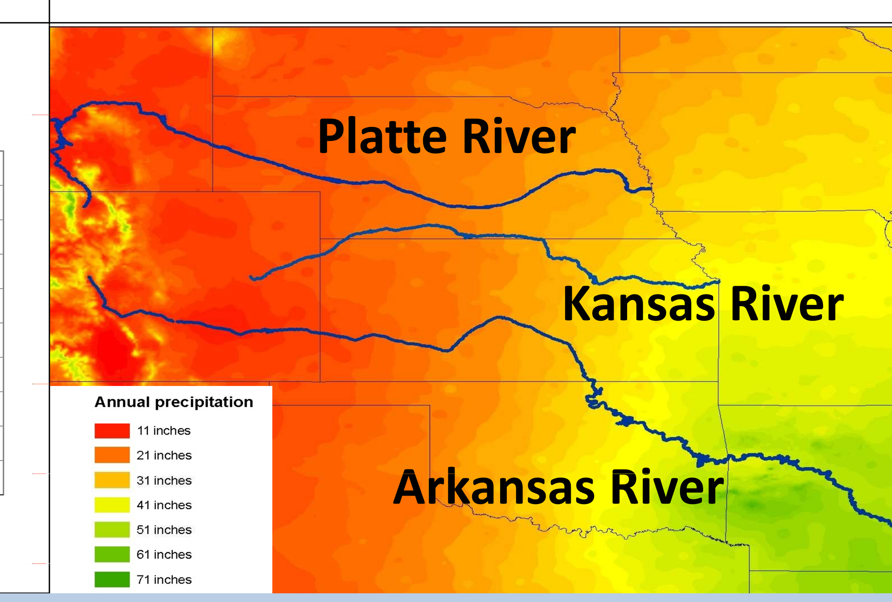












Three rivers, three stories

Three river systems, the Platte, Kansas, and Arkansas, whose watersheds share similar elevation and precipitation values but exhibit different *c* values. All three rivers have more variability in their *c* values before the 1920 's when large dams and other river control devices were constructed. The secular trends after ~1960 for the Kansas and Arkansas are opposite, which may be due large groundwater withdrawals that influenced the *c* values in the Arkansas after ~1960. To the north the Platte has remained fairly steady but low in its *c* values, fluctuating between 0.2-0.6.

Conclusions and next steps

The analysis of these seven rivers present intriguing results, but the interpretation of these results is not straightforward. The Androscoggin and Peace rivers suggest there may be multiple processes that produce similar results. The different results from the three Midwestern rivers (Platte, Kansas, and Arkansas) implies that rivers with similar size and precipitation patterns may have different hydrologic characteristics. More detailed studies of each watershed's climatic and hydrologic variables as well as its history of human influence are needed before stronger conclusions can be drawn.