Improving Paleohydrologic Source-to-Sink Estimates by Merging Big Data and the Fulcrum Approach

School of Geology, Energy, and the Environment

TCU College of Science & Engineering

SciCom Let's Talk Science

Nicole Wilson, Dr. John Holbrook

School of Geology, Energy, and the Environment

Texas Christian University Student Research Symposium 2018

Abstract

Quantifying source-to-sink sediment flux for stratigraphic systems is critical for accurate basin models, but all available methods are hampered by low precision and most require data not readily attained by common subsurface studies. The Fulcrum approach uses the variables of channel bankfull thickness and grain size to calculate sediment bankfull discharge and converts this to an annual sediment volume. The fulcrum approach uses commonly collected data but similarly yields only approximate flux estimates. In order to calculate a more precise source-to-sink estimate for long basin durations, the amount of time the fluvial systems runs at bankfull flow and the annual proportion of sediment discharged during this bankfull flow must also be determined. By categorizing fluvial systems by attributes such as drainage area and paleoclimate at the time of discharge, a more specified and accurate bankfull flow duration and total bankfull sediment discharge is estimated. We constructed a database that stores and categorizes these data and a user interface (RAFTER: River Analogue and Fulcrum Transport Estimates Repository) to query and display this data. Daily stream gauge data spanning decades is used in conjunction with measured bankfull values from literature to populate the datasets for the database and derive stream specific data attributes. This bankfull flux searchable database evaluates stream gauge data for modern fluvial systems according to classes such as climate setting and is also a useful tool for identifying analog stream data scaled to drainage basin and channel size. It evaluates designated parameters of days within a year that the river runs at bankfull flow, as well as the yearly proportion of sediment discharged over bankfull duration. The database can thus yield a more accurate value for duration at bankfull flow and sediment discharge at bankfull from modern rivers that can be used as an analog for stratigraphic rivers with interpreted climate and size parameters. Results show a key breakdown in bankfull duration, with arid and tropical rivers on the order of a fraction of a day per year boreal climates tending to be an order of magnitude longer and temperate climates still longer. Categorizing stratigraphic rivers by known climate and other parameters, can lower the total error in sediment flux from paleohydrology by a geometric factor.

Purpose

The accuracy of the Fulcrum approach relies on estimating the duration of time a stream runs at bankfull flow (t_{bd}) and the proportion of sediment discharged during this flow (b). Mean annual sediment discharge (Q_{mas}) is estimated for a channel by multiplying the variables of (t_{bd}) and (b) against a calculated value for bankfull sediment discharge (Q_{bts}), with full methods for calculation of (Q_{bts}) provided in Holbrook and Wanas (2014).

$$Q_{mas}=Q_{bts}(t_{bd})b$$

The purpose of this study is to minimize error in the Fulcrum approach (Figure 1) by replacing the currently used generic value of 7.3 days a year for bankfull flow duration (t_{bd}) with a climate specific value for t_{bd} (Figure 2).

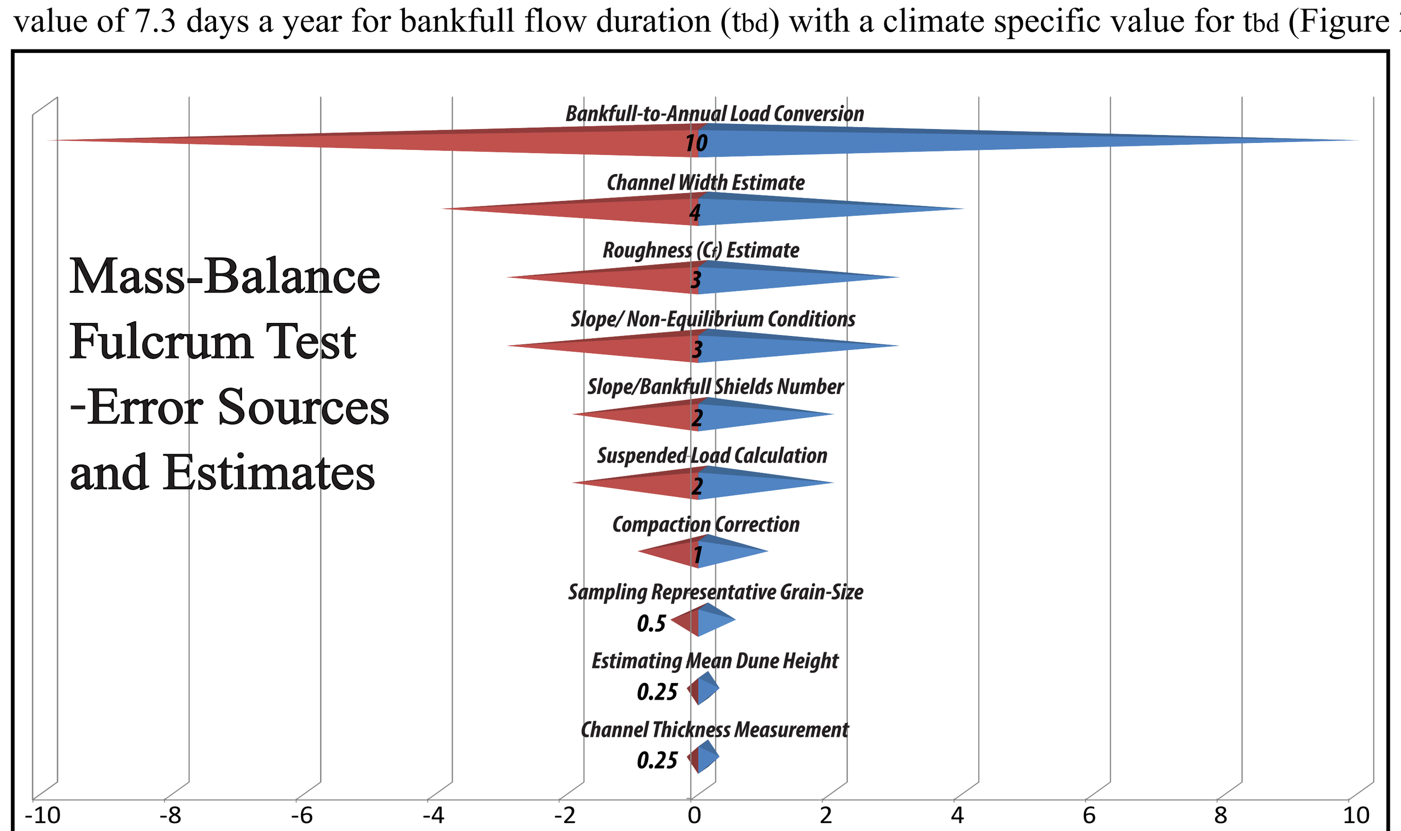


Figure 1

Figure 1: The greatest source of error in the Fulcrum approach is within the Bankfull-to-Annual Load Conversion; by improving variables within this calculation the accuracy of this sediment flux estimate approach can be most affected (Holbrook and Wanas, 2014)

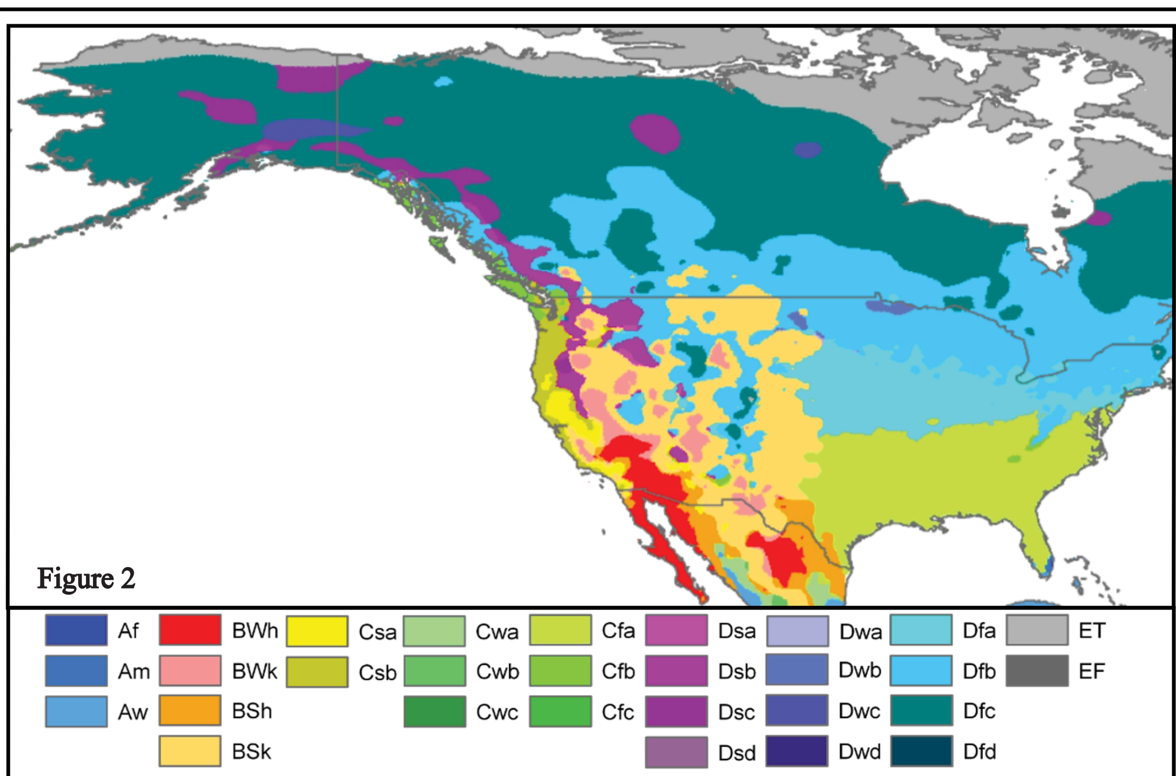


Figure 2

Figure 2: Köppen-Geiger type climate map (Peel et al, 2007)

Methods

- Bankfull estimate values have been acquired through literature research for over 500 streams. Values are only considered within this study where bankfull discharge is measured by workers on streams where daily stream gauge data spanning a minimum of 5 years was also available for acquisition.
- Basic workflow for acquisition and data management was established (Figure 3), and a data structure for the architectural model of the SQL database was developed (Figure 4).
- Partnering with the Texas Christian University Computer Science Department a SQL database was created and all acquired data including both stream specific attributes such as location of the gauging unit and drainage area, and daily discharge values have been loaded into this SQL database for analysis. The RAFTER user interface was also built by the Computer Science Senior Design team to make the data more accessible.
- Daily water discharges from these gauges where compared to the measured bankfull discharge values collected from literature, deriving on average how many days in a year each stream flows at bankfull levels (t_{bd}). How daily discharge values are collected by stream gauges is explained in detail by Olson and Norris of the USGS (2007).
- Days at bankfull were binned based on the criteria of climate. Climate being defined by using the Köppen classification (Figure 4a, 4b), which is over a century old but remains the most used climate classification to date (Peel et al, 2007). To address a large variety of climates, data was acquired from both domestic and international sources including the United States Geological Survey (USGS), The Water Survey of Canada (HYDAT), Institute of Hydrology, Meteorology and Environmental Studies: Colombia (IDEAM), and The Office of Public Works: Ireland (OPW).

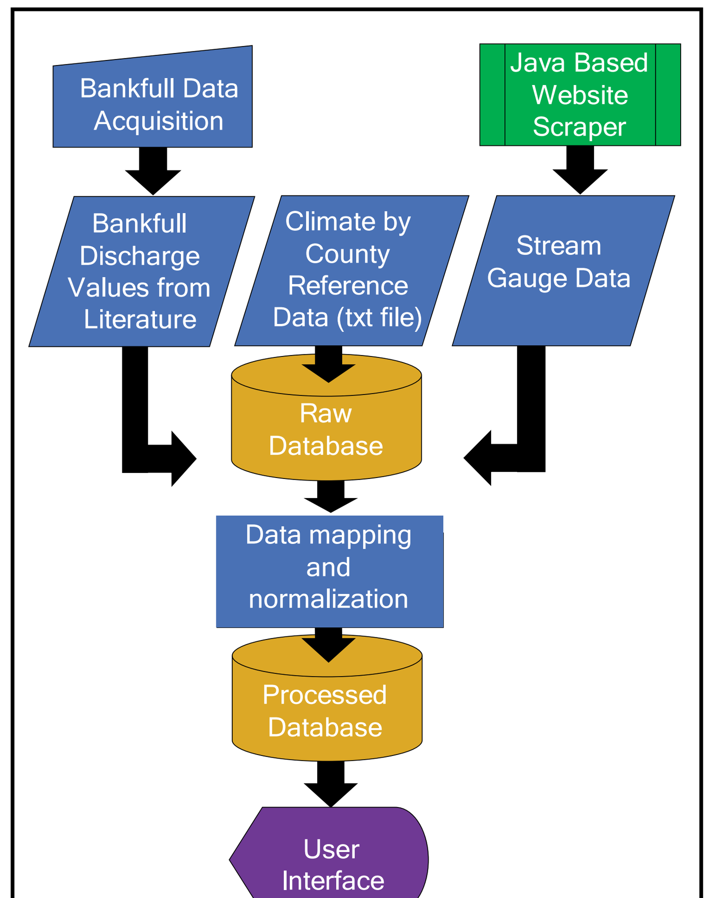


Figure 3

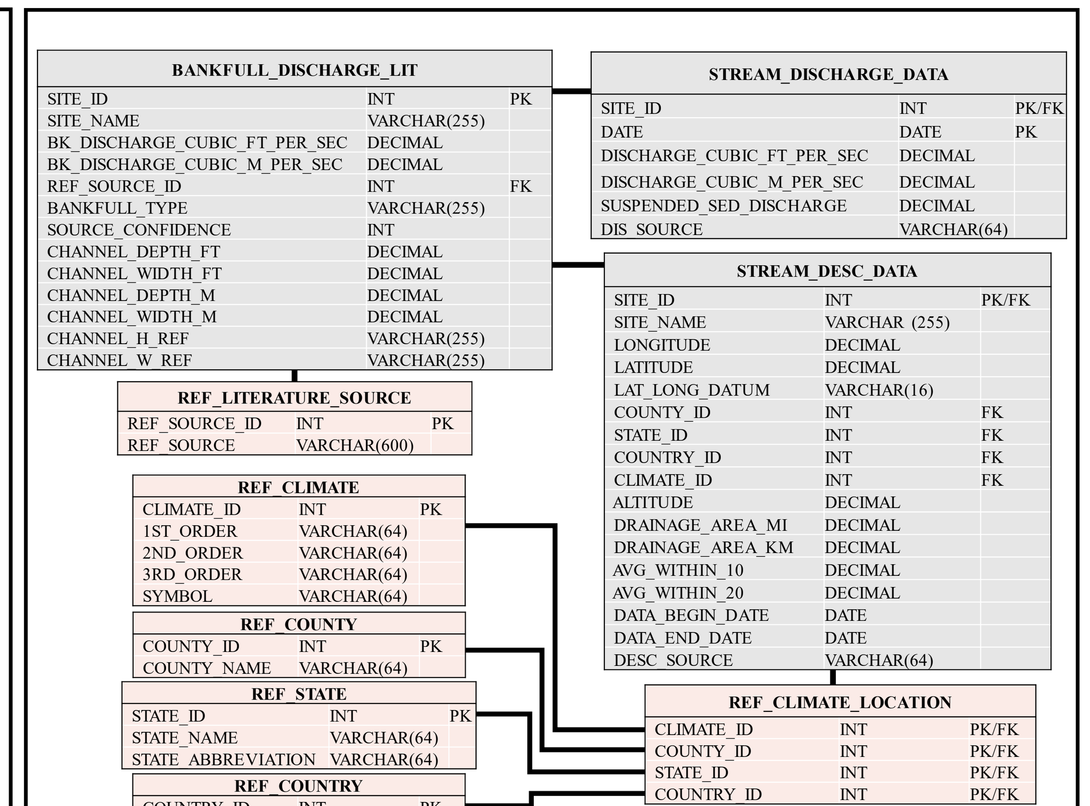


Figure 4

Figure 3 (left): Workflow for acquisition and development.
Figure 4 (Above): Architectural model of the SQL database.

Results

- I have queried the created SQL database in order to complete analysis to determine how often each specific stream runs within 10 percentage of the bankfull values collected from the literature and to determine the relationship between days at bankfull and the attributes of drainage area, mean bankfull-channel depth, bankfull-channel cross-sectional area and climate.
- A total of 524 streams, addressing 17 of the 30 Köppen climates, met the data requirements and were leveraged in this analysis (Figure 5).

Number of Sites	Köppen Climate Classification	Climate Description
5	Af	Tropical Rainforest
5	Am	Tropical Monsoon
1	Aw	Tropical Savannah
17	BSh	Arid Steppe Hot
35	BSk	Arid Steppe Cold
4	BWh	Arid Desert Hot
2	BWk	Arid Desert Cold
90	Cfa	Temperate Without dry season Hot Summer
41	Cfb	Temperate Without dry season Warm Summer
8	Csa	Temperate Dry Summer Hot Summer
36	Csb	Temperate Dry Summer Warm Summer
83	Dfa	Cold Without dry season Hot Summer
158	Dfb	Cold Without dry season Warm Summer
12	Dfc	Cold Without dry season Cold Summer
7	Dsa	Cold Dry Summer Hot Summer
17	Dsb	Cold Dry Summer Warm Summer
3	ET	Tundra

Figure 5: Köppen climate classifications with climate descriptions (Peel et al., 2007) as assigned for each stream included in this study.

Results Cont.

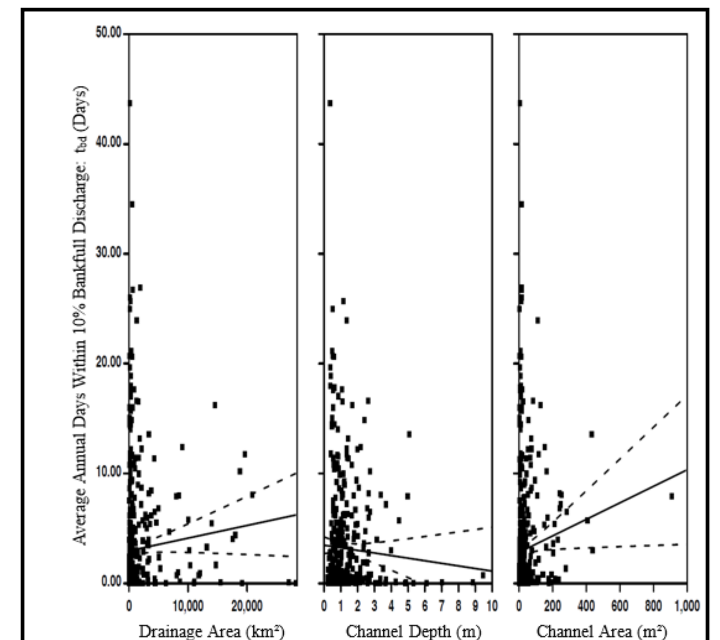


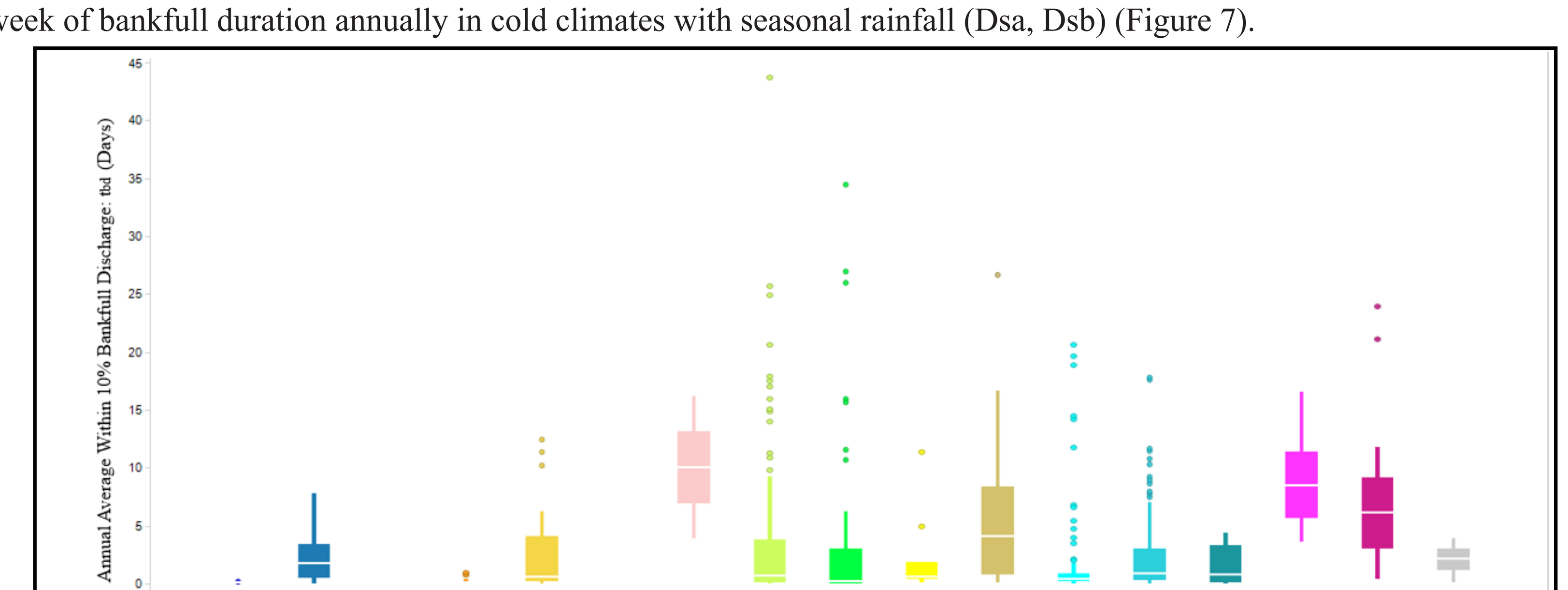
Figure 6

Dependent	Independent	R	R²	Adjusted R²	Std. Error of the Estimate
t_{bd} (Days)	DA (km²) D_{bf} (m) A_{bf} (m²)	0.200972	0.04039	0.033486	5.09156
t_{bd} (Days)	D_{bf} (m) A_{bf} (m²)	0.156586	0.024519	0.019929	5.09692
t_{bd} (Days)	DA (km²) A_{bf} (m²)	0.103189	0.010648	0.006738	5.39108
t_{bd} (Days)	DA (km²) D_{bf} (m)	0.138192	0.019097	0.014404	5.14157

Table 1

Figure 6: Linear regression models with confidence bands for the dependent variable of t_{bd} and the independent variables of drainage area, mean bankfull-channel depth and bankfull-channel cross-sectional area for all streams with a drainage area less than 30,000km². Table 1: Statistical summary of multiple regression model for all streams with a drainage area less than 30,000km², computed by the Aabel software [t_{bd}, average annual days within 10% of bankfull flow; DA, Drainage Area; D_{bf}, mean bankfull-channel depth; A_{bf}, Bankfull-channel cross-sectional area; R, correlation coefficient; R², coefficient of determination; m, meters; m², square meters; km², square kilometers]

- For all linear regression tests as well as the multiple regression model no correlation was found between average annual days at bankfull (t_{bd}) and the spatial attributes of drainage area, mean bankfull-channel depth and/or bankfull-channel cross-sectional area.
- While correlation between the tested spatial attributes and t_{bd} was not supported, when binning by Major climate or by 3rd order Köppen climate significant variance indicating distinct populations in average t_{bd} is observed and supported by ANOVA testing with average t_{bd} values ranging from less than 1 day in tropical rainforest climate streams (Af) to more than a week of bankfull duration annually in cold climates with seasonal rainfall (Dsa, Dsb) (Figure 7).



	Af	Am	Aw	BSh	BSk	BWh	BWk	Cfa	Cfb	Csa	Csb	Dfa	Dfb	Dfc	Dsa	Dsb	ET
Count	5	5	1	17	35	4	2	90	41	8	36	83	152	12	7	17	3
Avg	0.09	2.70	1.62	0.22	2.43	0.04	10.04	3.96	4.15	2.40	5.69	1.95	2.26	1.57	8.94	7.59	2.07
Median	0.09	1.72	1.62	0.14	0.55	0.03	10.04	0.66	0.23	0.62	4.09	0.37	0.91	0.76	8.44	6.17	2.14
Outliers	1	0	0	2	3	0	0	14	7	2	1	14	12	0	0	2	0
StdDev	0.07	3.16	(Empty)	0.26	3.43	0.05	8.72	7.35	8.27	3.96	6.05	4.43	3.17	1.75	4.52	6.49	1.90
U95	0.14	5.47	1.62	0.34	3.56	0.09	22.12	5.47	6.68	5.14	7.66	2.90	2.76	2.56	12.29	10.67	4.22
L95	0.03	-0.07	1.62	0.10	1.29	-0.01	-2.04	2.44	1.62	-0.35	3.71	0.99	1.76	0.58	5.60	4.50	-0.08

Figure 7

Figure 7: Box-and-whisker plots comparing t_{bd} when binned by Köppen climate category for all streams with a drainage area less than 30,000 km² [t_{bd}, average annual days within 10% of bankfull flow; Avg, Average; StdDev, Standard deviation; U95, upper endpoint of 95% confidence interval; L95, lower endpoint of 95% confidence interval]

Discussion and Conclusions

- Correlation between the temporal attribute of days at bankfull (t_{bd}) and the spatial attributes of drainage area, mean bankfull-channel depth and/or bankfull-channel cross-sectional area is not supported in this study.
- Climate significantly impacts average annual bankfull duration (t_{bd}) of a stream whether binning by major or Köppen climate. Applying climate specific t_{bd} values minimizes error in sediment flux estimates when leveraged in the Fulcrum approach.
- Outlier t_{bd} values, i.e. the 14 outliers in the temperate humid hot climate of Cfa, primarily result from additional parameters not considered in this study such as differing physiographic regions.

References

Holbrook, John, and Hamdalla Wanas. "A Fulcrum approach to assessing source-to-sink mass balance using channel paleohydrologic paramaters derivable from common fluvial data sets with an example from the Cretaceous of Egypt." Journal of Sedimentary Research 84.5 (2014): 349-372.

Olson, Scott A., and J. Michael Norris. US Geological Survey Streamgaging... from the National Streamflow Information Program. No. 2005-3131. Geological Survey (US), 2007.

Peel, Murray C., Brian L. Finlayson, and Thomas A. McMahon. "Updated world map of the Köppen-Geiger climate classification." Hydrology and earth system sciences discussions 4.2 (2007): 439-473.