PS Global River Discharge Analyses: Impact of Variable Precipitation in the Context of Different Climate Zones*

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Abstract

Models for fluvial architecture are important for predicting reservoir presence, distribution, quality, and connectivity in continental basins. However, most fluvial models are based on perennial precipitation zone rivers and do not take discharge variability into account; this oversight means many systems preserved in the sedimentary record are modeled inaccurately. Multiple authors (Leier et al., 2005; Fielding et al., 2009; Plink-Bjorklund, 2015) have described a link between seasonal precipitation and variable river discharge in monsoon domain and subtropical rivers, which results in distinct morphodynamic processes and a noticeably different sedimentary record from perennial precipitation zone rivers in tropical rainforest zone and mid-latitudes. These seasonal effects on surface water supply affects river morphodynamics and sedimentation on a wide timeframe, ranging from large single events to an inter-annual or even decadal timeframe. The resulting sedimentary deposits lead to differences in fluvial architecture on a range of depositional scales from sedimentary structures and bedforms to channel complex systems. These differences are important to accurately model for several reasons, ranging from stratigraphic and paleoenviromental reconstructions to more economic reasons, such as predicting reservoir presence, distribution, and connectivity in continental basins.

This study further develops our understanding of discharge variability using a modern global river database created with data from the Global Runoff Data Centre (GRDC) and the University of Wisconsin's Center for Sustainability and Global Environment (SAGE). We compared river discharge patterns in a variety of climate zones (rainforest, monsoonal, sub-humid subtropics, arid to semi-arid subtropics, mid-latitude, and arctic) to establish the similarities and differences in discharge patterns as well as sediment distribution. A key difference between this study and previous studies is the inclusion of arctic rivers in the dataset. The ultimate objective of this research is to develop differentiated fluvial facies and reservoir models for each of these climate zones.

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Introduction

Models for fluvial architecture are important for predicting reservoir presence, distribution, quality, and connectivity in continental basins. However, most fluvial models are based on perennial precipitation zone rivers and do not take discharge variability into account; this oversight means many systems preserved in the sedimentary record are modeled inaccurately. Multiple authors (Leier et al., 2005; Fielding et al., 2009; Plink-Bjorklund, 2015) have started to describe a link between seasonal precipitation and variable river discharge in the monsoonal domain and subtropical rivers, which results in distinct morphodynamic processes and a noticeably different sedimentary record from perennial precipitation zone rivers in tropical rainforest zone and mid-latitudes. These seasonal effects on surface water supply affects river morphodynamics and sedimentation on a wide timeframe, ranging from large single events to an inter-annual or even decadal timeframe. The resulting sedimentary deposits lead to differences in fluvial architecture on a range of depositional scales from sedimentary structures and bedforms to channel complex systems. These differences are important to accurately model for several reasons, ranging from stratigraphic and paleoenviromental reconstructions to more economic reasons, such as predicting reservoir presence, distribution, and connectivity in continental basins.

Aims

- Further develop understanding of discharge variability using a global river database created with data from the Global Runoff Data Centre (GRDC).
- Examine daily gauging data from 595 river stations worldwide and group them based on the location of the gauging station and group them into seven different climate zones: Arid to semi-arid Subtropics, Cold, Humid Subtropics, Monsoonal, Polar, Rainforest, and Temperate.
- Use the seven climate zones to better understand the nature of discharge variability and thus the transportation of sediment.
- Develop differentiated fluvial facies and reservoir models for each climate zones.

Methods

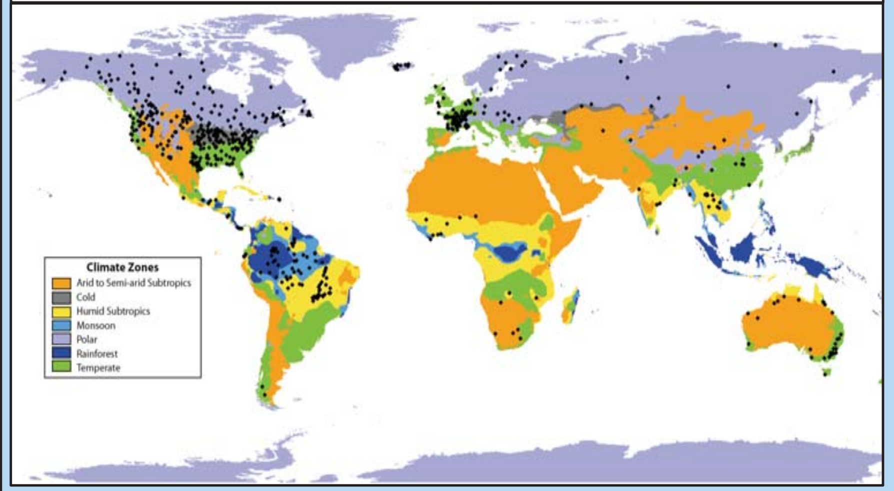
Rivers were compared by two main metrics: discharge variability (both monthly and yearly, see below for equations) and climate. The rivers used in this study are from the GRDC's pristine river database and were screened to ensure a long enough historical record for analysis of decadal-scale variability. The seven climate zones definitions and boundaries were adapted from the Peel et al, 2007 update of the Köppen-Geiger climate classifications and were combined with the Monsoon Precipitation Domain Index (Wang and Ding, 2008). Rivers were assigned climate zones based on the location of the gauging stations and their respective drainage basins. Sediment discharge data comes from the USGS Water Data for the Nation database.

1) Monthly Discharge Variability: $DVI_m = \frac{\text{Average Discharge of Wettest Month} - \text{Average Discharge of Driest Month}}{\text{Average Discharge}}$

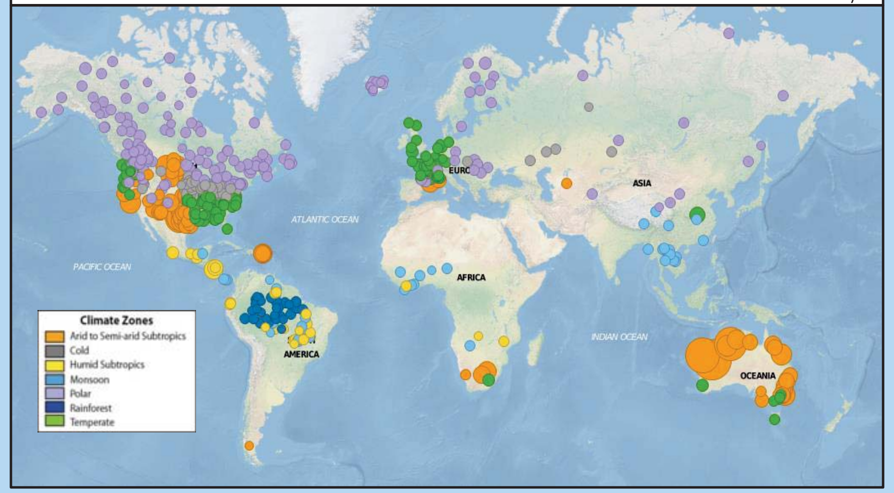
2) Yearly Discharge Variability: $DVI_y = \frac{\sum \frac{\text{Maximum Daily Discharge of Year x} - \text{Minimum Daily Discharge Year x}}{\text{Average Discharge}}}{\text{n years}}$

How to Examine Discharge Variability

Global Map of Climate Zones and River Gauging Stations



Global Map of River Gauging Stations coloured by Climate Zone and sized by DVI_y



Discharge Variability Temporal Resolutions

- Variability needs to be considered on different temporal resolutions
- Annual variability → Inter-annual variability → Discharge Variability Index

Annual Variability

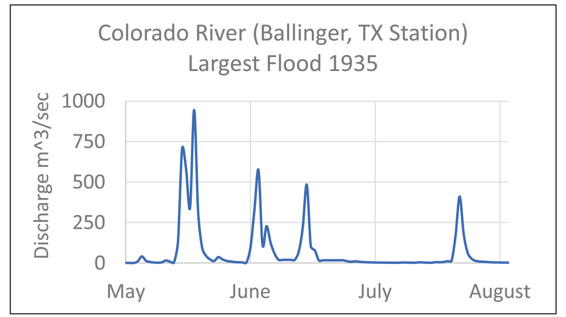
- Strength: Event based assessment (such as major flood analysis to understand the nature of flooding)
- Weakness: Difficult to compare multiple rivers against each other

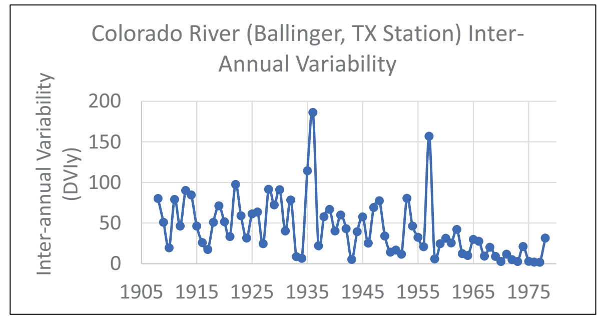
Inter-annual Variability

- Strength: Examines the range in variability for each river over time
- Weakness: Still difficult to compare multiple rivers against each other

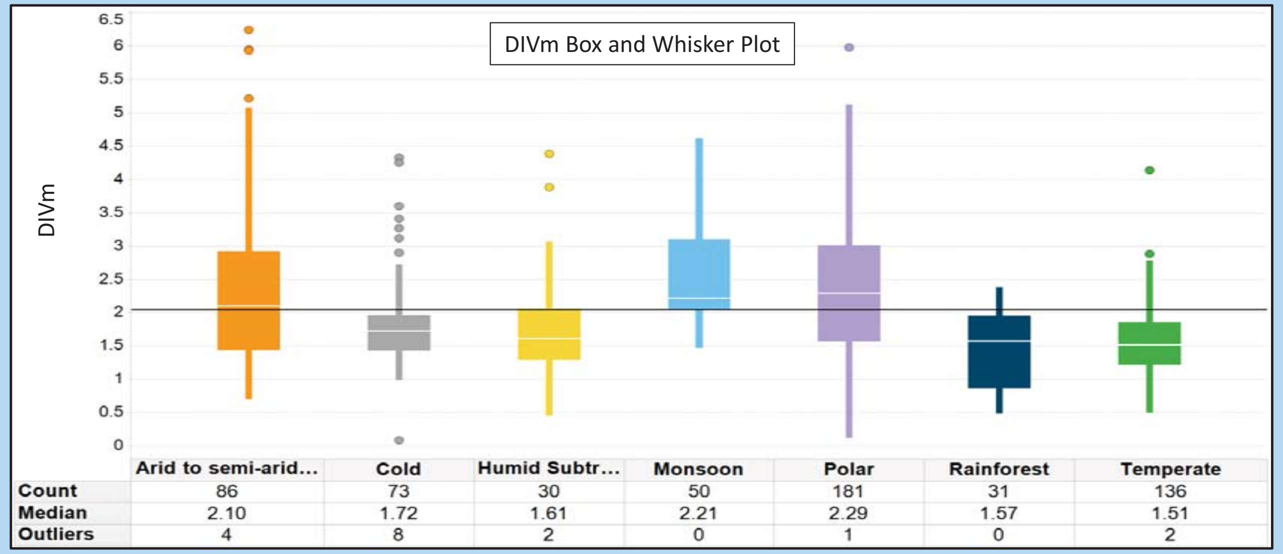
Discharge Variability Index

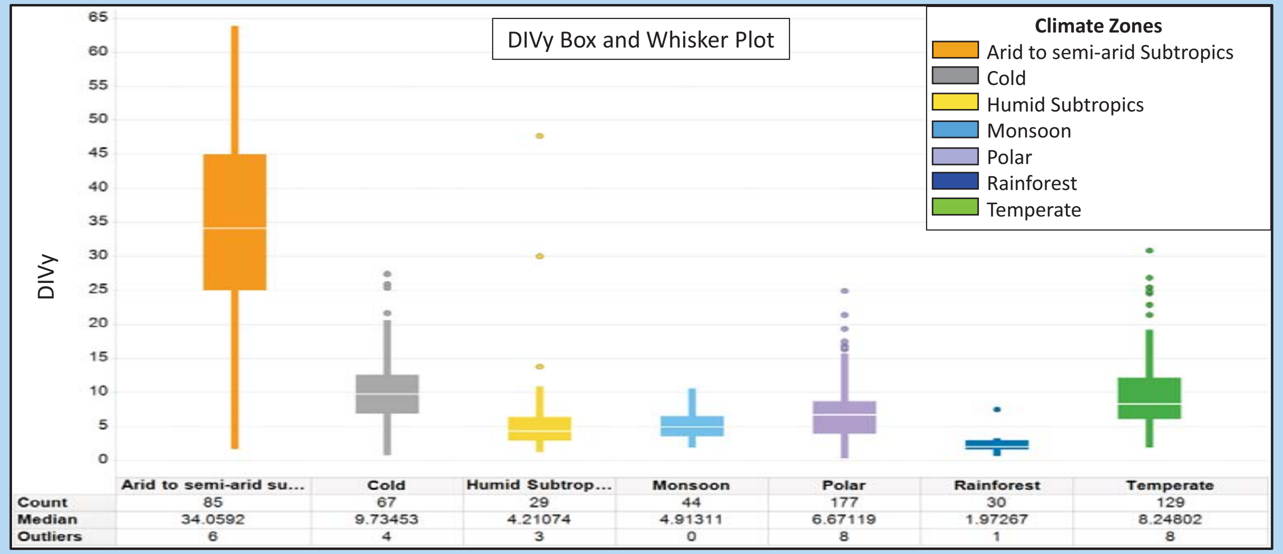
- Unit-less number for discharge variability
- Strength: Able to compare it against the entire database of rivers
- Weakness: DVI compresses variability into one number





Colorado River (Ballinger, TX Station) DVI_y	
Minimum DVI_y	1.81
Maximum DVI_y	186.21
DVI_y	43.47





Climate Zones	DVIm Median	DVIm Average	DVIy Median	DVIy Average	Q90 Frequency (years)	Q99 Frequency (years)	QRI2 Frequency (years)
Arid to semi-arid Subtropics	2.09	2.38	34.05	38.12	1.03	1.62	4.44
Cold	1.71	1.82	9.73	10.30	1.02	1.80	6.15
Humid Subtropics	1.60	1.74	4.21	7.08	1.02	2.16	6.20
Monsoonal	2.21	2.52	4.91	5.03	1.05	2.49	8.91
Polar	2.28	2.35	6.67	7.00	1.01	1.71	6.16
Rainforest	1.57	1.48	1.97	2.24	1.19	4.66	21.50
Temperate	1.51	1.55	8.24	9.67	1.01	1.44	4.06

Representative Rivers	DVIm	DVIy	Q90 Frequency (years)	Q99 Frequency (years)	QRI2 Frequency (years)	QRI2 Avg Length Over
Cleark Fork Brazos	4.41	35.00	1.00	1.66	6.00	2.93
Elkhorn	1.65	10.74	1.02	1.70	6.53	3.38
Rio Das Almas	1.58	4.72	1.00	1.70	5.12	2.63
Brahmaputra	3.21	4.77	1.00	2.44	22.00	11.00
Little Beaver	2.59	6.79	1.02	2.43	13.00	6.66
Rio Jurua	1.58	1.71	1.31	4.83	14.5	9.5
Little River	1.50	9.11	1	1.93	6.38	3.23

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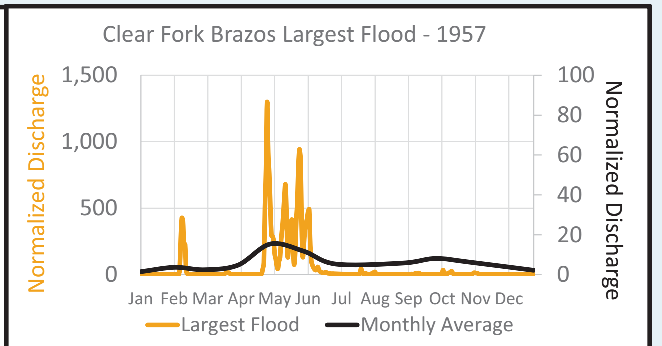
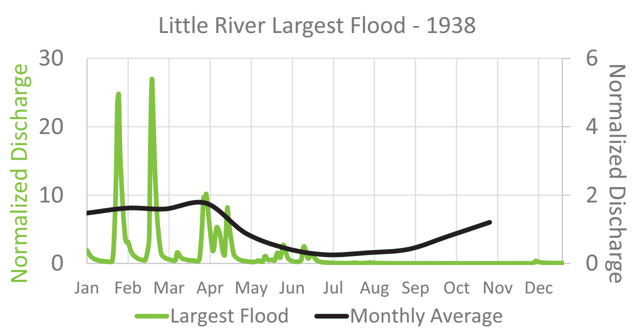
Largest Flood Analysis

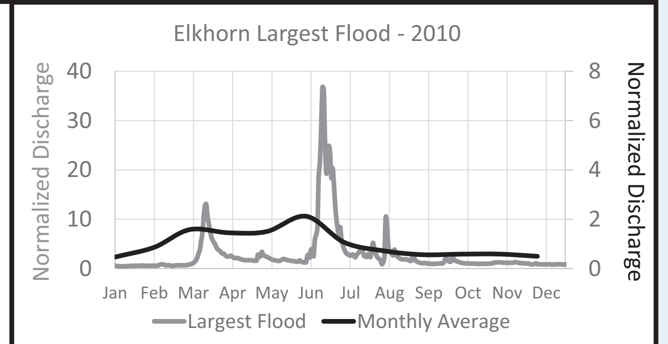
- How do large floods compare to average flow?
- Effect of single storm events vs seasonal buildups
  - Arid systems are dominated by punctuated single events
  - Monsoonal and Polar systems have strong seasonal controls
  - Rainforest systems rarely flood more than their yearly average

Erratic

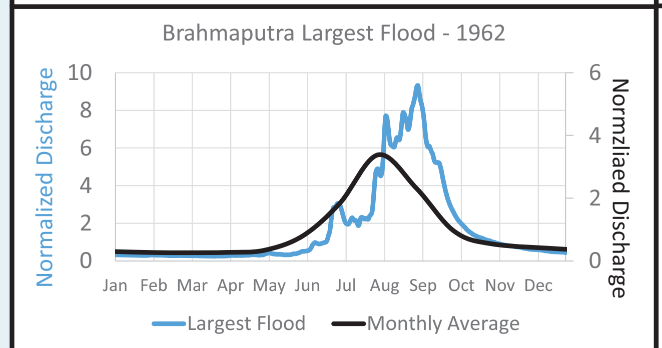


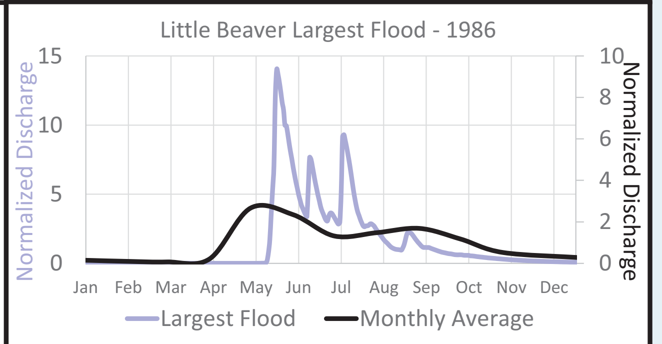
Moderate



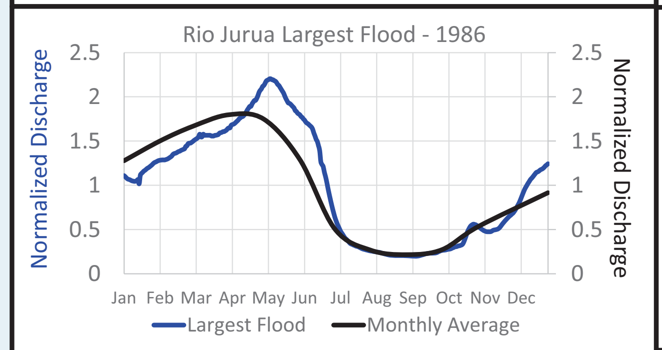


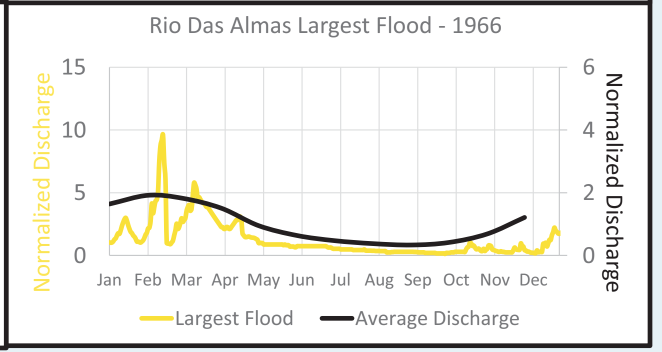
Seasonal





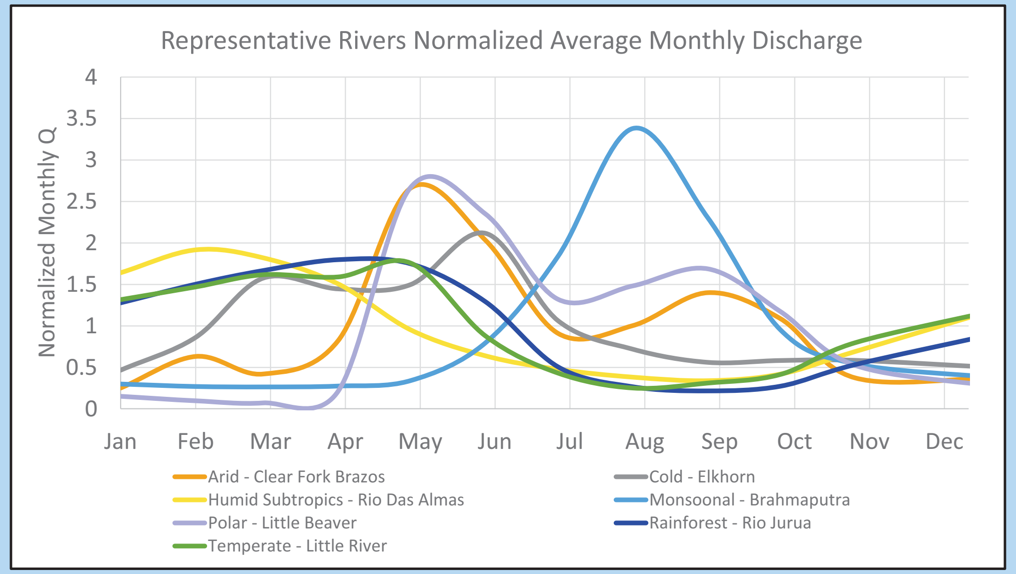
Persistent

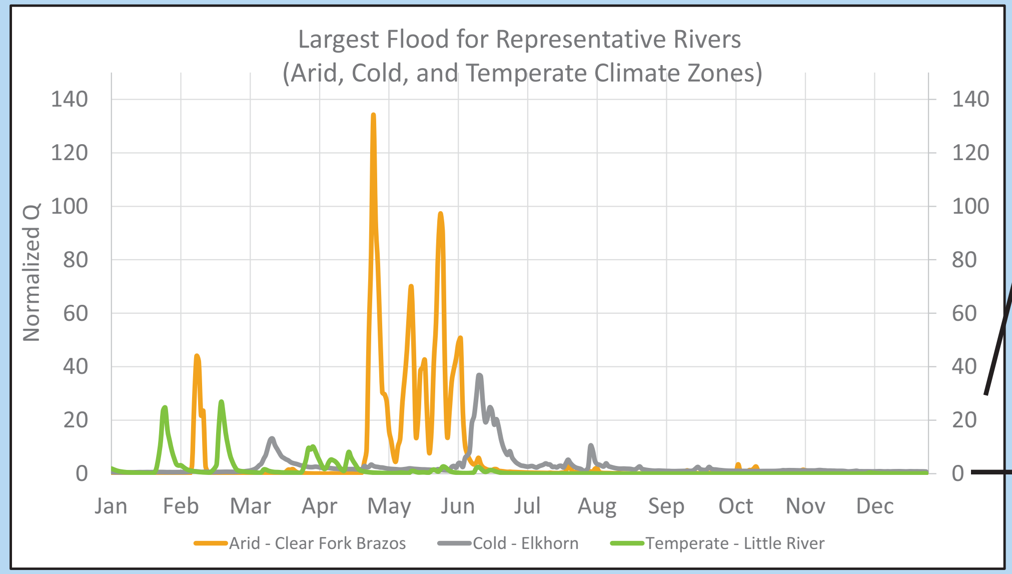


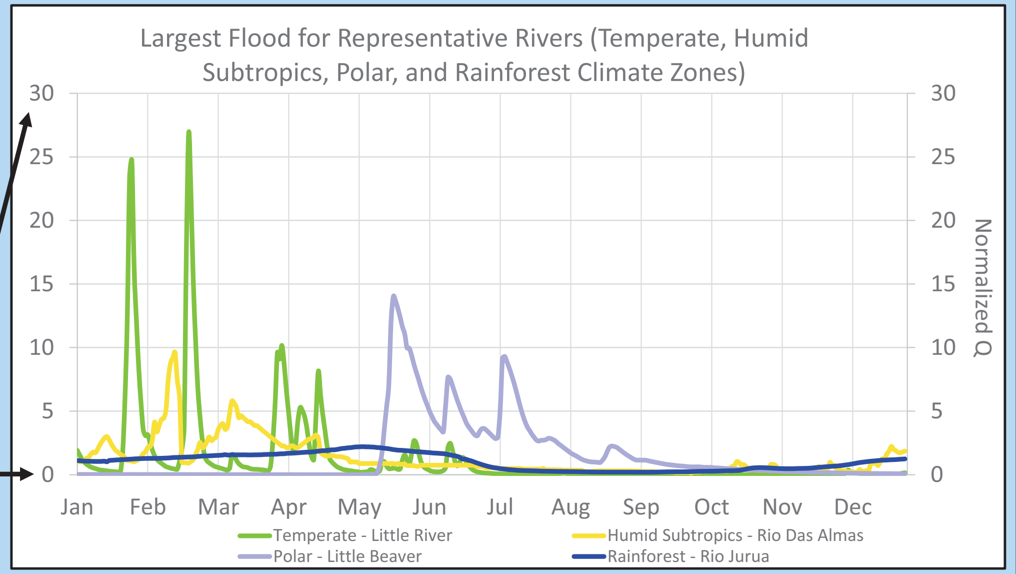


The Link Between Discharge Variability and Sediment Transport

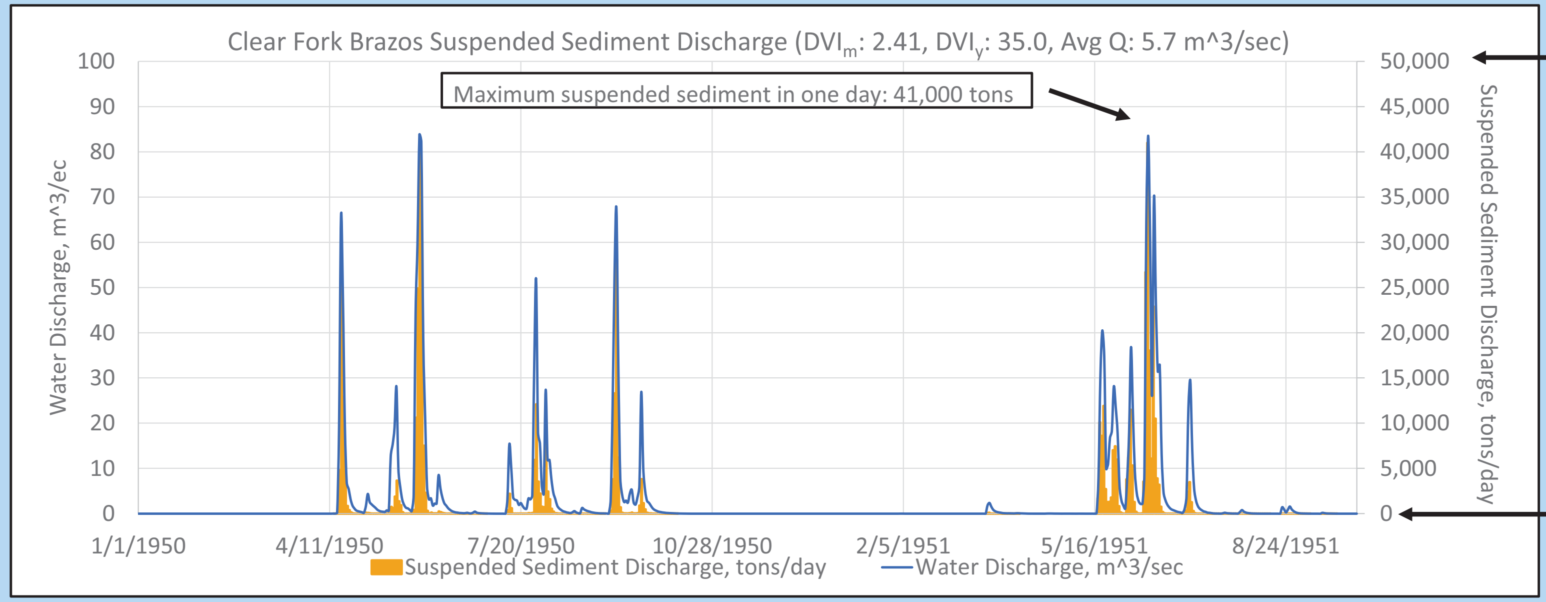
Monthly average and largest floods in all climates

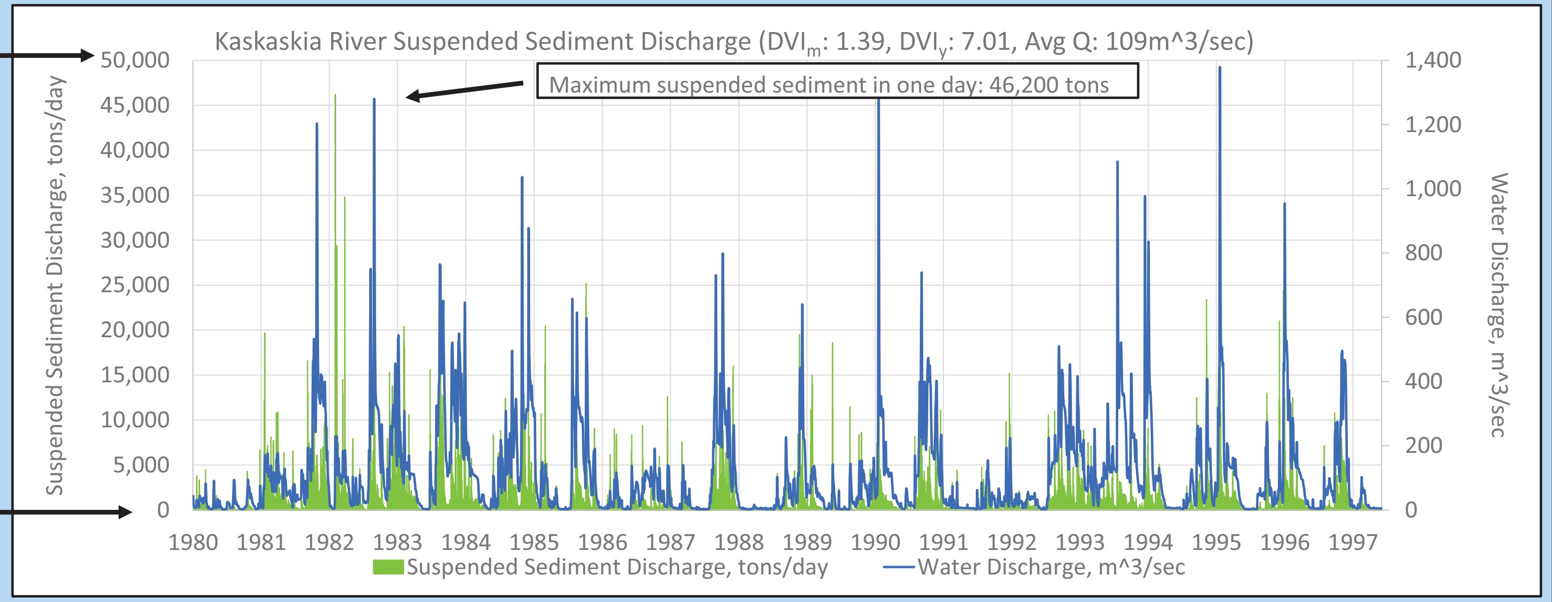






Water and Sediment Discharge Comparison





- Limited sediment discharge data
- Comparing Temperate and Arid Climates
- Order of magnitude difference in water discharge, yet sediment discharge peaks are on the same order of magnitude

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Outcrop Scale Fluvial Architecture

Channel to Multi-Channel Scale Architecture

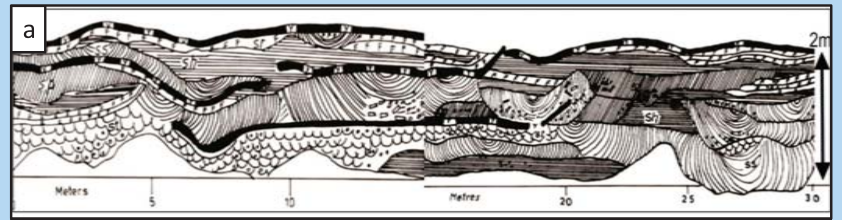
- Experience frequent avulsions
- Create highly tabular deposits with thicknesses that range from decimeters to 10's of meters

Avulsions that are common in rivers with seasonally variable discharge generate highly amalgamated tabular-looking channel zones. In areas with lower channel return frequency, flood units characteristically contain floodplain deposits with numerous tabular splay sands, overlain by channel fills.
(a) Eocene Wasatch Fm., Uinta Basin, USA – High channel return frequency
(b) Eocene Green River Fm., Uinta Basin, USA – Lower channel return frequency
(c) Cretaceous Williams Fork Fm., Piceance Basin, USA – Lower channel return frequency
Yellow arrows indicate channel fills. Images from Plink-Bjorklund, 2015.

Examples of flood units and macroforms.
(a) Thickness of individual flood deposits in lateral accretion sets in the lower part of the channel fill is on decimeter scale, in contrast to the overlying flood units that are 1–2m thick. Each flood deposit is draped by mud, Eocene Green River Fm., Uinta Basin, USA.
(b) Extremely thick, erosionally bounded flood deposits that consist of stacked scour and fill, convex-up low-angle and planar laminated sandstones are laterally continuous for more than 100 m, Eocene Wasatch Fm., Uinta Basin, USA. Paleocurrent from left to right.
(c) Thick flood units that display finer-grained (very fine sand to silt) upper parts that are climbing-ripple laminated, Cretaceous Piceance basin, USA. Paleocurrent obliquely into the cliff.

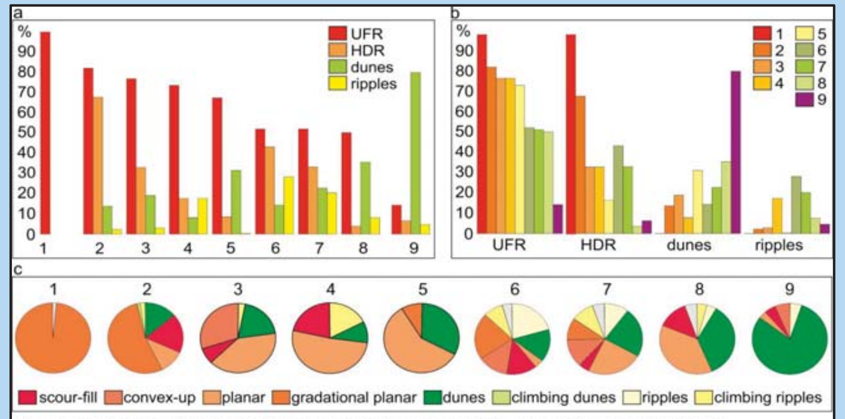
Inter-Channel Architecture

- Sedimentary structures are primarily composed of upper flow regime and high deposition rate structures
- Sandy channel fill is interbedded with in-channel mud layers

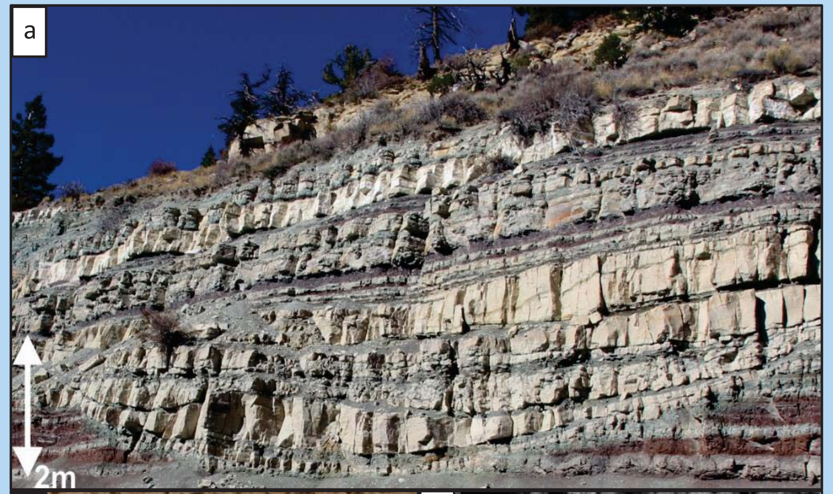


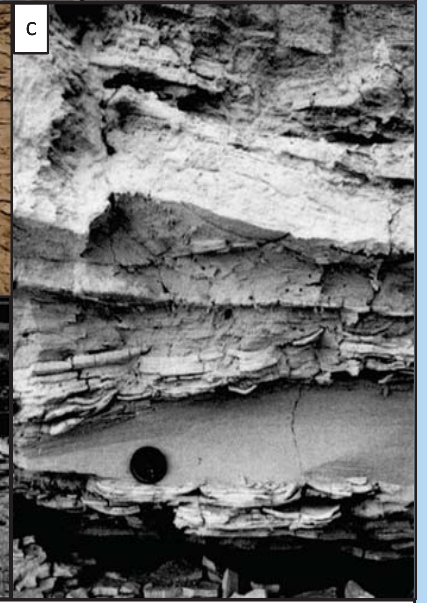
In-channel mud deposits are characteristically interbedded with sandy channel fill deposits. These events are separated by erosional contacts and deformed tens of meters wide mud horizons.
(a) Tens of meters wide mud horizons at the top of flow-perpendicular flood deposits in River Gash, Sudan. (Abdullatif, 1989).

Distribution of Sedimentary Structures



River deposits with a high proportion of upper flow regime and high deposition rate structures:
1 Kobo Basin, Ethiopia (Billi, 2007). **2** Eocene Wastach Fm., Uinta Basin, US (Plink-Bjorklund and Birgenheier, 2013. **3** Jurassic Kayenta Fm., US (North and Taylor, 1996). **4** Karoo, South Africa (Stear, 1985). **5** Cretaceous Williams Fork Fm. (McDowell and Plink-Bjorklund, 2013). **6** Eocene Wasatch and Green River Fm., Uinta Basin, US (Plink-Bjorklund and Birgenheier, 2013). **7** Eocene Wasatch and Green River Fm., Uinta Basin, US (Plink-Bjorklund and Birgenheier, 2013). **8** River Gash, Sudan (Abdullatif 1989).
River deposits with dominant cross strata:
9 North Horn Fm., Uinta Basin, US (Plink-Bjorklund and Birgenheier 2013).





In-channel mud layers commonly occur in monsoonal and subtropical rivers.
(a) Decimeter-thick pedogenically modified mud layers in lateral to vertical accretion sets. Eocene Green River Formation, Uinta Basin, USA.
(b) Desiccated and broken-up mud drapes at the bottom of seasonally dry Rio Colorado, Altiplano, South America (Donselaar et al., 2013).
(c&d) Desiccated, curled, and broken-up mud drapes in the deposits of Wadi El Arish, Egypt (Sneh, 1983).

Key Takeaways

- Variable discharge is a key control on fluvial sedimentation
- It is necessary to use different temporal resolutions when assessing a river system's variability
- Discharge variability is controlled by a number of factors, but can be predicted by climate zone
  - Different climate zones have different temporal controls on discharge and different degrees of predictability
- The majority of sediment transport occurs during flood stage
- Rivers with highly variable discharge have different fluvial architecture from rivers with lower discharge variability that is characterized by:
  - Tabular deposits
  - In-channel mud layers
  - Upper flow regime sedimentary structures

References

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