An Investigation Into the Meander and Bar Patterns in the Unchannelized Missouri River

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Abstract

Meander bend theory has been around since Albert Einstein popularized it in the 1920s. Since then, many geologists and physicists have grappled to understand the mechanics and concepts that cause rivers to meander in the ways that they do.

Through the years, scientists have learned that bedload, slope, and flow velocity are all major drivers of cutbank erosion and bar building. However, one answer that has eluded scientists to this point is whether bar building (bar push) or bank scour (bank pull) causes meander bend migration. Additionally, there are still many questions that remain in regards to mid channel bars in braided meandering rivers. Questions like life-cycle, fixed vs. free bars, and lateral migration habits have been asked with few answers.

This study aims to analyze meander bend patterns in an 88 Km unchannelized stretch of the Missouri River between Yankton, SD and Sioux City, IA. This stretch of river is ideal because it is downstream of the Gavin's point dam and best represents an unmodified version of the Missouri River. Landsat images of this stretch over the last 30 years have been processed in remote sensing software to track bank, bar, and channel changes over this span of time. Extensive remote sensing processing (ESRI ArcMap and ArcGIS Pro) via raster classification and shapefile statistical analyses will be performed on the river with respect to bank vs. bar movement, mid-channel bar migration, bar growth, and bar life cycles. Early results include preliminary bar life cycle estimates and general bar area statistics.

Intro and Study Area

Meander bends in terrestrial rivers are first and foremost a response to valley gradient. Meander sinuosity will increase with increased slope as the river lengthens its channel to expend increased stream power (Friend & Sinha 1993, Schumm 1963, Langbein & Leopold 1966). Meanders in rivers are classically characterized by opposing point bars and cutbank scours which each migrate through respective fill and scour as meander bends grow. Channel scour events depend on bed shear stress exerted by both flowing water, bedload, and - to a degree - suspended load (Andrews 1979, Langbein & Leopold 1966). Channel scour will mostly affect the outer bank of a meander while channel fill will mostly affect the middle to inner meander bend of a channel. Higher bed shear stress along the cutbank favors erosion, particularly during high-flow events (Callander, 1978). One unanswered question is whether bar building or cutback scour is what primarily drives meander loop transformation.

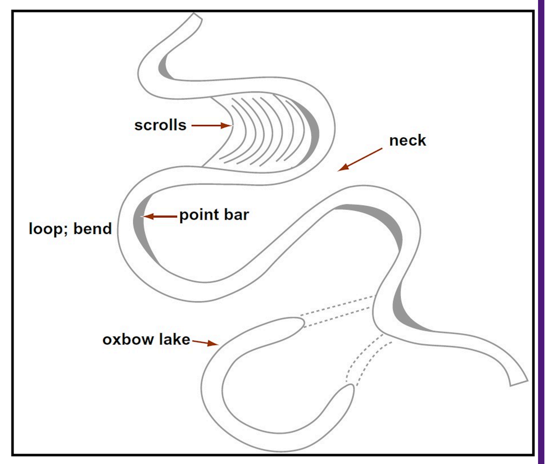


Figure 1. Ideal meander ben. Area of note is point bar and bends.

Whether channel scour on the outer bend of a meander or channel fill on the inner bend of a meander (bar formation) happens first to trigger bend growth remains both uncertain and debated and unconfirmed for lack of a successful field tests (van de Lageweg et al. 2014, Eke et al. 2014, Kasvi et al. 2017, Hooke 2007, Eke 2013). Valuable insights into this question have nonetheless been made through modeling and digital experimentation in recent decades that favor the bank-pull hypothesis (van de Lageweg et al., 2014 and Eke et al., 2014). There are yet no field studies on the chronology of meander bend formation that can confirm or refute findings from existing models. This is principally because additions of bar and removal of cutbank occurs as small slivers in normal single thread meandering rivers, below the resolution of easy or practical measurement in real time. Recent work shows the Missouri River grows bends as a meandering braided river (Holbrook and Allen, 2020), and currently presents a new and unique opportunity to field test these models using high resolution geospatial data and state of the art GIS processing software.

The focus of my study is an 88 km reach of unchannelized Missouri River in South Dakota running into Sioux City, IA. Meander bends grow here by addition of large midchannel bars, potentially large enough to provide visible distinction between timing and scale of co-developing cutbank growth and bend accretion. The purpose of my research will be to explore whether bank pull, bar push, or neither are the dominant method of meander bend transformation in a new and innovative method. Current studies on this topic have not fully utilized GIS data to constrain bender bend and bar transformations over time Landsat image archives, GIS software, and field observation will be used to methodically and sequentially map the temporal relationship between bank pull and bar push.

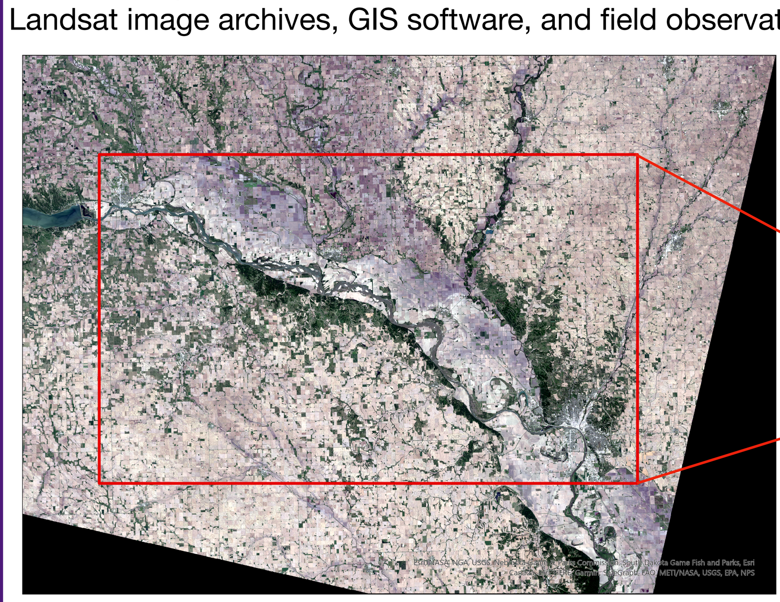


Figure 2. Study area, shown in red box.

Methods

- Gather Landsat images from USGS/NASA from 1989-2018.
  - Specific image dates are needed based on river stage data gathered from USGS.
- UGS streamflow data was provided at Yankton and Gayville, South Dakota.
  - This data was averaged and correlated to dates. A range of depths at each location was used in relation to their dates to select Landsat images. This kept the water level consistent for mid-channel bar analysis.
- Utilize ESRI ArcMap software to create false color composite band imagery.
  - Near Infrared (NIR) and Shortwave Infrared (SWIR) bands help delineate land/water boundaries.
- Classify Landsat images into Land/Water classes via supervised classification program.
  - Trained ArcMap to delineate land/water boundaries and produced a raster dataset with the two classes.
- Create polygon shape files, which contain geographic coordinate information for each bar and the river banks. These serve for later statistical analysis.
  - Polygons overlay the tiff images and are mainly placed over mid-channel bars.
- Create change-representation rasters over various time periods.
  - These rasters, shown on the left, show how the water and land cover has changed over a given period of time. Change over any time period is viewable.
- Other possible geometric data that can be calculated is bar axis averages, circumference, and bar height.

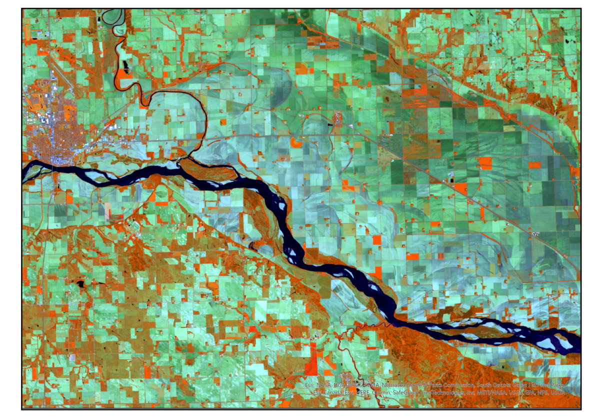


Figure 3. False color Landsat image from 2017

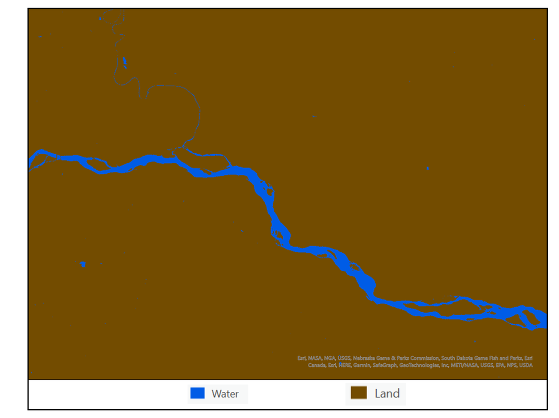


Figure 4. Classified version of 2017 image

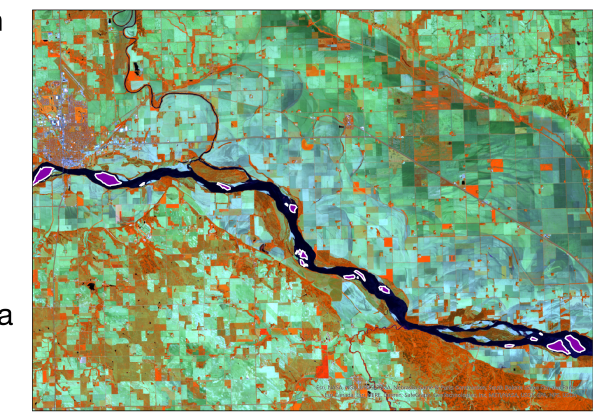


Figure 5. Bar shape files (magenta/white) overlain on false color image.

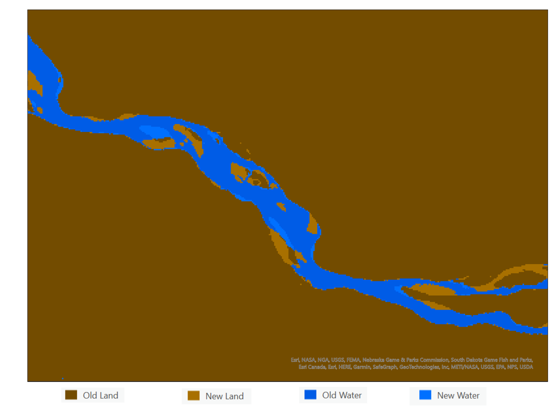


Figure 6. Change detection from 1993-2017. New land is tan, new water is light blue.

Data

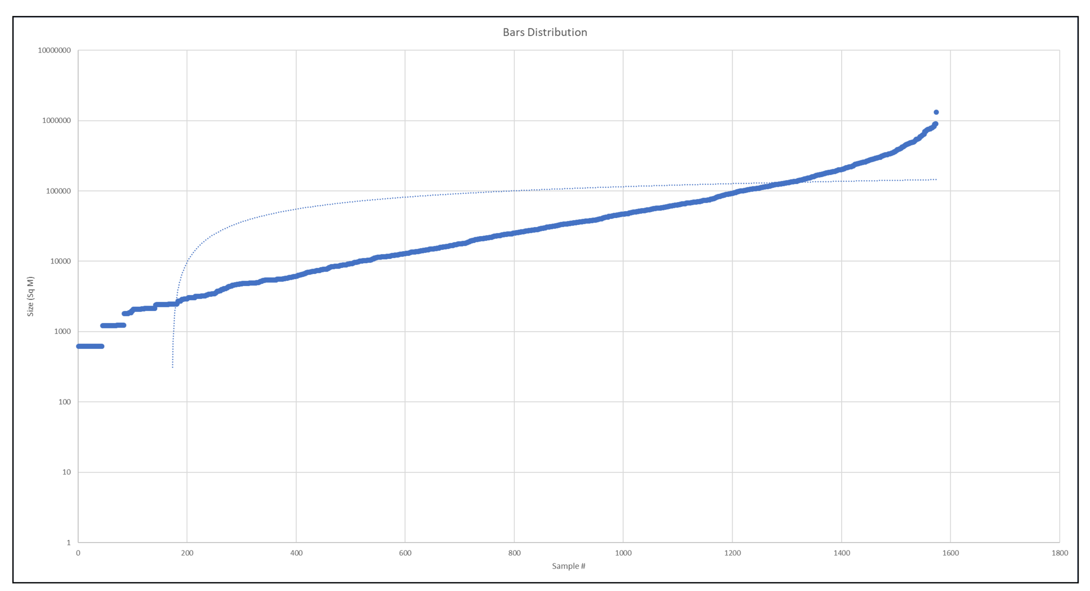


Figure 7. Single log graph (Y axis) of bar area.

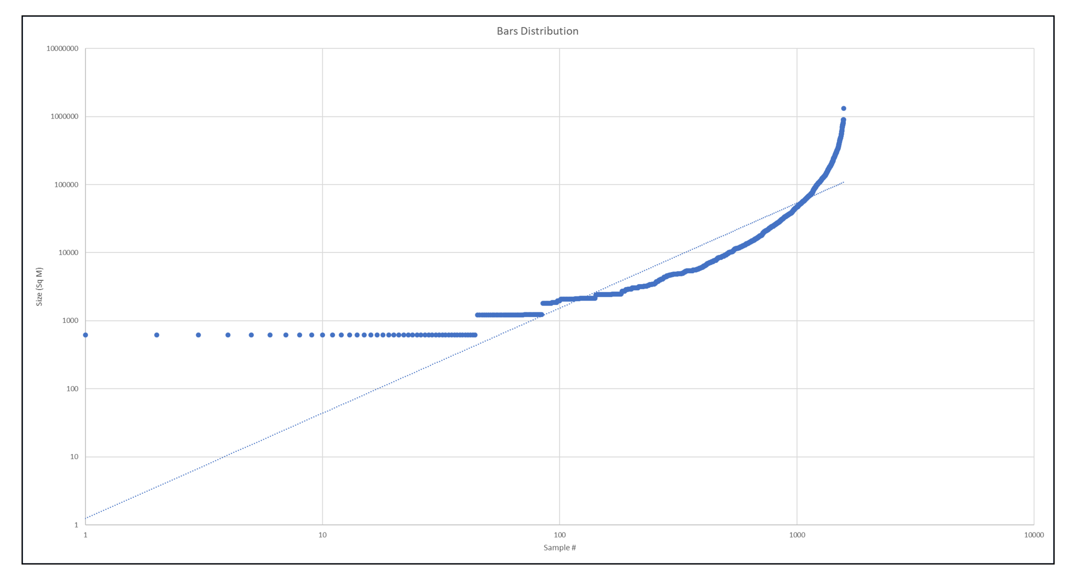


Figure 8. Double log graph of mid-channel bars plotted in ascending area.

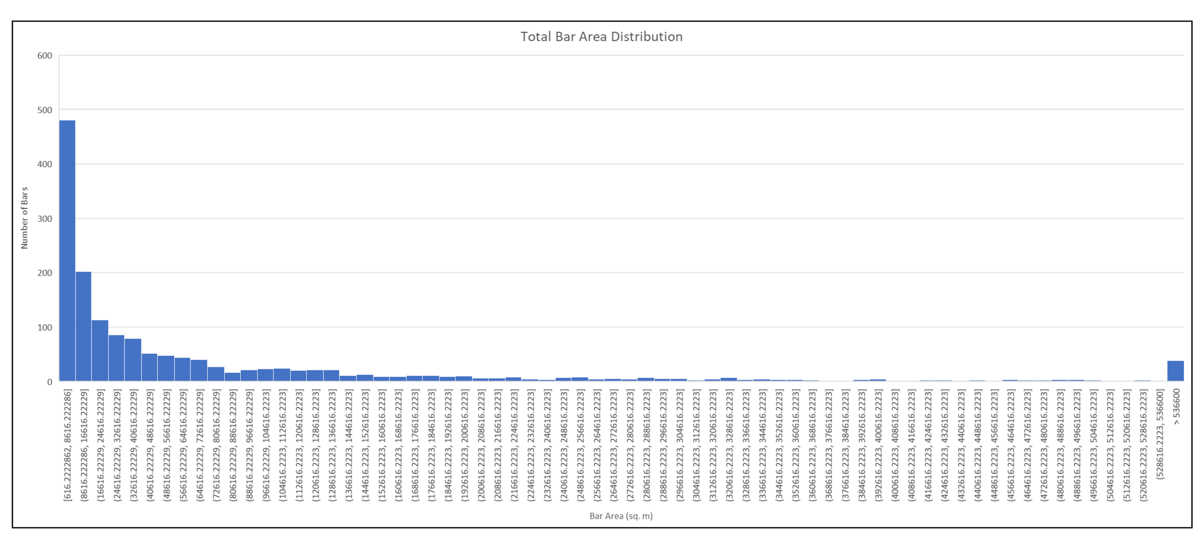


Figure 9. Bar area distribution histogram. Bin size is 8000 sq m intervals.

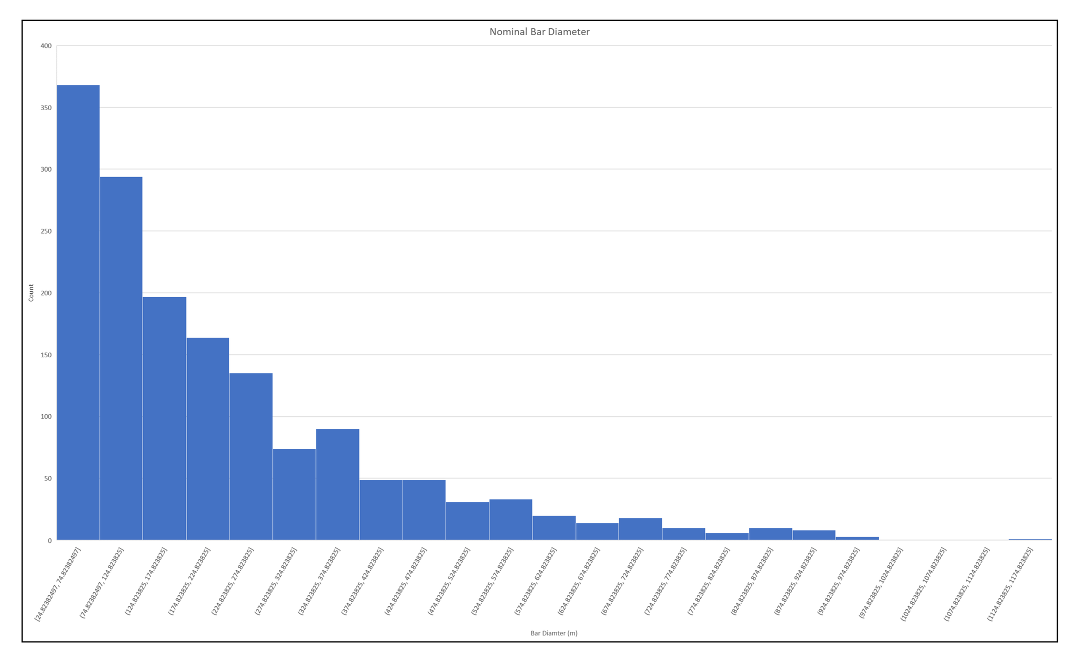
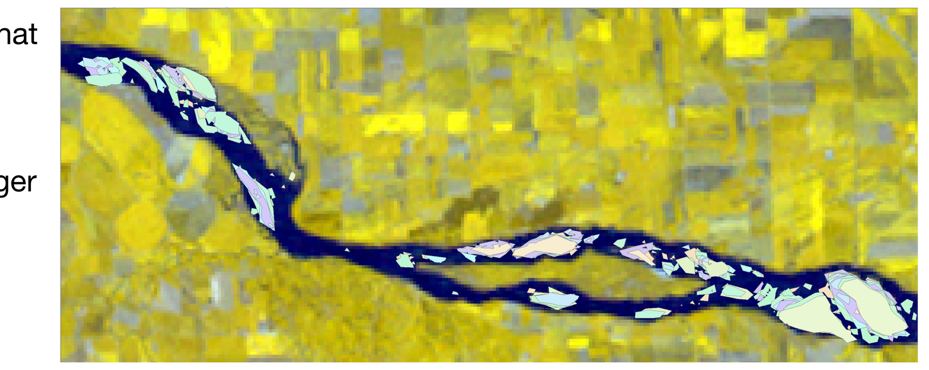


Figure 10. Square root of bar areas to calculate a nominal bar diameter. Bin size 50 m intervals.

- Note a generally straight line in **figure 7** trend besides the first ~100 bars. Light concave up deviation in the last ~150 bars. These outliers and concave up sections indicate potential areas where this data may be excluded in future studies.
- Note 2 outlier groups in **figure 8** around 650 sq m and 1200 sq m. Trendline fits double power function. These outlier groups confirm the outliers seen in **figure 7** for potential removal from the dataset.
- Note exponential downward trend in **figure 9** in the amount of bars per bin as area increases.
- Data in **figure 10** again shows an exponential decrease in the number of samples in each bin as diameter increases.

Discussion

- Valuable insights into bar forming patterns and trends have been made.
- The data confirms what we somewhat expected, there are exponentially more smaller bars than larger bars, and the distribution of these bars is linear on a logarithmic scale.



A stretch of the river showing bars at three year intervals over 30 years.

- Notice the bar distribution in the figure. Most of the bars seem to grow and shrink in place. In addition, and migration seems to be perpendicular to the bank rather than migrating downstream. Centroid tracking can determine overall movement laterally or downstream
- Floodplain islands, seen as the undigitized island in the figure, are ignored in the analysis as they generally do not migrate in any direction.
- With these bar area and distribution graphs, bars that are too large or small can be excluded from the dataset and tracking moving forward in order to track the most statistically significant bars.
  - Bars that are too large could possibly include the bars in the double log graph that fall in the upward curve (past sample 100)
  - Bars that are too small could include those in the two outlier sets below sample ~100.

Future Direction

- Draw conclusions on data and determine whether bar area trends are a result of channel morphology, bank pull, bar push, or a combination of these.
- A useful future statistical analysis would be bar area by XY coordinate.
  - This could help determine if there is any pattern to the distribution and size of the bars as you travel downstream.
- Tracking individual bars throughout their lifecycles via the GIS data imbedded in their polygons.
  - This will help constrain the life cycle (in years) on mid-channel bars
  - Do they stay in the middle? How long do they take to form? How long until they "die"?
- "Fixed vs free" do the mid-channel bars migrate downstream or only laterally (perpendicular to the bank)?
- Does bank pull or bar push drive meander bend transformation?
  - Does mid-channel bar migration drive bank pull or bar push?
  - At what rate does bank scour or bar building occur in the unchannelized Missouri River?

References

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