Using GIS to calculate geomorphological change in the Red River system near Fargo, North Dakota

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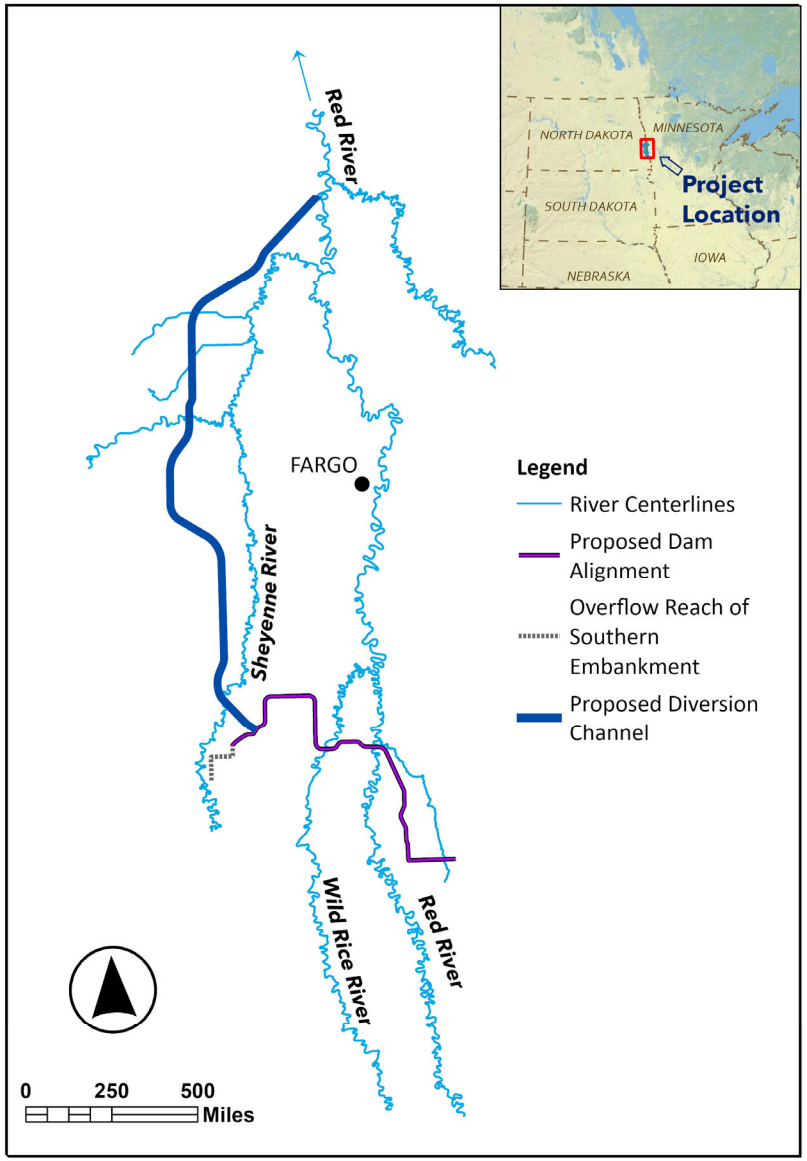
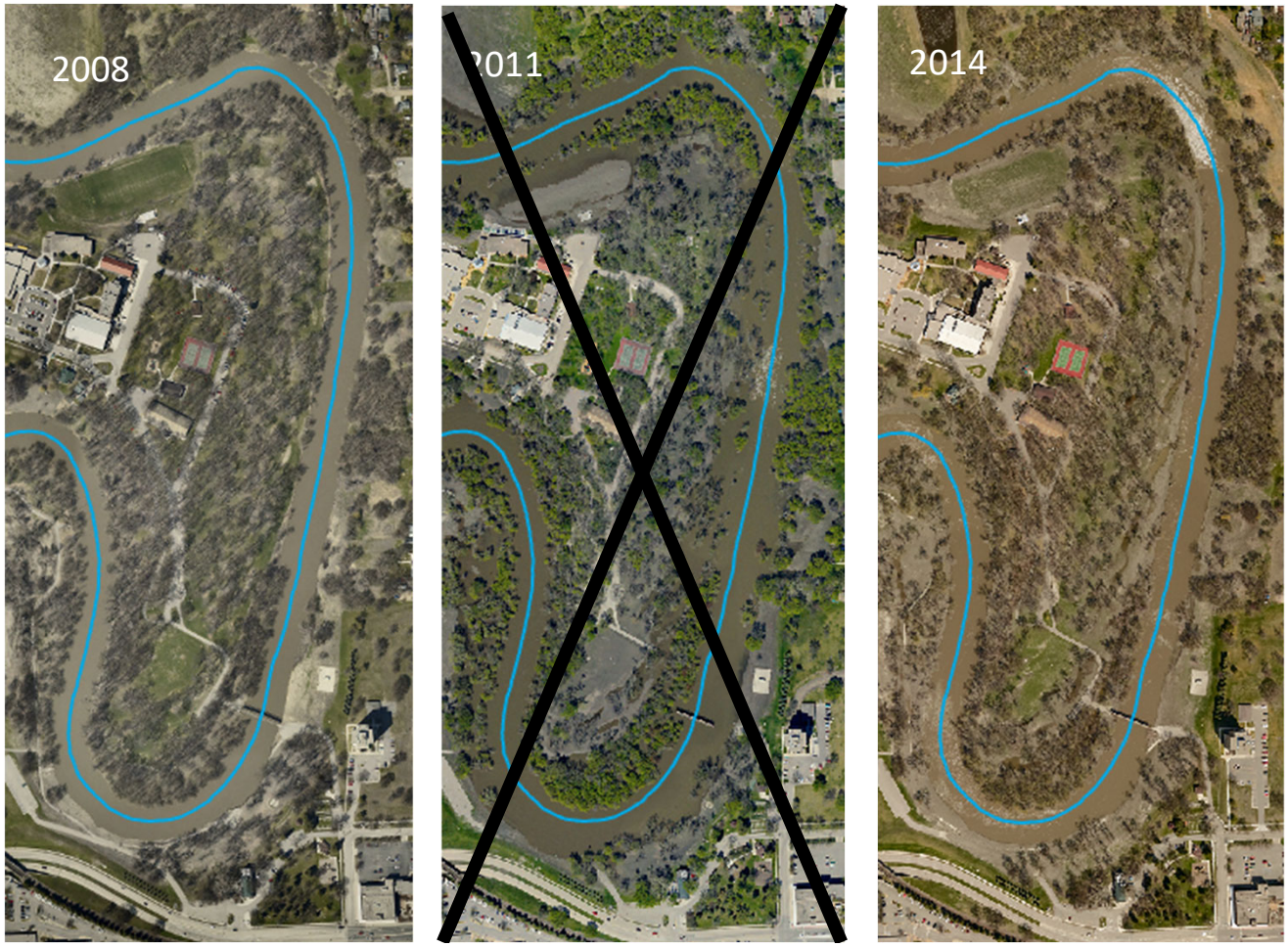
Background: the Red River system floods. **A lot.**

The Army Corps of Engineers and its non-federal partners propose to reduce flooding by building diversion channels and dam structures. In order to be able to measure the impact of these structures on the river system, certain things need to be measured in advance and then periodically after the fact to see if they have changed.



WEST Consultants performed a series of measurements across several years
to establish the **baseline stability** of the river system using multiple years of aerial imagery



- 2011 was no good because it was flown when the rivers were in flood
- Ultimately used 5 years of aerial imagery

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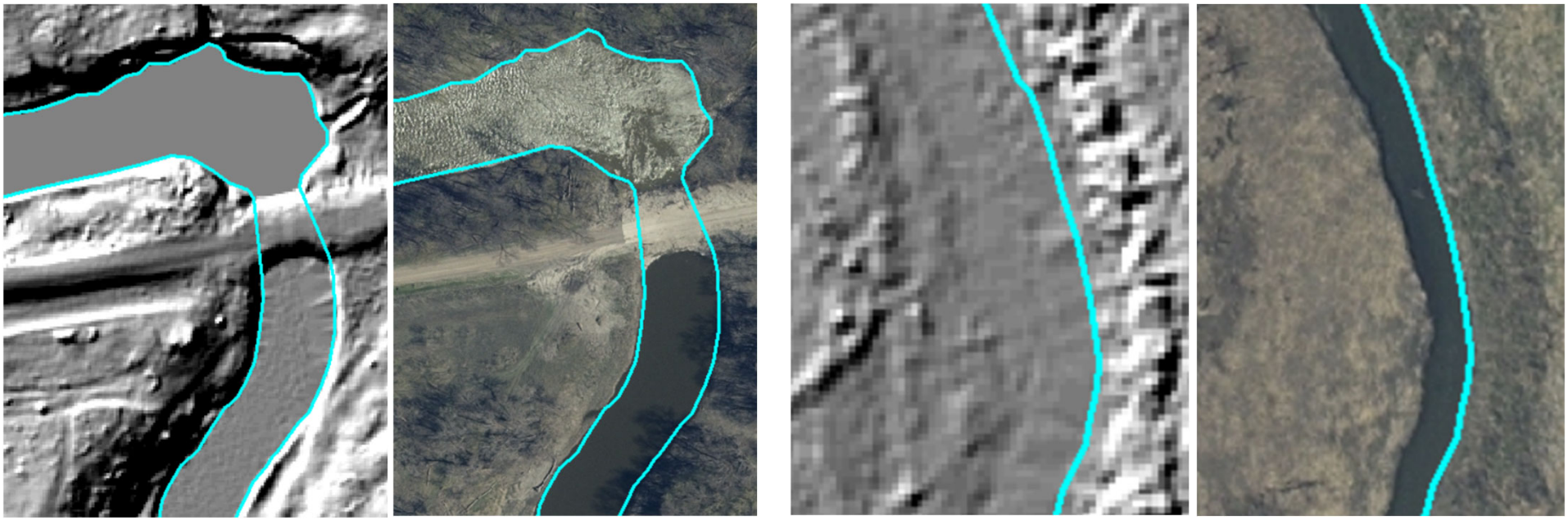
First things first: banklines are central to the geomorphological calculations

What is a bankline?

Hillshade LiDAR vs. Aerial photos



"All models are wrong, some are useful"

Accuracy **Reproducibility**

Five river channel characteristics

- Amplitude and Wavelength
- Average Width
- Meander Belt
- Meander Migration
- Sinuosity

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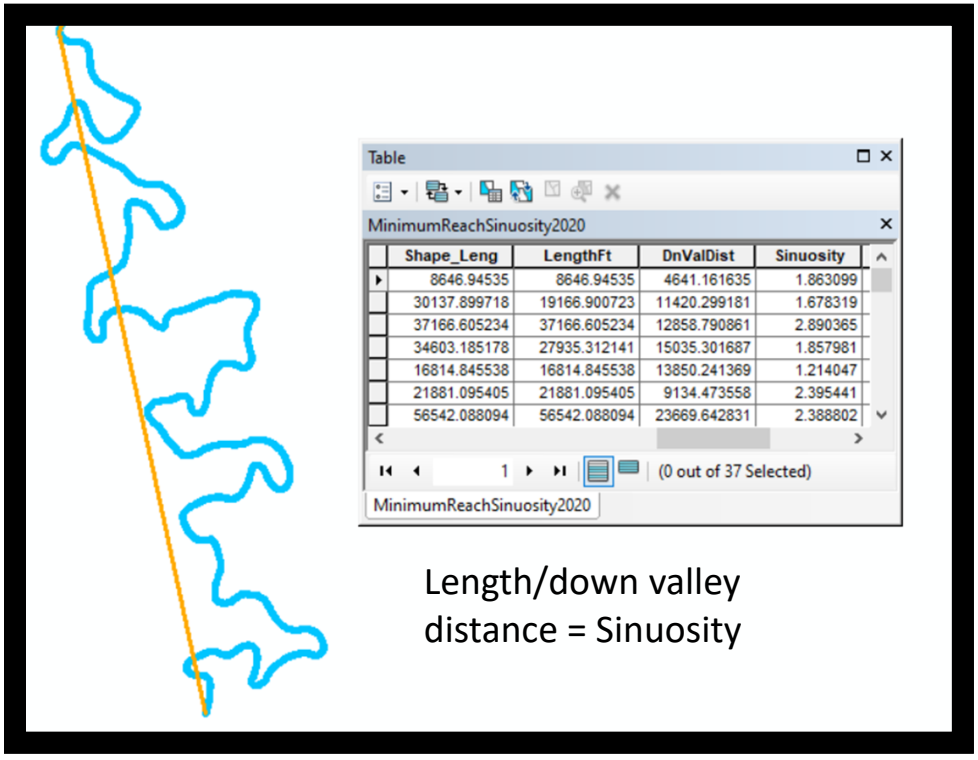
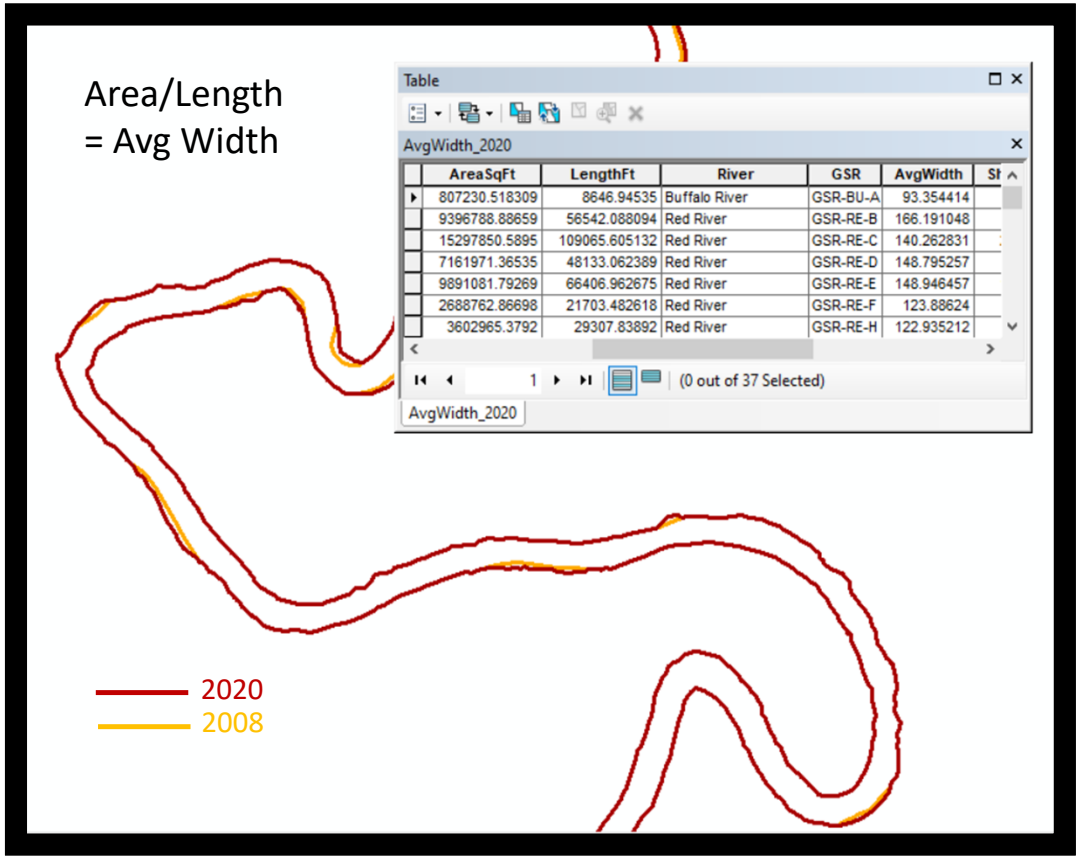




Amplitude and Wavelength: describing river bends

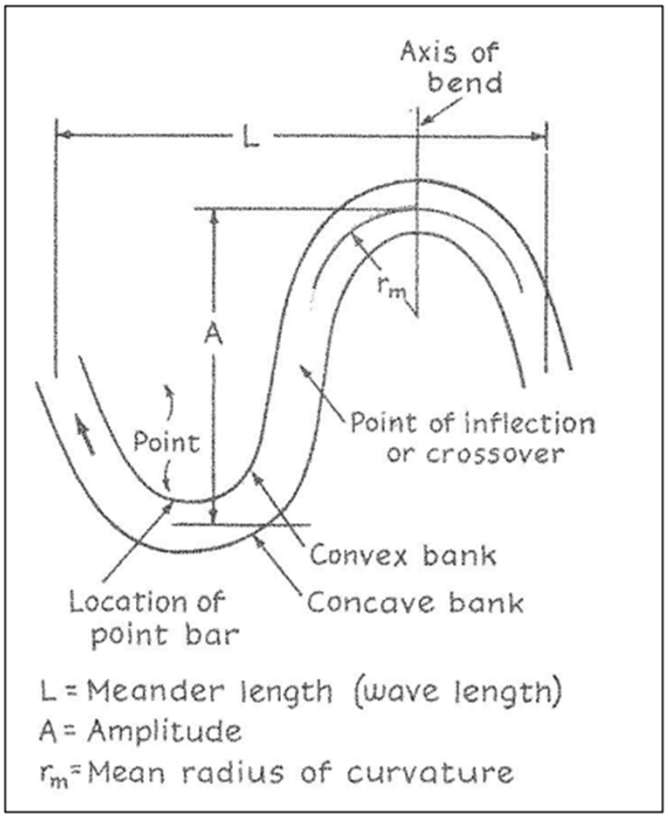
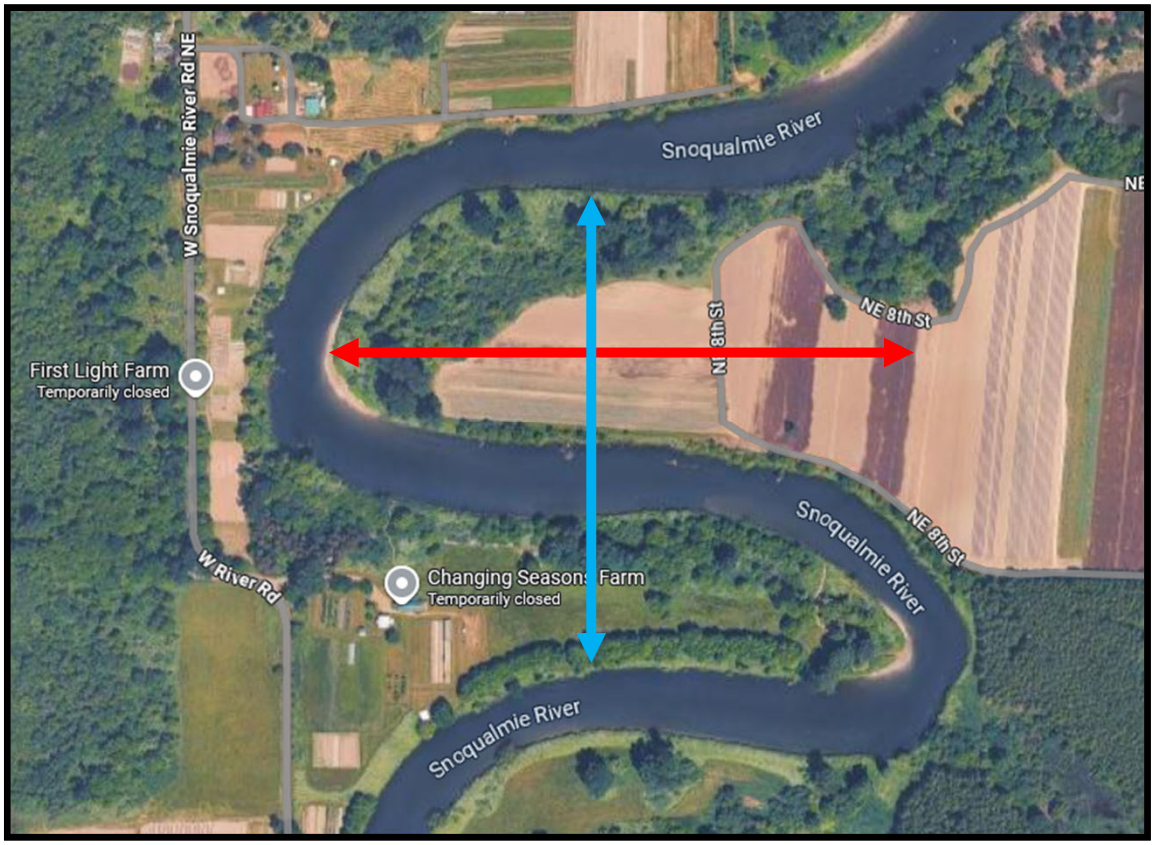


Figure 6-1. Definitions of amplitude and frequency (from Leopold et al., 1964)



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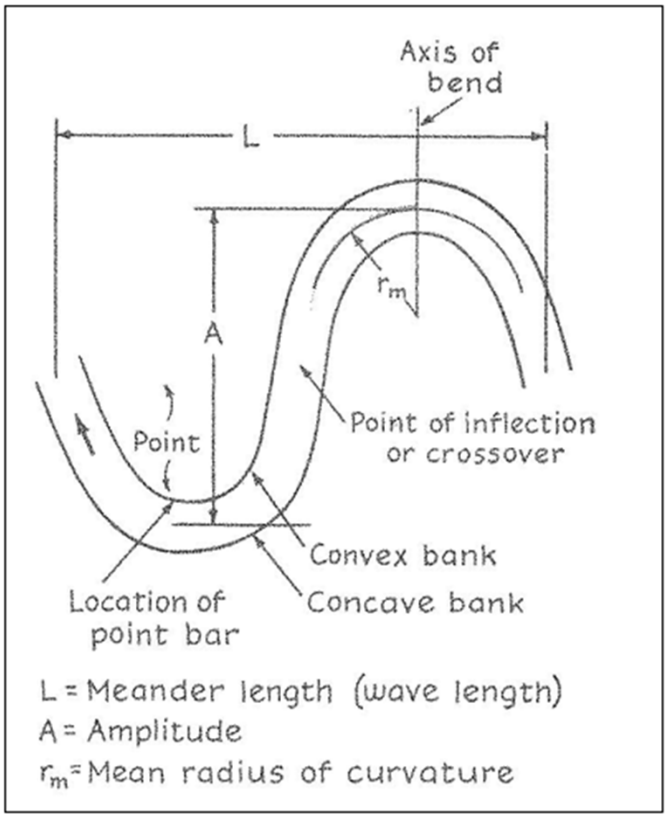

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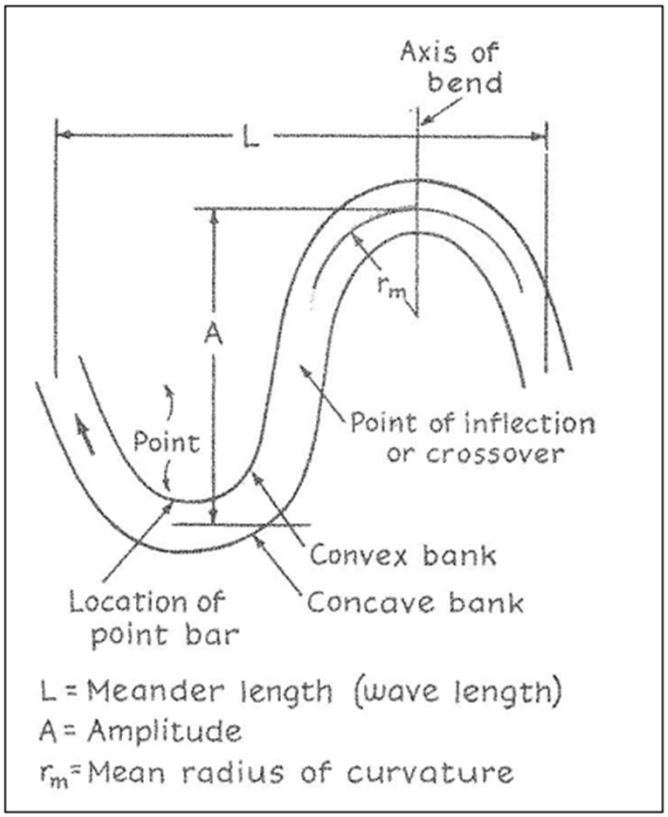

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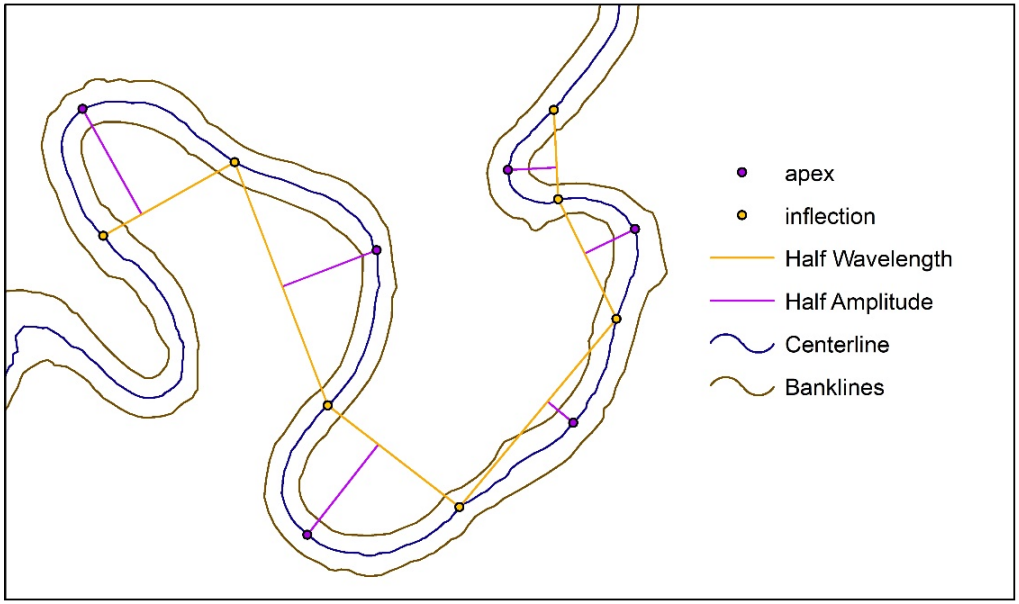


Meander Belt: measure the maximum* river meandering

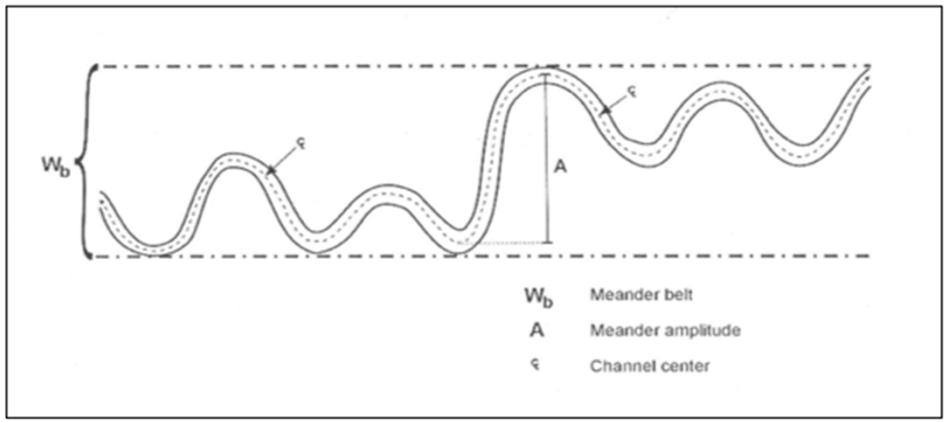
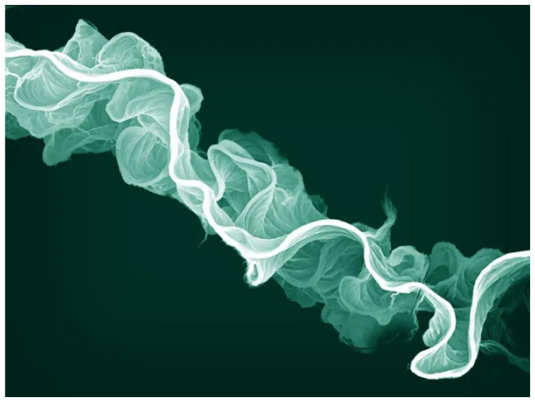
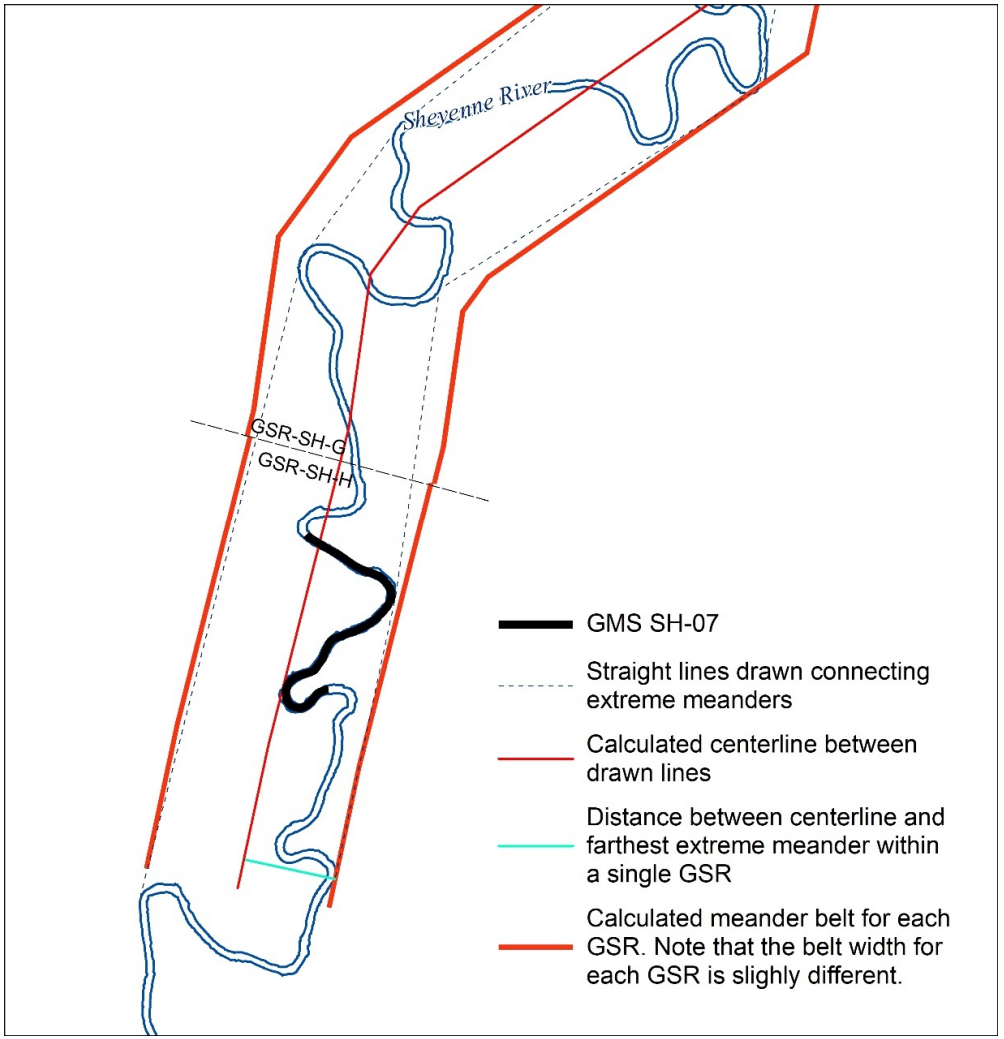


Figure 6-5. Example of meander belt width for a specific river reach (from Parish Geomorphic, 2004)



* On a human time scale…



Meander Migration: how and how much do the river bends move?

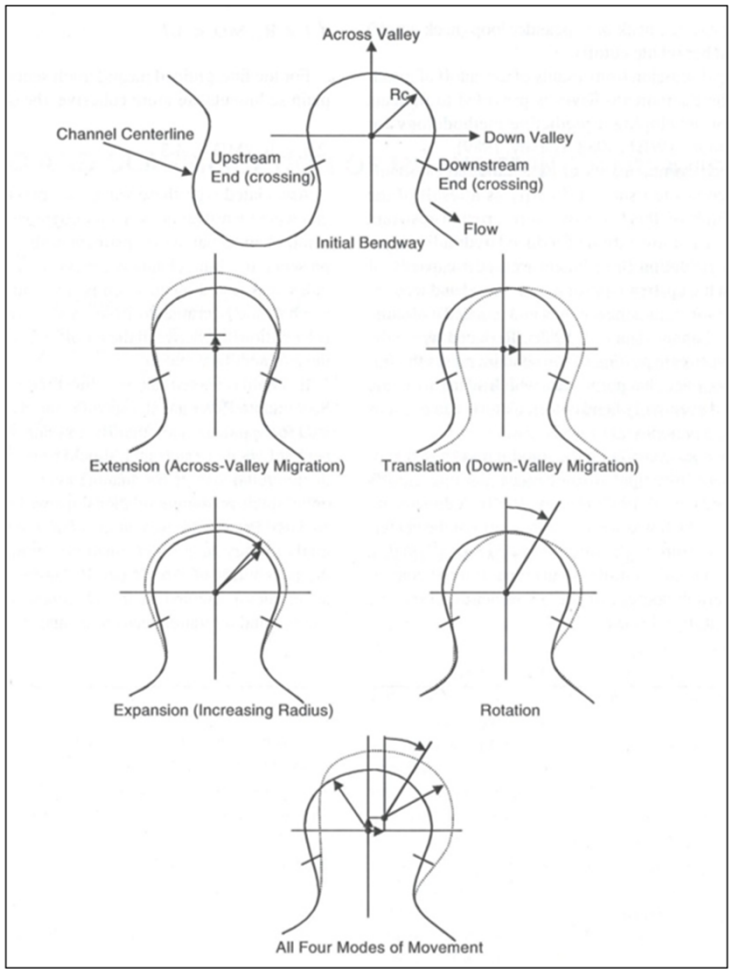
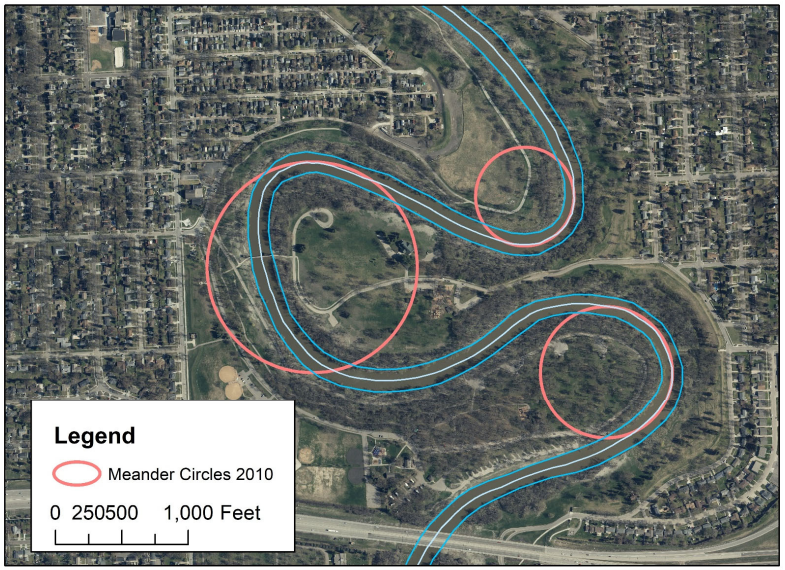


Figure 6-3. Types of meander migration (from NCHRP, 2004)

For the first iteration of this study in 2010, meander migration rates were calculated using a methodology similar to the guidance found in National Cooperative Highway Reach Program Report 533 (NCHRP, 2004). **Circles were inscribed** along the channel line at each meander bend.



Environ Monit Assess (2009) 152:155–165
DOI 10.1007/s10661-008-0304-8

Characterization and prediction of meandering channel migration in the GIS environment: A case study of the Sabine River in the USA

Joon Heo · Trinh Anh Duc · Hyung-Sik Cho · Sung-Uk Choi

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Based on this fact, least squares estimation for determination of the bend centroid and bend radius of a meander is applied in this study as a solution avoiding or at least limiting the random measurement errors. This approach was used to explore

Least squares estimation was used to find the center location (centroid) and radius of an imaginary circle best fit to the data points representing the bend line. The equation for this circle with the center—the bend centroid—at (a, b) and radius R is given by:

$$(x-a)^2+(y-b)^2=R^2. \tag{1}$$

Let (x_i, y_i), $i=1, 2, \ldots n$ be a set of data points in the xy plane. To determine the values of a, b, and R that provide a least squares estimation of a circle according to the data points, the following equation was minimized:

$$F(a,b,R)=\sum_{i=1}^{N}\left[(x_i-a)^2+(y_i-b)^2-R^2\right]^2. \tag{2}$$

https://dtcenter.org/sites/default/files/community-code/met/docs/write-ups/circle_fit.pdf

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Least-Squares Circle Fit

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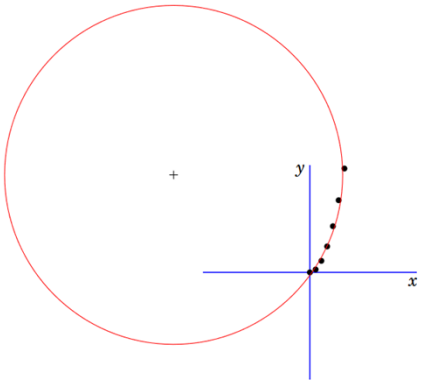
Given a finite set of points in $\mathbb{R}^2$, say $\{(x_i, y_i) \mid 0 \leq i < N\}$, we want to find the circle that "best" (in a least-squares sense) fits the points. Define

$$\overline{x} = \frac{1}{N}\sum_i x_i \quad \text{and} \quad \overline{y} = \frac{1}{N}\sum_i y_i$$

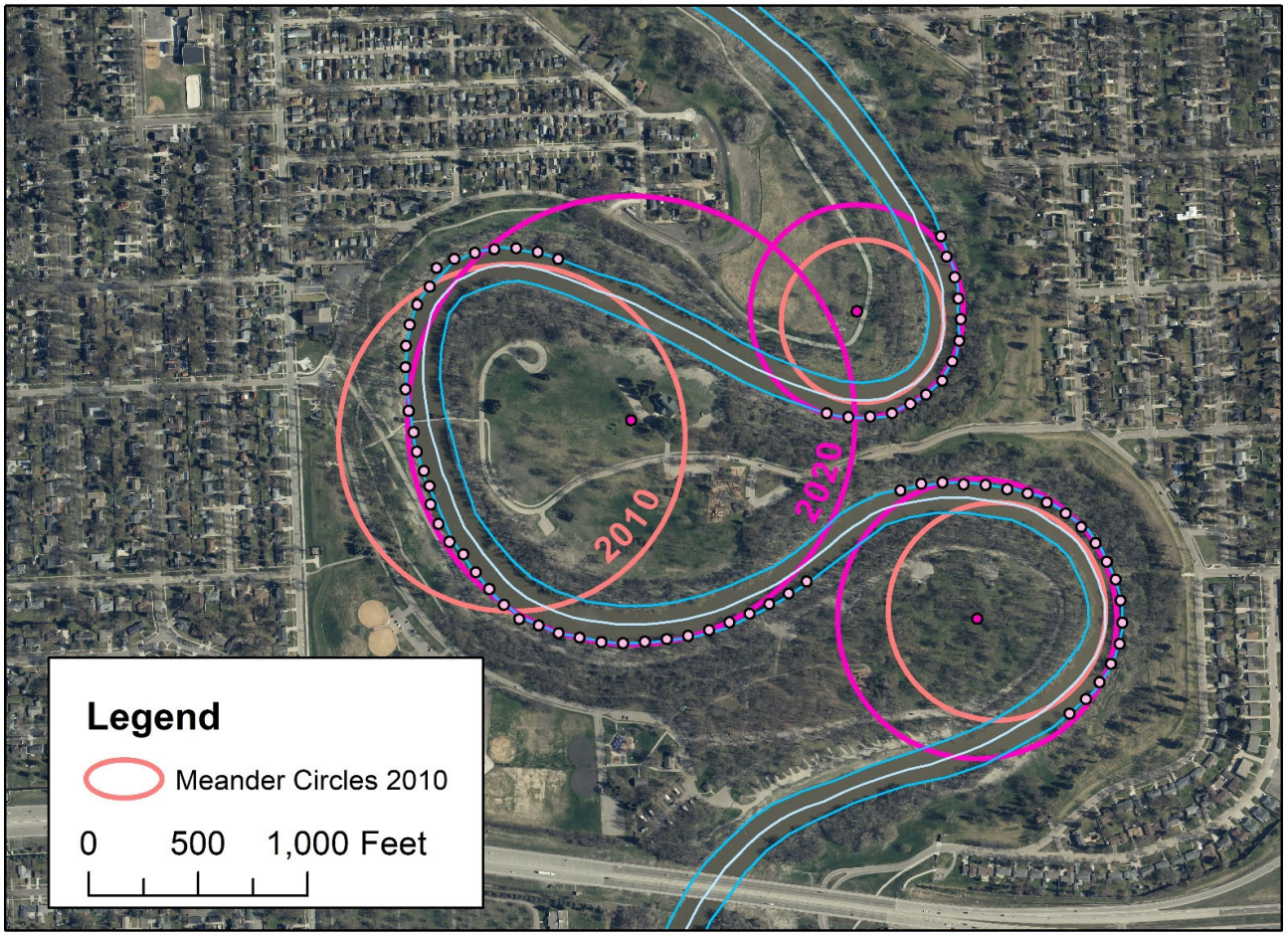
and let $u_i = x_i - \overline{x}$, $v_i = y_i - \overline{y}$ for $0 \leq i < N$. We solve the problem first in (u, v) coordinates, and then transform back to (x, y).

Note: this method only works in a projected x,y coordinate system like State Plane

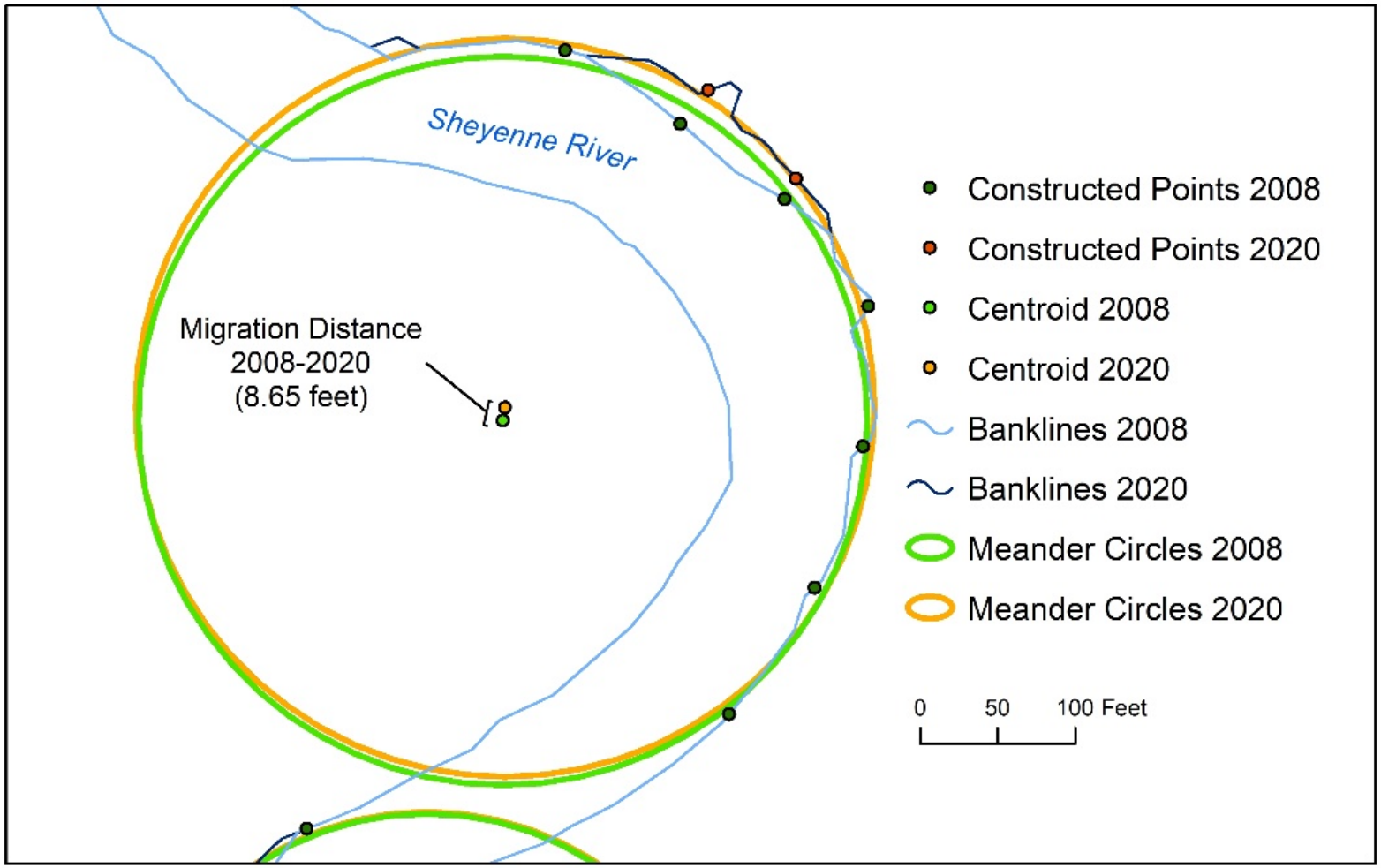


Sheyenne River - 8i 2020

Sheyenne River - 8i_2020			Summary Inputs		Sheyenne River - 8i_2020 Centroid				
x_{i_used}	y_{i_used}				Calculate Determinant				
2861791.99	381613.37		N=	6	D= 0.00000000029305317				
2861865.22	381631.01		x_{avg}	2862045.34	Dot Product				
2862280.57	381466.46		y_{avg}	381560.05	u_c =	1.81379E-05	3.0818E-05	X	9757989.848
2862318.31	381377.51		S_{uu}	233812.63	v_c =	3.0818E-05	6.85195E-05		-8912364.422
2861960.31	381650.18		S_{uv}	-105161.80	Solve for u_c and v_c		Solve for x_c and y_c (Centroid)		
2862055.63	381621.78		S_{vv}	61892.96	u_c =	-97.672	x_c = 2861947.665		
#N/A	#N/A		S_{uuu}	10638083.84	v_c =	-309.949	y_c = 381250.103		
#N/A	#N/A		S_{vvv}	-5426140.49	Solve for α		Solve for R		
#N/A	#N/A		S_{uvv}	8877895.85	α =	154892.5629	R = 393.564		
#N/A	#N/A		S_{vuu}	-12398588.35					

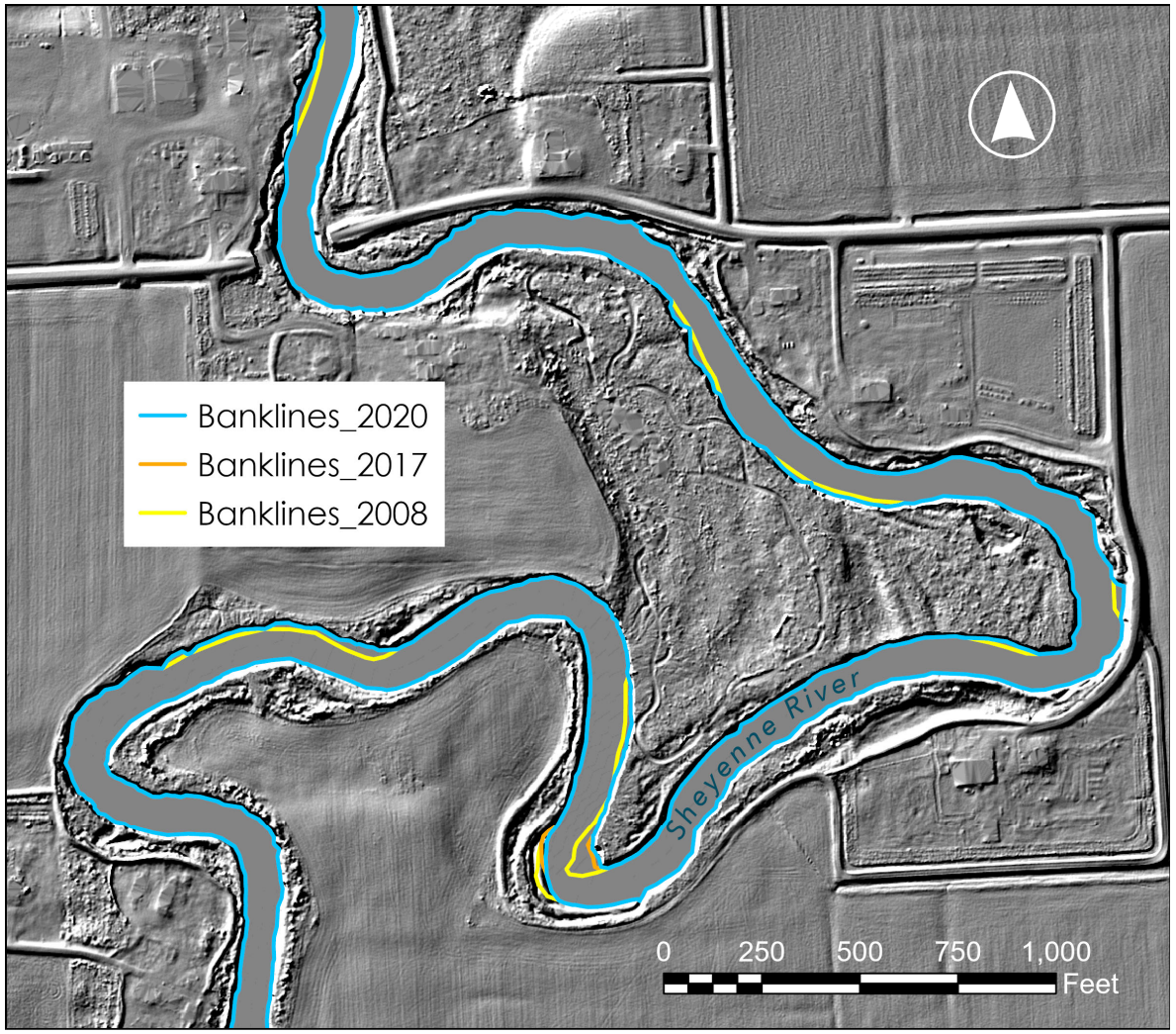

2010
2020
Legend
Meander Circles 2010
0
500
1,000 Feet

Our Solution



Summary

- Aerial imagery + hillshade LiDAR to delineate banklines
- Used banklines to create centerlines and both as a basis for calculating change in geomorphological characteristics
- Developed reproducible methodologies for calculations
- Looked at change over 12 years as a baseline prior to construction
- The same methodologies will be used post-construction to determine project impacts on river migration



Thanks!

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