In Search of the Fundamental Cause of River Meandering

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Abstract

Various meandering systems have been considered in the past, but have been studied independently. In this study, we consider meandering systems as a whole in an attempt to determine the fundamental cause of the instability that leads to meandering across systems. It is suggested that an adverse pressure gradient would cause such an instability. In rivers, an adverse pressure gradient occurs when water flows into a section downstream that is flowing slower than a section upstream, and the flow needs to decelerate. Examples of this phenomenon include a river flowing into an ocean or lake, or encountering a decrease in slope, among other cases.

Both Google Earth Engine and a laboratory flume are utilized to determine the conditions necessary for the onset of the meandering instability. The results indicate that there is some correlation between meandering and an environmental obstruction or perturbation. Better understanding of the meandering instability should allow for improved predictability of river channel evolution, and has widespread implications in other meandering systems.

Figure 1: Glacial melt water meanders due to friction along banks and bottom, like laboratory rivulets, but with a pseudo-cylindrical surface.

Figure 2: The sudden deceleration of this locomotive caused a force imbalance that extended rearward (upstream), and was sufficient to overcome the potential barrier of the wheel rims on the tracks.

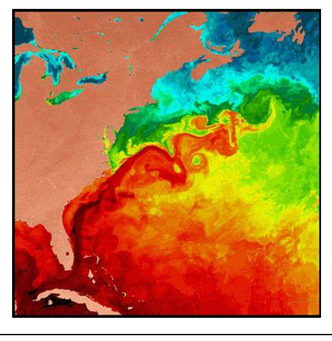


Figure 3: The eastward component of the water velocity decelerates as it moves north due to the Coriolis effect, causing a force imbalance and meanders in the Gulf Stream.

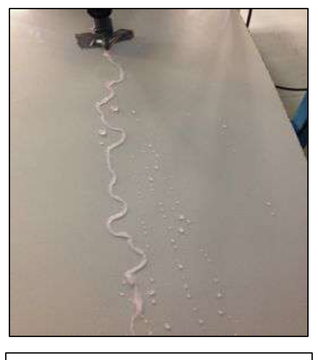
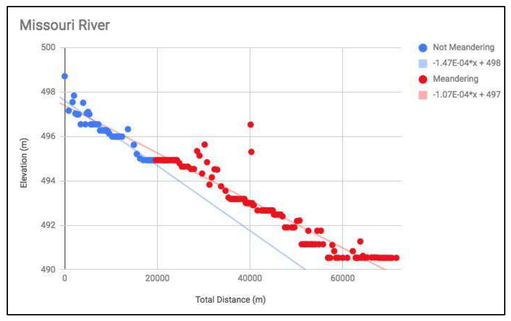


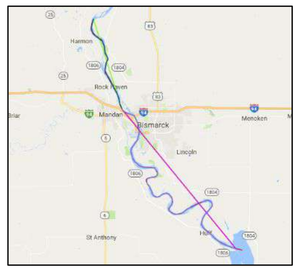
Figure 4: Meanders in rivulets generated on inclined surfaces with a steady laminar stream of water under adjustable hydraulic head.

Methods

Google Earth Engine

We use Google Earth Engine to analyze various meandering rivers globally, detecting correlations between slope change and consequent shifts in sinuosity. We overlay Digital Elevation Models to collect elevation data and run slope analyses to compare straight and meandering sections.





Figures 5 and 6 (above): We collected elevation data and calculated slope change and sinuosity along a stretch of the Missouri River. The river meanders more (has a higher sinuosity) before the channel widens and the slope decreases (a perturbation which results in an adverse pressure gradient).

Flume Experiments in Fritz Laboratory

The flume in Fritz is 16 feet long and 1.5 feet wide with an adjustable slope. In the flume, we can control the median sediment grain size, discharge, channel dimensions, and channel bed slope. For our experiments, the flume is filled with sand and the channel is formed with a trapezoidal wooden board that molds the shape of the channel cross section. To create an adverse pressure gradient, the channel is built with a milder slope at the downstream end so that water decelerates downstream and backs up upon itself, resulting in meandering tendencies.

Figure 7: Upstream to downstream view of the initial channel setup.

Figure 8: Initial upstream view of the flume with water running through the channel.

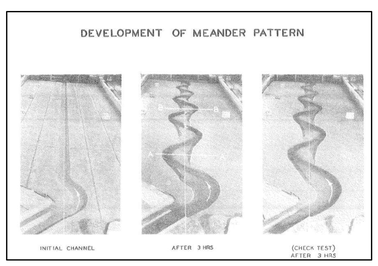


Figure 9 (left): Photographs from the 1945 Army Corps of Engineers meandering study. We used this study to determine how to create meanders in the laboratory using a diverted channel entrance.

Results

We have obtained several examples from Google Earth Engine which correlate meandering tendencies with slope and other environmental conditions. These examples generally show that where the slope becomes milder, the channel meanders, and that it straightens in steeper sections. We also have found that where the river is flowing into a larger water body, there is deceleration and subsequent meandering.

We have created meandering in an initially straight channel by making the downstream slope milder relative to that of the upstream section. This creates an adverse pressure gradient or backup of flow which causes the river to meander upstream of the change.

Figures 10 and 11: Channel that developed natural meanders with an adverse pressure gradient (slope change) downstream.

Future Work

Our work will continue to include data collection via Google Earth Engine in order to obtain more natural examples to study the conditions under which meandering does and does not exist. We will also conduct more laboratory experiments using the flume in Fritz Laboratory to create and eliminate meandering under certain conditions. We will adjust aforementioned variables to evaluate which factors and conditions fundamentally cause river meandering. Additionally, by applying an adverse pressure gradient to a fluid stream, we hope to observe and quantify meandering and coiling behaviors in three dimensional systems.

References

Friedkin, J.F. (1945). A Laboratory Study of the Meandering of Alluvial Rivers. *U.S. Army Corps of Engineers*, Vicksburg, Miss, Mississippi River Commission.

Shelef, E., Haviv, I., & Goren, L. (2018). A potential link between waterfall recession rate and bedrock channel concavity. Journal of Geophysical Research: Earth Surface, 123, 905–923.