River Meanders: Initial Experimental and Observational Results of a Fundamental Instability

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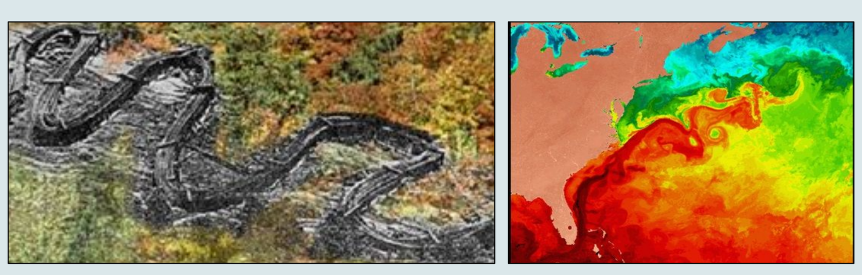
Abstract

Rivers with erodible banks represent one of several meandering systems. Other such systems include the Gulf Stream, Jet Stream, lava flows, and derailed trains. ***It is advocated here that the fundamental cause of instability that leads to meandering exists any time a fluid is decelerated due to an obstruction or perturbation.*** We present initial laboratory results of river meandering in which the instability is identified under conditions of decelerating flow, but is absent in the case of accelerating flow. These results are complemented by remote sensing observations from Google Earth Engine. These experiments and observations set the stage for development of a universal theory for meandering systems in one, two, or three dimensions. This improved understanding of meandering systems will allow for better prediction of river channel evolution, design of resilient bridge crossings, and development of stream restoration methodologies.



Demonstration of meandering in other systems that cannot be explained by erosion and sedimentation. These examples include a derailed train (above left) and the Gulf Stream (above right).

Image on left is initial trapezoidal channel formation, with no flow. Image on right is when flow has begun and erosion is not significant. Blue arrow indicates flow direction.

Methods

Google Earth Engine

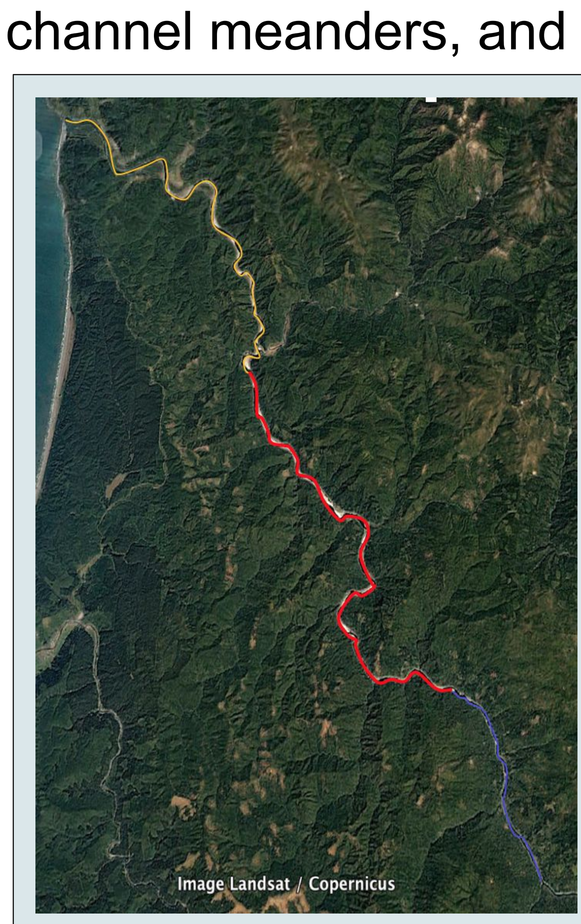
We use Google Earth Engine to analyze various meandering rivers globally, detecting correlations between slope change and consequent shifts in sinuosity. We overlay Digital Elevation Models to collect elevation data and run slope analyses to compare straight and meandering sections.

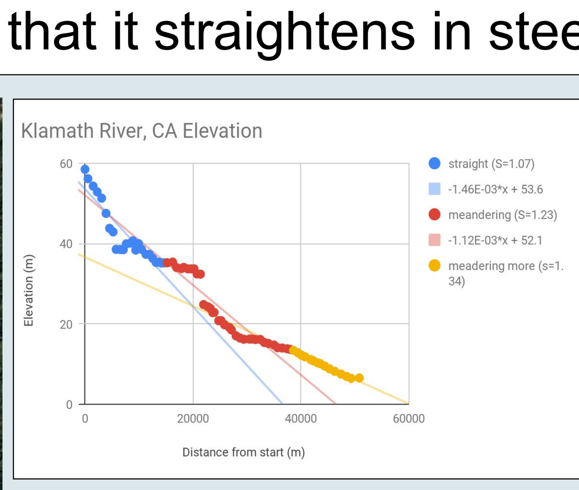
Laboratory Experiments

We utilize the flume in the Imbt Hydraulic Laboratory, and control the sediment grain size, discharge, initial channel dimensions, and channel bed slope. For our experiments, the flume is filled with fine sand and a trapezoidal wooden board is used to mold the shape of the channel cross section. To create an adverse pressure gradient (backup of flow), the channel is built with a milder slope or a metal obstruction at the downstream end so that water decelerates downstream and backs up upon itself.

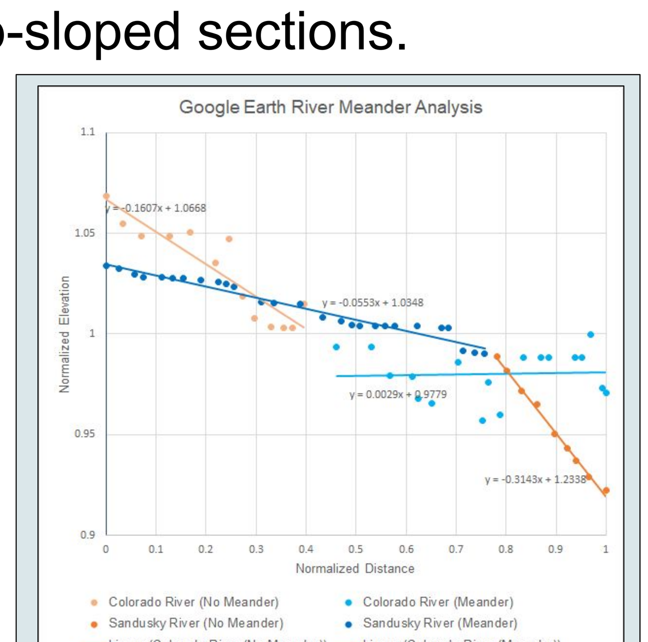
Digital Results

We have obtained several examples from Google Earth Engine which correlate meandering tendencies with slope and other environmental conditions. These examples generally show that in deceleration, where the slope becomes milder or the channel flows into a larger water body, the channel meanders, and that it straightens in steep-sloped sections.





Data collected from Google Earth Engine on the meandering patterns of Klamath River. Google Earth Engine and Google Earth Pro were used to collect elevation data and coordinates for the examples below. Slope is derived from this elevation data. Sinuosity is the ratio of the curvilinear length of the river to the Euclidean distance between the points and was calculated by collecting the distance of each of these lines on Google Earth Engine.



Normalized elevation profiles for Colorado and Sandusky Rivers. The cool colored best fit lines represent sections of rivers with meandering, and the warm colored best fit lines represent sections of rivers without meandering.

Laboratory Results

Decrease in Slope

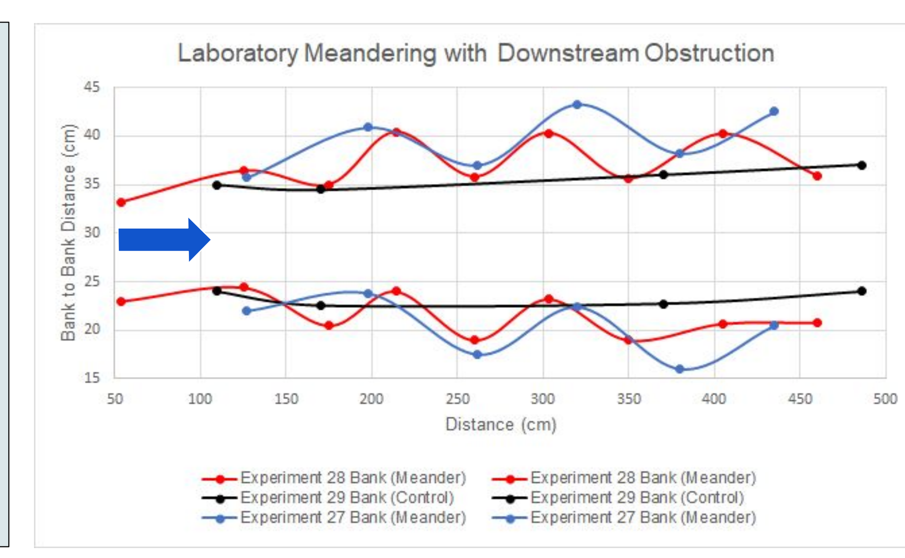
Meandering was created in an initially straight channel by making the downstream slope milder than that of the upstream section, creating an adverse pressure gradient which causes the river to meander upstream of the change. The meandering behaviors were formed from the scour of angled banks. No new banks are formed due to a lack of sediment source from upstream.

Meandering patterns present in the channel, caused by a reduction in downstream slope. Due to a lack in constant sediment feed upstream, the geometry of the channel is formed purely from the scouring of the sloped banks. The blue arrows denote flow direction.

Downstream Obstruction

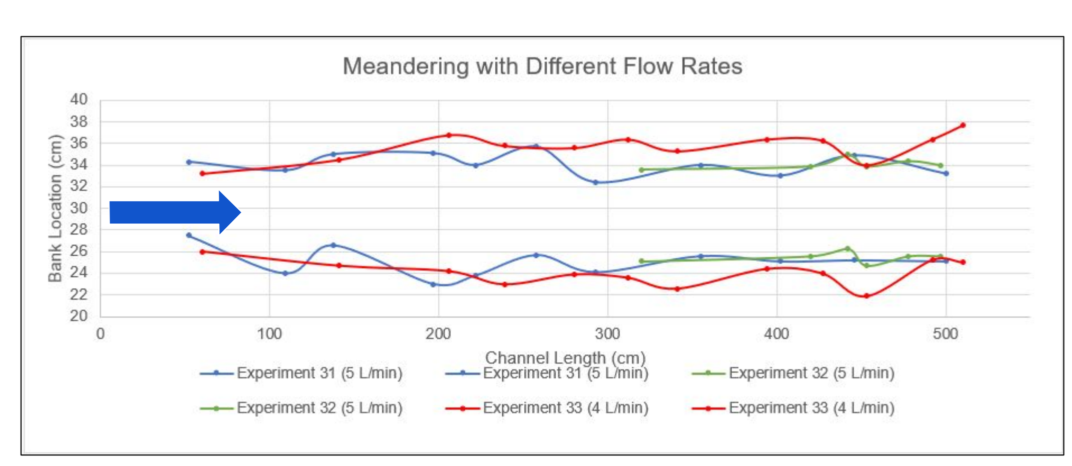
To demonstrate an alternative source of an adverse pressure gradient, we placed a metal sheet obstruction downstream to decelerate the flow. These experiments also produced meandering in an initially straight channel similar to patterns produced by a decrease in slope.

Meandering patterns produced by the addition of a metal obstruction downstream (left). Channel is straight without metal obstruction (right). Blue arrows indicate flow direction.



Experiments with Porous Downstream Obstruction

To further test the role of adverse pressure gradient, a porous metal sheet was used to quantify the effect of obstruction porosity and flow rate in triggering the meandering instability. It was demonstrated that flow rate and obstruction porosity can have an effect on meandering tendencies.



Meandering patterns produced in the flume from a porous board downstream. The blue arrows denote flow direction.

Conclusions

- Meandering occurs in many systems, most of which do not involve sediments.
- Deceleration of fluid flow due to an obstruction or reduction in slope leads to an adverse pressure gradient that propagates upstream in mild sloped channels.
- Natural rivers show meandering when slope decreases and straightening when slope increases.
- ***The existence of meandering in natural and laboratory conditions with adverse pressure gradients suggests a universal principle for the onset of the meander instability.***

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