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Rivers choose their path based on erosion — a discovery that could transform flood planning and restoration

Rivers are Earth’s arteries. Water, sediment and nutrients self-organize into diverse, dynamic channels as they journey from the mountains to the sea. Some rivers carve out a single pathway, while others divide into multiple interwoven threads. These channel patterns shape flood risks, erosion hazards and ecosystem services for more than 3 billion people who live along river corridors worldwide.

Understanding why some waterways form single channels, while others divide into many threads, has perplexed researchers for over a century. Geographers at UC Santa Barbara mapped the thread dynamics along 84 rivers with 36 years of global satellite imagery to determine what dictates this aspect of river behavior.

“We found that rivers will develop multiple channels if they erode their banks faster than they deposit sediment on their opposing banks. This causes a channel to widen and divide over time,” said lead author Austin Chadwick, who conducted this study as a postdoctoral researcher at UCSB.

The results, published in the journal Science, solve a longstanding quandary in the science of rivers. They also provide insight into natural hazards and river restoration efforts.

Two types of rivers

Earth scientists have long divided rivers into single and multi-channel categories, and generally investigate the two separately. While neither type clearly outnumbers the other, most of the world's largest rivers are multi-channeled. The notable exception is the single-channel Mississippi River, in the United States, where a lot of river research has occurred.

Most field research has focused on single-threaded rivers, partly because they're simpler. Meanwhile, experimental work has focused on multi-threaded rivers due to the challenges of recreating single-threaded channels in laboratory tank experiments.

It was while working on one of these tank experiments at University of Minnesota's St. Anthony Falls Laboratory that Chadwick got the inspiration for this study. While examining multi-channel rivers in the lab, he noticed that they were constantly widening and splitting. "I was banging my head on the wall because I kept measuring more erosion than deposition. And that was not what we're taught in school," he recalled. "That led me to read some old books from the Army Corps and other sources about examples where there's more bank erosion than deposition." Eventually, he became curious whether this occurred in nature.

It was a classic example of the scientific method: "You generate a hypothesis in a laboratory setting and then you're able to test it in nature," said co-author Evan Greenberg, a former doctoral student at UCSB who received the prestigious Lancaster Award for best dissertation.

Long-term data at 2,300,000 feet

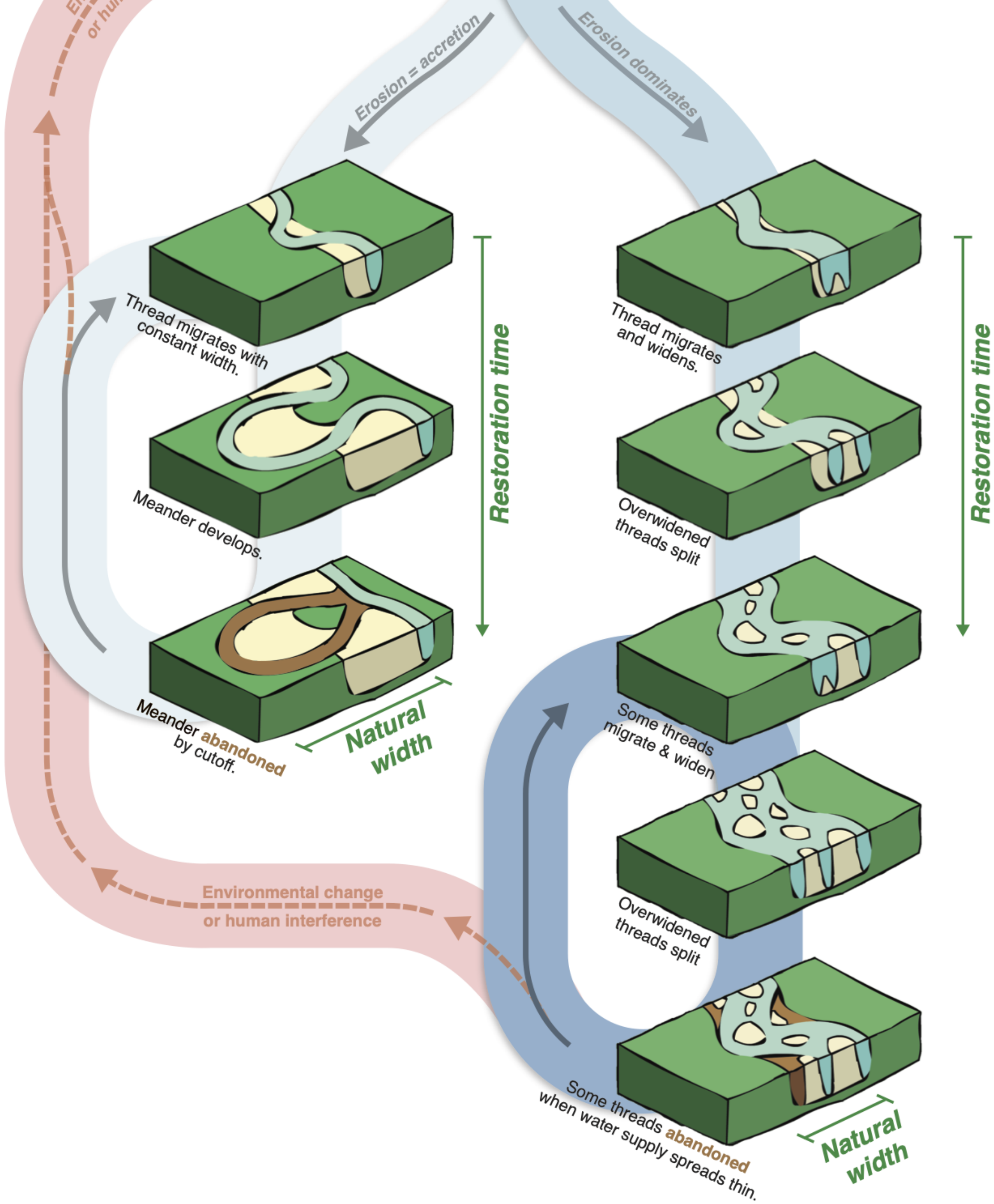
The team leveraged Landsat data housed at the Google Earth Engine repository, focusing on 84 rivers in different regions of the globe. They tracked erosion and deposition on each river's banks using an image-processing algorithm called particle image velocimetry. The authors adapted this algorithm — originally designed to track particle motion in lab photos of a fluid — to track channel position in satellite images of their floodplains.

In single-threaded rivers, erosion and deposition balanced out. As a result, the channel’s width remains constant, allowing these rivers to lean into their bends and form wide, meandering paths across the landscape. In contrast, bank erosion outpaced deposition in multi-channel rivers, causing a given channel to widen over time until it splits in two. As a result, multi-channel rivers reshuffle their channels before they can meander too far across the floodplain.

Each of these dynamics occurs while a river is in a steady state (neither growing nor shrinking). “It is not like multi-threaded rivers are gaining water on average. They are still conveying the same amount of water through time, but they are doing that by constantly shuffling the size of the individual threads,” explained senior author Vamsi Ganti, an associate professor of geography at UCSB.

When the authors say that erosion exceeds deposition, they’re referring to the river’s banks. For multi-channel rivers, the extra sediment eroded from the banks is redeposited on the river bottom, eventually forming the islands and bars that separate the different channels.

Image



Erosion = accretion
Erosion dominates
Thread migrates with constant width.
Meander develops.
Meander abandoned by cutoff.
Natural width
Restoration time
Thread migrates and widens.
Overwidened threads split
Some threads migrate & widen
Overwidened threads split
Some threads abandoned when water supply spreads thin.
Restoration time
Natural width
Environmental change or human interference

Photo Credit
Chadwick et al.
Rivers can follow one of two trajectories depending on the balance between bank erosion and deposition.

The researchers tallied a few exceptions to the erosion-deposition trend, but they discovered that each of them coincided with apparent changes in the watershed that forced the river out of its natural steady state. For instance, the Sao Francisco River in Brazil didn't exhibit excess erosion like other multi-channel rivers because the river has been shrinking in response to the damming of its headwaters and water extraction for irrigation.

"The question of what causes a river to be single-threaded or multi-threaded is pretty much as old as the field of geomorphology," said Ganti.

Generally, geographers have understood river dynamics in terms of myriad variables, including downstream slope, water flow rate, sediment type and bank stability. The new model explains river type solely in terms of the balance between deposition and erosion. The various geographic factors affect this balance, explaining why specific environments tend to favor certain kinds of rivers.

Giving rivers space to flow

The 20th century has seen many rivers boxed into narrow channels disconnected from their historic floodplains. This reclaims more land for settlement and mitigates some of the inherent hazards of living near a river. However, this is disastrous for riparian ecosystems and can even exacerbate long-term hazards. Cutting a river from its floodplain means sediment settles on the riverbed, elevating the river relative to the neighboring, sediment-starved floodplain. This makes it more likely to jump its banks in the event of a flood or a levee failure, a phenomenon the team has investigated in depth.

"Consider Hurricane Katrina," Chadwick said. "When the levee broke, there was widespread flooding in part because the floodplain had been cut off from the Mississippi for so long that it had sunk relative to the river, allowing the floodwaters to pond there."

There’s a growing effort to reconnect channelized rivers with their floodplains and give them more space to move. Nature-based restoration efforts require figuring out how wide a corridor a given river needs in order to return to its natural state, as well as how long it will take to do so. With their newfound understanding of river dynamics, the team devised a formula for this, which includes variables like how long a river takes to abandon a channel. The formula also describes whether a river returns to a single- or multi-channel state. They calculated the restoration widths and times for various types of rivers based on their satellite observations.

Chadwick, Ganti and Greenberg found that the time and space a river needs to reestablish its natural behavior varied widely between single and multi-threaded rivers. A single-threaded river requires about ten times more space and time to reestablish itself as a multi-threaded river of the same stream power, which is the amount of energy the stream has to erode and move sediment.

The paper’s insights can guide infrastructure and revitalization projects. The formula developed by the authors enables engineers and scientists to estimate the width a restoration project will need, a deciding factor in a project’s feasibility and cost. The analysis can also help policymakers prioritize candidates for recovery. Research, restoration and hazard mitigation have historically focused on single-threaded channels, but shifting toward projects on multi-threaded waterways could yield greater returns for lower costs.

In fact, the team’s findings suggest that river restoration may be less costly than anticipated. There’s growing recognition that many single-threaded rivers were historically multi-threaded before human intervention, especially in the western U.S. For instance, photos of the Los Angeles River from the 1930s, before it was channelized, show it with multiple threads. A project currently considered prohibitively large or expensive may actually be affordable if a river was misclassified, Chadwick explained.

Ganti’s lab is currently studying the acceleration and deceleration of rivers, as well as changes in the number of threads a river has over time. “These temporal trends are likely signatures of how climate change and human interference are affecting river dynamics,” he said.

Chadwick is still curious why erosion outpaces deposition in some rivers. He plans to further investigate the diversity of multi-threaded rivers as a postdoctoral research scientist at Columbia University's Lamont-Doherty Earth Observatory, with a particular interest in how they form. Meanwhile, Greenberg, now at the Jet Propulsion Laboratory (JPL), is using remote sensing to measure sediment transport in rivers. He's also finishing up work looking at how dams influence river shape over time and the development of the river corridor.

Rivers have played an important role in human history. They irrigate the crops we grow on their fertile plains and convey our goods to and fro. But they also flood our cities and suddenly forsake well-worn channels. Learning more about rivers will enable us to better coexist with these mercurial natural features in a time of unprecedented change.

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