Yellow River formula addresses flood risk, sustainability

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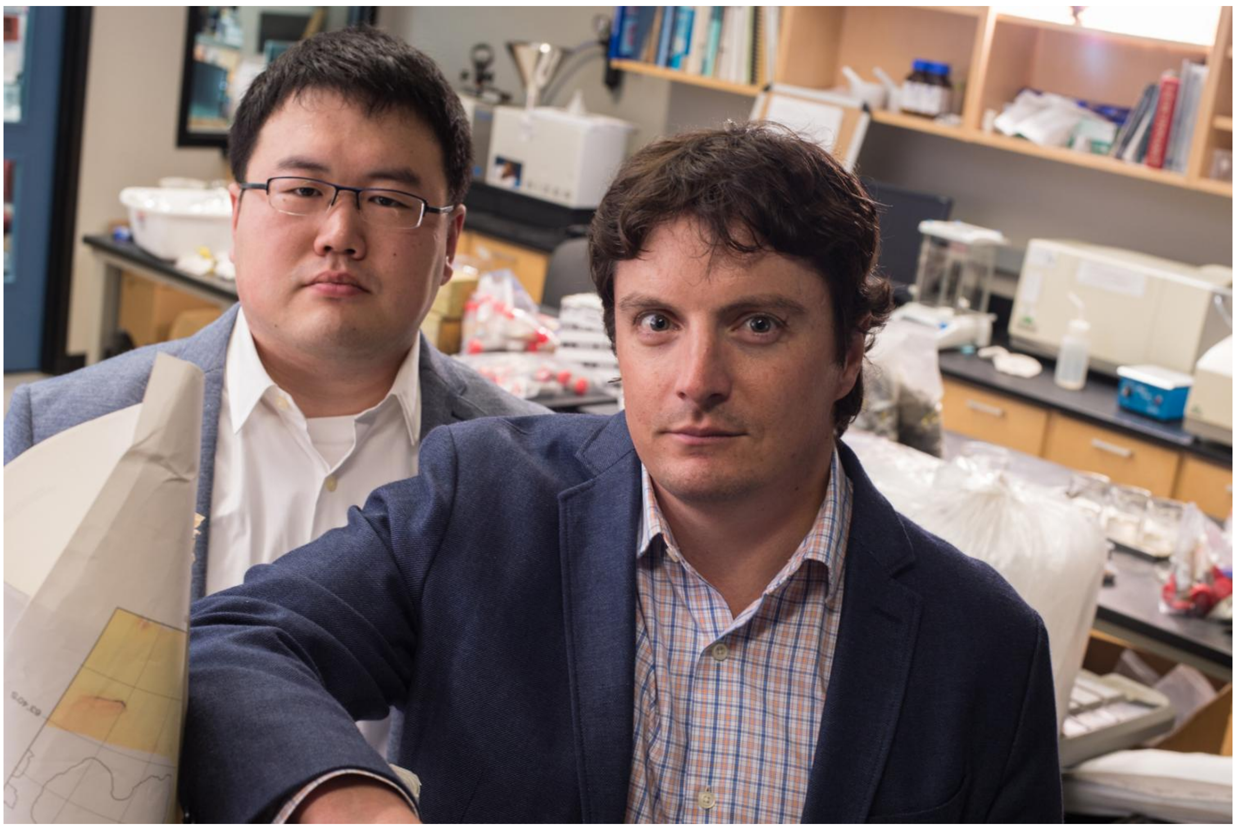

Rice University sedimentologists Hongbo Ma (left) and Jeff Nittrouer. Credit: Photo by Jeff Fitlow/Rice University

U.S. and Chinese geologists studying China's Yellow River have created a new tool that could help Chinese officials better predict and prevent the river's all-too-frequent floods, which threaten as many as 80 million people. The new tool, a physics-based formulation to calculate sediment transport, can also be applied to study the sustainability of eroding coastlines worldwide.

Known in Chinese as the Huanghe, the Yellow River holds a central but dichotomous place in history. As the cradle of Chinese civilization, it is often called the "mother of China." But its floods, including several of the deadliest natural disasters in recorded history, also have earned it the name "China's sorrow." Each identity—the fertile nurturer and the wanton killer—derives from the same feature: The Yellow River washes about a billion tons of sediment each year from the Loess Plateau to the Bohai Sea, and in so doing, it has a tendency to become so clogged that it not only floods but literally changes course, jumping to a new channel miles away.

"The Huanghe is probably the most-studied fine-grained river in the world," said Rice University sedimentologist Jeffrey Nittrouer, a primary author of the new study about the Yellow River that appears online this week in *Science Advances*. "Despite that, the typical formulae and relationships that are used to describe sediment flux in most other rivers simply do not work for the Huanghe. They consistently underpredict the sediment load of the river by a factor of 20."

In the study, Nittrouer and lead author Hongbo Ma, a postdoctoral researcher from China who joined Rice in 2014, used the latest techniques in sediment sampling and 3-D river-bottom mapping to create a "universal sediment transport formulation." The formulation is the first physics-based sediment transport model capable of accurately describing how the Huanghe carries sediment.

"In terms of sediment transport, the Haunghe is almost the perfect river," Ma said. "Its bottom is nearly flat and featureless, which means it can use almost all of its energy for moving sediment."

Nittrouer, an assistant professor of Earth science who has studied dozens of rivers on three continents, said he has not seen anything like the Huanghe. "In typical lowland sand-bed rivers - like the Amazon, the Mississippi, you name it - only about 40 to 60 percent of the energy is used to transport sediment downstream. In the Yellow River, well over 95 percent of the energy is available to move sediment."

Nittrouer and Ma first visited the Huanghe in summer 2015 as part of a four-year, $2 million study funded by the National Science Foundation (NSF). Their intent was to examine the geological, socio-economic and engineering lessons from China's decadeslong effort to control the Huanghe and direct the growth of its delta into the Bohai Sea.

"The Haunghe moves so much sediment that it is extremely efficient at generating new land each year and is therefore the best place for us to learn about how to use sediment from rivers to enhance delta sustainability," Nittrouer said. "The example closest to home is the Mississippi River, where there are significant efforts to replenish coastal Louisiana. But an even more pressing reason to study the Yellow River is that 80 million people live in its floodplain and are threatened by its floods. The potential for human suffering is enormous. The aim of our work is to mitigate Huanghe floods, while developing techniques through research that are transferable so as to evaluate river systems worldwide."

Ma and Nittrouer said they will never forget their first attempt to create a 3-D map of the Huanghe bottom. They were planning to make a detailed picture of the river bed using a sonar system that Nittrouer had previously used to map several other rivers systems. In all previous studies, he'd found that the channel contained bedform features similar to sand dunes of deserts.

"I took one look at the readout on the boat and thought the instrument was broken," Nittrouer said. "The bottom looked flat as glass."

Ma said, "Only when we brought the data back to the lab did we see that there were features, but the aspect ratio was such that we could not see them on the boat."

For example, when Nittrouer imaged the bottom of the Mississippi River, he typically saw bedforms up to 10 meters tall and spaced about 200 to 300 meters apart. In contrast, the data from the Yellow River showed 1-meter-tall dunes every 500 to 2,000 meters.

Using that data and other measurements from the lower Huanghe, including from its sprawling delta, Ma created a physics-based formulation capable of accurately predicting the flux—the volume of sediment transported for a given time period—in the Huanghe.

"The aim is to look at the connectedness, in terms of sediment movement and water flow, among the river, the delta and the near-shore marine region," said Ma, who chose to become a sedimentologist following the devastating 2008 Sichuan earthquake in China.

While still an undergraduate at Tsinghua University, Ma joined a lab that was studying the potential flooding that could result from dam breaches caused by landslides in the 2008 quake. The potential loss of life from the floods was greater than the 90,000 people killed or injured by the quake itself, and Ma became fascinated with creating technologies that could help prevent such large floods.

"I was born and grew up far from the Haunghe in the northeastern Heilongjiang Province, but I, like many Chinese, deeply feel the sorrow of the Huanghe, which has killed millions over the past 2,000 years, and I bear the sorrow of all the flooding hazards in mind in conducting my research," he said.

Ma said he hopes the new formula may prove useful to Chinese engineers who manage the flow of water and sediment from dams along the Huanghe. For example, engineers have for decades tried to reduce the risk of Huanghe floods by periodically scouring the river bottom with massive releases of sediment-depleted lake water.

Ma said one finding from the new model is that such scouring may inadvertently increase the risk of flooding in certain parts of the river because although it clears silt, it also creates a rough-textured riverbed that reduces the amount of energy the river can use to move sediment.

"Our formula indicates this will lower sediment transport efficiency by an order of magnitude," he said. "Additionally, the added drag produced by dunes could increase water stage and leave the system prone to levee overtopping during flood events. This threat may be unique to the case of the Haunghe."

Judy Skog, program director in the NSF's Directorate for Geosciences, which funded the research through its Coastal Science, Engineering and Education for Sustainability Program, said, "Understanding the flow of sediment in rivers is important to the large number of people around the world who live near rivers. This study can lead to predictions of when and where rivers transport sediment, and to an understanding of how that sediment flow is affected by conservation and management efforts, such as the removal of dams."

More information: "The exceptional sediment load of fine-grained dispersal systems: Example of the Yellow River, China," *Science Advances* (2017). DOI: 10.1126/sciadv.1603114 , advances.sciencemag.org/content/3/5/e1603114

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