Scientists add the human element to long-term flood predictions

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Scientists, from left, Ethan Coon, Phong Le, Gabriel Perez and Saubhagya Rathore, discuss flood-prone areas in the ORNL Everest visualization lab. The team developed a 3D modeling framework to more accurately assess long-term flooding hazards and population risks. Credit: Carlos Jones/ORNL, U.S. Dept. of Energy

To better predict long-term flooding risk, scientists at the Department of Energy's Oak Ridge National Laboratory developed a 3D modeling framework that captures the complex dynamics of water as it flows across the landscape. The framework seeks to provide valuable insights into which communities are most vulnerable as the climate changes, and was developed for a project that's assessing climate risk and mitigation pathways for an urban area along the Southeast Texas coast.

The modeling framework offers a powerful tool for urban planning by providing robust estimates of both frequent and rare flood events. By modeling the physical processes that transform rainfall into runoff, the framework accounts for factors such as land cover, soil properties and slope of the land.

These elements, incorporated alongside population density data, provide a unique perspective on flood risk across vast areas such as river basins. This comprehensive approach is detailed in a study published in the *Journal of Hydrology*.

The modeling capability was developed for the Southeast Texas Urban Integrated Field Laboratory, or IFL, a DOE project using multidisciplinary science to inform pathways for climate resilience in the Beaumont-Port Arthur, Texas, region. The area is home to the world's largest oil refinery and is a major industrial center for the United States. Its proximity to the Gulf Coast makes the region vulnerable to flooding and land subsidence—the gradual sinking of the ground over time—with additional stressors from population density and pollution presenting multiple challenges to local decision-makers.

"This new state-of-the-art model not only estimates the streamflow magnitude of rare events such as a 100-year flood, but it also quantifies its associated flood depth, allowing us to assess the impact on the population directly," said Gabriel Perez, who co-led the work as a postdoctoral researcher in ORNL's Watershed Systems Modeling group, and is currently an associate professor at Oklahoma State University.

"That's a very unique framework, that can help us better understand how flood risk is evolving due to climate change and urbanization."

In developing such a model, "it becomes much more important to rely on the underlying physics of flooding because those are true throughout time, as opposed to a model that's calibrated under today's conditions and might not be right in tomorrow's climate or tomorrow's cities," said Ethan Coon, project co-lead, senior R&D staff, and principal investigator for ORNL's research for the Southeast Texas Urban IFL.

The new framework incorporates the Amanzi-ATS software, an integrated surface-subsurface hydrological model developed by ORNL, Los Alamos National Laboratory, Lawrence Berkeley National Laboratory and Pacific Northwest Natural Laboratory. Amanzi-ATS provides a holistic view of hydrological systems.

It captures subsurface flows, considering complex geology and soil properties, and accounts for unique topography, including the representation of water infrastructure and disturbances such as changes in land use by accelerated urbanization. Results may identify new flood-prone areas, specifically pinpointing risks for area populations.

On the 2,227-kilometer-square Village Creek basin upstream of Beaumont-Port Arthur, ORNL scientists used the framework to simulate thousands of flood events to estimate flood hazard and population flood exposure for events up to the 500-year return period. The case study relied on population estimates from the ORNL LandScan dataset, in addition to land and soil datasets, hourly radar rainfall data, streamflow measurements and a multitude of other datasets, resulting in an Amanzi-ATS model setup with nearly 1.9 million elements.

"Modeling flood events across an entire river basin with this level of detail requires immense computing power," Perez said. The model was run on the Perlmutter supercomputer at the National Energy Research Scientific Computing Center (NERSC), a DOE Office of Science user facility, at Lawrence Berkeley.

Forward-looking framework

"We're able to replicate a wide range of observations, including streamflow, vegetation effects, soil moisture content and even groundwater changes. These initial results boost our confidence in capturing flood processes and enhance our ability to quantify flood changes over the coming decades. This approach is crucial to meeting the mission of the Urban IFLs," Perez said.

"What's different here is that we're not just analyzing precipitation," Coon said. "We're computing stream flows, but we're also computing inundated areas and tying that to population data so we understand what these events mean for people on the ground."

"Models calibrated mostly on precipitation have a goal of predicting conditions in the next 30 days, and that is very useful for short-term flood planning," Coon added. "But for our longer horizon, it's important to lean on physics-based models. You don't want to make a 10- or 20-year plan based on today's events and infrastructure. You need different statistics and an idea of what conditions will be in the decades ahead."

Next, the scientists will apply the new modeling capability to a larger section of the Beaumont-Port Arthur region. One of their objectives is to simulate flood responses that reflect various future climate projections and land use changes. Among the challenges will be modeling compound flooding, an event in which multiple hazards interact, from coastal storm surges to river flooding, simulating the influence of precipitation on impervious surfaces in urban corridors and how water infrastructure interacts with flood events.

The end goal, Coon said, is providing the ability for urban planners to best answer planning commissioners' questions about approaches such as wetland restoration or other full-basin integration projects. "For instance, would such an approach avoid the need to build more culverts and ditches? We want to have a tool that can respond to such scenario-driven queries," he said.

Developing mitigation solutions that are transferrable—proven successful in one region that can be deployed in other states—is one of the project goals. The Southeast Texas Urban IFL is one of four field labs sponsored by DOE across the country with a mission of better understanding climate change impacts and developing equitable adaptation strategies alongside local partners. Contributing to this larger climate resilience effort is important.

"That's where the national lab participation comes in. We can help understand and facilitate that transferability. What we learn at each of the Urban IFLs can be made more broadly relevant," Coon said.

More information: Gabriel Perez et al, Advancing process-based flood frequency analysis for assessing flood hazard and population flood exposure, *Journal of Hydrology* (2024). DOI: 10.1016/j.jhydrol.2024.131620

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