The New York Times

The Coming California Megastorm

A different ‘big one’ is approaching. Climate change is hastening its arrival.

By Raymond Zhong | Graphics by Mira Rojanasakul Photographs by Erin Schaff
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California, where earthquakes, droughts and wildfires have shaped life for generations, also faces the growing threat of another kind of calamity, one whose fury would be felt across the entire state.

This one will come from the sky.

According to new research, it will very likely take shape one winter in the Pacific, near Hawaii. No one knows exactly when, but from the vast expanse of tropical air around the Equator, atmospheric currents will pluck out a long tendril of water vapor and funnel it toward the West Coast.

This vapor plume will be enormous, hundreds of miles wide and more than 1,200 miles long, and seething with ferocious winds. It will be carrying so much water that if you converted it all to liquid, its flow would be about 26 times what the Mississippi River discharges into the Gulf of Mexico.

When this torpedo of moisture reaches California, it will crash into the mountains and be forced upward. This will cool its payload of vapor and kick off weeks and waves of rain and snow.

The superstorm that Californians have long feared will have begun.

In centuries past, great rains deluged the Pacific Coast, and strong storms in recent decades have caused havoc and ruin. But, because of climate change, this one would be worse than any in living memory.

Drenching rain will pummel cities and towns.

At times, the hills around Los Angeles could get nearly two inches of rain an hour.

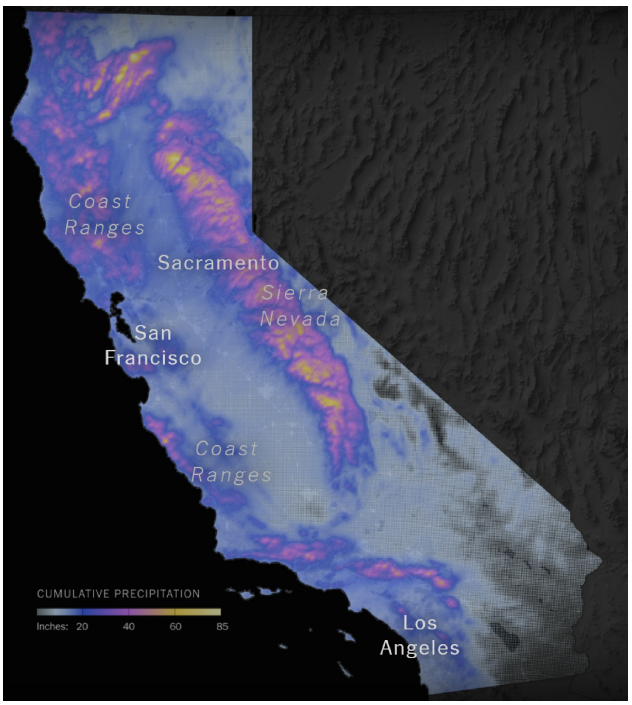
Heavy rain and snow in the Sierra Nevada will test dams in the Central Valley, one of the world’s most productive farm belts.

While all this has been happening, another filament of moisture-laden air will have formed over the Pacific and hurtled toward California.

Then another.

And another.

After a month, nearly 16 inches of precipitation, on average, would have fallen across the state.



Large swaths of mountainous areas would have gotten much more.

Communities might be ravaged beyond resettling. None of the state's major industries, from tech and Hollywood to farming and oil, will be untouched.

The coming superstorm — really, a rapid procession of what scientists call atmospheric rivers — will be the ultimate test of the dams, levees and bypasses California has built to impound nature's might.

But in a state where scarcity of water has long been the central fact of existence, global warming is not only worsening droughts and wildfires. Because warmer air can hold more moisture, atmospheric rivers can carry bigger cargoes of precipitation. The infrastructure design standards, hazard maps and disaster response plans that protected California from flooding in the past might soon be out of date.

As humans burn fossil fuels and heat up the planet, we have already increased the chances each year that California will experience a monthlong, statewide megastorm of this severity to roughly 1 in 50, according to a new study published Friday. (The hypothetical storm visualized here is based on computer modeling from this study.)

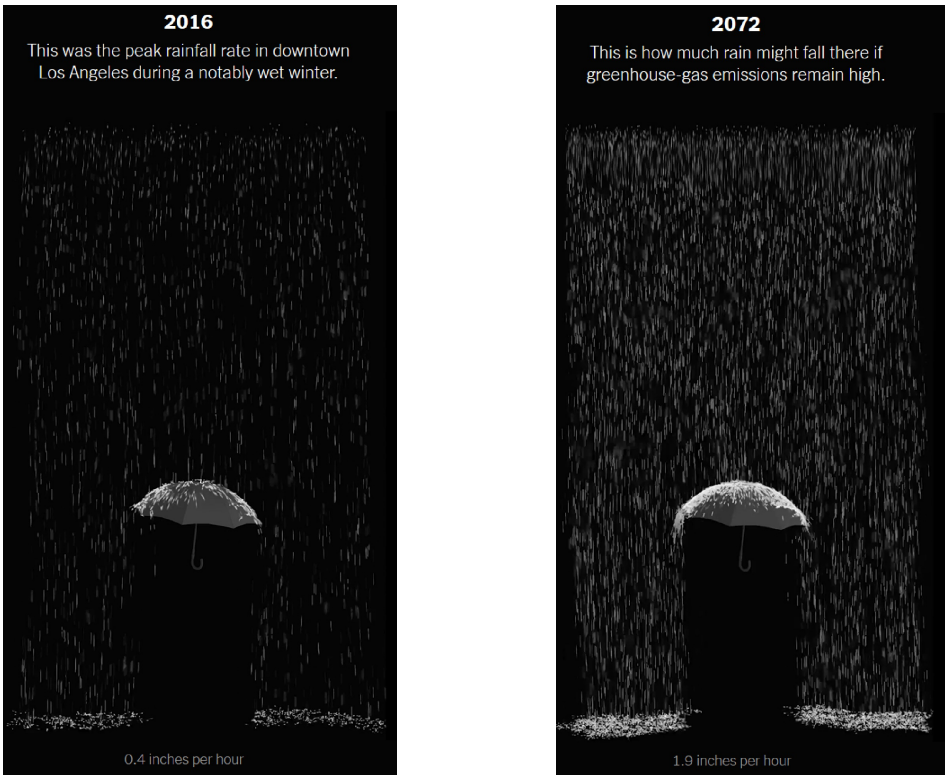
In the coming decades, if global average temperatures climb by another 1.8 degrees Fahrenheit, or 1 degree Celsius — and current trends suggest they might — then the likelihood of such storms will go up further, to nearly 1 in 30.

At the same time, the risk of megastorms that are rarer but even stronger, with much fiercer downpours, will rise as well.

"We got kind of lucky to avoid it in the 20th century," said Daniel L. Swain, a climate scientist at the University of California, Los Angeles, who prepared the new study with Xingying Huang of

the National Center for Atmospheric Research in Boulder, Colo. “I would be very surprised to avoid it occurring in the 21st.”

Unlike a giant earthquake, the other “big one” threatening California, an atmospheric river superstorm will not sneak up on the state. Forecasters can now spot incoming atmospheric rivers five days to a week in advance, though they don’t always know exactly where they’ll hit or how intense they’ll be.



Using Dr. Huang and Dr. Swain’s findings, which include detailed descriptions of two hypothetical yet plausible “worst case” superstorms, California hopes to be ready even earlier. Aided by supercomputers, state officials plan to map out how all that precipitation will work its way through rivers and over land. They will hunt for gaps in evacuation plans and emergency services.

The last time government agencies studied a hypothetical California megaflood, more than a decade ago, they estimated it could cause $725 billion in property damage and economic disruption. That was three times the projected fallout from a severe San Andreas Fault earthquake, and five times the economic damage from Hurricane Katrina, which left much of New Orleans underwater for weeks in 2005.

Dr. Swain and Dr. Huang have handed California a new script for what could be one of its most challenging months in history. Now begin the dress rehearsals.

“Mother Nature has no obligation to wait for us,” said Michael Anderson, California’s state climatologist.

In fact, nature has not been wasting time testing California’s defenses. And when it comes to risks to the water system, carbon dioxide in the atmosphere is hardly the state’s only foe.

[Reconstructed Oroville Dam main service spillway]

THE ULTIMATE CURVEBALL

On Feb. 12, 2017, almost 190,000 people living north of Sacramento received an urgent order: Get out. Now. Part of the tallest dam in America was verging on collapse.

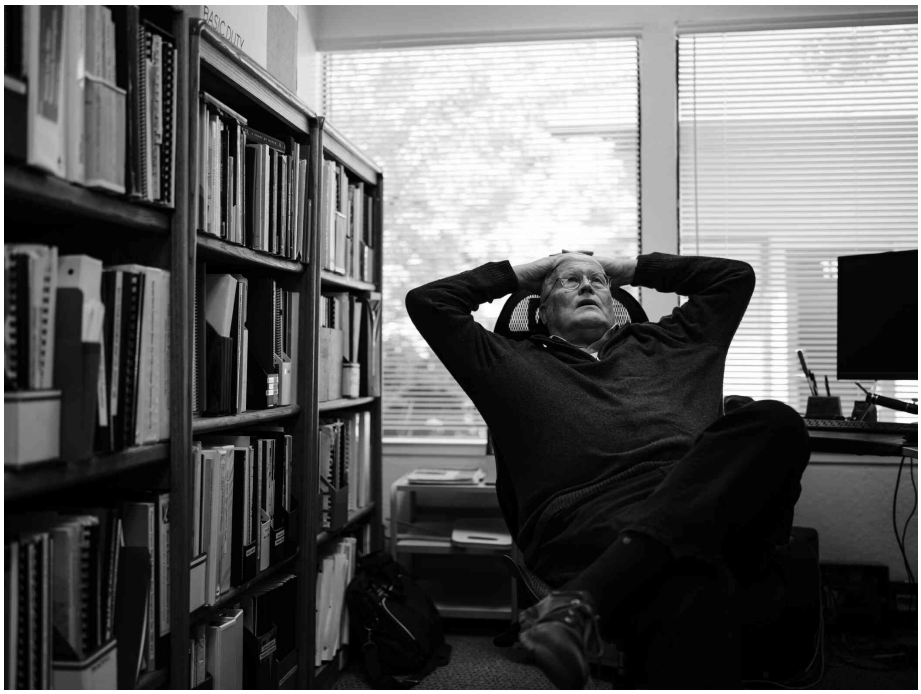
That day, Ronald Stork was in another part of the state, where he was worrying about precisely this kind of disaster — at a different dam.

Standing with binoculars near California’s New Exchequer Dam, he dreaded what might happen if large amounts of water were ever sent through the dam’s spillways. Mr. Stork, a policy expert with the conservation group Friends of the River, had seen on a previous visit to Exchequer that the nearby earth was fractured and could be easily eroded. If enough water rushed through, it might cause major erosion and destabilize the spillways.

He only learned later that his fears were playing out in real time, 150 miles north. At the Oroville Dam, a 770-foot-tall facility built in the 1960s, water from atmospheric rivers was washing away the soil and rock beneath the dam’s emergency spillway, which is essentially a hillside next to the main chute that acts like an overflow drain in a bathtub. The top of the emergency spillway looked like it might buckle, which would send a wall of water cascading toward the cities below.

Mr. Stork had no idea this was happening until he got home to Sacramento and found his neighbor in a panic. The neighbor’s mother lived downriver from Oroville. She didn’t drive anymore. How was he going to get her out?

Mr. Stork had filed motions and written letters to officials, starting in 2001, about vulnerabilities at Oroville. People were now in danger because nobody had listened. “It was nearly soul crushing,” he said.



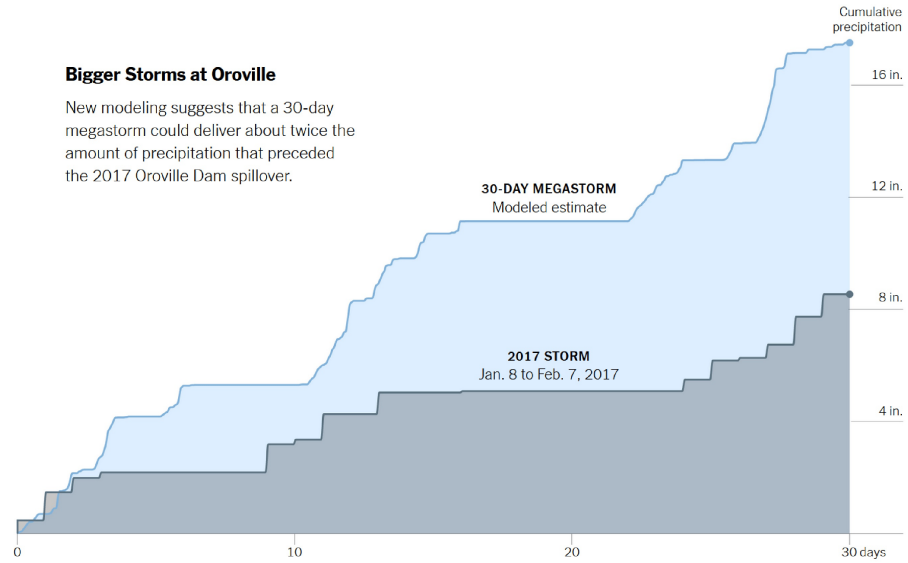
Ronald Stork in his office at Friends of the River in Sacramento.

The spillway of the New Exchequer Dam.

“With flood hazard, it’s never the fastball that hits you,” said Nicholas Pinter, an earth scientist at the University of California, Davis. “It’s the curveball that comes from a direction you don’t anticipate. And Oroville was one of those.”

Such perils had lurked at Oroville for so long because California’s Department of Water Resources had been “overconfident and complacent” about its infrastructure, tending to react to problems rather than pre-empt them, independent investigators later wrote in a report. It is not clear this culture is changing, even as the 21st century climate threatens to test the state’s aging dams in new ways. One recent study estimated that climate change had boosted precipitation from the 2017 storms at Oroville by up to 15 percent.

A year and a half after the crisis, crews were busy rebuilding Oroville’s emergency spillway when the federal hydropower regulator wrote to the state with some unsettling news: The reconstructed emergency spillway will not be big enough to safely handle the “probable maximum flood,” or the largest amount of water that might ever fall there.



Sources: Global Historical Climatology Network, Huang and Swain (2022) Measurements taken from the Oroville weather station and the nearest modeled data point

This is the standard most major hydroelectric projects in the United States have to meet. The idea is that spillways should basically never fail because of excessive rain.

Today, scientists say they believe climate change might be increasing “probable maximum” precipitation levels at many dams. When the Oroville evacuation was ordered in 2017, nowhere near that much water had been flowing through the dam’s emergency spillway.

Yet California officials have shrugged off these concerns, which were raised by the Federal Energy Regulatory Commission. Such extreme flows are a “remote” possibility, they argued in a letter last year. Therefore, further upgrades at Oroville aren’t urgently needed.

In a curt reply last month, the commission said this position was “not acceptable.” It gave the state until mid-September to submit a plan for addressing the issue.

The Department of Water Resources told The Times it would continue studying the matter. The Federal Energy Regulatory Commission declined to comment.

“People could die,” Mr. Stork said. “And it bothers the hell out of me.”

WETTER WET YEARS

Donald G. Sullivan was lying in bed one night, early in his career as a scientist, when he realized his data might hold a startling secret.

For his master’s research at the University of California, Berkeley, he had sampled the sediment beneath a remote Sierra lake and was hoping to study the history of vegetation in the area. But a lot of the pollen in his sediment cores didn’t seem to be from nearby. How had it gotten there?

When he X-rayed the cores, he found layers where the sediment was denser. Maybe, he surmised, these layers were filled with sand and silt that had washed in during floods.

It was only late that night that he tried to estimate the ages of the layers. They lined up neatly with other records of West Coast megafloods.

“That’s when it clicked,” said Dr. Sullivan, who is now at the University of Denver.

His findings, from 1982, showed that major floods hadn’t been exceptionally rare occurrences in the Sacramento Valley over the past eight centuries. They took place every 100 to 200 years. And in the decades since, advancements in modeling have helped scientists evaluate how quickly the risks are rising because of climate change.

For their new study, which was published in the journal Science Advances, Dr. Huang and Dr. Swain replayed portions of the 20th and 21st centuries using 40 simulations of the global climate.

Xingying Huang of the National Center for Atmospheric Research in Boulder, Colo. Rachel Woolf for The New York Times

Extreme weather events, by definition, don't occur very often. So by using computer models to create realistic alternate histories of the past, present and future climate, scientists can study a longer record of events than the real world offers.

Dr. Swain and Dr. Huang looked at all the monthlong California storms that took place during two time segments in the simulations, one in the recent past and the other in a future with high global warming, and chose one of the most intense events from each period. They then used a weather model to produce detailed play-by-plays of where and when the storms dump their water.

Those details matter. There are "so many different factors" that make an atmospheric river deadly or benign, Dr. Huang said.

The New Don Pedro Dam spillway.

In the high Sierras, for example, atmospheric rivers today largely bring snow. But higher temperatures are shifting the balance toward rain. Some of this rain can fall on snowpack that accumulated earlier, melting it and sending even more water toward towns and cities below.

Climate change might be affecting atmospheric rivers in other ways, too, said F. Martin Ralph of the Scripps Institution of Oceanography at the University of California, San Diego. How strong their winds are, for instance. Or how long they last: Some storms stall, barraging an area for days on end, while others blow through quickly.

Scientists are also working to improve atmospheric river forecasts, which is no easy task as the West experiences increasingly sharp shifts from very dry conditions to very wet and back again. In October, strong storms broke records in Sacramento and other places. Yet this January through March was the driest in the Sierra Nevada in more than a century.

“My scientific gut says there’s change happening,” Dr. Ralph said. “And we just haven’t quite pinned down how to detect it adequately.”

Better forecasting is already helping California run some of its reservoirs more efficiently, a crucial step toward coping with wetter wet years and drier dry ones.

Wes Monier, a hydrologist, with a 1997 photo of water rushing through the New Don Pedro Reservoir spillway.

On the last day of 2016, Wes Monier was looking at forecasts on his iPad and getting a sinking feeling.

Mr. Monier is chief hydrologist for the Turlock Irrigation District, which operates the New Don Pedro Reservoir near Modesto. The Tuolumne River, where the Don Pedro sits, was coming out of its driest four years in a millennium. Now, some terrifying rainfall projections were rolling in.

First, 23.2 inches over the next 16 days. A day later: 28.8 inches. Then 37.1 inches, roughly what the area normally received in a full year.

If Mr. Monier started releasing Don Pedro's water too quickly, homes and farms downstream would flood. Release too much and he would be accused of squandering water that would be precious come summer.

But the forecasts helped him time his flood releases precisely enough that, after weeks of rain, the water in the dam ended up just shy of capacity. Barely a drop was wasted, although some orchards were flooded, and growers took a financial hit.

The next storm might be even bigger, though. And even the best data and forecasts might not allow Mr. Monier to stop it from causing destruction. "There's a point there where I can't do anything," he said.

KATRINA 2.0

How do you protect a place as vast as California from a storm as colossal as that? Two ways, said David Peterson, a veteran engineer. Change where the water goes, or change where the people are. Ideally, both. But neither is easy.

Firebaugh is a quiet, mostly Hispanic city of 8,100 people, one of many small communities that power the Central Valley's prodigious agricultural economy. Many residents work at nearby facilities that process almonds, pistachios, garlic and tomatoes.

Firebaugh also sits right on the San Joaquin River.

For a sleepless stretch of early 2017, Ben Gallegos, Firebaugh's city manager, did little but watch the river rise and debate whether to evacuate half the town. Water from winter storms had

already turned the town's cherished rodeo grounds into a swamp. Now it was threatening homes, schools, churches and the wastewater treatment plant. If that flooded, people would be unable to flush their toilets. Raw sewage would flow down the San Joaquin.

Luckily, the river stopped rising. Still, the experience led Mr. Gallegos to apply for tens of millions in funding for new and improved levees around Firebaugh.

Levees change where the water goes, giving rivers more room to swell before they inundate the land. Levee failures in New Orleans were what turned Katrina into an epochal catastrophe, and after that storm, California toughened levee standards in urbanized areas of the Sacramento and San Joaquin Valleys, two major river basins of the Central Valley.

The idea is to keep people out of places where the levees don't protect against 200-year storms, or those with a 0.5 percent chance of occurring in any year. To account for rising seas and the shifting climate, California requires that levees be recertified as providing this level of defense at least every 20 years.

Firebaugh, Calif., on the San Joaquin River, is home to 8,100 people and helps power the Central Valley's agricultural economy.

Ben Gallegos, the Firebaugh city manager.

A 6-year-old's birthday celebration in Firebaugh.

The problem is that once levees are strengthened, the areas behind them often become particularly attractive for development: fancier homes, bigger buildings, more people. The likelihood of a disaster is reduced, but the consequences, should one strike, are increased.

Federal agencies try to stop this by not funding infrastructure projects that induce growth in flood zones. But “it’s almost impossible to generate the local funds to raise that levee if you don’t

facilitate some sort of growth behind the levee," Mr. Peterson said. "You need that economic activity to pay for the project," he said. "It puts you in a Catch-22."

A project to provide 200-year protection to the Mossdale Tract, a large area south of Stockton, one of the San Joaquin Valley's major cities, has been on pause for years because the Army Corps of Engineers fears it would spur growth, said Chris Elias, executive director of the San Joaquin Area Flood Control Agency, which is leading the project. City planners have agreed to freeze development across thousands of acres, but the Corps still hasn't given its final blessing.

The Corps and state and local agencies will begin studying how best to protect the area this fall, said Tyler M. Stalker, a spokesman for the Corps' Sacramento District.

The plodding pace of work in the San Joaquin Valley has set people on edge. At a recent public hearing in Stockton on flood risk, Mr. Elias stood up and highlighted some troubling math.

The Department of Water Resources says up to $30 billion in investment is needed over the next 30 years to keep the Central Valley safe. Yet over the past 15 years, the state managed to spend only $3.5 billion.

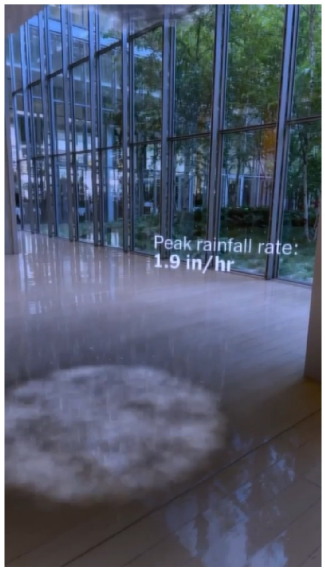
"We have to find ways to get ahead of the curve," Mr. Elias said. "We don't want to have a Katrina 2.0 play out right here in the heart of Stockton."

As Mr. Elias waits for projects to be approved and budgets to come through, heat and moisture will continue to churn over the Pacific. Government agencies, battling the forces of inertia, indifference and delay, will make plans and update policies. And Stockton and the Central Valley, which runs through the heart of California, will count down the days and years until the inevitable storm.

The Sacramento-San Joaquin Delta near Stockton, Calif.

Augmented Reality

What will the megastorm's rain look like?



This augmented-reality experience simulates the extreme rainfall in a future California megastorm. To experience this effect in your space, you will need the Instagram app.

To view on Instagram, open the camera on your device and point to the QR tag below.

Sources

The megastorm simulation is based on the "ARkHist" storm modeled by Huang and Swain, Science Advances (2022), a hypothetical statewide, 30-day atmospheric river storm sequence over California with an approximately 2 percent likelihood of occurring each year in the present climate. Data was generated using the Weather Research and Forecasting model and global climate simulations from the Community Earth System Model Large Ensemble.

The chart of precipitation at Oroville compares cumulative rainfall at the Oroville weather station before the 2017 crisis with cumulative rainfall at the closest data point in ARkHist.

The rainfall visualization compares observed hourly rainfall in December 2016 from the Los Angeles Downtown weather station with rainfall at the closest data point in a hypothetical future megastorm, the ARkFuture scenario in Huang and Swain (2022). This storm would be a rare but plausible event in the second half of the 21st century if nations continue on a path of high greenhouse-gas emissions.
Additional credits

The 3D rainfall visualization and augmented reality effect by Nia Adurogbola, Jeffrey Gray, Evan Grothjan, Lydia Jessup, Max Lauter, Daniel Mangosing, Noah Pisner, James Surdam and Raymond Zhong.

Photo editing by Matt McCann.

Produced by Sarah Graham, Claire O'Neill, Jesse Pesta and Nadja Popovich.

https://www.nytimes.com/interactive/2022/08/12/climate/california-rain-storm.html