Tears in Rain

VANTAGE

The inevitable megaflooding of California

By Dr. Steve Smith, Head of Research & Development, Vantage Risk
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11 min read

Introduction

> *"Rain filled the gutters and splashed knee-high off the sidewalk...*
>
> *It was too early in the fall for that kind of rain."*
>
> *– Raymond Chandler, The Big Sleep (1939)*

It begins like this: Years of drought drying out the soil, wildfires scarring the forests, reservoirs lower than ever, and Californians convinced it will never rain again. An El Nino forms in the Pacific and as the cool season starts, it begins to rain a heavy, drenching rain. For two months, the rain barely stops.

It ends like this: The Central Valley flooded, widespread mudslides, towns and cities inundated, agriculture decimated, dams breached, infrastructure destroyed, and a bill over three times that of a major earthquake.

This might sound like a far-fetched, apocalyptic scenario, but it has happened before and will happen again -- with increasing frequency and severity.

This paper will examine the history and future of Californian megafloods.

This Has Happened Before – The Great Flood of 1862

> "The tumbling rain was a solid white spray in the headlights."
>
> – Raymond Chandler, The Big Sleep (1939)

The Great Flood of 1862 [1] was the largest recorded flood in the history of not only California, but also Oregon and Nevada. November 1861 was very wet in Oregon as the jet stream pumped moisture up from the tropical Pacific. In December of 1861, the jet stream drifted southwards over northern California and locked in place through late January 1862 until moving further southward over southern California. This brought a succession of heavy rain and snow events across the state. Over December and January, San Francisco recorded 34 inches of rain, Sacramento 37 inches (with a one day maximum of 4 inches), and Los Angeles close to 35 inches.

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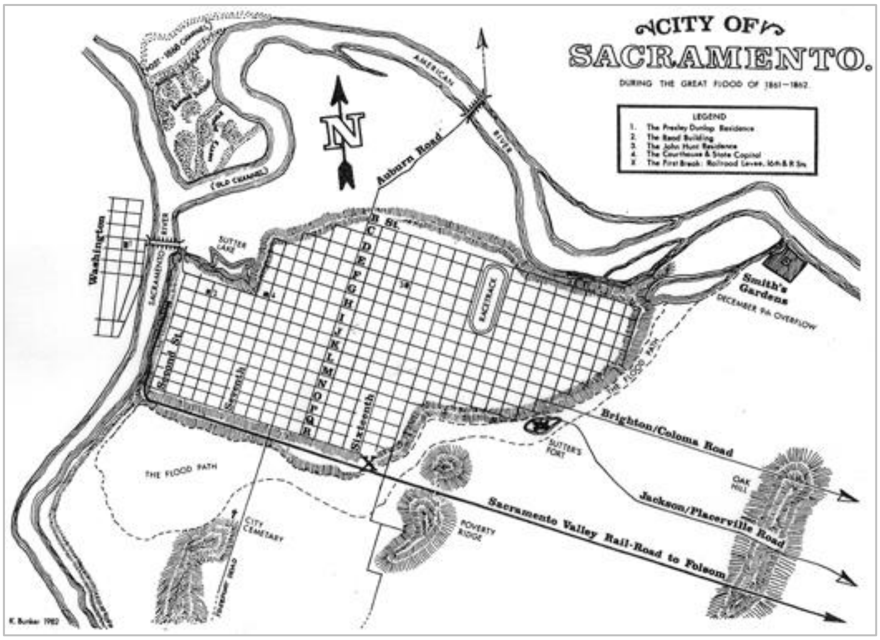

Figure 1: Map of Sacramento as of 1861 (from Valley Community Newspapers, https://www.valcomnews.com/sacramentans-developed-indomitable-attitude-toward-floods-in-19th-century/)

The foothills of the Sierra Nevada saw astronomical amounts of precipitation – Nevada City tallied a snowfall equivalent of 115 inches of rain, Sonora in Tuolumne County recorded 102 inches of rain.

All that rain had to go somewhere. Sacramento bore the brunt of the flooding, initially, as one of the levees protecting the city failed early in December. The Sacramento River peaked at over 22 feet above low water mark on December 27th, 1861. As the water poured in from both the Sacramento and American Rivers (Sacramento sits at the confluence of these two rivers), the levee acted to keep water inside the city limits – at one stage the water level in the city was 10 feet higher than the water level on the Sacramento River on the outside. The Sacramento River peaked again on January 10th, 1862, at 24 feet.

But it wasn't just Sacramento. A widely quoted report from William Brewer (a Yale geologist who was in Sacramento at the time) on January 18th, 1862, is worth reading [2]:

> *The great Central Valley of the state is under water—the Sacramento and San Joaquin valleys—a region 250 to 300 miles long and an average of at least 20 miles wide,*

a district of 5,000 or 6,000 square miles, or probably three to three and a half million acres! Although much of it is not cultivated, yet a part of it is the garden of the state. Thousands of farms are entirely under water—cattle starving and drowning. Benevolent societies are active, boats have been sent up, and thousands are fleeing to [San Francisco]

…The floods have still more deranged finances and make some action imperative. The actual loss of taxable property will amount to probably ten or fifteen million, some believe twice that, but I think not even the latter sum. I suppose the actual loss in all kinds of property, personal and real, will rank anywhere between fifty and a hundred million dollars, surely a calamity of no common magnitude!

Figure 2: Inundation of the State Capitol, city of Sacramento, 1862, Rosenfield, A, publisher.

Southern California suffered too. Towns were washed away (Eldoradoville in the San Gabriel mountains ceased to exist), agriculture along the Los Angeles River was wiped out, in what is now Orange County the Santa Ana River created a standing lake over 4 feet deep extending 4 miles from the river which lasted 3 weeks. At one point the Los Angeles, Santa Ana, and San Gabriel Rivers merged and from Signal Hill to Huntington Beach (18 miles) was continuously under water.

It is difficult to put the losses from 1862 in any sort of modern context given that California is vastly different place now – at the time of the Great Flood something less than 500,000 people lived in California, compared to around 40 million in 2022. Taking Brewer's (somewhat uninformed) estimate of $50-100m, that would translate into around $3b in 2022 dollars. It is worth noting that around a quarter of the taxable real estate in California was declared destroyed, causing the state to ponder bankruptcy due to loss of revenue.

There has been some work to determine how likely is a flood similar to 1862. Looking at sediment records and tree rings, most recent estimates suggest that a flood of 1862 magnitude or greater has somewhere around a 100-to-200-year return period (1% to 0.5% annual probability) [3]. This, naturally, relies on historical data and, as we know, the past is an increasingly poor predictor of the future. We will return to this below. Also, the return period results can be contradictory – while the flooding event might have a 100-to-200-year return period, the return periods for 1862 in terms of individual locations are estimated to be smaller: San Francisco flooding is estimated as a 10,000-year event, Sacramento a 2,300-year event. Location return periods are heavily dependent on meteorological or hydrological measurements for which data sets remain short (i.e., only around 200 years); we feel that the sediment/tree ring studies give a more stable result.

This Will Happen Again – ARkStorm 1.0 and 2.0

> *"It was raining again the next morning, a slating grey rain like a swung curtain of crystal beads."* — *Raymond Chandler, The Big Sleep (1939)*

2011 saw the publication of the ARkStorm study by the U.S. Geological Survey (USGS) [4]. This study (which we will refer to as ARkStorm 1.0) was part of USGS' Multi Hazards Demonstration Project (MHDP) which uses hazards science to improve resiliency of communities to natural disasters and engages with emergency planners, businesses, universities, government agencies, and others in preparing for major natural disasters. MHDP's first study, ShakeOut in 2008, was a simulated 7.8 magnitude San Andreas Fault earthquake and resulted in the largest earthquake drill in U.S. history. ARkStorm 1.0 (where ARkStorm means Atmospheric River 1000) was designed to examine the consequences (to the built environment, society, and the economy) and response to a 1862-type flooding event where the storm is estimated to produce precipitation that in many places exceeded levels only experienced on average once every 500 to 1,000 years. ARkStorm 1.0 was also influenced by the 2005-2006 California winter floods which, while not approaching 1862 levels,

Figure 3: Flooding simulated in ARkStorm 1.0 (blue shaded area are flooded) (from [4])

did flood parts of Healdsburg, Guerneville, and Sacramento (for context, a total of 15 inches of rain fell in San Francisco in 2005-2006, compared to 34 inches in 1861-62).

Like 1862, ARkStorm 1.0 simulated significant flooding across California by simulating 100–500-year return period rainfall across the state using a nested series of computer weather models. This allows water to flow realistically, and not just be a resimulation of 1862. Figure 2 shows the general areas flooded in ARkStorm 1.0 and Figure 3 shows inundation for a number of select areas.

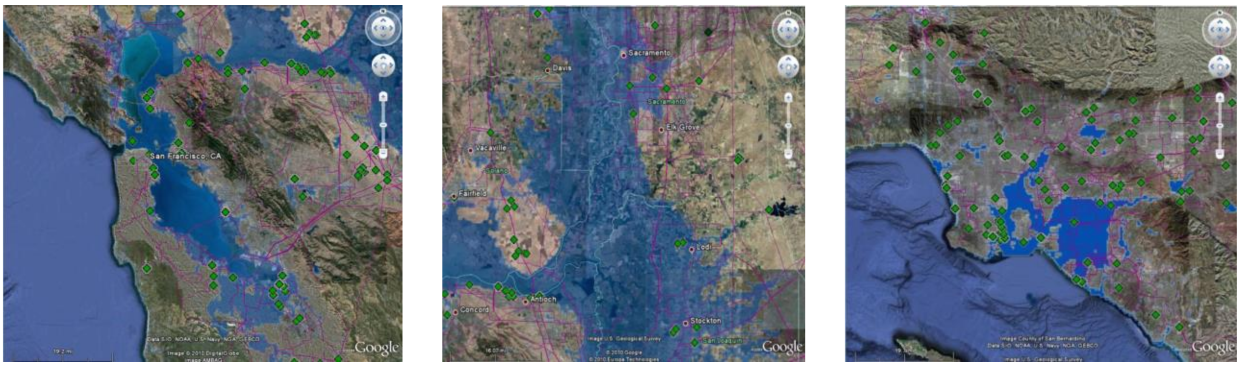

Figure 4: Flooding simulated in ArkStorm 1.0 for San Francisco (left), Sacramento to Stockton (middle), and Los Angeles (right) (from [4])

The basic loss drivers from the ARkStorm 1.0 study:

- Flood protection system: Extensive flooding overwhelms the state's flood protection system, designed to resist 100- to 200-year runoffs. Widespread breaching or overtopping of dams and levees.
- Flooding: The Central Valley experiences hypothetical flooding 300 miles long and 20 or more miles wide. Depths in some areas could reach 10-20 feet.
- Wind: Wind speeds in some places (i.e., at high elevation) reach 125 miles per hour, hurricane force winds. Across wider areas of the state, winds reach 60 miles per hour.
- Landslides: Hundreds of landslides damage roads, highways, and homes.

The ARkStorm 1.0 study did extensive work on the economic losses from this event. Much of the loss is uninsured (or uninsurable).

Table 1 *(next page)* shows the loss, both for direct damage and business interruption, in billions of 2007 dollars over the 5 years post-event. To summarize, the total economic loss is around $1 trillion in 2007 dollars, or roughly $1.4 trillion in 2022 dollars, without accounting for societal changes since 2007.

	Property Repair/Reconstruction Costs	Business Interruption	Total
Building Flood Damage	195.00	591.50	786.50
Related Content Damage	103.00	-	103.00
Building Wind Damage	5.60	1.70	7.30
Agricultural Damage	3.60	7.30	10.90
Power System Damage	1.00	18.10	19.10
Telecommunication System Damage	0.10	5.20	5.30
Wastewater System Damage	0.30	27.60	27.90
Water System Damage	3.00	54.10	57.10
Highway/road Damage	2.50	0.02	2.52
Levee Repair and Island Dewatering	0.50	-	0.50
Evacuation	-	2.40	2.40
Relocation	39.00	-	39.00
Total	353.60	707.90	1,061.50
Total After Double-Counting Adjustment	353.30	627.40	980.70

Table 1: Summary of ARkStorm 1.0 costs and business interruption (without recapture and stimulus/reconstruction) for California over a 5-year time horizon (in billions of 2007 U.S. dollars) (from [4])

The ARkStorm 1.0 study also looked at the pure physical damage insured losses, for NFIP (as it was constituted in 2007) and for the non-residential market for a moderate and high take up rate. The study concluded that the insured flood damage losses would be between $20 and $30 billion in 2007 dollars ($30-$40 billion in 2022 dollars, again without accounting for societal changes).

The study did not attempt to estimate the business interruption/supply chain insured loss, which could well be multiples of the flood damage loss. Neither did the study contemplate liability issues (such as pollution), which could generate considerable insured long tail losses. In general, ARkStorm 1.0 found that a severe California megaflood would be **three times** as costly as a major earthquake.

Since the release of ARkStorm 1.0 in 2011, several of the assumptions used in the study have been challenged or tested:

- In 2017, the near failure of the Oroville dam shed light on the fact that dam infrastructure in California (and the U.S. in general) is not in a state of excellent maintenance. Dams built in the 1950s through the 1970s to a 1-in-200-year tolerance are likely not to perform at the designed level.
- A prolonged drought in California has dried the earth in many areas such that it resists water absorption. Rain hitting this earth would just run off and not sink in, which could push more water into rivers, exacerbating a river flood problem.
- Increased wildfires, both in frequency and extent, have scoured the land. Trees in burned areas are unable to stabilize the soil, making mudslides more likely.
- California continues to experience growth, with building encroaching further into the wildland-urban interface and onto flood plains.

Climate change is a major contributing factor to the first three of the points above:

- The goal posts have moved – what was 1-in-200 tolerance in 1970 is not a 1-in-200 today. It is likely that dams build in the mid-20th Century would perform at a level substantially below what a 1-in-200-year tolerance is in our current, climate change impacted, environment.
- Increased temperatures and lengthening droughts are a calling card of climate change. This, in turn, has increased wildfire frequency and severity.

2022 saw the publication of a study by Huang & Swain [3] which attempts to update the physical characteristics of the ARkStorm work. This ARkStorm 2.0 was specifically designed to reimagine the ARkStorm scenario for a climate change era. The ARkStorm 2.0 study made three key conclusions:

1. ARkStorm events are highly correlated with El Nino phase of ENSO. From the study: *"These findings strongly suggest that there is a substantially elevated likelihood of month-long storm sequences capable of producing very large precipitation accumulations during moderate to strong El Niño conditions..."* This suggests that there might be some skill in forecasting ARkStorm events.

2. Increasing temperature (i.e., climate change) is robustly linked with increased frequency of ARkStorm events. To quote the study: *"Our analysis suggests that the present-day (circa 2022) likelihood of historically rare to unprecedented 30-day precipitation accumulations has already increased substantially and that even modest additional increments of global warming will bring about even larger increases in likelihood."* Figure 4, from the study, shows how the likelihood of events increases with increasing global temperature.

Increasing temperature (i.e., climate change) is robustly linked with increased severity of ARkStorm events. From the study: *"Future extreme storm sequences will bring more intense moisture transport and more overall precipitation… [that will] yield runoff that is much higher than that during historical events. In addition, we find even larger increases in hourly rainfall rates during individual storm events, which have high potential to increase the severity of geophysical hazards such as flash flooding and debris flows. This is especially true in the vicinity of large or high-intensity wildfire burn areas, which are themselves increasing due to climate change and yielding large increases in associated compound hazards."*

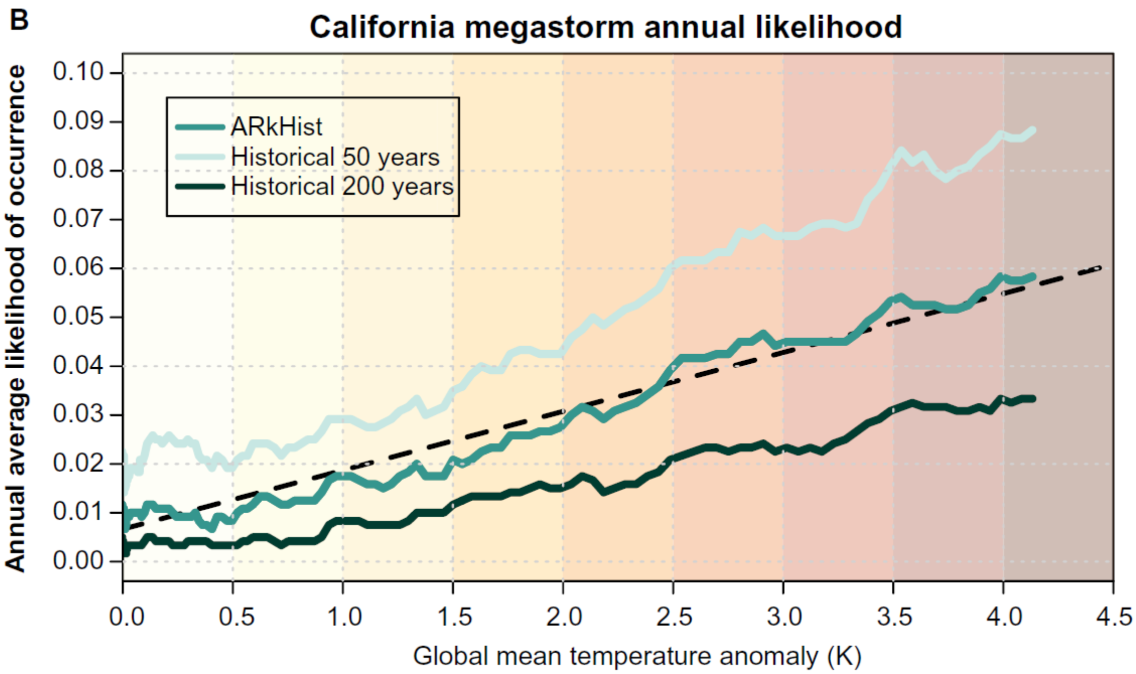

Figure 5: Annual likelihood of extreme 30-day cumulative precipitation events as a function of projected global mean surface temperature (GMST; K)

Conclusions

> *"It was about eleven o'clock in the morning, mid-October, with the sun not shining and a look of hard wet rain in the clearness of the foothills."*
>
> *— Raymond Chandler, The Big Sleep (1939)*

After the ARkStorm 1.0 and 2.0 studies, what can be concluded?

- A megaflood in California has a historical return period of 100-to-200 years. Climate change has changed this supposition and the annual likelihood is probably sub-100 years and decreasing as the Earth continues to warm.
- A megaflood would result in widespread damage to infrastructure, buildings, and agriculture. Failure of water control structures (dams, levees) would likely be extensive. Climate change and changes in exposure are increasing the potential severity of a megaflood.
- The costs of a megaflood would be measured in trillions of U.S. dollars. From an insurance standpoint, if a 'typical' large Californian earthquake has an insured loss in the $50-70 billion range and if, as has been shown, a megaflood would costs around three times an earthquake,
- The insured loss from a megaflood could well be in the $150-200 billion range, before factoring in potential liability.

Given the truly catastrophic potential of a Californian megaflood, and the increasing likelihood of such an event occurring, we hope to see growing recognition in the insurance industry and society at large to reckon with this peril.

At Vantage, examining these counterfactual potential events is just one way we see risk differently.

About the author

Dr. Steve Smith, Head of Research & Development, Vantage Risk

Steve has spent over 20 years in re/insurance in analytic roles. He is a Fellow of the Royal Meteorological Society, a Certified Catastrophe Risk Management Professional, a Chartered Physicist, and holds a doctorate in atmospheric physics and a first-class honors degree in physics, both from the University of Oxford.

He was the 2007 recipient of The Review Worldwide Reinsurance Future Industry Leader award and a 2008 recipient of a Risk & Insurance Risk Innovator award.

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This article was edited by John Flannery, Vantage's Interim Head of Marketing and Communications.