Sustainability Insights

How high-resolution data translates flood risk into financial risk

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Key Takeaways

- New high-resolution river flood projections from S&P Global Sustainable1 provide analysis of flood exposure zoomed into 30x30 meters and potential damage down to the individual building level. This exposure is projected through time for four major scenarios of climate change.
- The new model, combining S&P Global Sustainable1 climate projections with historical data from flood-modeling firm JBA Risk Management, includes data on local and regional flood defense systems such as levees. This shows which buildings depend on municipal flood-protection infrastructure and where protection may be inadequate for anticipated future risks.
- In our analysis of three major cities in the US, Europe and Asia-Pacific, we estimate the potential costs to residential real estate during floods of different depths. For example, in Sacramento, we estimate the total cost of property damage to single-family residential real estate at about $378 million for a 20-year flood and $3.6 billion for a 100-year flood during the 2030s decade, under the SSP2-4.5 climate scenario.
- Flood depths that were historically infrequent — a probability of once every 100 years, for example — are projected to become more common in many regions as the world warms. Property owners, investors and banks with mortgage portfolios in developed areas around rivers may seek to reassess their exposure to floods as historical trends may no longer reflect long-term resilience.

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Fluvial or river flooding is one of many climate hazards expected to worsen because of human-caused climate change. About half of the world's population lives within 3 km of a freshwater body, and for about 88% of people, that freshwater body is a river[1] — making the prospect of more intense river flooding a widespread risk.

Floods at a depth that historically occurred rarely, such as a probability of once every 100 years, are projected to become more frequent in many regions. Flood exposure is commonly measured using the concept of a return period, a probabilistic metric that combines both the flood depth and the expected frequency of occurrence. [2] For example, a 1-in-100-year return period flood event represents a flood depth with a 1% probability of being exceeded in a given year. In many regions, climate change is projected to drive an increase in the frequency of low-probability, high-impact events, turning a 1-in-100-year flood into a 1-in-75-year or 1-in-50-year event.

While flood defenses such as levees are a common feature of towns and cities with structures and infrastructure alongside rivers, these defenses have a breaking point. The 100-year flood depth is often considered the benchmark for flood defense design, and so in regions where climate change increases the frequency of deeper floods, the chances of historically projected structures becoming inundated by overtopping of defenses increases.

Understanding flood exposure down to the level of individual buildings is critical for many stakeholders, including companies with assets located near rivers, investors with assets exposed to fluvial flooding and banks with residential and commercial real estate lending exposure because flood depths can vary widely over small areas. Many factors influence localized flood depth and the potential for property damage and business interruption beyond just proximity to the riverbank. These factors include terrain elevation, river current strength, vegetation and local weather patterns. Flood water 1 meter deep could cause material damage to a single-family home on a street facing a river during a flood, while a neighbor two houses away might only face flood depth of a few inches due to a change in elevation or flood defenses. Flood damage worsens with water depth and can vary significantly, from limited disruption to inundation or structural failure.

Range of flood damage to buildings by flood depth	
Flood depth	Potential impact
>1 meter	Material impact to structural integrity as the weight of floodwater creates hydrostatic pressure that risks building collapse or foundation damage.
0.5–1 meter	Material impact to operations as first floor may be inundated and electrical, communication and ventilation systems may be impacted.
0.1-0.5 meter	Damage to flooring, subfloor and property.
<0.15 meter	Flood water reaches the lower-floor level, causing minor nuisance damages and potential temporary disruption of access.

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[1] Kummu M, de Moel H, Ward PJ, Varis O (2011) How Close Do We Live to Water? A Global Analysis of Population Distance to Freshwater Bodies. PLoS ONE 6(6): e20578. doi:10.1371/journal.pone.0020578. https://www.researchgate.net/publication/51233091_How_Close_Do_We_Live_to_Water_A_Global_Analysis_of_Population_Distance_to_Freshwater_Bodies#:~:text=We%20present%20a%20high%2Dresolution,the%20distance%20to%20fresh%20water.

[2] The "return period" terminology has been widely used in statistics, risk management and science for many years but remains poorly understood by the general public. Return periods are simply another way of describing probability. A 100-year return period for flood is the same as a 1% chance of a flood depth being exceeded in a single year. A common misconception is that when a 20-year or 100-year flood depth occurs, another depth of that level will not occur for another 20 or 100 years. In fact, the return period refers to the annual probability of the event (5% or 1%, respectively). It is possible — though unlikely — that just one year after a 100-year flood, another one could occur.

That difference between nuisance flooding and material structural and operational damage is determined at hyper-local scale. This increases the need for high-resolution flood analytics to enable financial institutions to stress test their lending and investing exposures for current-day and future climate physical risk.

In this report, S&P Global Sustainable1 uses new high-resolution climate projections of flood hazard in a series of case studies to show how more detailed modeling can identify structures exposed to material flood depths and how exposure patterns change over time. This climate-conditioned model provides fluvial flood depths at 30-meter resolution globally. It combines baseline, present-day probabilistic flood hazard and defense data from flood-modeling firm JBA Risk Management with climate projections and interpretation from S&P Global Sustainable1.

Flood depths are modeled for the current climate (the 2020s decade) and projected to the end of the century under four climate scenarios. The model data are probabilistic and cover a range of outcomes — from frequent nuisance flooding of shallow depth (2-year return period) to rare catastrophic flooding (1,000-year return period). JBA also provides information on local and regional flood defense systems such as levees, and these measures are reflected in our projections of flood depths for the four future climate scenarios.

While the model is applicable to buildings of any size or purpose, our analysis focuses on risk to single-family homes for two return periods, 20-year and 100-year, as illustrative examples of a) moderate floods that existing flood defenses may be capable of containing and b) severe floods that risk overwhelming flood defenses and extending the depth and extent of inundation.

The analysis focuses on the SSP2-4.5 climate change scenario, which assumes strong mitigation of greenhouse gas emissions resulting in global average temperatures rising by 2.7 degrees C (2.1 degrees C-3.5 degrees C) by 2100. Warmer scenarios, in which less action is taken to curtail emissions, in turn display more severe climate hazards such as flooding. S&P Global has estimated there is a 50% likelihood of the global average temperature increase will exceed 2.3 degrees C by 2040, indicating that SSP2-4.5 is a useful approximation of the likely outcome of current climate policies.

Future changes to river flood risk due to climate change vary by region , driven by changing precipitation, temperature and weather patterns. In many places, future climate scenarios indicate that the current 100-year floods will become more frequent (shorter return period) over time. There remains considerable uncertainty in regional impacts, which motivates S&P Global Sustainable1's use of more than 20 state-of-the-science climate models to provide a range of projections. The high-resolution flooding model is driven by the mean climate signals over these 20+ models.

In past research, we have projected the total financial impact of climate physical risk for major publicly traded companies. Chronic physical hazards such as extreme heat, drought and water stress, which affect wide geographic areas and account for the vast majority of projected future financial impact on companies in the aggregate.

However, geographically localized hazards such as floods can produce catastrophic impacts for companies with operations or exposure in affected areas. For example, from the perspective of a financial institution wanting to stress test its portfolio against significant individual events that generate material losses at the property level, acute hazards such as floods and wildfires are equally, if not more, important. Loan portfolio risk comes down to individual properties, and projecting risk at that granularity requires higher-resolution models.

More details about the model, including comparisons of the model's output to historical observations of major flood events in select locations, are available in the Appendix.

Sacramento, California

- Sacramento's levees are effective at containing floods below the 100-year return period depth. Our projections indicate that a 20-year flood could still inundate more than 5,000 homes with at least 0.5 meters of flooding in the 2030s.
- A 100-year flood risks overwhelming Sacramento's current flood defenses in the 2030s, putting more than 19,000 homes at risk of 0.5 meters or more of flood depth.
- We estimate the total cost of property damage to single-family residential real estate at about $378 million for a 20-year flood and $3.6 billion for a 100-year flood during the 2030s decade.
- These projections represent results for one climate scenario (SSP2-4.5) as an illustration of a potential outcome for the evolution of flood risk in the future.
- In the context of mortgage lending, a higher frequency of severe flood and associated property damage raises the probability of loans becoming 'underwater' — meaning that the borrower owes more on the property after flood repairs than the property's value. Negative equity and major financial shocks can raise the probability of borrower default.

Key terms

Return period refers to the annual probability that a flood of a specific depth or greater will occur in a specific location. A 20-year flood depth has a 5% annual chance of being exceeded, and a 100-year flood depth has a 1% annual chance of being exceeded. Return periods are based on modeling that uses historical data; as the Earth's climate changes, severe flooding is expected to become more frequent in many locations. For example, a flood depth seen in the past on average once every 100 years may be seen once every 50 years in future decades.

The river flood model produces continuous flood depth results. In this analysis, for illustrative purposes we measure flood depth in bands, from no flooding to flooding of 1 meter or deeper from ground level at a given location. Depending on factors such as terrain or elevation, these bands typically radiate out from the river, with flood depth receding as distance from the river increases. The height of a building's interior ground floor and any flood defenses will influence how much flood water enters the building. Damage to a foundation is more likely at flood depth of 1 meter or more.

Levees are manmade barriers raised alongside water sources such as rivers to contain storm surges and flood water. They are often made of compacted earth but can include reinforced floodwalls made of concrete or other material.

The SSP2-4.5 climate change scenario used in this analysis assumes strong mitigation of greenhouse gas emissions resulting in global average temperatures rising by 2.7 degrees C (2.1 degrees C-3.5 degrees C) by 2100.

In this analysis, we apply the high-resolution fluvial flood model to residential real estate in the city of Sacramento, California's state capital. The analysis uses a sample of 88,699 single-family home buildings identified using property footprints sourced from the Microsoft Planetary Computer global building footprint dataset[3] and S&P Global Sustainable1 single-family home classification assumptions.[4]

The model's resolution allows for precise estimates of the number and floor area of homes affected by flooding of different depths, which in turn informs estimates of the associated property damages and repair costs.[5] For example, in the climate scenario used for this analysis (SSP2-4.5), we find that in a 20-year flood taking place during the 2030s, about 5,000 homes could face flooding of 0.5 meters or more — a small share of our total sample of buildings, thanks to the protection offered by the Sacramento River levee system. In a 100-year flood during the 2030s, which in this scenario could overtop the levees, more than 19,000 homes are exposed to flooding of this depth.

Our projections of flood depth and potential damage reflect the current state of municipal flood protection and make no assumptions about the effectiveness of future improvements to flood defenses.

Quantifying flood risk and financial exposure

Sacramento sits in the overlapping floodplains of the Sacramento River and the American River, making it one of the most flood-prone major cities in the US. About 12 miles of levees protect much of the city south of the rivers' confluence. Significant investment in the levee system was made throughout the 1990s, and following Hurricane Katrina, state and federal requirements for urban levees were raised. In 2016, a $1.8 billion upgrade project to further strengthen the system began.

To illustrate how flooding will become more severe as the Earth's climate warms, we select a single 30-meter location in Sacramento and show the evolution of the nine flood depth return periods the model outputs (2, 5, 10, 20, 50, 100, 200, 500, and 1000 years) for the SSP2-4.5 climate scenario, projected across the rest of this century. Under current climate conditions, the Sacramento River levees offer protection to the city up to a return period of 100 years.

This level of protection translates to various flood depth protection levels, depending on location. In the 2020s at the selected location, the 100-year flood depth (about 3.049 meters) is nearly equal to the depth that the nearby levee is able to contain. In the 2030s, however, the small increase in flood depth we project in this scenario (to 3.074 meters) results in the 100-year flood depth overtopping the levee, and the location is inundated. Currently protected structures could become vulnerable to flood damage as 100-year floods make the levees ineffective in the 2030s.

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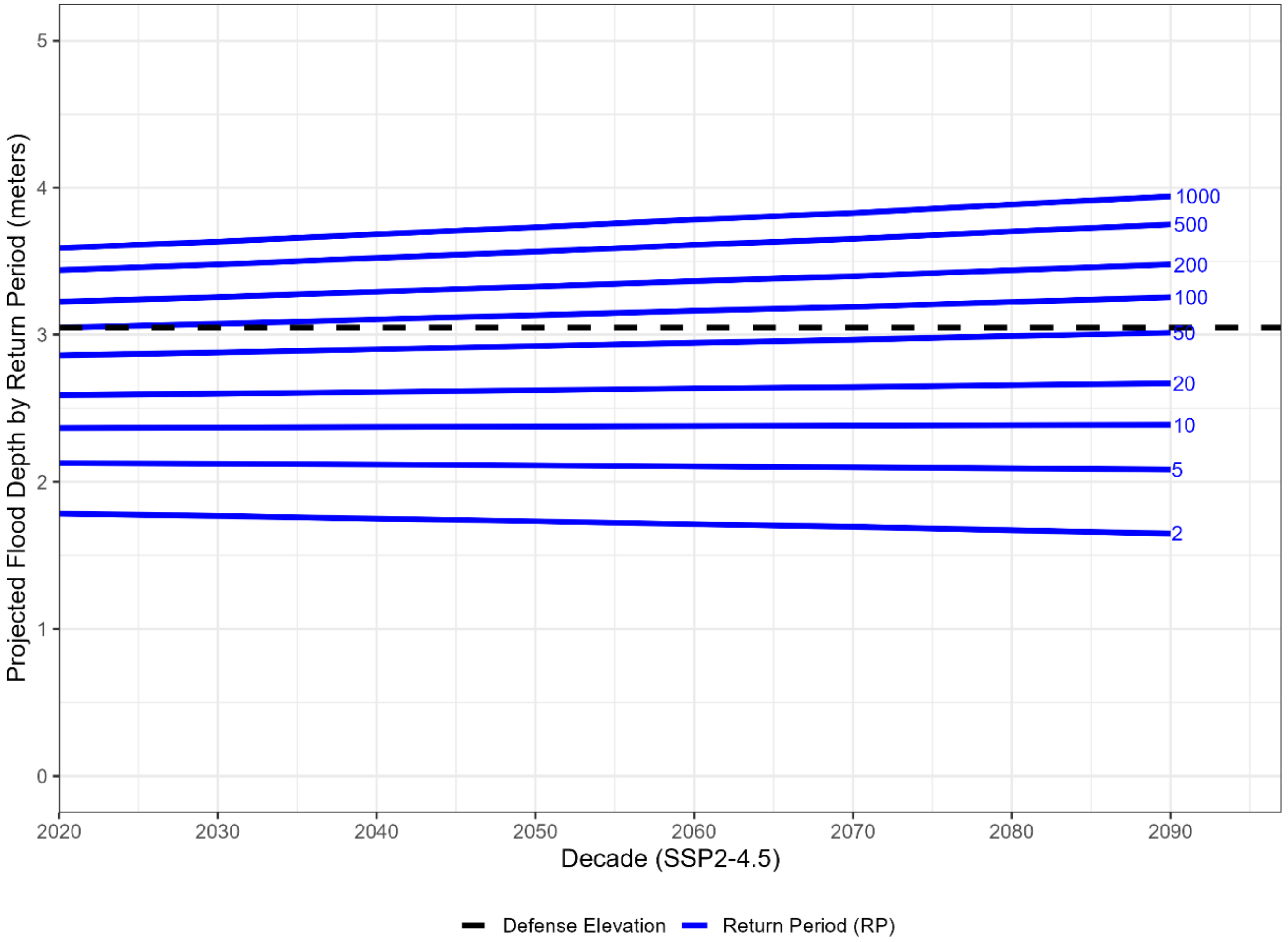
[3] Microsoft. Microsoft Building Footprints (Global ML Building Footprints Dataset). Microsoft Planetary Computer. Accessed [11 March, 2026]. https://planetarycomputer.microsoft.com/dataset/ms-buildings

[4] We classify single-family homes as any buildings with two or fewer floors, assuming a typical floor height of 3 meters, but exclude structures with floor area outside the typical range for a single-family home.

[5] Huizinga, J., de Moel, H. and Szewczyk, W., 2017. Global flood depth-damage functions: Methodology and the database with guidelines. European Commission, Joint Research Centre. Available at: https://publications.jrc.ec.europa.eu/repository/handle/JRC105688

Flood depth is projected to increase for severe floods in the 2030s and beyond

Projected flood depth by return period in meters, 2020-2100, under the SSP2-4.5 scenario



As of April 9, 2026.

SSP2-4.5 is a medium climate change scenario that contemplates strong mitigation, in which total greenhouse gas emissions stabilize at current levels until 2050 and then decline to 2100. This scenario is expected to result in global average temperatures rising by 2.7 degrees C (2.1 degrees C-3.5 degrees C) by the end of the century.

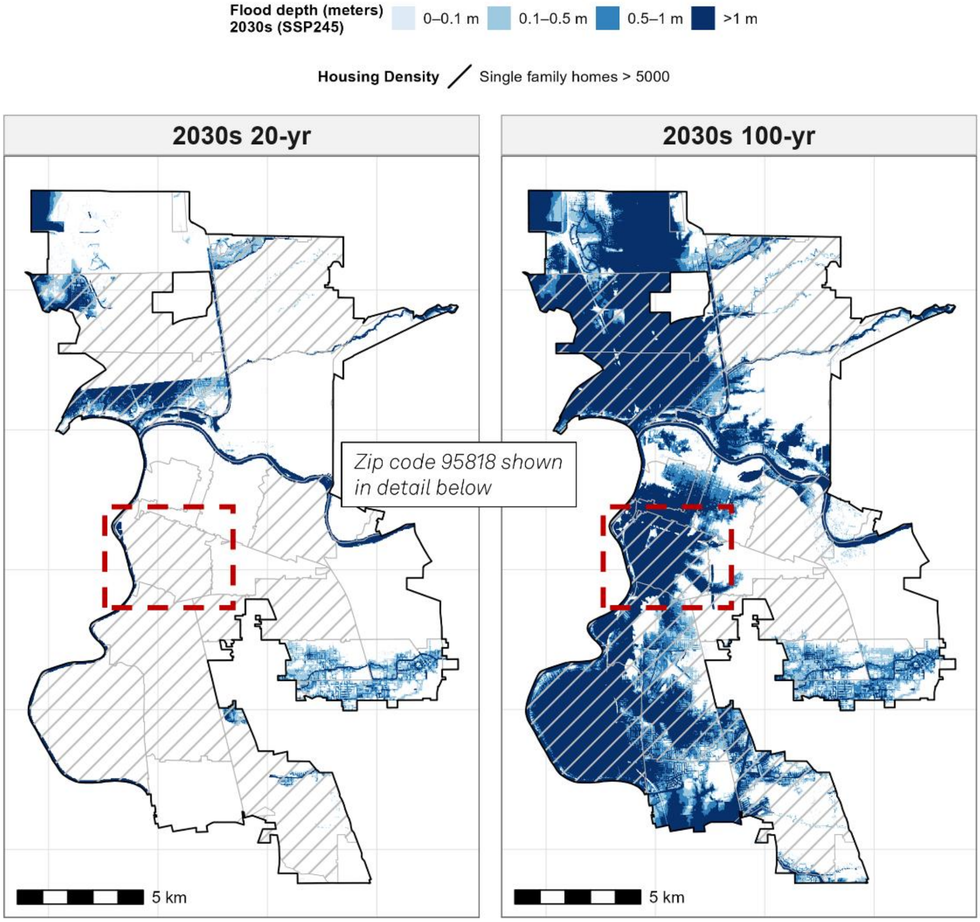
Source: S&P Global Sustainable1.

As return periods “contract” in future decades, the flood depth associated with a 50-year event in the 2090s will approach the depth of a 100-year flood depth today. This is consistent with the climate change signal common to many regions that precipitation occurs in less frequent but more intense bursts. In this location and scenario, by the end of century, the 50-year flood depth rises to meet what is currently the 100-year flood depth. In other words, the annual probability of exceeding the current flood defense (3 meters) is nearly doubled.

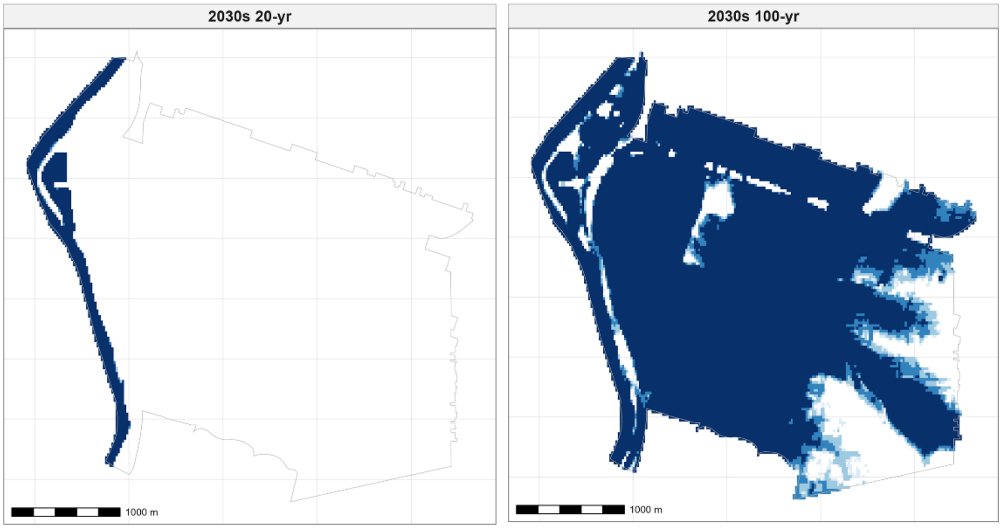
The high resolution of the model allows us to identify flood exposure and potential damage to individual buildings. The spectrum between no flood damage, nuisance flooding and catastrophic structural damage can all fall within 1 meter of flood depth, and property elevations can greatly exceed this range even within a small area. The ability to distinguish flood exposure at the property scale advances climate financial risk analysis for financial institutions from an abstract worst-case scenario to a more realistic quantification of the expected risks and damages to a real estate portfolio.

Sacramento River levees protect homes from 20-year floods but not 100-year floods in the 2030s

Flood depth at 30-meter resolution and single-family home concentration by zip code, 2030s, under the SSP2-4.5 scenario



Detail of zip code 95818



As of April 9, 2026.

SSP2-4.5 is a medium climate change scenario that contemplates strong mitigation, in which total greenhouse gas emissions stabilize at current levels until 2050 and then decline to 2100. This scenario is expected to result in global average temperatures rising by 2.7 degrees C (2.1 degrees C-3.5 degrees C) by the end of the century.

Source: S&P Global Sustainable1.

Below, we lay out the step-change in flood and financial exposure that comes with projected changes in flood patterns that are expected to threaten existing flood defenses in Sacramento in future decades Future flood risks are inherently uncertain; the results presented here represent potential outcomes based on S&P Global Sustainable1 projections.

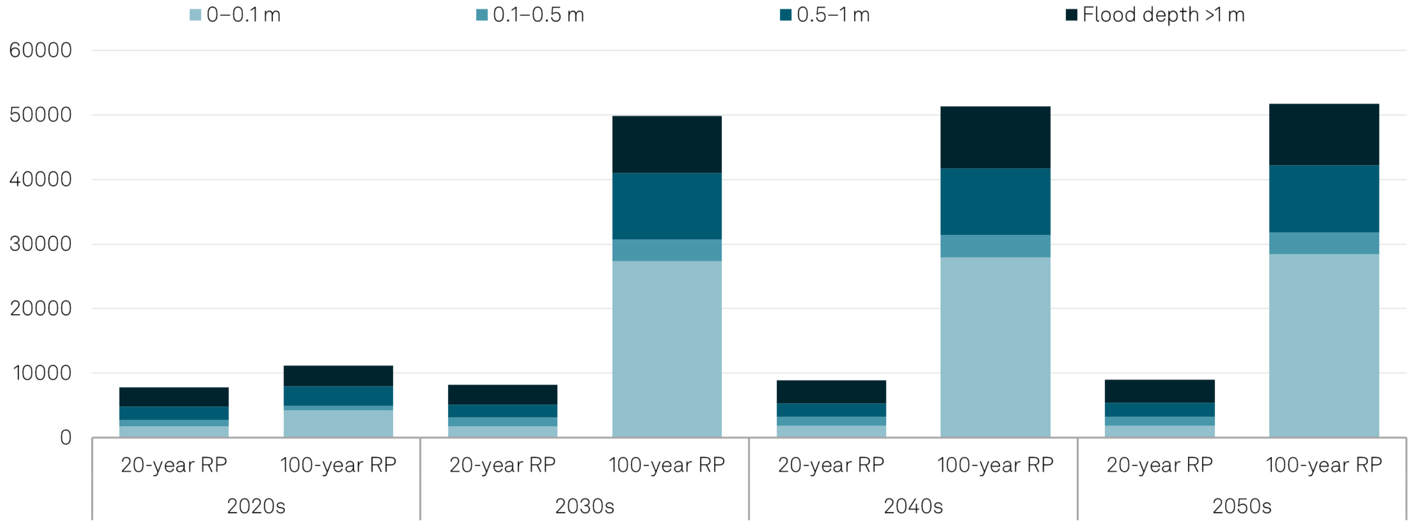
Under current conditions in the 2020s, the levee system is capable of limiting the number of homes exposed to flooding in both a 20-year and a 100-year flood. However, in the 2030s, we project that a small increase for the 100-year return period flood depth could be sufficient to overcome the levees' protection, resulting in widespread inundation and property damage. We will focus on the 2030s as an inflection point at which changing flood frequencies and depths make existing municipal flood defenses ineffective in this scenario.

While flooding of any depth can create repair or cleanup costs, financial risk becomes more material at or above 0.5 meters, when damage to flooring, mechanical systems such as heating or air conditioning or foundations becomes possible. Some homes face inundation above this level even during a 20-year flood. Our analysis identifies 5,059 structures projected to face at least 0.5 meters of flooding in the 2030s during a 20-year flood. This number of materially at-risk homes rises about 12%, to 5,641, during the 2040s. These are structures that may fall outside the protection zone of the levees, and additional flood defenses at the property level may be needed to limit financial risk.

In the 2020s, existing flood defenses protect homes against a 20-year flood and a 100-year flood alike. As we move to the 2030s, the projected increase in the 100-year flood depth in this scenario overtops the existing flood defenses and putting thousands of previously levee-protected homes at risk of inundation and material property damage. There are 19,157 homes projected to face 0.5 meters or more of flooding in the 2030s during a 100-year flood.

Flooding could reach 6x more homes in Sacramento during 100-year floods in the 2030s

Projected number of homes by flood depth exposure in a 20-year flood and a 100-year flood during future decades, SSP2-4.5 scenario



As of April 9, 2026.

RP = return period.

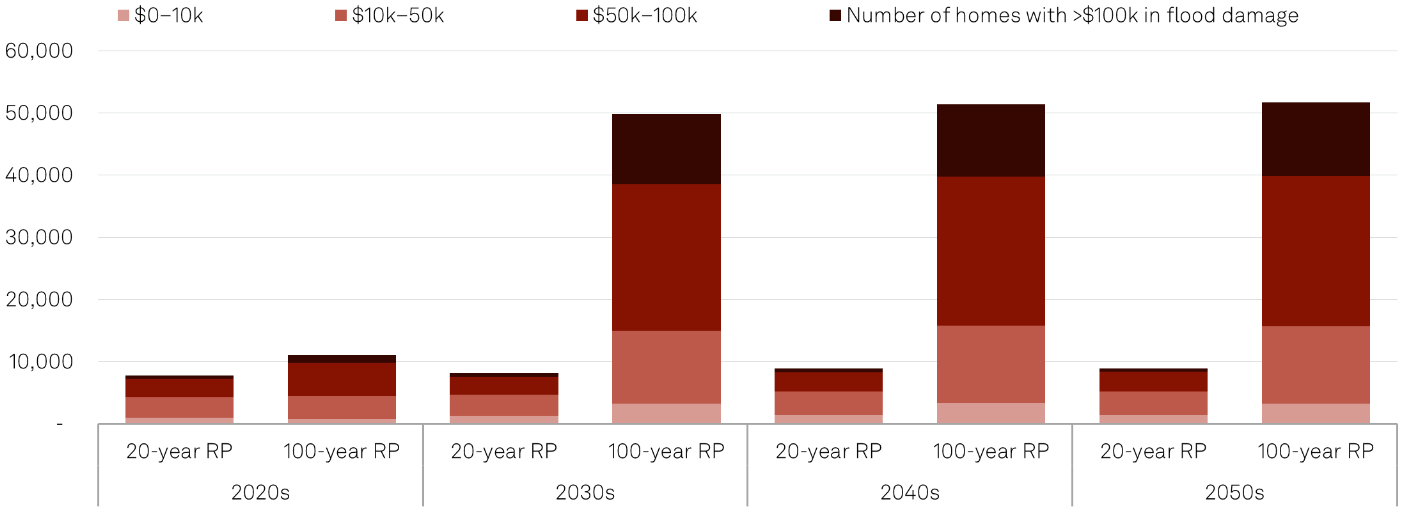
Chart reflects modeled outputs for the 2020s-2050s decades under SSP2-4.5, a medium climate change scenario that contemplates strong mitigation, in which total greenhouse gas emissions stabilize at current levels until 2050 and then decline to 2100. This scenario is expected to result in global average temperatures rising by 2.7 degrees C (2.1 degrees C-3.5 degrees C) by the end of the century.

Source: S&P Global Sustainable1.

The financial stakes of either category of flood are substantial. For the 2030s decade, we project the total cost to single-family residential real estate in Sacramento across our sample of 88,699 properties at about $378 million for a 20-year flood event and $3.6 billion for a 100-year flood — a nearly tenfold increase in monetary damage.

100-year flood could expose over 11,000 Sacramento homes to damage of $100k or more in the 2030s

Projected number of homes by flood damage in a 20-year flood and a 100-year flood during future decades, SSP2-4.5 scenario



As of April 9, 2026.

RP = return period

Chart reflects modeled outputs for the 2020s-2050s decades under SSP2-4.5, a medium climate change scenario that contemplates strong mitigation, in which total greenhouse gas emissions stabilize at current levels until 2050 and then decline to 2100. This scenario is expected to result in global average temperatures rising by 2.7 degrees C (2.1 degrees C-3.5 degrees C) by the end of the century.

Source: S&P Global Sustainable1.

The distribution of financial costs among homes exposed to floods is not a one-to-one reflection of the distribution of flood levels. For example, a 20-year flood in the 2030s is projected to put 3,012 homes at risk of more than 1 meter of flooding. However, only 538 homes in that group are projected to face $100,000 or more of damage each. Some borrowers may face repair costs combined with outstanding loan values that exceed the value of the home, creating the potential for losses at the lender.

100-year floods present greater financial risk by an order of magnitude. The model identifies 11,333 homes with projected damages of more than $100,000 each in a 100-year flood event in the 2030s. This is 21x the number of homes facing this level of damage during a 20-year flood and represents about 13% of all the Sacramento homes in our analysis.

A higher frequency of severe flood and associated property damage raises the probability of loans becoming "underwater" — meaning that the borrower owes more on the property after flood repairs than the property's value. While a loan becoming underwater is rarely the exclusive cause of borrower default, negative equity combined with major financial shocks to the borrower, such as loss of income, are often behind borrower default.[6]

Floods of this severity are important to consider particularly in the context of climate change: Even in the medium climate change scenario (SSP2-4.5) considered in our analysis, the annual probability of a 100-year flood nearly doubles by the end of the century for the selected location. In different scenarios, in which less global action is taken to reduce emissions and a higher global average temperature is reached by the end of the century, flooding hazards worsen further.

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[6] Peter Ganong and Pascal J. Noel, "Why Do Borrowers Default on Mortgages?," NBER Working Paper 27585 (2020), https://doi.org/10.3386/w27585.

As we reach the 2030s — less than five years away — existing flood defenses may be unable to contain a flood of this size. A single occurrence of a 100-year flood in the coming decade would lead to widespread monetary damage, making it a significant tail risk for financial institutions with real estate holdings in Sacramento.

Appendix

Methodology for identifying single-family homes and estimating building damage

We used the following approach to classify buildings as single-family homes:

- Building footprints were sourced from the Microsoft global building dataset derived from Bing Maps aerial imagery using deep learning classification.
- Buildings within a city were extracted and screened to identify single-family homes.
- Building height was used to estimate the number of floors, assuming a typical floor height of 3 meters.
- Buildings with two or fewer floors were classified as single-family homes. Where height information was unavailable, buildings were conservatively assumed to be single-family homes.
- Gross floor area was calculated as *footprint area* × *number of floors*, and buildings outside the typical size range for single-family homes were excluded.

Flood damage at the building level was estimated as follows:

- Flood depth values are extracted at each building location from flood hazard maps.
- Flood depth is converted into a fractional structural damage ratio using North America depth-damage functions from the Joint Research Centre.
- The fractional damage ratio is applied to the building’s ground floor area to estimate the portion of the structure affected by flooding.
- The damaged floor area is multiplied by maximum structural damage cost expressed in $/m² to estimate the total structural loss.

Flood model comparison to observed flood events

To evaluate the fluvial flood model, we compare modeled flood depth maps at return periods with flooded area extents from documented events. The flood model predicts probabilities (reciprocal of return period) of annual flood depth at individual locations, not specific flood events. Conceptually, these probabilistic location-by-location flood depths can be thought of as resulting from a statistical analysis of many potential events, rather than any single event. Nonetheless, comparison to single events offers a qualitative assessment. While such a comparison does not validate the model, it can invalidate the model if the flooding occurs in a region where the model assigns little or no probability.

Figures 1-3 compare observed flooded area extents from single events to model return-period flood-depth maps in California, (Fig. 1), Altenahr, Germany (Fig. 2), and Bangkok, Thailand (Fig.

3). In each example, return periods are selected to approximately bracket the observed flood extent. In other words, the model assigns plausible flood depth probabilities to these major flood events in most regions. For each region, we also calculate the fraction of the observed flooded area that the model indicates has non-zero flood depth at all nine return periods (Tables 1-3).

If the model displays flooding in most of the observed flooded region at long return periods, then the model is not invalidated by the observations. In addition, the change in this fraction with return period provides an estimate of the return period of the majority of the event's flooded locations.

San Jose, California, experienced significant flooding in January 2017. The observed flood extent is larger than the modeled regions with non-zero 100-year flood depth, but smaller than the regions with 200-year flood (Fig. 1), indicating that most of the observed flooding had return periods between 100 and 200 years. The fraction of the observed flood area inundated in the model increases from 0.25 to 0.82 from 100 to 200 years. At the 1000-year return period, most but not all the observed flood area is reproduced by the model (0.84). The remaining 0.16 could indicate model shortcomings. It could also indicate the presence of pluvial (direct rain on surface) or coastal flooding in the observations, which are modeled separately.

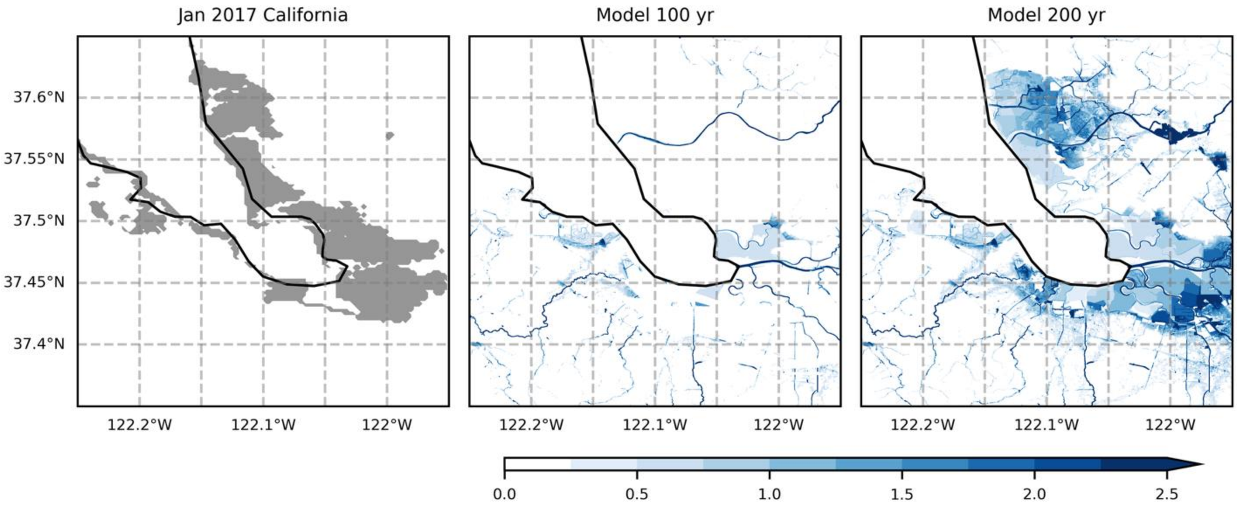

Fig. 1: Observed January 2017 flood area extent in a 30km vicinity of San Jose, California vicinity (left). Modeled flood depth maps (meters) for the 100-year (center) and 200-year (right) return periods. Observed flood extents come from MODIS satellite flood data (https://global-flood-database.cloudtostreet.ai).

RP (years)	2	5	10	20	50	100	200	500	1000
fraction	0.09	0.10	0.12	0.15	0.16	0.25	0.82	0.84	0.84

Table 1: Fraction of the San Jose flooded extent (Fig. 1) that is flooded by the model at different return periods.

The town of Altenahr in the Ahr River Valley of Germany experienced devastating flooding in July 2021. Much, though not all, of the flood extent falls between the modeled 50-year and 500-year return period flood depths (Fig. 2). The fraction of the observed flood area also flooded in the model increases steadily from 0.36 at the 2-year return period to 0.84 at the 1000-year return period.

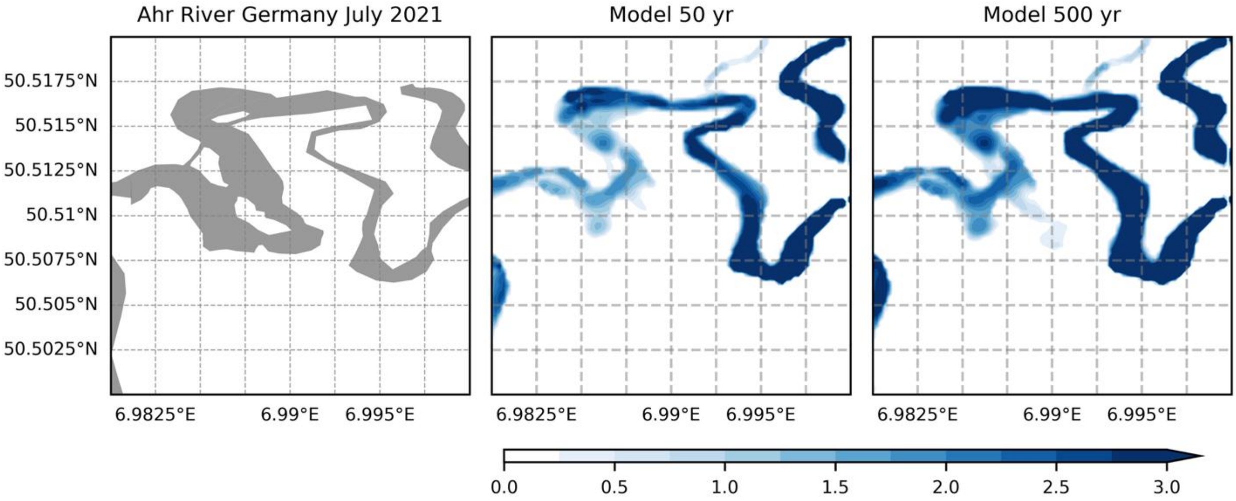

Fig 2: Observed July 2021 flood area extent in a 2km vicinity centered on the town of Altenahr in the Ahr River Valley, Germany (left). Modeled flood depth maps (meters) for the 50-year (center) and 500-year (right) return periods. Observed flood extents come from the data supplement published for the study "A multi-disciplinary analysis of the exceptional flood event of July 2021 in central Europe," Schäfer, Andreas, and Julian Francesco Daniel Quinting. https://www.radar-service.eu/radar/en/dataset/XoHpmcjErwsfADvg

RP (years)	2	5	10	20	50	100	200	500	1000
fraction	0.36	0.54	0.63	0.67	0.72	0.74	0.77	0.82	0.84

Table 2: Fraction of the Altenahr flooded extent (Fig. 2) that is flooded by the model at different return periods.

Central Thailand experienced widespread flooding in September of 2012, much of which (0.91) is flooded by the 50-year modeled flood depths (Fig. 3). In fact, the model indicates that half (0.50) of the observed flooded area floods frequently, on average every 2 years (2-year return period), though the typical depth of such flooding is much less than at longer return periods.

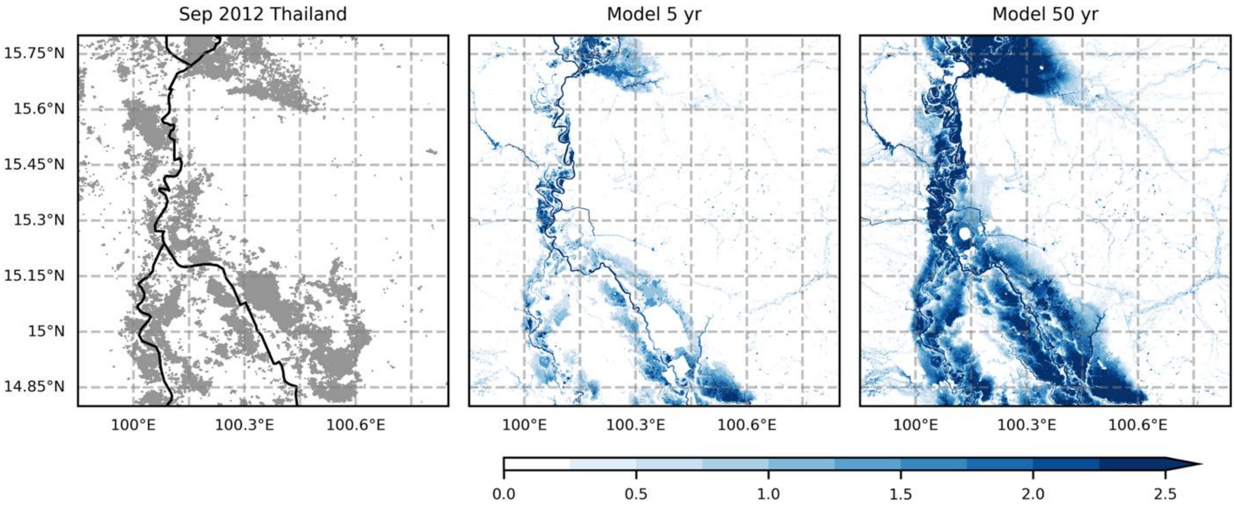

Fig 3: Observed September 2012 flood area extent in a 100km vicinity of central Thailand (left). Modeled flood depth maps (meters) for the 10-year (center) and 100-year (right) return periods. Observed flood extents come from MODIS satellite flood data (https://global-flood-database.cloudtostreet.ai).

RP (years)	2	5	10	20	50	100	200	500	1000
fraction	0.50	0.69	0.79	0.84	0.91	0.93	0.95	0.97	0.99

Table 3: Fraction of the central Thailand flooded extent (Fig. 3) that is flooded by the model at different return periods.

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