

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 at 30x30 meters spatial resolution and potential damage at individual building level 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 and commercial real estate during floods of different depths. For example, in Frankfurt, we estimate under the SSP2-4.5 climate scenario that about 282 MW of data center capacity faces a 5% or higher annual probability of exceeding 0.5 meters of flooding in the 2030s.
- Data center development is accelerating around the world. For hotspots like Frankfurt, our projections show that future data center development is pushing into areas of greater flood risk.

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 river¹ — making the prospect of more intense river flooding a widespread risk. River flooding is often driven by severe rainfall, which in addition to increasing a river's volume beyond its banks can saturate other low-lying areas to create pluvial flooding that presents material risks.

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.

The 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 and pluvial 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, the following analysis of Frankfurt, Germany, focuses on identifying the risk of material flood depth for data centers. The analysis uses 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 and rainfall-driven flood risk due to climate change vary by region, driven by changing precipitation, temperature and weather patterns. In many places, future

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.

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 Sustainable'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 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 hyperscaler choosing data center properties to lease capacity from, or where to invest in future data center construction, acute hazards such as floods are also important because severe flooding can force a complete shutdown of the facility. Data center customers such as major tech firms and financial institutions expect extremely high uptime — ideally only minutes of planned downtime over an entire year — and any prolonged disruption is a major business liability. Managing this kind of risk requires modeling at individual asset-level resolution.

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.

Frankfurt data centers

- Frankfurt is one of five key data center hubs in Europe, and about 22% of its existing capacity (about 282 MW) is projected to have a 5% or greater annual chance of material flood depth exposure in the 2030s.
- Some of Frankfurt’s largest data centers, with capacity above the market average of 10 MW, are located in high flood risk areas.
- Data centers outside of typical river flood zones may still be vulnerable to rainfall-driven flooding, depending on terrain and elevation.
- Future data center development in Frankfurt is expanding into more flood-prone areas, making strong flood mitigation at the property level essential. About 36% of planned data center locations are within high flood risk zones.

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 flood model produces continuous flood depth results. Depending on factors such as terrain or elevation, flood depth typically radiates out from a river, stream, or, in the case of rainfall-driven flooding, a low-lying area. The height of a building’s interior ground floor and any flood defenses will influence how much flood water enters the building.

In this analysis, we treat 0.5 meters of flood depth at ground level as a baseline materiality threshold at which damage to a data center property is possible. Individual properties may have flood defenses that protect against flooding above this level. However, we make no assumptions about the strength of flood protection on a property-by-property basis.

For data centers, 0.5 meters of flooding is sufficient to pool at ground-level entryways or to enter basement or other below-ground levels where electrical, utility or telecommunications equipment and connections are housed.

The flood model does take municipal flood defenses such as levees into account. 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 data centers in the city of Frankfurt, Germany. The analysis uses a sample of 155 data center facilities, based on the S&P Global Energy 451 Research Data Center KnowledgeBase as of March 2026.

We treat 0.5 meters of flood depth at ground level as a baseline materiality threshold at which damage to a data center property is possible, depending on the property’s flood defenses. This level of flooding is sufficient to pool at ground-level entryways or to enter basement or other below-ground levels where electrical, utility or telecommunications equipment and connections are housed. Automatic shutoffs are typically triggered by standing water in these areas to prevent catastrophic damage to servers and other equipment.

The model’s resolution allows for the identification of facility locations that face a high annual probability of flood depth that exceeds 0.5 meters. For example, in the climate scenario used for this analysis (SSP2-4.5), we find that 13 data centers representing about 282 MW of capacity in total each have a 5% or greater annual probability of experiencing 0.5 meters or more of flooding at ground level during the 2030s. During flooding of this depth, a facility faces the possibility of extended downtime, which can have significant financial consequences for investors and data center operators and tenants.

Our projections of flood depth take into account the current state of municipal flood protection and make no assumptions about the effectiveness of future improvements to municipal flood defenses. Individual properties may have flood defenses that protect against flooding above this level; however, we make no assumptions about the strength of flood protection on a property-by-property basis.

Data centers and climate risk

As the bedrock underneath AI models and cloud services, data centers are the [defining infrastructure of the digital economy](#). The resource-intensive training of large language models takes place in data centers that house tens or even hundreds of megawatts of computing capacity, and data centers are in high demand from the handful of large tech firms, known as hyperscalers, that are driving AI development. The sector is increasingly responsible for [macroeconomic growth](#), moving the GDP needle for entire countries.

Data centers are sensitive to a range of environmental risks, many of which are expected to worsen as the global climate warms. Growing climate physical risks such as extreme heat, drought and water stress represent major operational challenges to managing the heat generated by servers and equipment and to securing the large volume of water that some cooling methods require.

These structures are also vulnerable to acute climate physical risks such as flooding. While persistent extreme heat may challenge data center operators by raising their cooling costs or accelerating the degradation of cooling systems, a severe individual event like a major flood — whether from an overtopped river or from rainwater inundation — could take an entire data center offline as emergency shutoffs activate.

Financial risks of flood-induced data center downtime	
Investors	Asset write-downs, excess capex, higher financing costs (risk premium), depressed capitalization rates
Operators	Breach of uptime service level agreements, customer churn and vacancy, increased operating costs
Tenants	Service outages, reputational damage, disruption to AI model training windows, wasted compute

While data centers have robust on-site uninterruptible power supply (UPS) in case grid or primary collocated power is disrupted, the presence of standing water may shut down all on-site electricity to prevent catastrophic damage to servers and electronic systems. Extremely high uptime is the goal for any data center, and for some clients in financial services or technology, the so-called “five nines” of uptime — 99.999% availability — is a practical necessity. Downtime measured in minutes is viewed as a serious failure; flooding raises the possibility that a facility is offline for hours or longer.

Frankfurt is the second-largest data center market in Europe, with about 1,262 MW of capacity³ across 125 currently operating properties, according to the S&P Global Energy 451 Research Data Center KnowledgeBase as of March 2026. There are an additional eight locations categorized as under construction, and 22 categorized as planned. Like many cities around the world, Frankfurt is built along a major river, the Main, and much of its commercial and industrial development sits near the riverbank. This includes significant clusters of data centers, some of which use cooling methods that rely on the river. Proximity to the river also offers access to energy infrastructure, such as gas-fired power plants, that were built near the Main.

Exposure to material flood depth

We express exposure to 0.5 meters of flood depth as the annual probability of exceeding this threshold at a given location, using four bands: 0-0.01% (very low annual probability), 0.01-1% (low), 1-5% (moderate) and >5% (high). These annual probabilities of exceedance correspond to return periods.

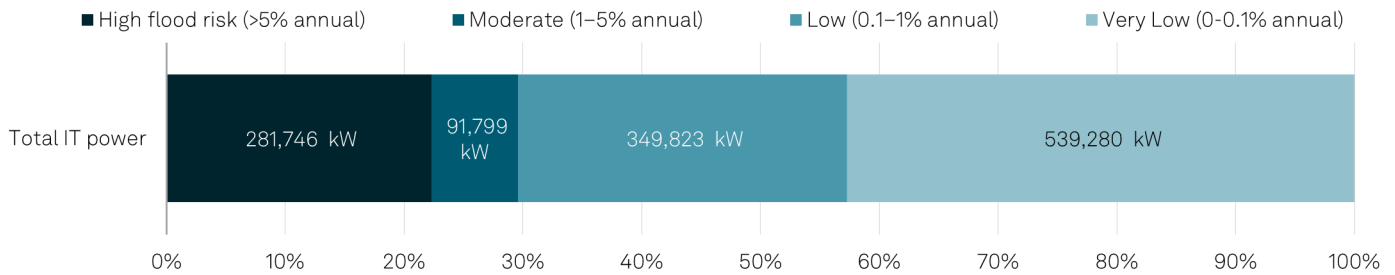
This analysis includes both river (fluvial) and rainfall-driven (pluvial) flooding. Heavy rainfall is often the cause of river flooding, but it can also result in flooding in low-lying areas outside of river floodplains. We take either flood hazard into account. A location with a very low probability of 0.5 meters of fluvial flooding but a high probability of pluvial flooding is categorized as high flood risk.

We find that 13 operational data centers with about 282 MW of capacity are located where there is high annual probability of disruptive flood events. Some of these locations are not alongside the Main River. The source of flood risk may be nearby streams or the buildup of rainwater during heavy storms.

³ Measured as “total IT power” in the 451 Research Data Center KnowledgeBase. Total IT power represents cumulative installed usable IT power (kW) usable at the rack for client IT equipment.

About 282 MW of current data center capacity is at high risk of 0.5m or more of flooding annually in the 2030s

Operational data center capacity by annual probability of experiencing 0.5 meters or more of flood depth at location



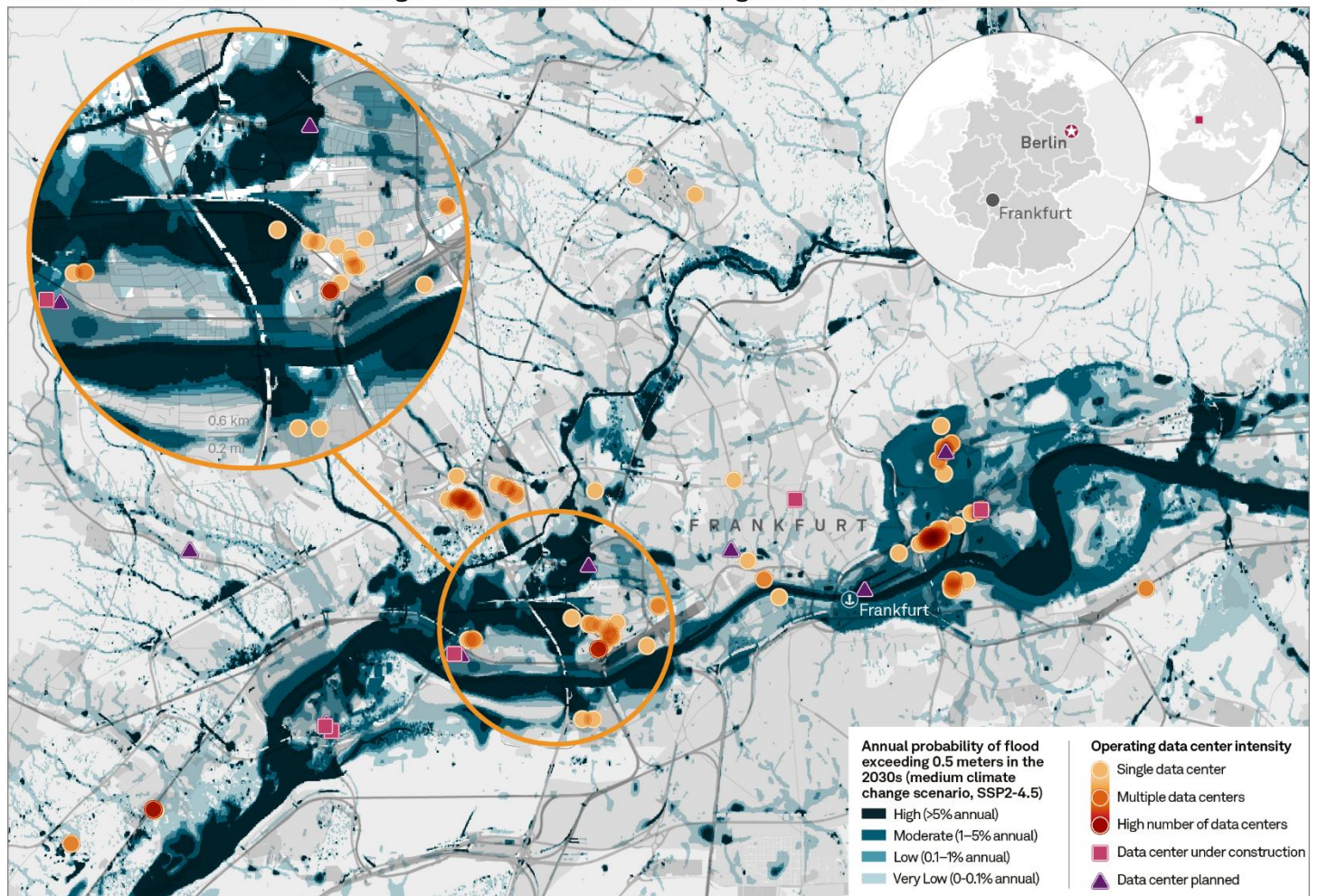
As of April 24, 2026.

Chart represents 125 data centers with "operational" status in the 451 Research Data Center KnowledgeBase as of March 2026. Total IT power represents cumulative installed usable IT power (kW) usable at the rack for client IT equipment. Chart reflects modeled outputs for the 2030s decade 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. Annual probability is interpolated from the log-return period depth curve. For example, the high (>5% annual) risk band includes return periods of RP20 and lower. 0.5 meters of flood depth is used as a potential threshold for material exposure to flood damage. Both fluvial (river) and pluvial (rainfall-driven) flooding hazards are considered as the cause of flooding at this depth.

Sources: S&P Global Energy Horizons; Sustainable1 Physical Risk dataset.

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Some Frankfurt data centers face high annual risk of flood exceeding 0.5m in the 2030s



Data from 451 Research, Sustainable1. Compiled May 01, 2026.

Basemap sources: MapTiler; OpenStreetMap contributors; OpenMapTiles.org.

Sources: JBA Risk Management; S&P Global Energy; 263113-01

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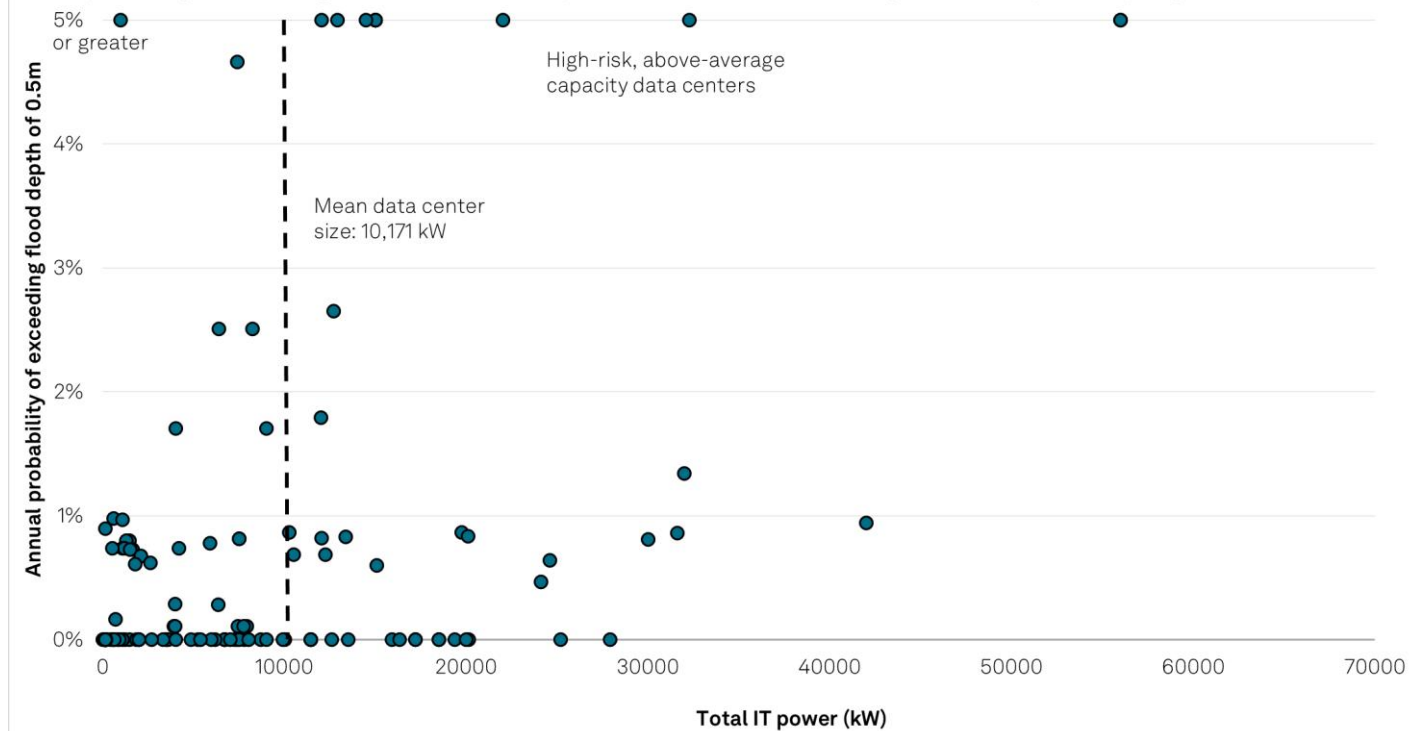
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While we have identified the probability of floodwater exceeding this depth at the ground level, whether water enters a facility in enough volume to cause a shutdown depends on the structure's architecture and its flood defenses. Equipment and server racks are likely elevated within the main area of a data center, but underground cable vaults typically house connections with the electrical grid, on-site UPS or telecommunication and internet service. These tunnels are at greater risk of water entry and could trigger a sitewide shutdown. The infrastructure climate risk firm Climatwin has [identified](#) water depth of 0.15-0.3 meters at doors, cable vaults or switchgear as sufficient to trigger a shutdown. We use a threshold of 0.5 meters to represent a hypothetical flooding event with a greater likelihood of entering a facility.

The average size of these high flood risk data centers (22 MW) is roughly twice the average for the wider Frankfurt market (10 MW). A 5% annual probability of exceeding 0.5 meters of flooding corresponds to a 20-year return period; several of the data centers in this risk band face flooding exposure at even lower return periods.

Some of the largest Frankfurt data centers have high flood risk in the 2030s

Annual probability of exceeding 0.5 meters of flood depth for Frankfurt data centers, by data center power capacity



As of April 24, 2026.

Chart represents 125 data centers with "operational" status in the 451 Research Data Center KnowledgeBase as of March 2026. Total IT power represents cumulative installed usable IT power (kW) usable at the rack for client IT equipment. One outlier point (96,300 kW, 0% annual probability) excluded for scale. Chart reflects modeled outputs for the 2030s decade 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.

Annual probability is interpolated from the log-return period depth curve. For example, the high (>5% annual) risk band includes return periods of RP20 and lower. 0.5 meters of flood depth is used as a potential threshold for material exposure to flood damage. Both fluvial (river) and pluvial (rainfall-driven) flooding hazards are

Sources: S&P Global Energy Horizons; Sustainable1 Physical Risk dataset.

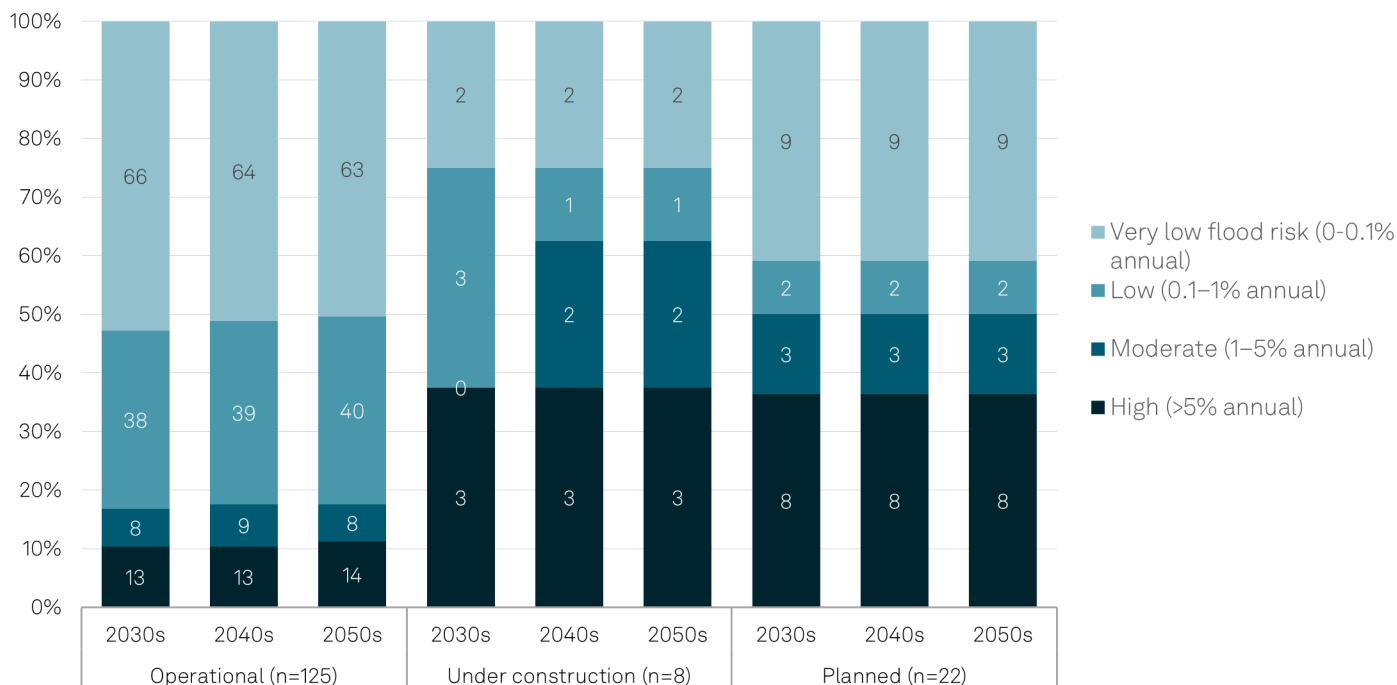
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Globally, the pace of data center rollout is [accelerating](#), from a built-out capacity of 200 GW in 2024 to a projected 382 GW by 2030, according to S&P Global Energy 451 Research. A review of data center sites categorized as planned or under construction shows that a significant share of this development is occurring in more flood-prone areas. While about 10% of existing data center locations lie within areas that are high-risk in the 2030s, that share is 36% for planned locations and 38% for sites already under construction.

In projections to the 2050s, the number of data centers exceeding the 0.5 meters threshold shows little change. However, the actual flood depth at these locations could worsen in future decades.

Data center development in Frankfurt is expanding to more flood-prone areas

Currently operating and future data center locations by annual probability of flood depth exceeding 0.5 meters, 2030s-2050s



As of April 24, 2026.

Chart represents 155 data centers in any development status in the 451 Research Data Center KnowledgeBase as of March 2026. Total IT power represents cumulative installed usable IT power (kW) usable at the rack for client IT equipment.

Chart reflects modeled outputs for the 2030s-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.

Annual probability is interpolated from the log-return period depth curve. For example, the high (>5% annual) risk band includes return periods of RP20 and lower. 0.5 meters of flood depth is used as a potential threshold for material exposure to flood damage. Both fluvial (river) and pluvial (rainfall-driven) flooding hazards are considered as the cause of flooding at this depth.

Sources: S&P Global Energy Horizons; Sustainable1 Physical Risk dataset.

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Data center construction is increasingly emphasizing site resilience beyond standard UPS, particularly when it comes to sites designed to use natural water resources like rivers for cooling efficiency. For example, Swedish developer Green Mountain's new FRA-Mainz facility, located near Frankfurt on the Rhine River, includes flood protection up to the 1,000-year return period.

Developers choosing to build away from rivers to avoid flood risk may not be considering the possibility of rainfall-driven flooding, however. This makes elevation a key consideration in future data center site selection, and flood protection at the site level should be included in risk management and security planning.

Data center operators will contend with the direct impact of a potential flood event, as they implement disaster recovery plans and work to restore service as quickly as possible. But flood risk flows through to the real estate investors with data center portfolios as well. Depending on the severity of flood damage and downtime length, an investor could face fixed asset write-downs or higher operating costs in the form of raised insurance or financing premiums. If the length of the flood interruption to service results in breaches to uptime agreements with data center tenants, an investor's portfolio could see vacancies, higher churn and negative pressure on capitalization rates.

Severe flood risk is important to consider particularly in the context of climate change. We have examined flood probabilities under a medium climate change scenario (SSP2-4.5), but in other 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.

With thanks to Matt Ramsdale for map design.

Appendix

Methodology for data center flood risk exposure

We used the following approach to identify data center locations:

- The point coordinate locations of data centers in the Frankfurt market was gathered from the S&P Global Energy 451 Research Data Center Knowledgebase, which includes site level records of 14,544 datacenter facilities over 2,600+ providers across 130 countries and over 400 markets.
- Data centers categorized as operational (125), under construction (8) and planned (22) were used.
- Total IT power, or capacity, is available for operational data centers. Total IT power represents cumulative installed power usable at the rack for client IT equipment.
- Data center locations were provided as point coordinates. Each data center was tagged to a building polygon from Microsoft Office Footprint. This step allows for better attribution of hazard impact, particularly given the higher resolution of the flood model.
- For planned or under construction data centers, gross building space is used to create a circular polygon of the same size as a proxy.

For each data center, we calculate the probability of exceeding a flood threshold depth (0.1m, 0.5m, 1m, 2m, 2.5m, 3m) from the 2020s through 2050s under the SSP2-4.5 scenario under flood defense assumptions by interpolation from the log-RP depth curve. Both fluvial and pluvial hazards are considered.

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.

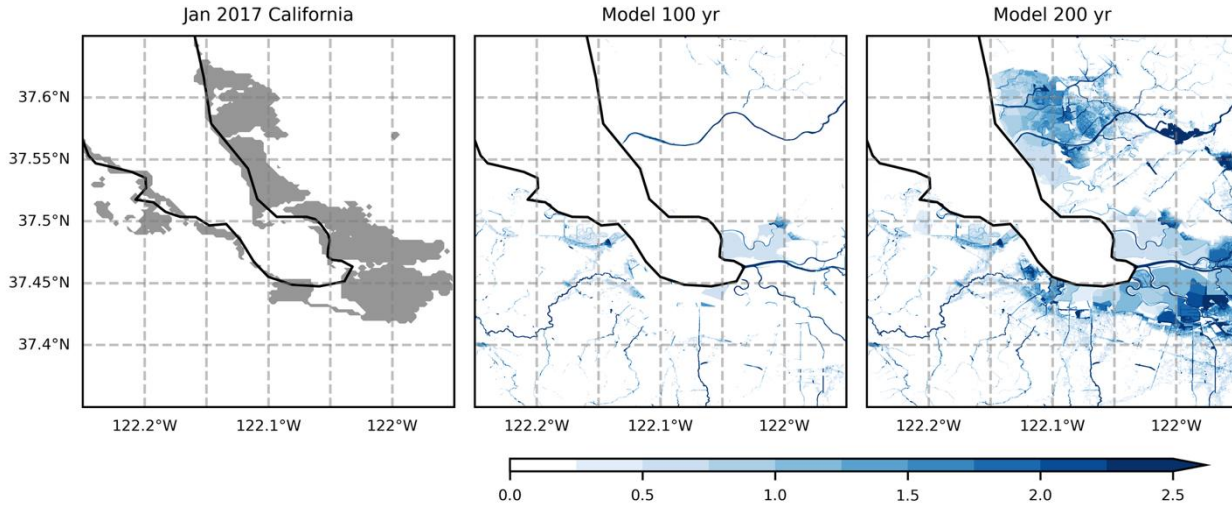


Fig. 1: Observed January 2017 flood area extent in a 30km vicinity of San Jose, California vicinity (left). Modeled flood depth maps (meters) for the 100-year (center) and 200-year (right) return periods. Observed flood extents come from MODIS satellite flood data (<https://global-flood-database.cloudtostreet.ai>).

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.

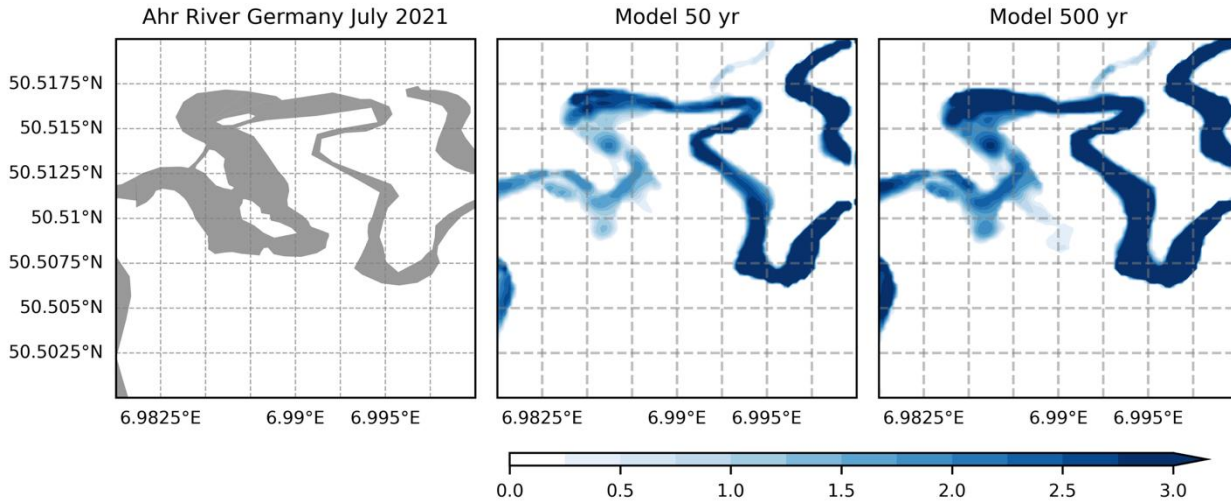


Fig 2: Observed July 2021 flood area extent in a 2km vicinity centered on the town of Altenahr in the Ahr River Valley, Germany (left). Modeled flood depth maps (meters) for the 50-year (center) and 500-year (right) return periods. Observed flood extents come from the data supplement published for the 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.

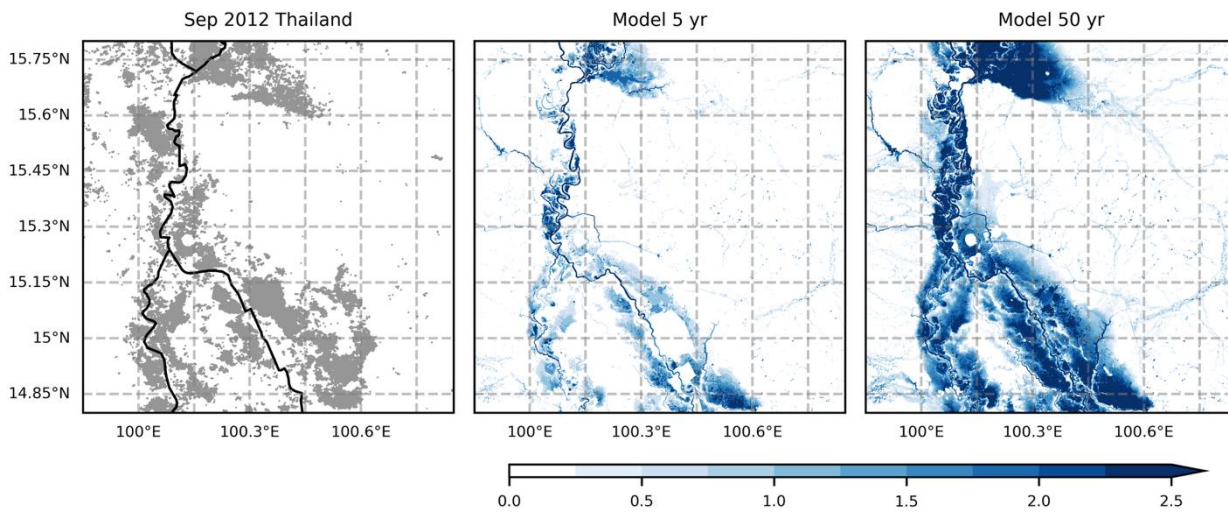


Fig 3: Observed September 2012 flood area extent in a 100km vicinity of central Thailand (left). Modeled flood depth maps (meters) for the 10-year (center) and 100-year (right) return periods. Observed flood extents come from MODIS satellite flood data (<https://global-flood-database.cloudtostreet.ai>).

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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