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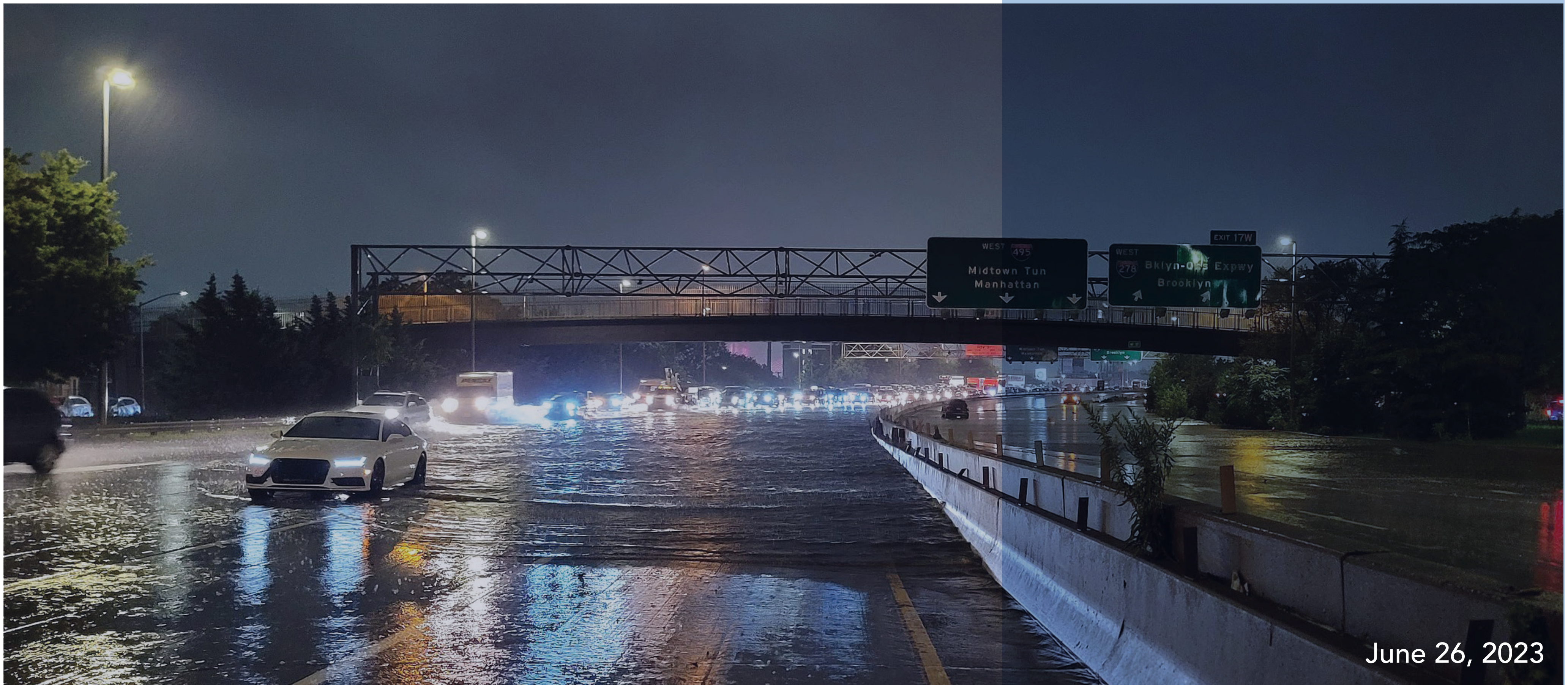

June 26, 2023

Long Island Expressway in New York City shut down due to flash flooding from Post-Tropical Storm Ida's landfall.

The 8th National Risk Assessment

The Precipitation Problem

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Disclaimers

This report is based on peer-reviewed models developed by the non-profit First Street Foundation. All current and forward-looking statements are based on models and as such contain uncertainties

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amazon aws

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LIGHTBOX

To define building characteristics and property parcel details, the Foundation leveraged data from LightBox, a leading provider of CRE data and workflow solutions.

mapbox

To calculate precipitation exposure and incurred damage to the building structure, the Foundation leveraged building footprint data supplied by Mapbox. Mapbox also provided geocode lookups and map integrations for the Risk Factor experience.

State, Metropolitan Area, and County boundaries from the U.S. Census TIGER dataset is used on all pages showing maps. This report is not endorsed or certified by the Census Bureau.

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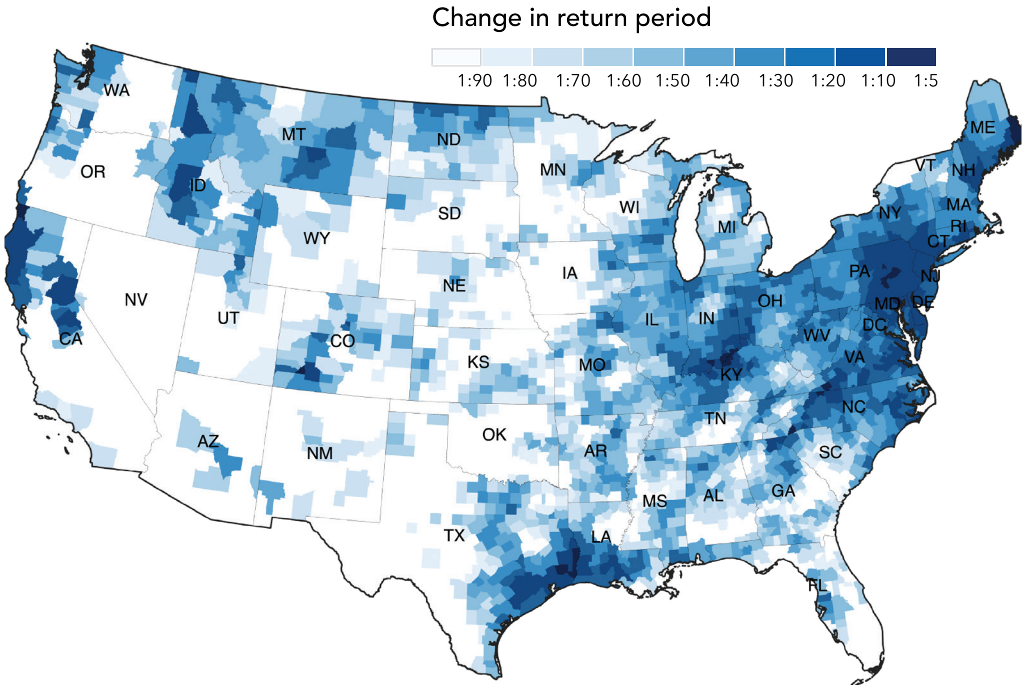
Executive Summary

Flooding from heavy rainfall events is a dangerous phenomenon and has become increasingly more probable and severe in the United States due to climate change. As air temperatures increase, more water vapor may be held in the atmosphere and discharged during rainfall events. For every 1°C increase, 7% more water vapor is carried by the same air volume (Coumou & Rahmstorf, 2012). Increasing temperatures have thus created changes in the expectations of the Intensity, Duration, and Frequency (IDF) of rainfall events. Rainfall events that were thought to occur only once every hundred years are now occurring with far greater frequency. In some places, these formerly rare events are now occurring as often as every 5 or 10 years based on the First Street Foundation Precipitation Model (FSF-PM). The consequences of not understanding these changes include overwhelmed stormwater systems that lead to residential and commercial flooding, impassable roads, critical infrastructure failure, and even loss of life in unexpected high-intensity flash flood events.

The National Oceanic and Atmospheric Administration (NOAA) created a series of precipitation IDF analyses for the US from 1973-2018 that are captured in two publications (Atlas 14 and Atlas 2). These are routinely used as the standard and basis for understanding rainfall events, and in the design of infrastructure to protect communities against standard and extreme precipitation impacts (NOAA Atlas 15 Announcement). However, these analyses assumed that the climate was not changing – resulting in data that do not reflect current rainfall conditions, nor the conditions that US communities will be experiencing in the near term and long term future. These analyses were also generated for different parts of the country at different times, leading to inconsistencies across regions as the datasets used were continuously changing from a warming climate. NOAA is well aware of these issues and received appropriations in 2023 from the US Congress to update its Atlases comprehensively and to reflect the current and future rainfall characteristics for the Nation under a changing climate. However, NOAA projects that this work will not be completed until 2027 at the earliest (NOAA OWP).

FSF-PM correction (in years) to Atlas 14's 1-in-100 year return period



Counties and Population at Risk by Increased Frequency of Current 100-Year Flood Event (FSF-PM vs. Atlas Comparison)

1 In 100 is actually	# of counties impacted	Population impacted (millions)	Percent of counties impacted (%)	Percent of popualtion impacted (%)
1 in 50 year or lower (+200%)	1128	167.2	36.3%	51.1%
1 in 25 year or lower (+400%)	367	69.8	11.8%	21.3%
1 in 20 year or lower (+500%)	221	43.6	7.1%	13.3%
1 in 15 year or lower (+667%)	95	22.4	3.1%	6.8%
1 in 10 year or lower (+1,000%)	20	1.3	0.6%	0.4%
Total US	3107	327.5		

Executive Summary

Since the United States faces the threat of intense rainfall and associated flooding today and is preparing to build infrastructure projects to protect against future flooding – including those funded by the $1.2 Trillion in Federal appropriations in 2022 known as the Infrastructure Investment and Jobs Act (IIJA) – there is an urgent need for accurate information about rainfall event characteristics. Without such data, the allocation of these dollars, the design standard of these projects, and the useful life of the infrastructure investments will all be based on inaccurate data and result in wasted taxpayer dollars. To correct for this, First Street Foundation (FSF) undertook its own analysis of 795 NOAA Automated Surface Observing Station (ASOS) high-quality weather stations' data across the US to estimate the likely rainfall IDF characteristics in the current year. Based on NOAA's Atlas 14 methodology, the First Street Foundation analysis focused on the last 20 years of rain gauge data to resolve climate change's impacts on these characteristics and ensured that those major, intense events that have occurred over that period were appropriately weighted in the results. In addition, First Street Foundation's analysis covers future facing risks to account for a continuously changing environment that infrastructure and planning must take into account in order to build to the right standard for infrastructure's useful life. First Street Foundation is making this new analysis, called the FSF-PM, available for public use to help the Nation prepare for the threat of climate-change-induced flooding from heavy rainfalls. First Street is also using these new analyses as inputs to its Flood Model (FSF-FM) Version 3 (available July 2023) which enables property-specific, probabilistic assessments of flooding today and for 30 years into the future. These data will be available through the Risk Factor (riskfactor.com) tool, which is integrated with real estate websites like realtor.com and Redfin, trusted by the Federal Government, and leveraged by the top banks and institutional investors in the country.

The FSF-PM results reveal that 167.2 million people in the US (over 51% of its population) reside in a county where stormwater system failure is likely to occur today, as those areas are now at least twice as likely to experience severe levels of flooding (associated with the previously thought of 1-in-100 year events) from rainfall each year. Of that group, 43.6 million Americans (13.3% of the population) are over 5 times more likely to experience that same level of severe flooding. The depths of water associated with severe flooding that was previously considered a rare 1-in-100-year storm in Atlas 14 will now be experienced every 20 years on average by those Americans. Over the past 20 years, NOAA's ASOS rain gauges have recorded 30 locations that have experienced multiple 1-in-100 year events, and 13 locations that have reported 1-in-500 year events, based on the Atlas 14 classification. The outdated understanding of flood risk due to changes in extreme precipitation estimates is compounded by the use of the Federal Emergency Management Agency (FEMA) Special Flood Hazard Area (SFHA) designation as the current authoritative flood risk information standard in the United States – which does not account for precipitation in its analysis. Over half the risk in the country is unaccounted for due to the lack of precipitation in the SFHA modeling process. Across the nation, the FSF-FM, which has been updated with the newly developed FSF-PM, reveals that approximately 17.7 million properties across the country that are at substantial risk or greater (1-in-100 year risk or greater), which is 2.2 times more than the amount included in the FEMA 1-in-100 SFHA designation. Not only has flood risk across the United States changed significantly from what it once was, but it will continue to change in the near and long term future due to climate change. In some areas, the risk that was previously associated with a 1-in-100 year event may now occur as often as every 10 years in the most severe case, and in the next 30 years may be better characterized as an even more frequent event (1-in-5 year event for instance). Climate change impacts are changing the frequency at which these heavy rainfall events occur in the US, and the FSF-PM is now available to help Americans more accurately understand their current risk and to help communities design protections at appropriate standards to adapt to that risk.

Extreme Precipitation in the US

Extreme precipitation refers to intense, localized heavy rainfall and snow events that occur within a short time frame.

These events tend to be overwhelmingly rainfall based. Additionally, these extreme events occur very rarely for any given location and are often referred to by their expected frequency, for example as a “1-in-100 year event”. Supercell thunderstorms in the Midwest, atmospheric rivers in the Western US, tropical storm systems (e.g., hurricanes) along the Gulf and Atlantic Coasts, and strong midlatitude storms in the northern states are some well-known examples of weather phenomena that bring extreme precipitation. These types of events can lead to flash flooding and landslides, which in turn may lead to loss of life and significant damage to infrastructure and property. However, the levels of rainfall associated with extreme precipitation events that have been experienced historically are rapidly becoming more frequent and may be the “new normal” in many parts of the US – all due to the changing climate. One way of gauging the increase is by looking at NOAA’s reported Billion Dollar Disasters. In terms of billion-dollar precipitation-related flooding disasters adjusted for CPI, the US now sees an average of 1.5 events per year, up from less than half an event per year on average in the early 1980s (NOAA NCEI, 2023).
To better understand the language used to describe the results presented in this report, it is important to note that the term precipitation is primarily concerned with rainfall. That being said, precipitation can also include much rarer events such as snow in the observations included below. Most often, precipitation events are referred to by their intensity, based on water depths resulting from rainfall (i.e. 1 inch, 2 inches, etc.) over a given amount of time (daily, hourly, etc.), and each water depth can be associated with a specific likelihood of occurring at that location. That likelihood is referred to as the expected “return period” of the event that produced the specific water depth in question. For instance, a location may rarely see rainfall rates of 3 inches per hour, with a return period of 1-in-100 years (or, a “100-year event”). The likelihood of that 100-year event occurring in any given year is 1% , which therefore may have a return period of 1-in-100 years. That same likelihood compounds over time, and the probability of that same event occurring at least once over specific time intervals can be computed using the cumulative likelihood equation found on page 7.

To calculate the probability of a 100-year event (with a 0.01 or 1% annual chance) occurring at some point over a 5-year period, replace the likelihood with 0.01 and period of time with 5, which would equal 4.9% (see Equation 1).

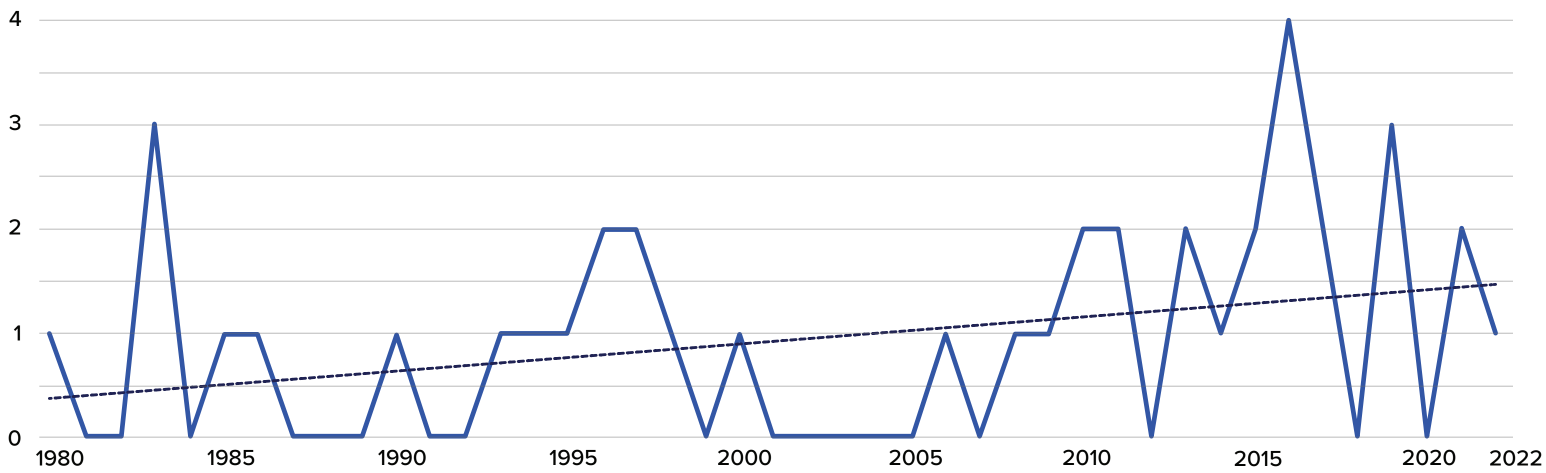


Figure 1: Recorded occurrence of billion dollar precipitation related disasters by year

Extreme Precipitation in the US

Said in a different way, over a 5-year period, a 100-year event has a 4.9% probability of occurring. Using the table below, you can see that over a 30-year period, there is a 26% probability of a 100-year event occurring at least once - meaning that the rare event is rather likely to occur sometime over those 30 years. That being said, these return periods are computed at a specific point in time. As the observations of more severe precipitation events increase, the depths currently associated with 1-in-100 year flood events occur more frequently and what was historically described as a 100-year flood becomes a more frequent event (for example, 1-in-50 year flood event).

Equation 1.

Probability (%) = [1 - (1 - likelihood)$^{\text{period of time}}$) X 100

Table 1: Conversion of return periods to cumulative probabilities over time

	5 years	10 years	15 years	20 years	25 years	30 years
1 in 500	1.0%	2.0%	3.0%	3.9%	4.9%	5.8%
1 in 100	4.9%	9.6%	14.0%	18.2%	22.2%	26.0%
1 in 50	9.6%	18.3%	26.1%	33.2%	39.7%	45.5%
1 in 25	18.5%	33.5%	45.8%	55.8%	64.0%	70.6%
1 in 20	22.6%	4.0.1%	53.7%	64.2%	72.3%	78.5%
1 in 15	29.2%	49.8%	64.5%	74.8%	82.2%	87.4%
1 in 10	41.0%	65.1%	79.4%	87.8%	92.8%	95.8%

These probabilities are developed using rainfall observations that are accumulated over many years from historical precipitation events. Historic records show that the total annual amount of average annual precipitation has increased on average about 0.2 inches per decade across the United States since 1900. This increasing rate is five times the global annual precipitation increase over the same period (EPA, 2023). Additionally, some areas in the US have been affected more than others. Some regions in the eastern half of the US have seen as much as a 30% increase in annualized rainfall over that period. The western half of the country has seen very little increase in annual precipitation outside of the Pacific Northwest, and annual precipitation totals are decreasing in most of the western US. The additional annualized precipitation is not only impacting some parts of the country more than others, but it also comes in the form of intense single-day events (extreme precipitation events) at a higher rate than in the past (EPA, 2022). Over the last 100 years, until about 1980, the prevalence of intense single-day events remained relatively consistent. However, the occurrence of extreme precipitation events has increased substantially since 1980, as evidenced by the fact that in the past 25 years, 10 of the top 10 years with the highest percentage of land area in CONUS experiencing a heavy precipitation event have occurred (see Figure 2).

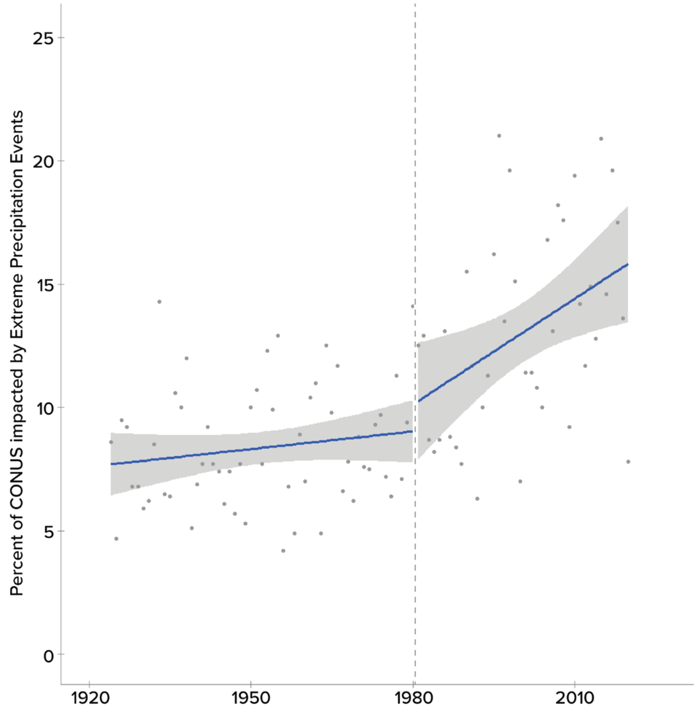


Figure 2: Percent of CONUS impacted by extreme rainfall events, pre- and post-1980. Data source: EPA

Extreme Precipitation in the US

The information used to understand these patterns and trends comes from the precipitation reports produced for the NOAA Atlas 14 (and Atlas 2 for the Northwest states, but for the sake of brevity will be considered as part of Atlas 14 in this discussion). NOAA Atlas products that are being used as the standard for the development of these projects are produced through the National Weather Service's (NWS) Office of Water Prediction's (NWS-OWP) Hydrometeorological Design Studies Center (HDSC) at NOAA. Since the early 2000s, HDSC has been updating the precipitation reports across the country with a focus on the production of localized IDF distributions for every location across the contiguous United States (CONUS). The estimated IDF distributions allow for the understanding of the likelihood of events that reach specific rainfall depths. These data are further used in the estimation of the severity of past historic events, infrastructure design standards, and floodplain mapping, and have become the de facto standard in understanding any CONUS location's precipitation trends (Cornell, NOAA & NWS Joint Report).

There is tremendous value in having a standard precipitation report that sets expectations for the use cases above, but NOAA Atlas 14 has become less accurate in regard to the most extreme precipitation events as such events are increasingly becoming more prevalent across CONUS, due to a changing climate.

In the United States, the increased frequency and intensity of extreme precipitation events have resulted in an increase in the number of severe flood events, leading to dire consequences such as property damage, displacement, and – in the worst cases – loss of life. Stormwater infrastructure is designed to remove much of the excess precipitation produced by extreme precipitation events. This infrastructure is most often designed using Federal or State precipitation records and State and Local government guidelines, many of which rely on Atlas 14 (Lopez-Cantu and Samaras, 2018), which are updated relatively infrequently, resulting in out-of-date standards and stormwater infrastructure that no longer serves to protect municipalities and their residents from their actual current risk of flooding in a changing climate. The risk of building infrastructure that is immediately out of date upon project completion is of particular interest as the IIJA has recently (as of the time of this report) authorized $1.2 trillion in spending on transportation and infrastructure (GFOA, 2022). The funding for many of these projects have already been allocated and are currently in the design stage, raising concerns that the opportunity to vastly improve the resiliency of the Nation's transportation, stormwater management, and public service infrastructure will be missed as these projects are being selected and built to a standard that does not align with the actual flooding risk today, let alone how it will continue to get worse during the useful life of the project.

As the standard by which precipitation reports are measured, NOAA's Atlas 14 precipitation frequency estimates have been effectively out of date since their creation by not incorporating climate change's effects in their production. When new infrastructure projects are developed today using Atlas 14, they are instantly decades out of date and unable to adequately protect against current and future flood risks from heavy precipitation events (NPR). Additionally, these standards will continue to get worse over time, as they also do not consider future precipitation risk from climate change over an infrastructure project's useful life.

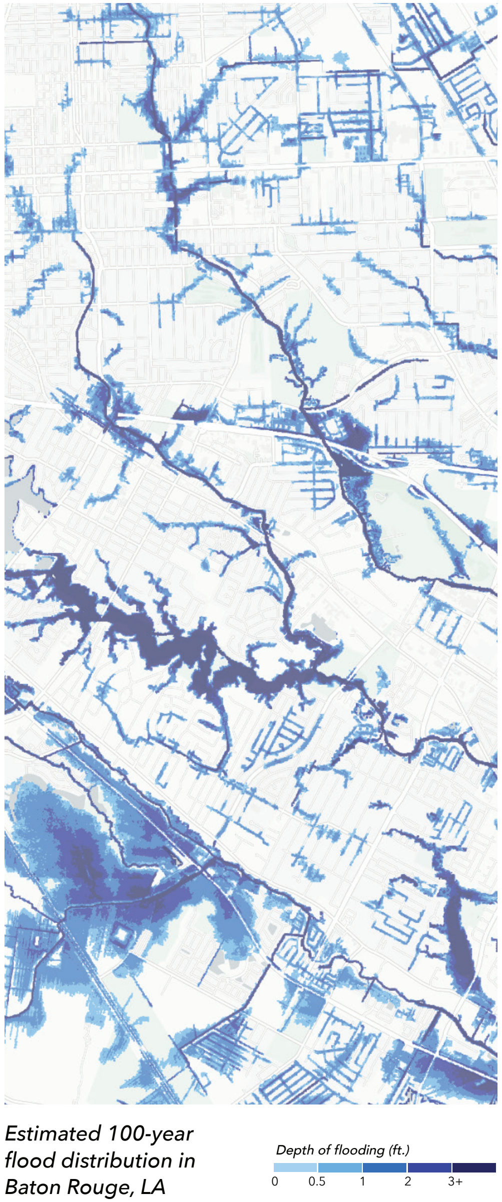
One example of such a project includes $86.1 million of IIJA money that has been allocated to New Jersey to fix a roadway flooding problem (NJ DOT, East Brunswick Project 18). This new system is designed using Atlas 14 to withstand a 10-year event and the pipes along the roadway at the lowest point are designed to a 15-year standard. However, when compared to the NOAA Atlas 14 standards in this area, the FSF-PM finds that the same depth of water is now expected to occur every 4 years (about one and half times more frequently) and over the next 30 years will flood every other year (a 1-in-2 year event). Therefore, once the project is completed it can be expected to flood every other year, despite the new features. This is one of many projects across the country being constructed by recent funding, many of which will be built with outdated and inadequate designed

Extreme Precipitation in the US

standards due to the known issues in NOAA Atlas 14 (Bipartisan Infrastructure Law (BIL) Funded Projects).

NOAA Atlas 14 Known Issues and Atlas 15 Planning

NOAA recognizes many of these issues and is actively working to improve itst estimates of precipitation risk across the country in the forthcoming "Atlas 15" project. The updates to the forthcoming Atlas 15 program are expected to greatly improve the accuracy of the precipitation estimates by including current and future year climate adjustments, or said another way, by correcting for the impact that the changing environment is having on the increasing likelihood and severity of extreme precipitation events over time. Additionally, the new Atlas 15 is going to project precipitation IDF estimates out to 2100, adding in a future expectation of precipitation changes for the first time in the program's history. Finally, and unlike recent versions of the Atlas 14 precipitation estimates which were completed region-by-region, Atlas 15 seeks to produce a consistent single national set of estimates in one seamless process (NOAA ATLAS 15 flier). Unfortunately, NOAA's timeline to completion of the NOAA Atlas 15 precipitation estimates runs through 2027, with work kicking off in earnest in late 2023 and 2024.



Estimated 100-year flood distribution in Baton Rouge, LA

In order to understand why these precipitation reports that are used as an authoritative benchmark for design standards are out of date, it is necessary to understand the methods and sources used in the development of the NOAA Atlas 14 precipitation frequency reports. These reports serve as the de facto national standards for precipitation IDF information in the US (Bonnin et.al, 2007) and have been shown to be problematic in a number of ways (discussed at further length later in this report), including issues with out-of-date estimates, the removal of extreme precipitation observations, and the use of inconsistent methods across the US as Atlas 14 was created piecemeal over time. Taken together, these issues create a standard of flood risk from heavy precipitation events that can be as much as a half-century out of date (Lopez-Cantu and Samaras, 2018; Kim et.al, 2022).

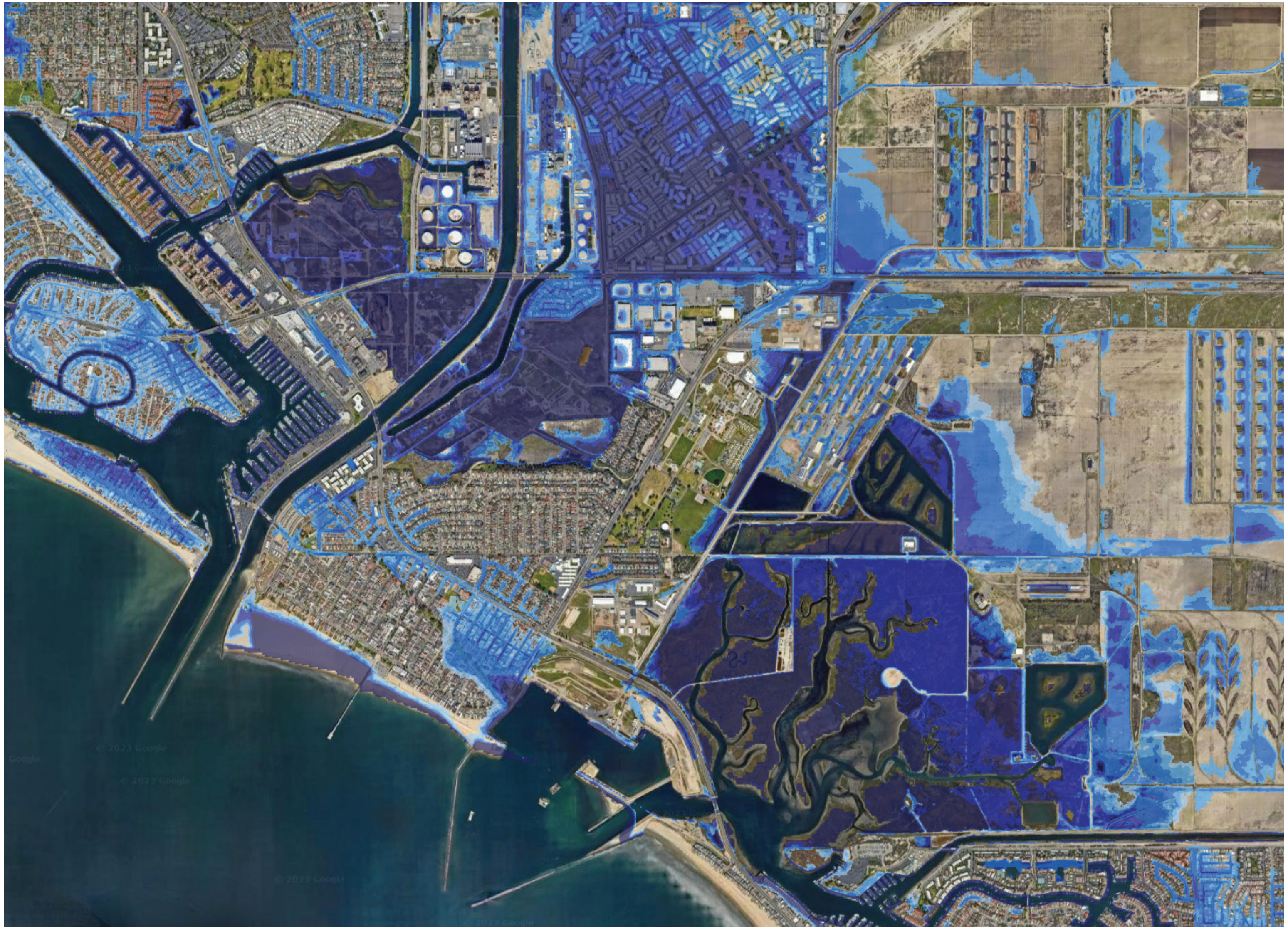
Rethinking How to Understand Precipitation Risk

Historically, the normalization of precipitation events' description has been problematic due to the focus on daily (24-hour) intervals, which neglect the occurrence of extreme precipitation in shorter time intervals (usually 1-6 hours). This issue is not directly tied to the Atlas 14 precipitation report's methodology but rather to historical observation and reporting methods. This emphasis on longer intervals fails to capture the most impactful bursts of precipitation that directly lead to flash floods and overwhelm stormwater infrastructure. Additionally, these shorter intense events are also the events that will be most impacted by climate change and thus are even more important to have an adequate understanding of. Shifting the perspective to shorter interval estimates allows for identifying the intense precipitation rates responsible for flash flooding, property damage, and community inundation, ultimately allowing adaptations to be designed and installed to reduce the risk. For example, while Fort Lauderdale, FL,

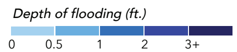
Extreme Precipitation in the US

may be reported to have received "2 feet of rain in a day," in mid-April of 2023, it fails to acknowledge that within that 24-hour period, 26 inches of rain fell in just 6 hours. The intensity of the rain event over such a short duration overwhelmed existing flood control infrastructure and caused flash flooding that closed the airport for over a day. It is crucial to shift the characterization of extreme precipitation events away from 24-hour averages in order to better protect from the consequences of the most intense rainfall events.

To enhance the understanding of flood risk, similar to how the focus has shifted to higher probability flood events, adopting hourly precipitation metrics becomes essential for capturing extreme events, such as flash flooding, and communicating risk over shorter durations. In addition to addressing the known issues of Atlas 14, communicating risk through shorter internals is also one of the main focuses of the FSF-PM.



Estimated 100-year storm flood distribution in Seal Beach, CA



The First Street Foundation Precipitation Model (FSF-PM)

To address the known issues in the NOAA Atlas 14 precipitation estimates, the First Street Foundation developed the FSF-PM, a new analysis of precipitation frequency estimates using early 21st-century rainfall records. The FSF-PM shows that the US will experience more occurrences of extreme precipitation (heavy rainfall) and that the recent experiences of catastrophic events over the last few decades should be treated as the "new normal" for many areas.

The FSF-PM consists of two main parts: (1) a baseline to develop the foundational standard accounting for temporal trends in recent-historical observations and (2) a climate adjustment to develop the current and future standards by adjusting the baseline standard with "change factors" based on future climate model projections. The technical details of the baseline are documented in Kim et.al, 2022. The methods employed in the creation of the FSF-PM are standard methods employed in the creation of IDF curves and precipitation estimates, but also correct for some of the known issues in the NOAA Atlas 14 estimates documented above and add a climate adjustment to account for current and future climate conditions. These adjustments allow for an early understanding of what the new NOAA Atlas 15 precipitation estimates are likely to look like once they are completed in 2027, today. The FSF-PM identifies significant differences across the country in regard to the alignment of NOAA Atlas precipitation estimates to actual rainfall risk in the area.

What this means for communities today is that their understanding of risk is often underestimated, and in many locations the infrastructure in place or that is currently being built to protect communities, property, and individuals is built to an insufficient standard. When the NOAA Atlas 14 estimates of the depths of precipitation corresponding to a 1-in-100 year event are examined, those events are estimated by the FSF-PM to occur in many locations much more frequently than previously estimated. In much of the Northeast, the Ohio River Basin, Northwestern California, the Texas

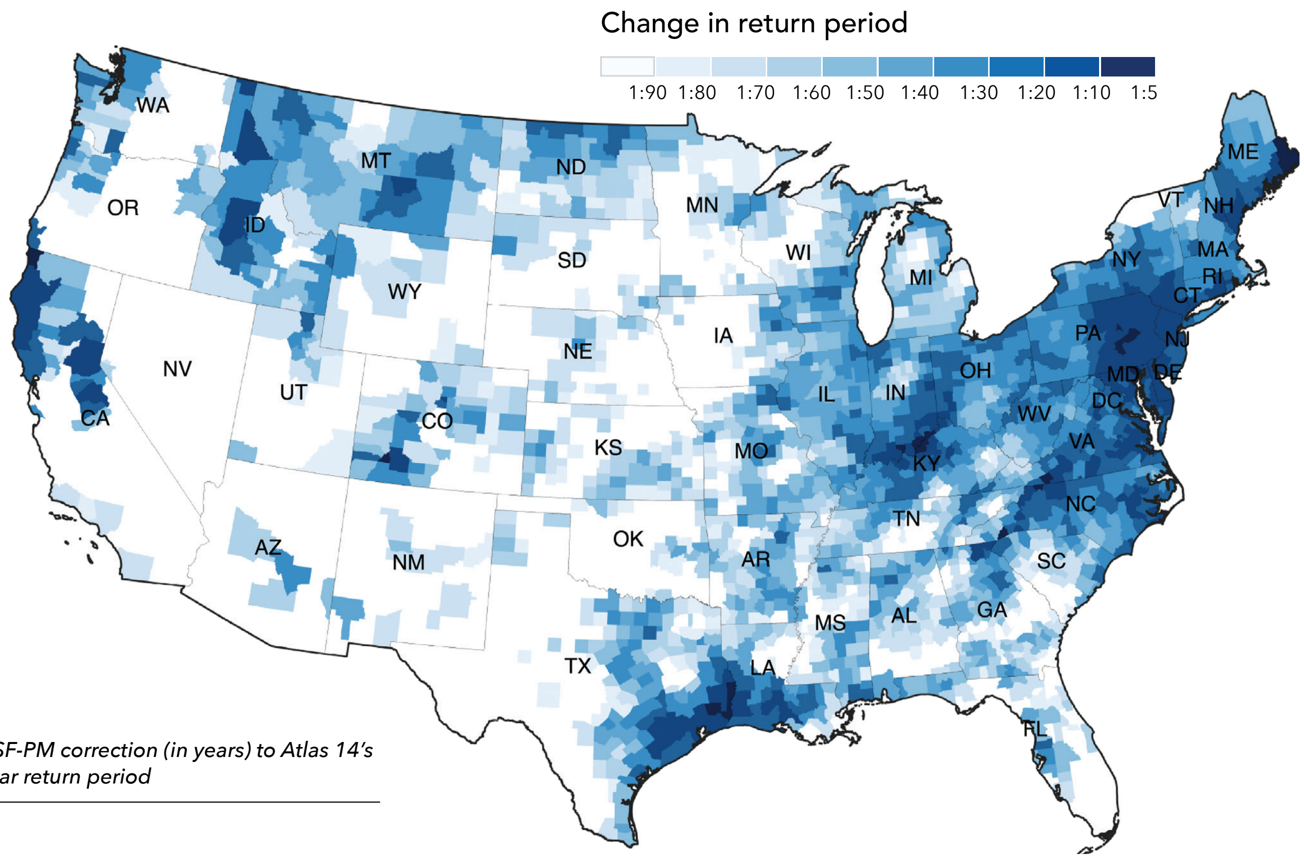


Figure 3: FSF-PM correction (in years) to Atlas 14's 1-in-100 year return period

The First Street Foundation Precipitation Model (FSF-PM)

Gulf Coast, and the Mountain West, the depths corresponding to a 1-in-100 year event (or 1% annual probability) are actually modeled to occur at least every 5 to 10 years (or up to a 20% annual probability). However, it is also important to note that the known issues in the Atlas 14 precipitation records also produce overestimates in some areas. For example, in some areas just east of the Sierra Nevada and Cascade mountain ranges running from Southeast California to Canada through Nevada, Oregon, and Washington, estimates are as much as 50% higher than FSF-PM estimated precipitation risk in the area. Infrastructure in this area is therefore being built to a level far above what would be sufficient to protect from the area's actual precipitation risk, using extra resources that could be better spent elsewhere.

From the map, it is clear that a disproportionate amount of the most impacted areas are also highly populated areas. When converting water depths that are currently associated with a 1-in-100 year flood in Atlas 14 to the equivalent return period in FSF-PM, the FSF-PM shows that in 1,128 counties the same depth of water from a 1-in-100 year event is actually reflective of a 1-in-50 year flood event. This represents 36% of all counties in which 167 million individuals currently live. This means that 51% of the population is now more than twice as likely to experience what the local communities currently would consider a 1-in-100 year flood. Moreover, the 1-in-100 year depth of floodwater from heavy precipitation is now equivalent to at least a 1-in-20 year flood depth in 221 counties, resulting in 7% of the total population (over 43 million individuals) now being five times more likely to experience an event of that severity. In the most extreme case, 20 counties are 10 times as likely to experience a 1-in-100 year in any given year than the current local community's expectations, impacting over 1 million residents in those areas.

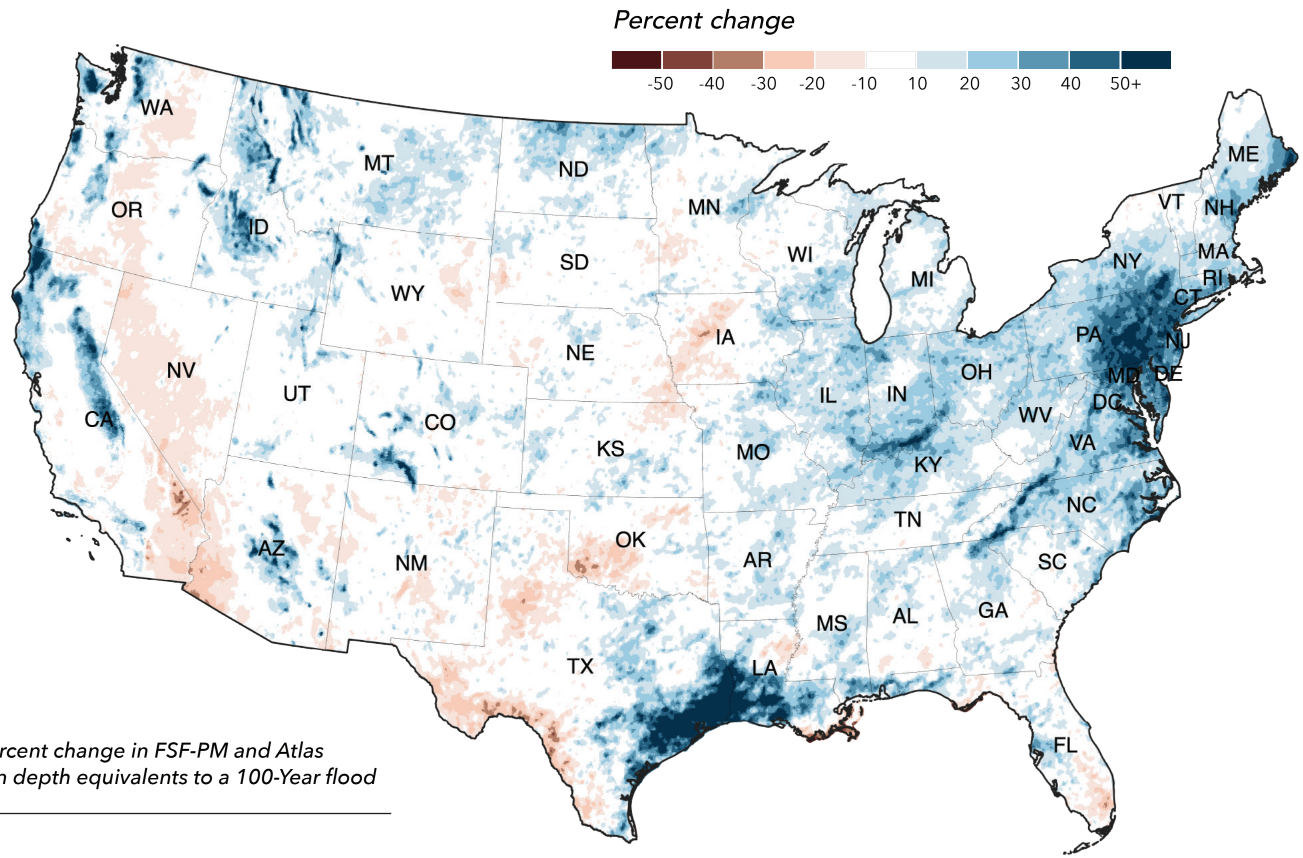


Figure 4: Percent change in FSF-PM and Atlas precipitation depth equivalents to a 100-Year flood

The First Street Foundation Precipitation Model (FSF-PM)

The population centers most likely to have the largest misaligned understanding of precipitation risk using Atlas 14 precipitation estimates tend to be clustered in the Northeast. Specifically, the percent increase in risk between FSF-PM and NOAA Atlas 14 is highest in Baltimore (+614%), Dallas (+376%), Washington D.C. (+376%), and New York City (+335%). In the Midwest, Chicago (+203%) and Detroit (+186%) both see significant increases in risk across the models as well. The size of the correction between NOAA Atlas 14 and FSF-PM current-year risk is also expected to grow into the future due to climate change. Most pronounced is the increasing level of risk over the next 30 years in Baltimore (+733%), Detroit (+525%), and Dallas (+456%).

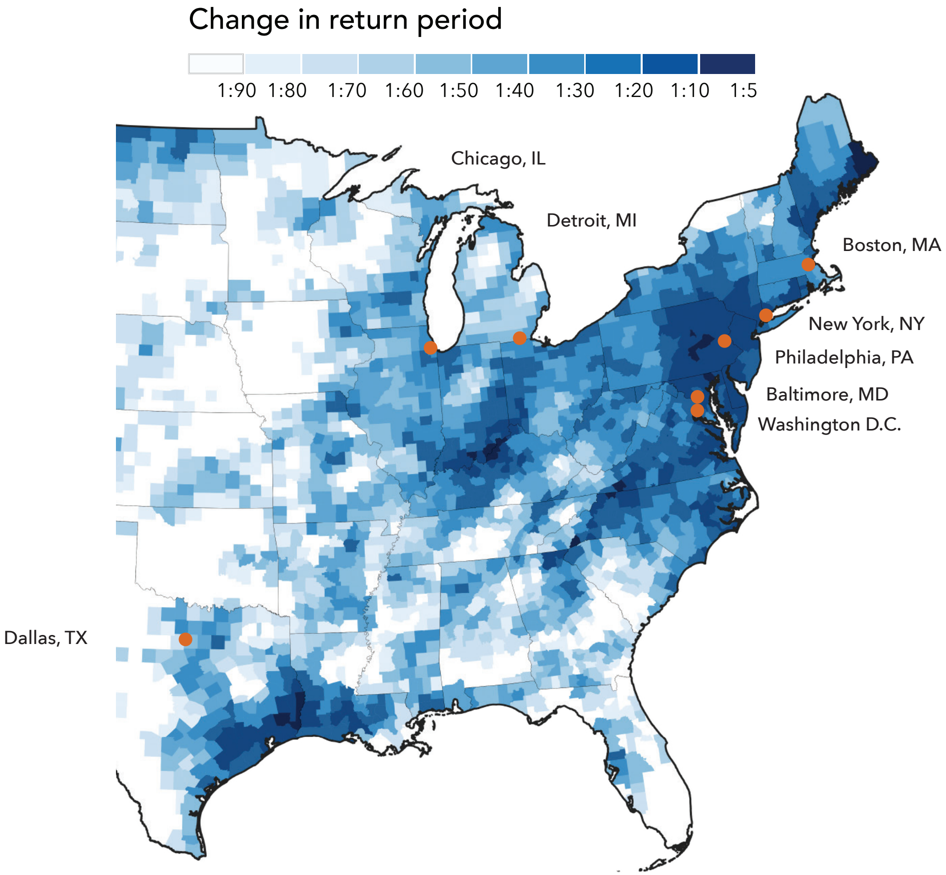


Figure 5: Major cities at more frequent risk of severe flooding compared to NOAA Atlas 14 100 year estimates

Table 2: Counties and population at risk by increased frequency of current 1-in-100-year flood event (FSF-PM vs. Atlas 14 comparison)

1 in 100 is (times more likely)	# of counties impacted	Population impacted (millions)	Percent of counties impacted (%)	Percent of popualtion impacted (%)
1 in 50 year or lower (+200%)	1128	167.2	36.3%	51.1%
1 in 25 year or lower (+400%)	367	69.8	11.8%	21.3%
1 in 20 year or lower (+500%)	221	43.6	7.1%	13.3%
1 in 15 year or lower (+667%)	95	22.4	3.1%	6.8%
1 in 10 year or lower (+1,000%)	20	1.3	0.6%	0.4%
Total US	3107	327.5		

Table 3: Selected highly populated cities impacted by Atlas 14 to FSF-PM corrections

City	Atlas 14	Corrected for today	30 year correction
Baltimore, Maryland	1 in 100	1 in 14 (+614%)	1 in 12 (+733%)
Dallas, Texas	1 in 100	1 in 21 (+376%)	1 in 18 (+456%)
Washington, D.C.	1 in 100	1 in 21 (+376%)	1 in 19 (+426%)
New York City, New York	1 in 100	1 in 23 (+335%)	1 in 19 (+426%)
Philadelphia, Pennsylvania	1 in 100	1 in 29 (+245%)	1 in 20 (+400%)
Chicago, Illinois	1 in 100	1 in 29 (+245%)	1 in 26 (+285%)
Detroit, Michigan	1 in 100	1 in 34 (+194%)	1 in 16 (+525%)
Boston, Massachusetts	1 in 100	1 in 37 (+170%)	1 in 33 (+203%)

NOAA Atlas 14 Methodology and the FSF-PM Corrections

Previous research has highlighted the known issues with NOAA Atlas 14 and its use as the standard precipitation frequency estimates for the country, leading to inaccurate flood risk assessments and inadequate infrastructure preparedness (Bonnin et.al; 2007, Lopez-Cantu and Samaras, 2018). The lack of comprehensive funding from Congress was one of the major obstacles to updating the outdated data; NOAA's Atlas 14 work had previously been funded sporadically on a state-by-state basis, not from a central Federal source. However, new appropriation and authorization bills have been passed, which provide both the funding and the mandate for NOAA to update the flood risk information. As of 2023, NOAA has initiated a five-year process to update the data, which will be known as NOAA Atlas 15, in 2 volumes. Volume 1 of Atlas 15 will provide a more representative and comprehensive understanding of the frequency and intensity of extreme precipitation events in the current year, while Volume 2 will provide projections of those rainfall events characteristics for future years to account for a changing climate. Atlas 15 will help improve the flood risk assessment and management in the United States, and thus enable better infrastructure preparedness and reduce the likelihood of drainage system failure, property damage, and loss of life due to flooding events.

However, there is an urgent need today for Atlas 15's results to meet the challenges of climate change, both to drive more accurate models of flood risk and to help design infrastructure projects today that will protect communities from that risk. To create more reliable and representative estimates of heavy precipitation occurrence and flood risk that are available right away, and using the same proposed methods as Atlas 15, First Street Foundation has taken on a new effort to create new rainfall statistics for CONUS that address the main causes of underestimation in the NOAA Atlas 14, which are highlighted in the sections below. This work has resulted in a new set of precipitation frequency estimates that are more representative of the current state of heavy precipitation occurrence and flood risk today and into the future, and that have undergone a rigorous peer-review process to be published in the Journal of Hydrology: Regional Studies (Kim et.al, 2022). This research details the process by which known issues in the NOAA Atlas precipitation frequency estimates were addressed, including 1) out-of-date data that do not capture climate change's influence, 2) extreme event removal, and 3) inconsistent calculation methods, including the use of only the most sophisticated rain observation ASOS stations in the larger network.

Out-of-Date Data

NOAA Atlas 14 assumed that extreme precipitation does not change, which is not in alignment with how extreme precipitation has evolved rapidly over the past 40 years due to climate change. The precipitation records used in the NOAA Atlas 14 development date back to the year 1816 and, in some cases, run for almost 200 years. There is nothing wrong with utilizing long-term period data early in the 20th century, where the increasing extreme precipitation was not statistically significant. But, the late 20th and early 21st century have seen a rapid increase in the evolution of precipitation events, in frequency, duration, and spatial coverage. Additionally, the focus on using all available data means that observations from inactive stations are also included in the regional estimation of precipitation rates. Currently, the NOAA Atlas 14 precipitation reports generally underestimate the changing risk by relying on a method that worked very well in the last century but is not able to accurately capture the increasing levels of precipitation in the current climate. As an example of this issue, the current method relies on an expectation of precipitation at the median year of the observation window. Across all of the stations, the median year of current NOAA records is approximately 1970, over 50 years ago. So, on average, the understanding of precipitation expectations today is about 50 years out of date because that analysis assumes that the statistical characteristics of rainfall events have not changed over time. In the most extreme case, a weather station in North Adams, MA, recorded precipitation observations from 1816 through 2014 (199 years of data) and reports a median year of 1914, meaning that the derived precipitation estimates for this specific station would be based on an expectation from over 100 years ago.

NOAA Atlas 14 Methodology and the FSF-PM Corrections

While such a long time series helps resolve very infrequent events, this reliance on the full set of observations to produce a median expectation more significantly means that the data do not represent the risk of extreme precipitation events in today's changing climate, given the increase in frequency, intensity, and duration in recent decades.

An example of the increasing occurrence of extreme precipitation events occurred in 2022, when the US saw five separate 1-in-1,000 year events within a single one-month period, including:

July 26th, 2022 in St. Louis, MO
July 28th, 2022 in Eastern KY
August 1st, 2022 in South Eastern IL
August 5th, 2022 in Death Valley, CA
August 22nd, 2022 in Dallas, TX

The occurrence of five 1-in-1,000 year events in the US within a month highlights the increasing magnitude and frequency of extreme precipitation events. However, these events should no longer be accurately characterized as a 1-in-1,000 year event in the current climate conditions due to changes in baseline expectations for precipitation estimates, although this characterization was accurate approximately 50 years ago when the baseline expectation for the areas' precipitation estimates were based. Additionally, the impact of any one single station is negated by the fact that the NOAA Atlas 14 approach combines homogenous (stations with similar characteristics) together in a "Regional Frequency Analysis" (RFA). This RFA ensures that multiple record locations are used to produce the best estimates of the modeled precipitation frequency. However, this approach, while taking into account more records, also depresses recent records which may be a better reflection of the current climate by weighing more recent records towards early time periods, and hence earlier climate conditions, based on the baseline expectation at each of the stations.

To resolve the new statistical characteristics of rainfall across the United States, the First Street Foundation has developed a new precipitation model from NOAA's early 21st-century record of rainfall collected from its network of Automated Surface Observing System (ASOS) stations, centered on the year 2011. Given the limitation of the 20-year length of the historical data time series, the First Street Foundation analysis still has the issue that the data themselves do not fully resolve the current year's extreme precipitation, and must rely on extreme value theory and mathematical techniques to estimate precipitation at higher return periods. To account for the non-stationarity issue, First Street Foundation introduces estimates of future climate conditions and centers the estimates of any area on today's climate (2023). This correction is then applied to every station in the creation of the First Street Foundation precipitation estimates prior to implementing the same RFA that NOAA uses in its analysis. The future climate "change factor" is computed as a scaled adjustment based on the trajectory of changes between the recent (2002-2021) precipitation patterns and the projected

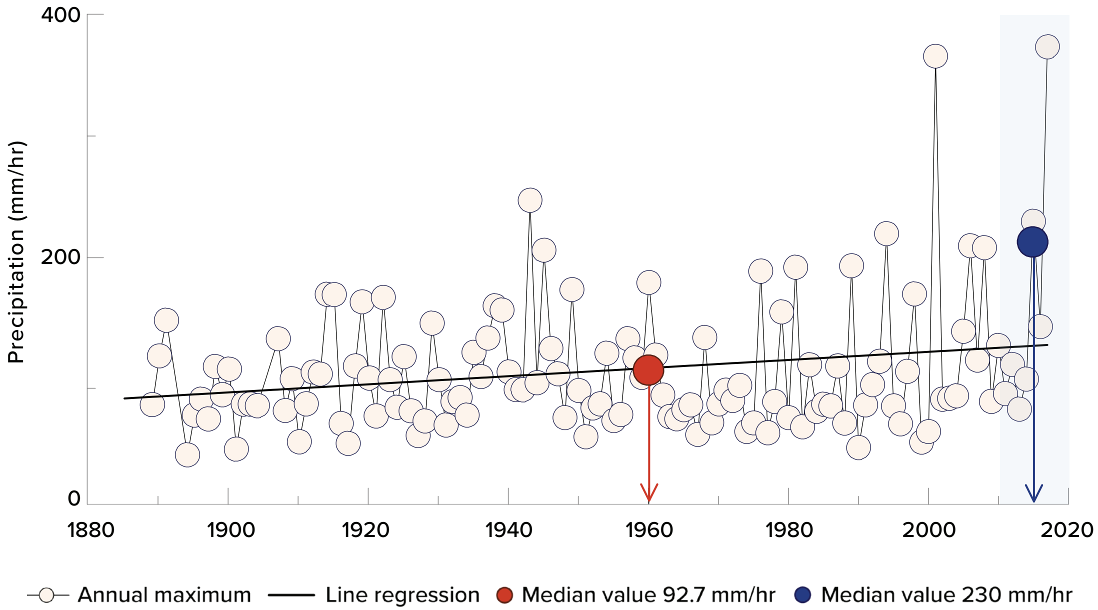


Figure 6: Illustration of the expected from larger period-of-record station observations (gauge location in central Texas)

NOAA Atlas 14 Methodology and the FSF-PM Corrections

future precipitation estimates derived from the international community's climate model output (i.e., from the United Nations World Climate Research Programme's Coupled Model Intercomparison Projection Project-Phase 6, known as "CMIP6") as expectations of future conditions and precipitation patterns. These change factors derived from the CMIP6 model outputs are applied to develop the First Street Foundation precipitation estimates corresponding to the current (2023) and future years (2053). The methods used by the First Street Foundation in the FSF-PM development are similar to the NOAA Atlas 14 method; however, by correcting for the nonstationary nature of increasing extreme precipitation patterns, the FSF-PM statistics reflect the impact of a changing climate in the way that NOAA Atlas 15 will in the future.

In the example observation record from this gauge in central Texas (Figure 6), the year represented by the median precipitation measurement is 1960. However, the last 5 years of recorded observations (median representing ~2018) show a 148% increase in the precipitation measurement by adjustment to a more recent climate condition over the nearly 60-year period.

Of the 10,854 stations used in the Atlas 14 product, 75% are representative of a climate indicative of the environmental conditions in 1980 or earlier. At the extreme end, there are some stations representative of the climate conditions in the late 1940s and about 14% of the gauges are representative of 1965 or earlier conditions.

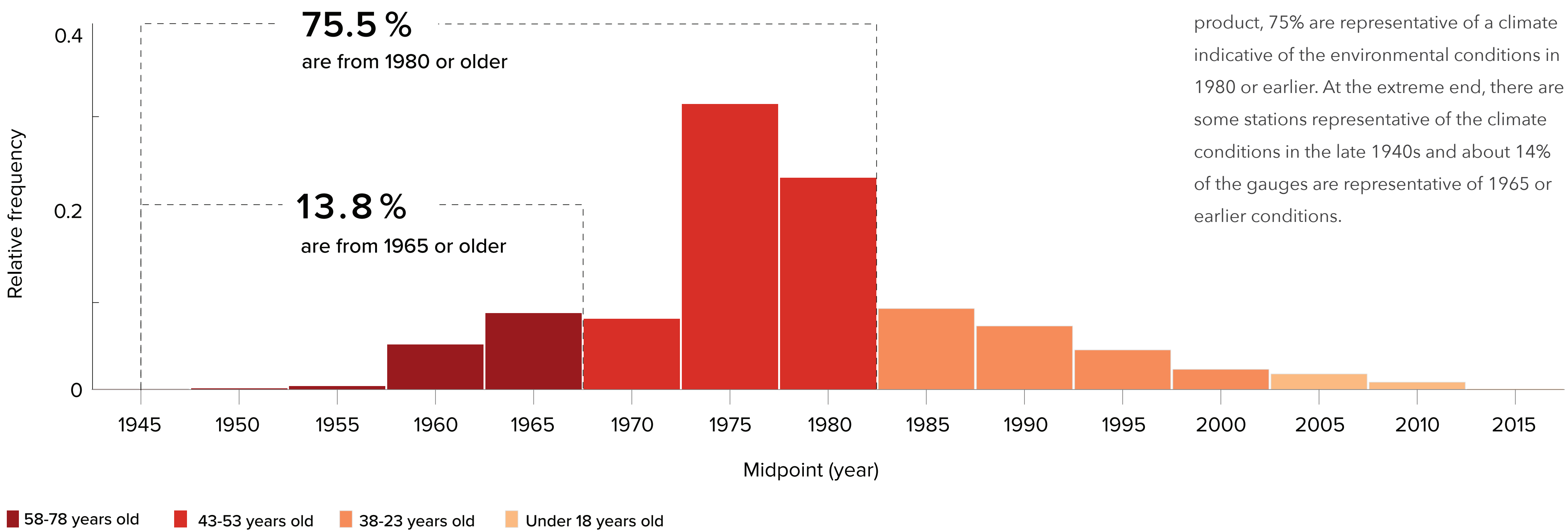


Figure 7: Climate representation of the number of Atlas 14 precipitation gauges

NOAA Atlas 14 Methodology and the FSF-PM Corrections

Inconsistent Calculation Methods by Region and Time

Closely related to the previous discussion of non-stationarity and out-of-date data, Atlas 14 precipitation reports were produced region-by-region and often state-by-state. The splitting of the process into smaller regional processes was related to the availability of funds to complete the work and allows for the ability to manage a more focused project in specific areas of the countries. However, this approach also has the systematic disadvantage of producing results across the country that are not standardized nationally in the same, single time period. Given that the most recent trends in extreme precipitation reflect an increasing rate, the use of varying time periods in neighboring regions means that areas that are spatially adjacent often have noticeably different results across the boundaries of those regions.

Other issues associated with the standardization of homogenous stations for the regional frequency analysis, as well as the implementation of the models by different scientists at different times, can also lead to some spatial discrepancies in the results. However, it is the use of data from varying time periods that most directly leads to differences across boundaries that are the result of data artifacts and not realistic differences in precipitation characteristics. Specifically, the use of different observational time periods serving as the baseline may result in dramatically different results along the boundaries of regions. Important decisions concerning the development of infrastructure and management of risk will therefore hinge, at least partially, on inconsistent methods, inconsistent timing, and different approaches to producing the results of the Atlas 14 precipitation reports across regional boundaries.

First Street Foundation, on the other hand, uses a single consistent method with a single consistent time period of data across the entire country which avoids those differences at the edges of regions identified in the different Volumes of the NOAA Atlas 14 precipitation estimates. Most importantly, the FSF-PM is produced with consistent precipitation observations from the ASOS stations, eliminating bias adjustments and sources of random error common across different types of surface weather stations used in the creation of Atlas 14, allowing for all of CONUS to be modeled in a way that better resolves the current levels of increasing risk of extreme precipitation events. The ASOS stations, typically installed at airports across the US, are considered to be a reliable, consistent standard in precipitation observations.

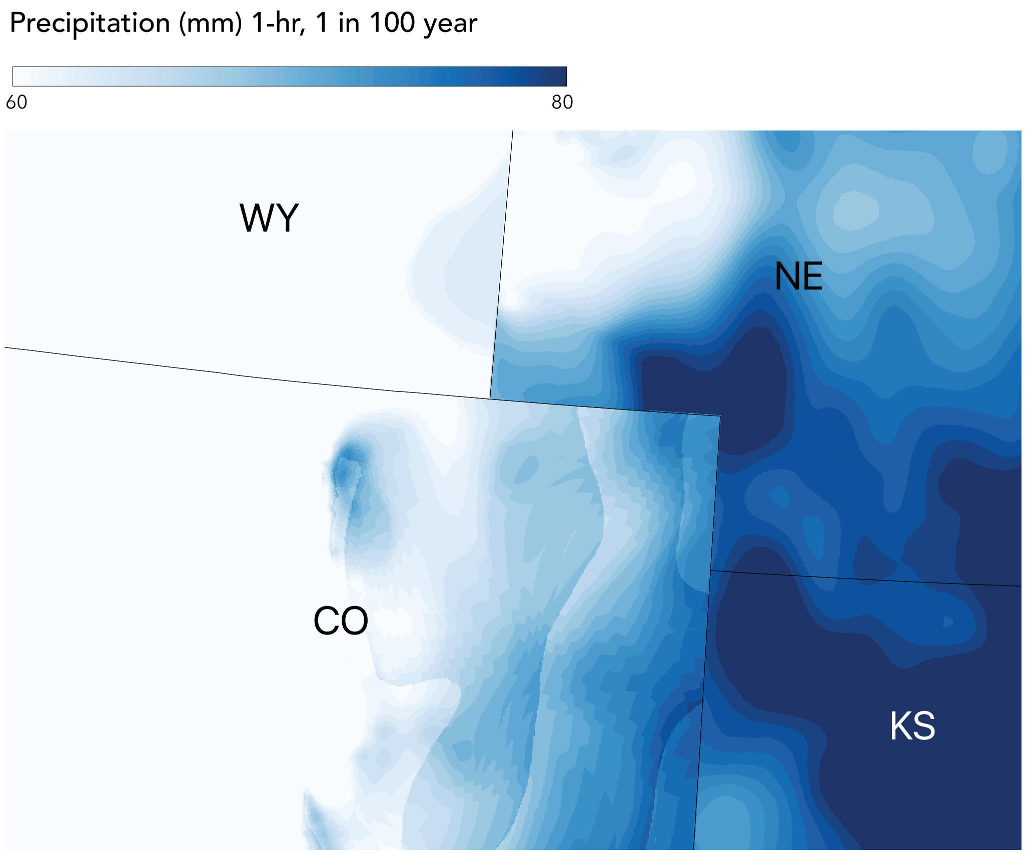


Figure 8: Highlighting man-made differences in Atlas 14 precipitation expectations across region boundaries

NOAA Atlas 14 Methodology and the FSF-PM Corrections

By using a single set of observation stations in the larger NOAA Atlas 14 network, the FSF-PM also reduces biases and eliminates measurement differences across various observing networks. It is important to note that the methods employed in the FSF-PM are very similar to those that were employed in the creation of Atlas 14 along with the proposed Atlas 15 improvements. However, the fact that a single consistent method is employed across the entire country ensures that only variations in the model are driven by the model inputs and not by arbitrary regional boundaries or different time periods considered, or the local adjustments made by different model teams.

ASOS Rain Gauges
High Reliability

All weather precipitation accumulation gauge sensor, developed by Ott Hydrometrie of Germany

Well- maintained as part of NOAA's observing system

Periodically calibrated and automatically collected

USGS Rain Gauges
Good Reliability

Added to some USGS stream gauges

Infrequently calibrated and manually collected (every 6 weeks)

Standard Rain Gauges
Lower Reliability

Network of 8,500 volunteer contributors with varying models and methods

Manually maintain, record, and submit data to NOAA with different systems

Figure 9: Examples of some types of the 10,000+ rain gauges used in Atlas 14

NOAA Atlas 14 Methodology and the FSF-PM Corrections

Extreme Event Removal

NOAA Atlas 14 maps the observed precipitation estimates to a regularly-spaced grid across the entire United States based on a combination of rain gauge data and PRISM Climate Group's spatial analyses (Daly et al., 1994; 2017). PRISM's smoothed climate spatial analyses were derived to account for variations in elevation across the landscape that can give rise to variations in atmospheric parameters. In this method, a smoothing technique is used which helps to remove noise and inconsistencies in the data but may result in overly smoothed data. By over-smoothing the data, the most extreme observations are removed on both the high and low end of the precipitation scale. In general, the process of smoothing ensures that problematic observations (i.e. noisy or erroneous data) are removed from the resulting precipitation reports. However, the process of an overly-strict correction of the data, via the smoothing process, can lead to the removal of the precipitation events that are most problematic to communities and the residents of those communities – extreme precipitation events that lead to flood risk. Both NOAA Atlas 14 and the FSF-PM map the precipitation estimates across the entire country based on weather station data and underlying PRISM climate spatial analyses, including temperature, distance to coast, precipitation records, topography, terrain height, terrain aspect, and elevation. The FSF-PM also applies a smoothing process to remove outliers, but localizes that process in an attempt to spatially limit the process to avoid over-correcting the estimates. A single smoothing correction is applied to preserve the contour edges while removing noise using surrounding values.

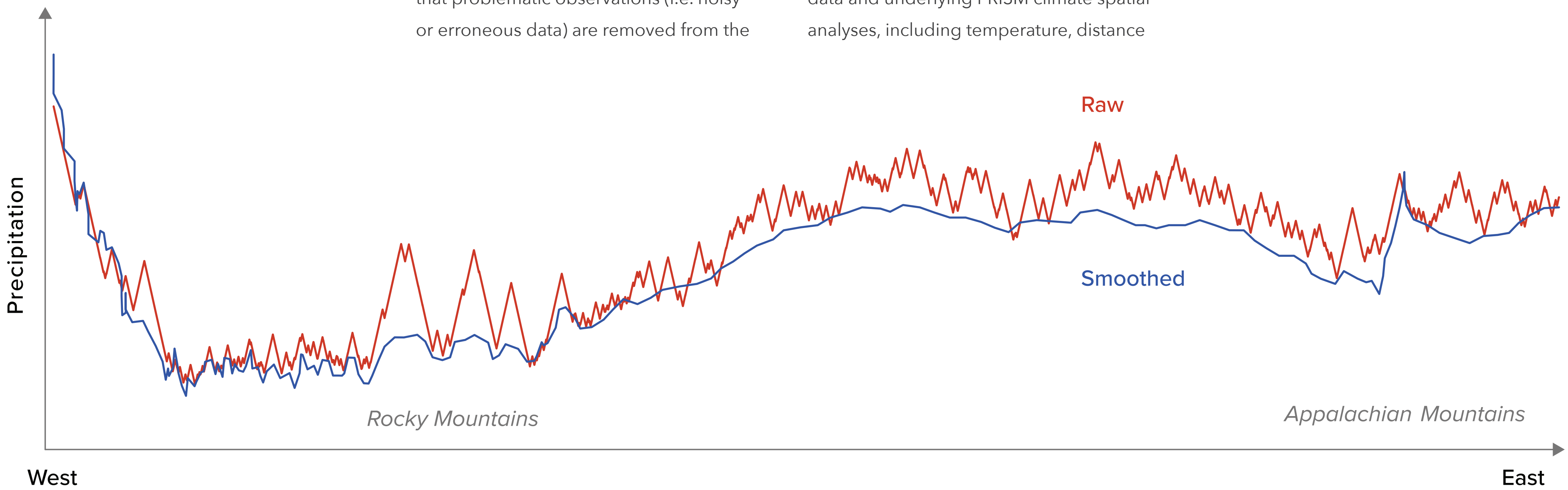


Figure 10: Raw (red) and NOAA Atlas 14's smoothed (blue) precipitation observations along a linear path across the US.

NOAA Atlas 14 Methodology and the FSF-PM Corrections

This approach is beneficial for removing spurious high or low data points that are not in line with the immediate area, allowing for a better understanding of the most extreme precipitation events. This allows the FSF-PM to retain the local signals of extreme precipitation events, rather than spatially over-smoothing and removing the meaningful signals arising from local elevation, distance to water, and climate features. This method allows estimations of the high-resolution differences between nearby areas, reflecting real changes and local impacts of extreme events. This is represented by the increased variation in the FSF-PM map, when compared to the NOAA map, in the next figure.

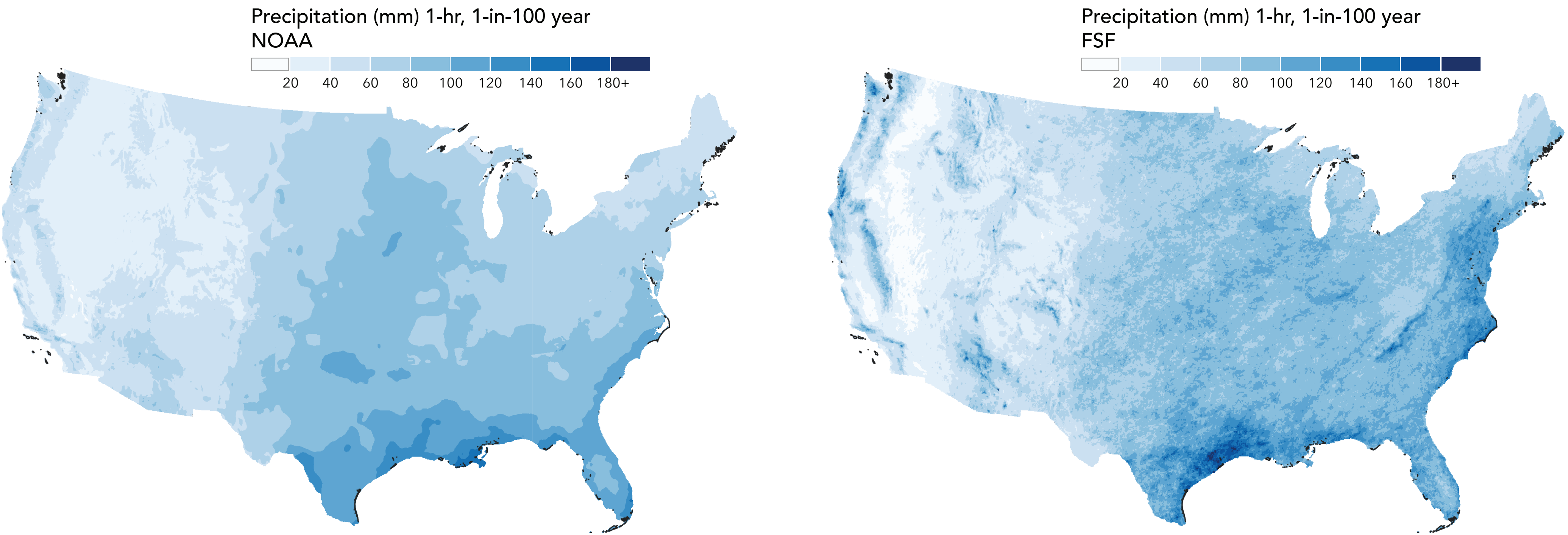


Figure 12: Comparison of NOAA Atlas 14 and FSF-PM smoothed precipitation estimates

FEMA's SFHA compared with FSF-FM and FSF-PM

The outdated characterization of flood risk across the nation due to a misrepresentation of extreme precipitation events under a changing climate is further exacerbated by the use of the FEMA SFHA as the prevailing authoritative standard for flood risk in the United States. A SFHA is, by regulatory definition, based on the 1-in-100 year flood zone due to riverine or coastal effects and does not account for precipitation or climate change as factors in flood risk. This has significant consequences regarding flood insurance price and availability, building code standards, and community adaptation to known flood risk. It also means exposure to the financial community as flood insurance is not mandated for federally backed mortgages in areas subject to only pluvial (precipitation) flood risk. This also means there is substantial risk of financial ruin for the homeowners who experience flood events without insurance. An estimated 40-60% of flood loss claims outside of the FEMA SFHA are estimated to be due to their lack of precipitation and climate change adjustments (FEMA).
The FEMA Risk Rating 2.0 (Equity in Action) insurance program was fully implemented on April 1st, 2023 as a way to use an actuarially sound pricing approach to account for the known shortcomings of the current FEMA SFHA designations and the associated pricing of policies. While there are other important and known limitations, the main model limitation of the SFHA is the lack of precipitation risk in the development of the SFHA. The FEMA Risk Rating 2.0 program was announced as a way to ensure that all flood risks are accounted for, and that properties with higher flood risk pay a price commensurate with that higher level of risk, while those properties with lower risk pay a lower premium regardless of their SFHA designation. The result is insurance premium pricing which better reflects flood risk, is equitable, and is an important step towards balancing the $36 billion deficit that the National Flood Insurance Program (NFIP) has accumulated since its founding in 1968. However, a known issue with this approach is that the pricing of flood insurance is, as a result, decoupled from the FEMA SFHA. The SFHA is now used to enforce the flood insurance mandates that come with federally backed mortgages, communicate flood risk publically, and to define standards such as for building codes but is not a part of pricing. FEMA now has one model that is (1) publicly available and the authoritative source used to communicate the SFHA, and (2) another, private flood model that corrects the known shortcomings of the FEMA SFHA mapping process and dictates the pricing for all properties in the United States.

While the new private model is not publicly available outside of the FEMA released ZIP Code level premium averages, the gap in the number of properties that have substantial flood risk in the private model and the publicly available SFHA maps may be approximated by substituting in the FSF-FM. These estimates provide an understanding of the hidden flood risk that is known to FEMA and the federal government, but not communicated to those who are at risk or provided to other levels of government as a way to understand flood risk and implement appropriate flood adaptation and mitigation efforts.

On a national scale, the FSF-FM, which now includes the newly developed First Street Foundation Precipitation Model (FSF-PM), reveals that approximately 2.2 times more properties are deemed to have a 1-in-100 annual flood risk or greater (significant risk) compared to the FEMA 1-in-100 SFHA designation. This amounts to approximately 17.7 million properties across the country that are at substantial risk or greater. Out of these properties, 9.8 million are likely to have an underestimated understandings of their home's risk because their properties are not recognized as being within the FEMA SFHA zone, and have therefore received no communication from FEMA or any other authoritative governmental agencies about this risk. In total, there are 12.6 million properties in the FSF-FM 100-year flood zone that are not in FEMA's SFHA. Likewise, there are 2.9 million properties in FEMA's SFHA that are not in the FSF-FM's 100-year flood zone. The latter represents properties in coastal regions and along main river channels that are grouped into the larger binary SFHA zone. When looking at the properties in the FSF-FM 100-year zone which are not identified as at risk within the FEMA SFHA, it is possible to estimate what proportion of this gap is due to the fact that FEMA does not integrate precipitation risk in

FEMA's SFHA compared with FSF-FM and FSF-PM

the development of the SFHA. Over 65% (8.3 million) of all properties with risk in the FSF-FM's 100-year zone and are not in the FEMA SFHA, are predominantly at risk of flooding due to precipitation. The states with the highest percentage of their properties not included in the SFHA due to precipitation risk include Washington D.C. (91%), Mississippi (90%), Iowa (83%), Kentucky (83%), and Rhode Island (83%). Additionally, the states with the largest absolute number of homes not included in FEMA's SFHA due to the lack of inclusion of precipitation risk include Texas (858k), Pennsylvania (531k), New York (417k), North Carolina (383k), and California (382k).

When comparing the number of properties with substantial flood risk defined by the FSF-FM with estimates from FEMA, some locations (Washington D.C.) are estimated to have as much as 14 times the amount of properties with substantial risk. These differences are especially stark throughout the central portion of the country (stretching from Montana) through western Texas. Other areas clustered from the Northeast through the mid-Atlantic states are also estimated to have large differences in the number of properties with substantial risk and also align with areas highlighted earlier in this report as having severely underestimated precipitation risk estimates from Atlas 14. The states with the most significant disparities between the estimates from the FSF-FM and the FEMA SFHA designation are Washington D.C. (1,284% difference), Utah (691% difference), Pennsylvania (451% difference), Tennessee (387% difference), and Maryland (342% difference).

The substantial differences between the identified properties with flood risk in the 1-in-100 year return period illustrates the significance of using a comprehensive flood modeling approach by considering various factors such as precipitation, adaptation, and other relevant flood inputs. The higher number of properties with substantial flood risk in the FSF-FM than what is estimated through the FEMA SFHA indicates that a large portion of the US population may

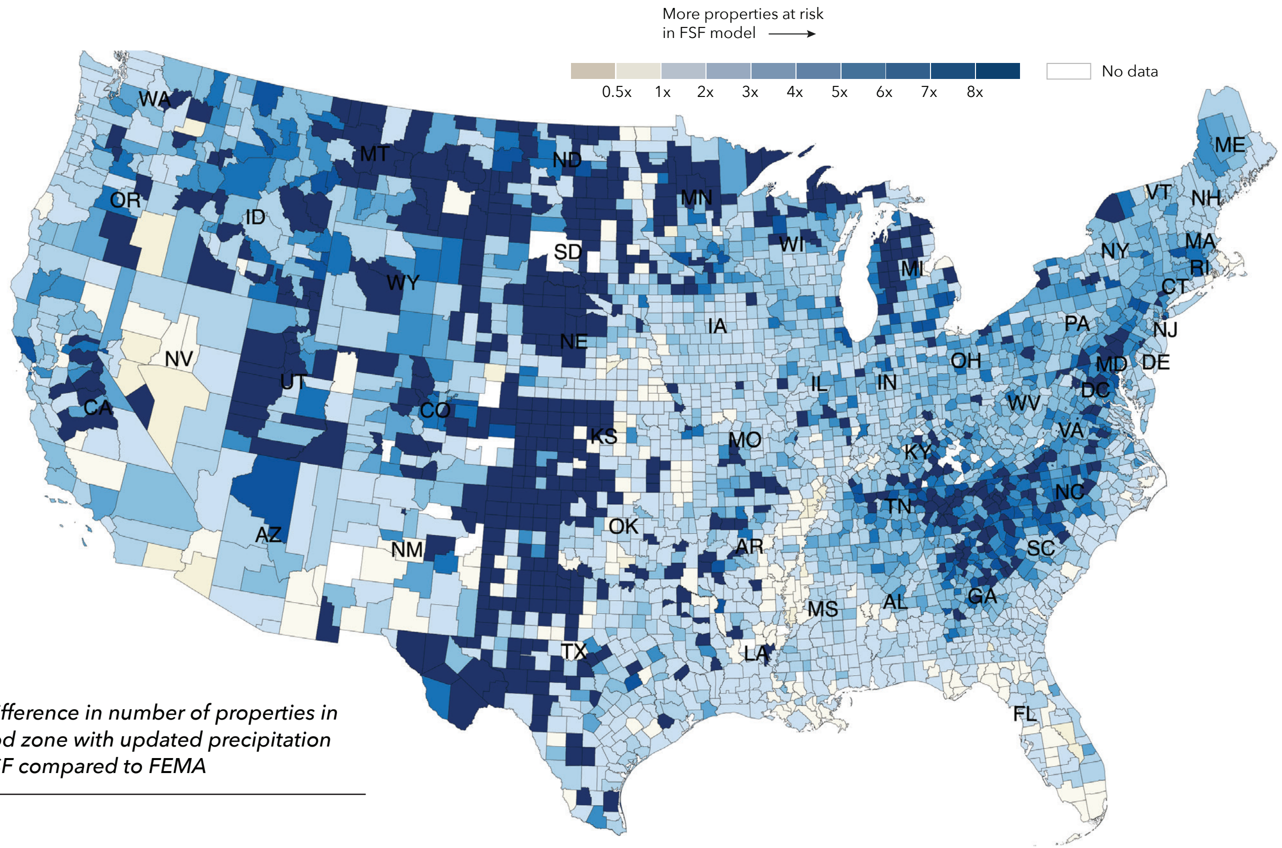


Figure 13: Difference in number of properties in 100 year flood zone with updated precipitation estimates, FSF compared to FEMA

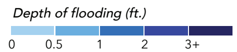
FEMA's SFHA compared with FSF-FM and FSF-PM

be living with unknown levels of flood risk, leading to potentially dire consequences for individuals and communities.

To validate that this is a known gap between the FEMA private pricing model and the public FEMA SFHA maps, the [newly released premium updates] by ZIP Code may be examined, which were released by FEMA in May of 2023. In areas that are outside of the FEMA SFHA and where the FSF-FM shows precipitation is the main cause of flooding, some ZIP Codes may see as much as a $6,580 increase in the average cost of their annual insurance premiums. In fact, in 187 of those ZIP Codes (~7% of all Zip Codes across the US) FEMA is estimating the insurance costs to rise by $2,400 annually to at least double over their current rates.

A stark example of this can be found in Glendale, CA. The 91201 ZIP Code in Glendale is an area that has zero properties located within the SFHA, and yet has a significant risk of precipitation flooding in the FSF-FM. FEMA's new Risk Rating 2.0 estimates show that, at the time of this report, the previous cost of flood insurance for policies in force in the ZIP Code averaged $688 per year but is now projected to grow to $5,766 per year (a 738% increase). Due to the fact that properties in this ZIP Code are not zoned into FEMA's SFHA, there is no insurance requirement and no communication effort made to notify these residents of their risk let alone a flood insurance mandate put in force to protect those federally backed mortgages from potential default. Yet we know that FEMA and the federal government knows this risk exists which is evidenced by the fact that these residents could expect to pay nearly $6,000 a year based on the risk-based RR 2.0 pricing algorithm. On top of the individual property price burden of additional insurance costs, the flood infrastructure which does exist in the larger city of Glendale, CA (slightly to the south of ZIP Code 91201) was built under 20th-century modeling assumptions of Atlas 14. These assumptions do not account for the increased likelihood or severity of climate-related flooding events and are known to be susceptible to flooding as a result (Glendale Narrows Vulnerable to Flooding).

Figure 14. Policies in force for properties at risk of flooding in a 1-in-100 year event in the FSF-FM in ZIP code 91201 (none are located in FEMA's flood zone)



Conclusions and Policy Implications

By addressing the issues that have hampered the use of Atlas 14 in a changing climate, the First Street Foundation has created rainfall estimates that reflect the climate of today and 30 years into the future, providing a more comprehensive understanding of the state of heavy rainfall occurrence and compound flood risk in the United States. This is particularly important given the increase in extreme precipitation events due to climate change's impacts on atmospheric air temperatures and water vapor content, and the outdated nature of current flood risk standards that rely on older 20th-century data. Using the newly developed FSF-PM, results of the First Street Foundation Flood Model reveal that approximately 17.7 million properties across the country have significant risk. Of that, 12.6 million of those properties are not included in FEMA's SFHA and 65% of those (8.3 million) are left out of the SFHA specifically due to the fact that their flood risk is precipitation based. The improved estimates based on 21st-century data and climate change model projections will allow for better flood risk assessment and management, as well as improved infrastructure preparedness to mitigate the potential consequences of drainage system failure, property damage, and loss of life due to flooding events.

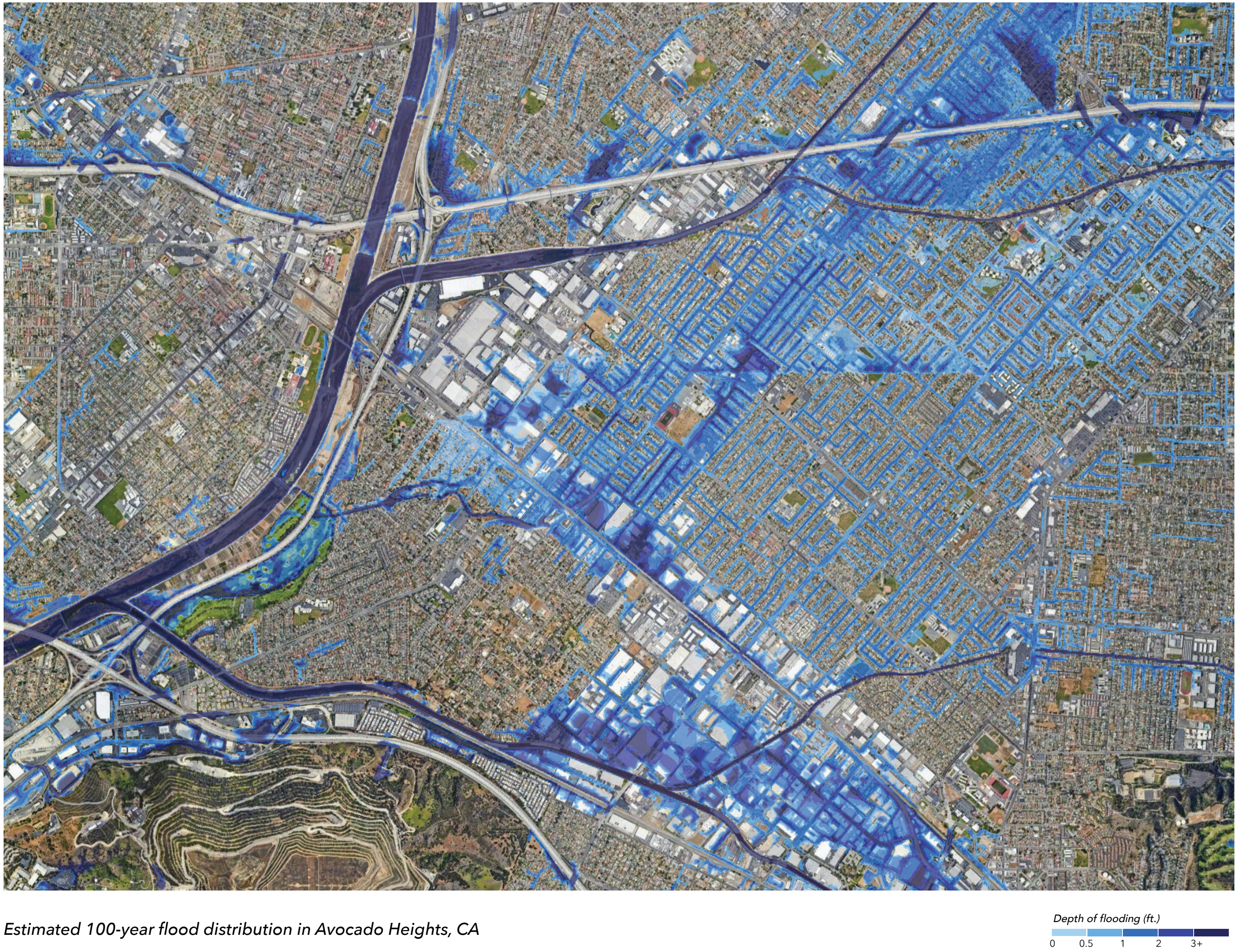
Related directly to the use of NOAA Atlas 14 data as the de facto standard for building and protection design, the IIJA, aka the Bipartisan Infrastructure Law (BIL), was signed into law by President Biden on November 15, 2021. The law authorizes $1.2 trillion for transportation and infrastructure spending with $550 billion of that figure going toward "new" investments and programs. Funding from the IIJA is expansive in its reach, addressing energy and power infrastructure, access to broadband internet, water infrastructure, and more including an eye towards improving communities' climate resilience. Of those allocations, $110 billion has been allocated to roads and bridges, $73 billion allocated to electric grid upgrades, $66 billion has been allocated to public transportation projects, $55 billion to improved water quality initiatives, and $50 billion to general climate change protection (GFOA). That totals at least $350 billion in allocation to projects that will depend directly on an accurate understanding of flood risk, which in part requires accurately and adequately resolving precipitation risk. There is an urgent need for the most up-to-date and accurate estimates of precipitation to inform the design of these projects.

Additional efforts led at the Federal level also have far-reaching implications for local communities and rely on adequately resolving precipitation and flood risk in a changing climate. In March 2023, the Federal Flood Risk Management Standard Climate-Informed Science Approach (CISA) State of the Science Report (National Climate Task Force, 2023) was released. The report provides guidance on the implementation of the Federal Flood Risk Management Standard (FFRMS), which informs the flood standards to which any Federally funded project should be built, and for which information on heavy precipitation plays a key role. At the same time, guidance was issued on *Selecting Climate Information To Use In Climate Risk And Impact Assessments* (OSTP, 2023) along with a description of how such data products and climate services can be brought to bear on climate change actions and policy decisions in *A Federal Framework and Action Plan for Climate Services* (National Science and Technology Council, 2023). The overall impact on the US Federal Budget was also estimated, with flood risk from changes in extreme precipitation playing a significant role, in the Office of Management and Budget's analysis, *Budget Exposure To Increased Costs And Lost Revenue Due To Climate Change: A Preliminary Assessment And Proposed Framework For Future Assessments* (OMB, 2023).

For any federal, state, or local actions that may be taken to address the impacts of climate change and to improve our communities' resilience in a changing climate, the availability of relevant, accurate information is key to enabling informed policy- and decision-making. The urgent provision of that information is emerging as a major requirement to inform climate action. FEMA's recent introduction of Risk Rating 2.0 has taken the positive step of including current pluvial risk in its flood insurance policy premium estimates, but the reliance on its legacy SFHA maps for insurance requirements and the inadequate

Conclusions and Policy Implications

communication of the actual flood risk to homeowners still leaves property owners inadequately informed -- especially on how climate change will impact that risk in the years to come. Both the Federal government and private industry entities should endeavor to rush climate information products to completion, enable wide access, and partner to find ways to create the full range of climate data and information services necessary to instill resilience across our economy and society. Impending regulatory requirements for climate risk reporting for the banking and financial industries require accurate and insightful projections of risk, and economists are attempting to understand how that risk may be transmitted through the US economy. First Street Foundation's efforts to create and disseminate useful, accurate climate risk information through Open Science methods continue to evolve, and the provision of the FSF-PM data for wide use is a major step forward in our preparation to address climate change.



Estimated 100-year flood distribution in Avocado Heights, CA