

Coping with Extremes

The impact of climate change on extreme

PRECIPITATION and FLOODING

in the United States and *how businesses can prepare now*

Our world's climate is changing—and with it comes changing weather patterns.

Of particular concern are changes that are subtle, on average, but more severe in the extremes. Extreme events have the greatest potential to produce natural catastrophes that affect businesses, jobs and economies on a regional or global scale. Although no individual extreme event can be attributed solely to climate change, given the high degree of natural variability, potential changes in risks associated with extreme precipitation and floods need to be assessed to ensure businesses can take action to improve their resilience.

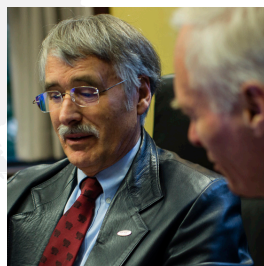
Such action has to be based on the best available observational data and science, and presented in an understandable manner that provides practical solutions to reduce business interruption and potential property loss. To meet this need, four of the world's leading atmospheric experts were brought together with FM Global researchers to evaluate the current state of knowledge and develop recommended actions to address the implications of climate change on extreme precipitation and flooding in the United States.

The results, summarized here, represent the collective expertise of Prof. Kerry Emanuel (professor of atmospheric sciences at the Massachusetts Institute of Technology), Dr. Kevin Trenberth (distinguished senior scientist at the National Center for Atmospheric Research), Prof. Minghua Zhang (dean of the School of Marine Atmospheric Sciences at Stony Brook University) and Prof. Dennis Lettenmaier (distinguished professor at the University of California, Los Angeles). The discussion focused on answering the following questions:

- 1. Is climate change affecting precipitation in the United States? If so, how?**
- 2. What are the main technical gaps to understanding the impact of climate change on precipitation, and how are they being addressed?**
- 3. How can business leaders prepare now to minimize or mitigate risk of property loss and business interruption?**



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Prof. Dennis Lettenmaier
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The fact-based, current consensus is:

Certain regions of the United States are expected to be prone to more intense precipitation events (see Figure 1) and a potentially increased risk of flooding; others are prone to less precipitation (see Figure 1), prolonged droughts and a potentially increased risk of wildfires. Since these anticipated changes are not uniformly distributed geographically, it is recommended that businesses and property owners prepare for locally intense precipitation or drought conditions, depending on their location.

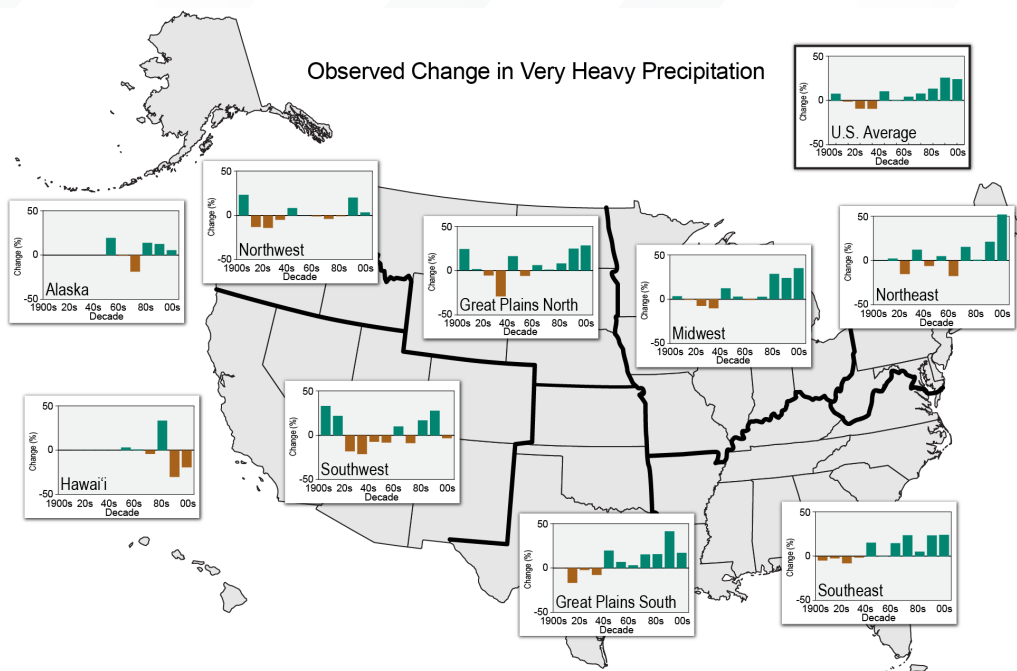


FIGURE 1 Percent changes in the annual amount of precipitation falling in very heavy events, defined as the heaviest 1% of all daily events from 1901 to 2012 for each region. The far right bar is for 2001-2012. In recent decades there have been increases nationally, with the largest increases in the Northeast, Great Plains, Midwest, and Southeast. Changes are compared to the 1901-1960 average for all regions except Alaska and Hawai'i, which are relative to the 1951-1980 average. (Meilillo, Jerry M., Terese (T.C.) Richmond, and Gary W. Yohe, Eds., 2014: *Climate Change Impacts in the United States: The Third National Climate Assessment*. U.S. Global Change Research Program, 841 pp. doi:10.7930/J0Z31WJ2 – Figure 2.17) **Click to view image on source website.**

The business forecast

Weather can have a positive or negative impact on the flow of commerce, affecting a wide range of businesses. Heavy rain or severe snowstorms can shut down transportation networks or flood buildings, and thus impact sales volumes. When businesses in the United States are significantly affected by extreme precipitation and flooding, the ramifications can be felt throughout the global supply chain.

The science behind it

While extreme precipitation and flooding events are as old as recorded history, the science of understanding the weather patterns that cause them has dramatically evolved with enhanced computing power and improved observational platforms. Available temperature data indicate a long-term warming trend on Earth since 1850. Prof. Kerry Emanuel, Dr. Kevin Trenberth and Prof. Minghua Zhang warned that American businesses and people will be exposed to changing precipitation patterns in the century ahead, depending on their geographic location. However, not all changes in weather patterns can be attributed to natural variability or specific climate phenomena like El Niño Southern Oscillation (ENSO).

El Niño Southern Oscillation

El Niño and La Niña are part of the El Niño Southern Oscillation (ENSO), a cycle of natural variability induced by atmosphere-ocean interactions in the tropics. The cycle occurs at irregular intervals, from two to seven years. Southern Oscillation refers to the oscillation of atmospheric sea-level pressure difference between the eastern and western tropical Pacific.

El Niño manifests itself in warmer than normal sea surface temperatures in the eastern and central parts of the equatorial Pacific. El Niño is typically accompanied by lower than normal upwelling of deep ocean waters along the northwestern coastline of tropical and subtropical South America as well as by weaker than normal trade winds. These wind anomalies lead to a transport of warm ocean waters eastward toward central and eastern Pacific regions. As a result, regions of tropical deep convection that form over warm ocean waters propagate eastward, leading to drier than normal conditions over Indonesia and Australia, and wetter than normal conditions further east (Figure 2).

While the physical reasons triggering El Niño events are still somewhat debated within the scientific community, it is well accepted that the effects of El Niño on seasonal temperature and precipitation patterns are felt worldwide. During El Niño, some areas experience conditions warmer and drier than normal and other regions experience conditions cooler and wetter than normal (Figure 3).

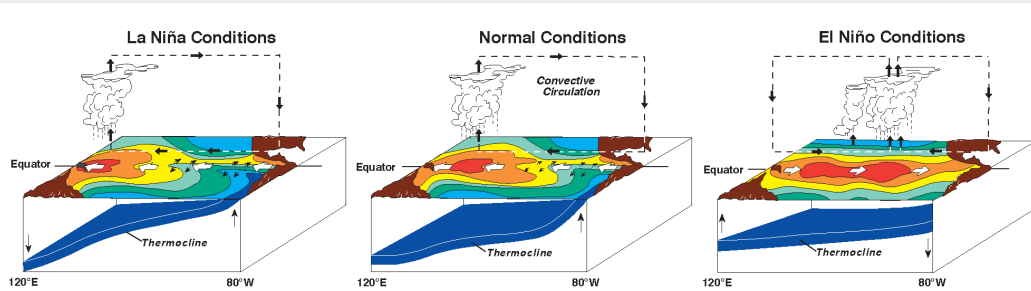


FIGURE 2 A model of sea surface temperatures (color map on the ocean surface), anomalous winds (white arrows above the ocean surface), areas of rising air (the areas underneath the black upward arrows and cartoon-like cloud), and the thermocline (blue surface) in the tropical Pacific during La Niña, normal, and El Niño conditions. Thermocline is a layer where ocean temperature changes rapidly vertically. (Source: NOAA / PMEL / TAO Project Office, Dr. Michael J. McPhaden, Director)

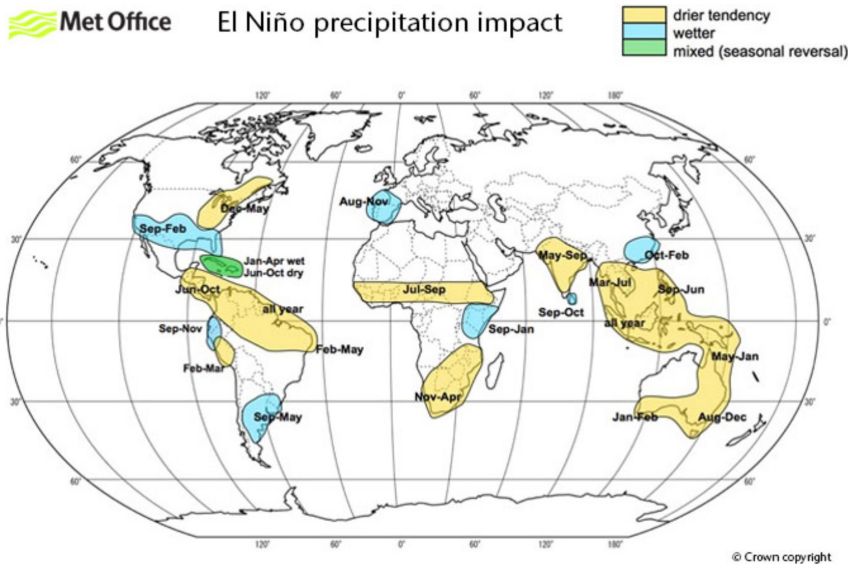


FIGURE 3 Worldwide weather impacts during El Niño. Contains public sector information licensed under the Open Government Licence v1.0. (Source: <http://www.metoffice.gov.uk/research/climate/seasonal-to-decadal/gpc-outlooks/el-nino-la-nina/ENSO-impacts>) **Click to view image on source website.**

A well-understood physical mechanism, the Clausius-Clapeyron relation, indicates that warmer air temperature will result in increased water vapor loading in the air, as explained by Dr. Trenberth. This additional water vapor supplements cloud formation, potentially leading to more intense precipitation. “When the climate becomes warmer in areas that already have high precipitation, the air as it rises will produce more precipitation because it contains more moisture,” said Prof. Zhang.

Prof. Emanuel reinforced this concept by analysis of the water cycle over oceans. He evaluated the radiative-convective equilibrium, and demonstrated that as sea surface temperature increases in a warming climate, surface air humidity will increase exponentially and faster than radiative cooling increases. The result is a decrease of convective mass fluxes (the amount of air mass rising in deep clouds per unit area) and an increase in rainfall intensity. This means that rain will be more intense but less frequent, and that, in general, wet places should become wetter while dry places should become drier. “Basic physics tells us that as the climate warms, the water cycle becomes more volatile,” Prof. Emanuel said. “Absent large changes in atmospheric circulations (e.g., wind velocity and patterns), this volatility means that places that are usually very dry, like Southern California, will likely get drier. And places where it rains a lot, like the Pacific Northwest and the Southeast United States, will probably experience more rain.”

But that’s *on average*. “It doesn’t mean that historically dry places won’t also experience heavy precipitation or rainy places won’t have weeks of sunshine,” Prof. Emanuel said. “What is conclusive is that based on strong theoretical expectations backed up by climate models, most places will experience more volatile weather, which is chaotic to begin with. We feel climate change not so much through subtle changes in the mean, but through changes in the extremes.”

The psychological hurdles

Among the challenges in the affected regions is that some business owners may lack a natural urgency to plan for extreme precipitation or flooding. “Anthropologists cite generational memory threshold as a key to a given culture’s adaptation to extreme weather events,” Prof. Emanuel said. “In a place where memory extends back 100 years, people might expect a single event of extreme rainfall and heavy winds since such an event occurred 75 years ago. It’s when the event is a 1-in-150-year massive hurricane that everything falls apart. Nobody builds for such events, and the result is colossal damage.”

Complicating matters is the difficulty in predicting such extreme events due to both their rarity and a general lack of fundamental understanding of exactly how all the interactions among physical processes unfold in time and space. Nonetheless, there is a growing body of scientific evidence that the warming climate, allowing for natural variability, is already having an impact on hydrological events—specifically, the likelihood of more or less precipitation in certain regions. “If there is systemic climate change, the consequences and impacts are greater,” said Dr. Trenberth.

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– Prof. Kerry Emanuel

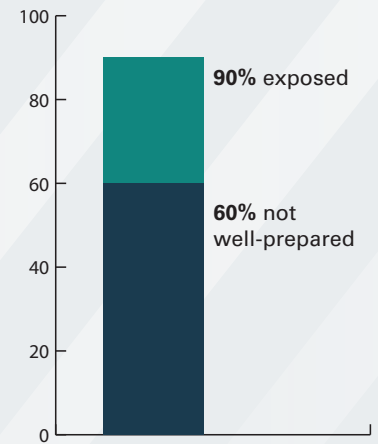
Risky Business

Findings from [Flirting with Natural Disasters: Why Companies Risk It All](#) indicate that many businesses fail to heed the risk of natural disasters. Ninety-six percent of financial executives surveyed said their companies have operations that are exposed to natural catastrophes like hurricanes, floods and earthquakes, yet fewer than 20 percent said their organizations were “very concerned” about such disasters negatively affecting their bottom line.

While 90 percent of companies in the study have operations located in regions exposed to floods, more than 60 percent of the respondents indicated their organizations are not well-prepared for a flood.

Fewer than 20 percent of organizations were “very concerned” about disasters, but most are not well-prepared.

FIGURE 4 Flood-exposed locations.



Timing is everything, in some places

The temporal and spatial distribution of precipitation may change differently than the long-term averaged total amount of precipitation. “The observed amount of total precipitation has shown little change since 1950, but with the increased water vapor in the air, the precipitation events become less frequent with stronger intensity,” said Dr. Trenberth.

These temporal and spatial precipitation characteristics are as important as the total precipitation, if not more so. “The precipitation amount over a long period may show no or little change,” Dr. Trenberth explained. “But, there will be different consequences depending on how the same amount of precipitation is distributed in space over the same time period.”

For example, a specific region of the country that has historically seen 10 inches of rain each May might see the same volume that month for decades to come. But the 10 inches of May rainfall might occur in two days as opposed to four, increasing the risk of a flooding event.

At the other end of the weather spectrum, similar phenomena affect prospects for less precipitation in certain regions. “In areas that are well inland and typically drier, higher temperatures and increased solar insolation (i.e., less shade from clouds) create more surface evaporation, exacerbating the already dry conditions,” said Prof. Zhang. He estimated that a one-degree Celsius increase in the temperature on average would create a 2-percent increase in precipitation. “If by the end of this century, the temperature has increased by two or three degrees Celsius based on global averages, it is possible for precipitation to change by 8 percent. Changes on a local basis could be much higher.”

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Local climate effects are the most difficult to predict. While current climate forecasting models can simulate the overall climatology of precipitation patterns on larger scales (on the order of thousands of kilometers), such models are less robust at predicting more localized scales of rainfall. The models are unable to produce the trends observed in the precipitation data in some regions of the world, and they tend to over-predict rainfall in the low-latitude oceans and underpredict rainfall inland, according to Prof. Zhang. There are many reasons for these imprecise predictions. One reason, according to Prof. Zhang, is the current limitations associated with detailed simulation of cloud and precipitation processes in climate models. These microphysical processes are critical. Small changes in them make a huge difference.

Future advances in modeling

Dr. Zhang anticipates improvements in the predictive capabilities of current models over the course of the next two decades, as scientists harness additional computing power and more detailed observations to simulate cloud and precipitation formation.

Despite the fact that specific weather events are still difficult to predict, the scientists are confident in the substance of their research. “Details may be complicated, but the concept is fairly simple,” Prof. Emanuel said.

The *hazards* ahead

1. Flooding

If certain regions of the United States experience more intense precipitation events, one may expect an increase in the risk of flooding. Yet, “there is not a lot of evidence in the last 50 years or so for trends in extreme floods,” according to Prof. Lettenmaier. Flooding is a complex interaction of precipitation extremes and other factors such as soil parameters, ground cover, basin geometry, antecedent conditions and water management systems.

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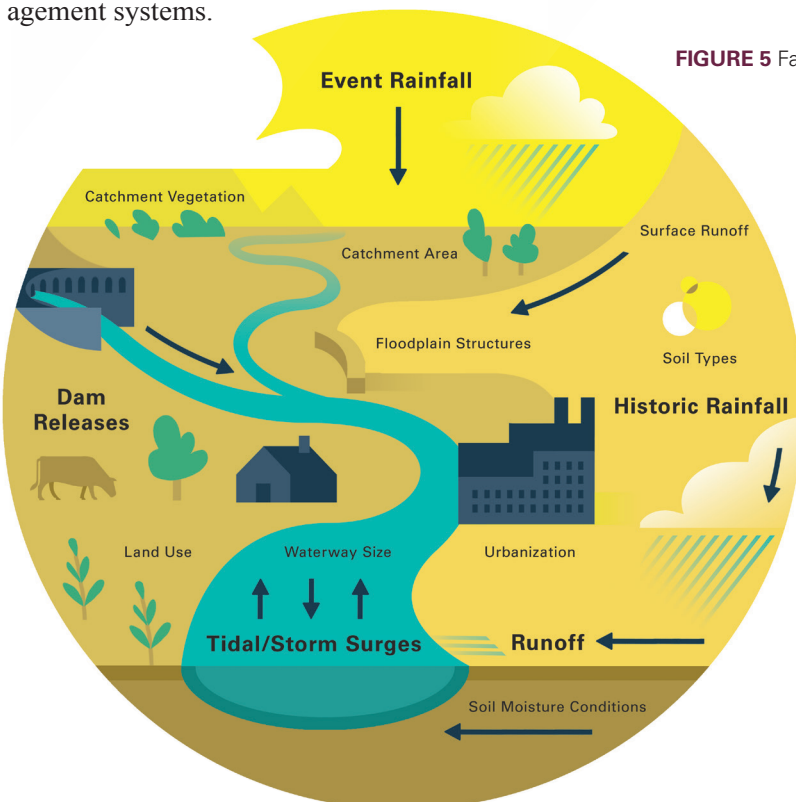


FIGURE 5 Factors affecting flooding.

Rainfall outstripping catchment rate is akin to pouring too much water too fast into a too small funnel or having a coffee maker injecting water too fast into the coffee-containing filter. In both cases, the water will overflow. In hydrology, this happens when the rainfall intensity exceeds the soil infiltration rate, causing the water to run off to the river (see Figure 5). When the rainfall is heavy, or long-lasting, the river may not be able to accommodate the large amount of water, and may overflow. “High precipitation duration relative to catchment response time can lead to riverine floods,” said Prof. Lettenmaier, whose expertise includes hydrologic modeling and prediction, and hydrology-climate interactions. The catchment response time is a way to quantify the response of a catchment to a rainfall event. It is the longest time needed for a drop of rain falling over the catchment area to reach the river.

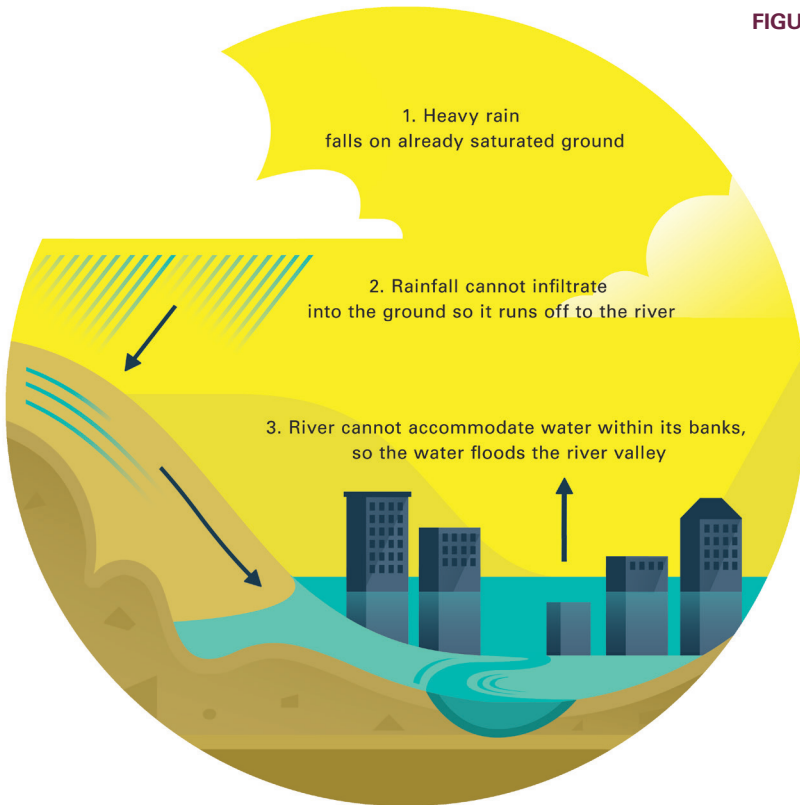
“There is not a lot of evidence in the last 50 years or so for trends in extreme floods.”

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“Soils, topography and vegetation are other factors (affecting catchment response), as is the storm movement relative to the catchment geography,” he added. “If the soil is already saturated from a prior precipitation event, this also can affect the catchment response time and the resulting flood severity.” (See Figure 6.)

In the western part of the United States, flood risk is affected by the impact of wintertime temperature on precipitation type (rain or snow), snow accumulation, and the timing of snowmelt and runoff in the spring. For example, if during the wintertime, precipitation occurs mostly in the form of rain instead of snow, it would run off immediately leading to less snow accumulation, and thus potentially less flood risk during the spring. However, flood risk can also be increased if warmer temperatures lead to earlier snowmelt and rainfall on top of snow, which could lead to increased runoff and elevated flood risk during spring storms.

FIGURE 6 How floods occur.



Dr. Trenberth added another factor to flood risk probability: human preparedness. “Everyone knows that when it rains harder, the risk of flooding goes up, but whether or not you have a flood depends in many cases on the water management systems,” he said. These range from natural systems like a catchment’s memory for water to a municipality’s preparedness for high rainfall events. Certainly, the design choices for facilities or different hydraulic structures on rivers can affect the risk of flooding.

2. Wildfires

As the temperature rises in areas that historically experience dry conditions, the additional heat has the effect of raising temperatures and depleting soil moisture and, therefore, “exacerbating the risk of wildfire,” said Dr. Trenberth. “At the same time, moisture that is evaporated is carried away by winds and into regions where moisture and storms are converging, resulting in higher rainfall events.”

Trends, not predictions

As sound as the underlying science is, no one should conclude that these are detailed scientific predictions of the future. While the atmospheric scientists have confidence in their research, uncertainties will always exist regarding the impact of climate change on precipitation events locally and regionally. Nevertheless, there is reason to take precautions and increase preparedness.

Rather than just focus on the 100-year flood zone, businesses are wise to protect to the 500-year flood period levels so they have less than a 0.2 percent (1/500) chance of flooding every year.

Flood matrix

The flood matrix at right represents the percent chance of a location experiencing one or more floods within a specified lifetime.

The return period is commonly misinterpreted as a regular interval in which floods of a specified severity occur at a location. This matrix provides a means of communicating flood risk that emphasizes the percent chance of flooding at a facility over a period of time (generally) rather than the return period of the flood event. Potential summary statements possible from these results include:

- 1) there is greater than a **1 in 4 chance** of experiencing flooding to the:
 - 50-year return period level over a 15-year lifetime
 - 100-year return period level over a 30-year lifetime
- 2) there is greater than a **1 in 3 chance** of experiencing flooding to the:
 - 50-year return period level over a 20-year lifetime
 - 100-year return period level over a 40-year lifetime
 - 250-year return period level in 100 years.

**Flood Hazard Matrix:
Percent Chance of
One or More Floods**

Life-time (yrs)	Return Period (yrs)			
	50	100	250	500
10	18%	10%	4%	2%
15	26%	14%	6%	3%
20	33%	18%	8%	4%
25	40%	22%	10%	5%
30	45%	26%	11%	6%
40	55%	33%	15%	8%
50	64%	39%	18%	10%
100	87%	63%	33%	18%

Proactive preparations

Companies with built or planned structures in affected regions can prepare for extreme weather events in the future by taking action now.

“Certainly, businesses must recognize that climate change is happening and it will generally get warmer,” Dr. Trenberth said. “Water management is critical.”

Prof. Zhang agreed with this perspective and offered other ways for companies to prepare for more extreme weather. “Risk managers should take into account these possibilities, making sure they review the resilience of their buildings or new locations to withstand the impact of an extremely high rainfall event and area flooding,” he said.

Now is the time for businesses to examine their buildings’ ability to withstand flooding, as well as evaluate their processes to manage surface water, roof drainage and water supply. Similarly, companies should be mindful as to where they build new plants, factories and office structures, closely evaluating the potential impact of extreme precipitation and flooding.

Additionally, consider current and prospective supply chain partners with respect to their ability to withstand business interruption caused by severe flooding. Rather than just focus on the 100-year flood zone, businesses are wise to protect to the 500-year flood period levels so they have less than a 0.2 percent (1/500) chance of flooding every year. Often this doesn’t mean a huge change—a slight relocation or modification will move a location from a 100- to a 500-year flood protection level. When viewed over the lifetime of a building or mortgage, the risk is significantly reduced. As changes in the hazards evolve, this also provides an additional level of protection.

A changing climate calls for extra vigilance regarding extreme events. By bringing together the work of the scientific and business communities, resilience is achievable.

How to withstand flooding

- Consider critical water management
- Evaluate flood risk and physical protections
- Manage surface water and roof drainage
- Examine and mitigate flood risk when locating new facilities
- Assess risks facing suppliers and other supply chain partners

For additional recommendations, refer to *FM Global Property Loss Prevention Data Sheets*, fmglobaldatasheets.com.

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About FM Global

Established nearly two centuries ago, FM Global is a mutual insurance company whose capital, scientific research capability and engineering expertise are solely dedicated to property risk management and the resilience of its client-owners. These owners, who share the belief that the majority of property loss is preventable, represent many of the world’s largest organizations, including one of every three Fortune 1000 companies. They work with FM Global to better understand the hazards that can impact their business continuity in order to make cost-effective risk management decisions, combining property loss prevention with insurance protection.