Union of Concerned Scientists

FACT SHEET

INLAND FLOODING

Climate Change, Extreme Precipitation, and Flooding: The Latest Science

Across the United States, inland and riverine floods—floods that occur outside coastal areas—are the most common type of natural disaster. They are also among the most dangerous to people and property.

In September 2013, 14 to 17 inches of rain fell over the course of five days in the Boulder and Denver, Colorado, areas, causing devastating flash floods. In May 2016, nearly 20 inches of rain fell in 48 hours in Brenham, Texas. Weeks later, 8 to 10 inches of rain fell in just 12 hours across West Virginia. Each of these events led to extensive damage and multiple deaths. In 2017, heavy spring rains caused similarly deadly and damaging flooding in Arkansas, California, Louisiana, Missouri, and Oklahoma. In April 2018, nearly 50 inches of rain fell in 24 hours in Kauai, Hawaii, requiring hundreds of people to evacuate.

Heavy rainfall (also called extreme precipitation) events are one of the primary contributors to flooding, and the warming atmosphere is causing these events to occur more frequently in some parts of the United States. In addition, human alteration of the land and development in floodplains are increasing flood risk and causing flooding—a natural process providing many benefits—to be more destructive and costly.

The consequences of flooding can reach far beyond the inundated land: lives lost, homes underwater, businesses shut down, crops destroyed, infrastructure made unusable. Sewage,

A flooded neighborhood near Wilson Ave. SW and Hamilton Street SW in Cedar Rapids, Iowa in June 2008. Extreme precipitation events are increasing in the continental U.S. Credit: Don Becker/USGS agricultural waste, leaked chemicals, and other contaminants can be washed into waterways, potentially harming people's health. The economic impacts can be large, even when the damage is temporary.

Here, we present a synopsis of the latest scientific findings on how and why precipitation and flooding patterns have changed in the United States, a summary of possible future scenarios, and recommendations for how to make communities more flood-resilient. While coastal flooding and sea level rise are important parts of the complete picture of flood risk, this synopsis focuses on flooding of inland areas.

How is Flooding Changing in the United States?

We have seen floods devastate cities and towns in recent years and thus may question whether such events are becoming more frequent or more intense and whether our changing climate is the culprit behind these floods.

Flooding is indeed changing, though not uniformly across the United States. According to the 2017 Climate Science Special Report (CSSR), which is part of the most recent and comprehensive report on the climate of the United States,[1] some parts of the country have experienced an increase in flood frequency over the last 50 years while others have experienced a decrease (Wehner et al. 2017). These variable patterns are not unlike those observed in other parts of the world (Seager et al. 2018; IPCC 2014).

Scientists analyze data collected from gauges placed in rivers and streams to quantify the frequency and magnitude of flooding events. These data consistently show that flood frequency has increased in the Mississippi River valley and across the Midwest over the last century (Slater and Villarini 2016; Mallakpour and Villarini 2015; Peterson et al. 2013; Groisman, Knight, and Karl 2012). Similarly, the Northeast—eastern Pennsylvania, New York, and New Jersey in particular—has experienced an increase in flood frequency over the last 50 years (Frei, Kunkel, and Matonse 2015; McCabe and Wolock 2014; Walsh et al. 2014; Peterson et al. 2013 and references therein; Armstrong, Collins, and Snyder 2011). These regions are mostly seeing more floods, not necessarily more severe floods (Mallakpour and Villarini 2015), although some increase in moderate and major flood frequency risk has occurred, especially in the Midwest (Slater and Villarini 2016). Over the same period, flood frequency in other parts of the country, including the Pacific Northwest, Rocky Mountains, Southwest, and Southeast, has decreased (Wehner et al. 2017; Sagarika, Kalra, and Ahmad 2014; Walsh et al. 2014; Peterson et al. 2013 and references therein; Hirsch and Ryberg 2012).[2,3]

Why is Flooding Changing?

Flooding primarily occurs when heavy precipitation falls on land or rivers unable to absorb and drain so much water. The shape and capacity of an individual river system, the condition of surrounding land and vegetation cover, the rainfall's duration, and the land's degree of saturation all influence flood occurrence and severity. During or after an intense or long-lasting precipitation event, the ground can become saturated and unable to absorb additional rainfall. Seasonal snowmelt can also cause flooding. In both cases, the volume of water entering streams increases, and full waterways can breech their banks, spilling floodwaters onto typically dry land.

EXTREME PRECIPITATION IS INCREASING

Across the United States, increasingly frequent heavy rain is one of the most obvious weather changes (Easterling et al. 2017). Some studies define extreme precipitation events as those that fall above a certain threshold of intensity or volume (e.g., Wuebbles 2016; Groisman, Knight, and Karl 2012; Karl and Knight 1998). Others define them by their probability of occurring in any one year or by their duration (Janssen et al. 2014; Kunkel 2003; Kunkel et al. 1999). Studies using different definitions and multiple methods have shown that extreme precipitation events have become more frequent and more intense in many parts of the United States since the early to mid-1900s, with the eastern half of the country seeing increases of 50 percent or more in extreme rainfall event frequency and the western half seeing smaller increases or even decreases (Easterling et al. 2017; Walsh et al. 2014; Groisman, Knight, and Karl 2012; Kunkel 2003; Kunkel, Andsager, and Easterling 1999; Karl and Knight 1998).

[***Heavy rainfall events are one of the primary contributors to flooding, and the warming atmosphere is causing these events to occur more frequently in some parts of the United States.***]

Precipitation events once considered rare are now occurring more often than historical records would lead us to expect. For example, the US National Weather Service recorded 10 rare rain events between May 2015 and August 2016 (NWS 2017) even though such events were expected to occur, on average, once every 500 years. All 10 events led to flooding.

The regions experiencing increases in extreme precipitation generally align well with those experiencing increases in flood frequency.

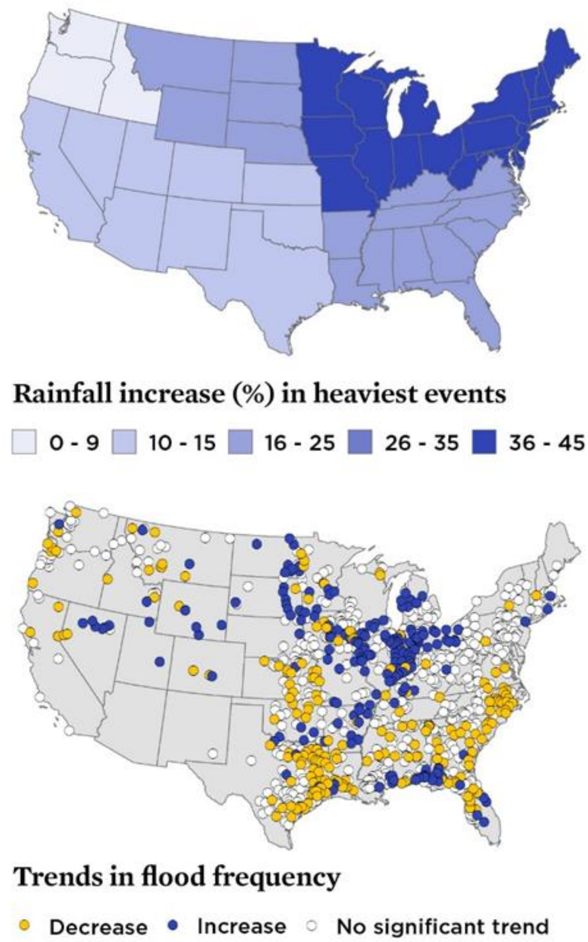
IS CLIMATE CHANGE CAUSING THE INCREASE IN EXTREME PRECIPITATION?

Scientists are working to understand whether and how the observed changes in precipitation are attributable to our changing climate. Warmer air holds more moisture (in the form of water vapor), and more moisture means more water can fall as rain (Wuebbles et al. 2014; Kunkel et al. 2013; Karl and Trenberth 2003). For every 1°C (1.8°F) increase in temperature, the atmosphere's potential moisture content increases by about 7 percent (Easterling et al. 2017); this is one reason, all else being equal, a storm occurring in very hot air can bring more precipitation than the exact same storm would in cooler air. Earth's average surface temperature is currently about 1.1°C (2.0°F) higher than it was in the late 1800s (NASA 2018), which indicates increased potential for heavy rain.

Recent studies suggest that warming through the 1900s and into the 2000s has contributed to increases in extreme precipitation in many regions, including the United States (e.g., Westra, Alexander, and Zwiers 2013; Zhang et al. 2013; Min et al. 2011). Armal, Devineni, and Khanbilvardi (2018) found that for 409 of 1244 rainfall stations across the United States, statistically significant trends in increases and decreases in extreme precipitation events were attributable to changes in global surface temperature; most of these 409 stations were in the Northeast and Southeast. Studies of precipitation extremes around the globe have also found that while they were "primarily attributable" to natural variability, human-caused warming also played a role (Fischer and Knutti 2015; Knutson et al. 2010).

Analyses of specific events are also yielding insights into the connection between human-induced warming and extreme precipitation. Human-caused climate change made the record-breaking rainfall during Hurricane Harvey in 2017 three times more likely and 15 percent more intense (van Oldenborgh et al. 2017). A study of the devastating rains in Louisiana in 2016—in which more than two feet of rain fell in a two-day period—concluded that such downpours are expected to occur 40

FIGURE 1. Heavy Rainfall and Flooding Trends in the U.S.



Top: Percent increase in the amount of rain falling during the top 1% of events per region in the continental United States between 1958 and 2016. The percentages are first calculated for individual stations, then averaged over 2° latitude by 2° longitude grid boxes, then averaged again over each region of the Fourth National Climate Assessment.

Bottom: Trends in the number of days per year above the National Weather Service (NWS) minor flood threshold based on published and provisional daily gauge height data measurements from the US Geological Survey from 1985-2015. Gauges without a statistically significant increase or decrease are shown in white.

DATA SOURCES: (TOP) CLIMATE SCIENCE SPECIAL REPORT (CSSR), EASTERLING ET AL. 2017. (BOTTOM) SLATER AND VILLARINI 2016, PROVIDED BY L. SLATER.

percent more often and be 10 percent more intense now, in a human-induced changed climate, than they were before the Industrial Revolution (van der Wiel et al. 2017). There is not yet a strong consensus among scientists that global warming is leading to increased extreme precipitation in general, but studies have linked individual extreme events to climate change, and the amount of evidence for a general connection continues to grow.

LAND USE CHANGES ARE INCREASING FLOOD RISK

Land use changes such as construction within floodplains, the increased use of impermeable surfaces such as asphalt, the removal of wetlands and river bank vegetation, the deterioration of water-management infrastructure, and the building of dams, levees, or channels can reduce or alter the ability of land to accommodate heavy precipitation and can change the natural flow of rivers and streams.

A recent study of the Mississippi River, for example, found an increase in flooding in the past 150 years that cannot be explained by precipitation patterns alone (Muñoz et al. 2018). The authors suggest that engineering of the river and, secondarily, agricultural expansion are to blame for the increased flood frequency and height and for up to 75 percent of the increased flood risk. Likewise, a recent analysis documented rapid suburban development of the prairie landscape in Harris County, Texas, which may have reduced the land surface's natural drainage capacity and increased flood risk during events such as Hurricane Harvey (Shaw, Satija, and Collier 2016).

Wildfires, which both climate and land use change have made more frequent and extensive, also play a role in flooding. The burning of hillside vegetation leads to less water retention and increased erosion. When rain falls, the extra water running down can add to the flood risk of nearby regions (Cleetus and Mulik 2014).

> ***Flooding primarily occurs when heavy precipitation falls on land or rivers unable to absorb and drain so much water.***

What Does the Future Hold?

Increases in extreme precipitation frequency and intensity are projected to continue across much of the United States over the 21st century, particularly in the northern and midwestern regions (Easterling et al. 2017; IPCC 2012), with important regional and seasonal differences. Precipitation intensity is projected to increase in the Northeast and Southeast in most seasons, while a decrease is expected over the Southwest (Wang and Kotamarthi 2015).

The projected changes in precipitation suggest that flooding will also increase in frequency and intensity (Wehner et al. 2017). However, because flooding depends not just on precipitation but also on river shape and characteristics, land surface conditions, and season, future flooding patterns are more difficult to project. The science and news organization Climate Central has done research on future inland US flooding risks (Climate Central n.d.) and has found that 42 of the lower 48 states face increased runoff—rainwater not absorbed by the land, which contributes to flooding because it leads to increased streamflow—by 2050.

How Else Might Climate Change Contribute to Increased Flooding?

HURRICANES

Hurricanes gather strength and moisture from the ocean as they develop; the warmer the ocean, the more strength the hurricane can gather. Also, the warmer the air, the more water vapor it can hold. North Atlantic hurricane activity has increased since the 1970s (Kossin et al. 2017) as ocean surface temperatures have risen (Wang et al. 2018). While recent science suggests the number of hurricanes is not expected to increase, the number of more intense hurricanes is (Knutson et al. 2010).

These "supercharged" hurricanes carry more water (Trenberth et al. 2018), and when this increased amount of rain falls, more flooding can happen—not only on the coasts, but also inland. Hurricanes Harvey and Maria both brought devastating inland flooding that will have consequences in Texas and Puerto Rico for years.

ATMOSPHERIC RIVERS

Atmospheric rivers are narrow atmospheric bands that move water vapor outside of tropical regions (NOAA 2015). They carry a huge amount of water that is ultimately released in the form of rain or snow when the river reaches land. Atmospheric rivers account for about 50 percent of the annual water supply and snowpack along the West Coast (Kossin et al. 2017) and are associated with severe flooding events (Samenow 2016). Their presence may increase the occurrence of floods by 80 percent; their absence increases drought occurrence by as much as 90 percent (Paltan et al. 2017).

The frequency, severity, and duration of atmospheric rivers are expected to change worldwide with global warming (Kossin et al. 2017). Recent research suggests the warming atmosphere will cause atmospheric rivers to become longer and wider and to transport more moisture (Espinoza et al. 2018). On the West Coast, they will likely arrive with increasing frequency and intensity (Wehner et al. 2017). How these patterns will affect precipitation is still unknown, but the phenomenon is worthy of attention.

SNOWPACK AND SNOWMELT

Rapid snowmelt can also lead to flooding, as seen in Michigan in 2018 and in California—notably in Yosemite National Park—in 2017. As the climate continues to warm, earlier snowmelt and runoff are expected on the borders of snowy regions in the United States (Wehner et al. 2017), including the Rocky Mountains and the Sierra Nevada range. In addition, when precipitation falls as rain instead of snow due to warmer winter temperatures, existing snow can melt faster and lead to flood-causing runoff.

How Do Floods Affect Us?

Flooding is a natural process that can provide a habitat for plant and animal species and maintain fertile floodplains. Historically, people sought to settle near waterways, and those settlements have grown to become towns and cities and to encompass vast agricultural landscapes, sprawling commercial and industrial complexes, and expensive, vital infrastructure. As we have flocked to rivers and built on their banks, the human and financial costs of flooding have risen dramatically (FEMA 2018; NCEI 2018).

Current Federal Emergency Management Administration (FEMA) flood maps underestimate the number of people at

The same extreme precipitation event may have very different outcomes in different locations depending on factors such as topography, land use, natural and built drainage, and flood control structures such as levees and dams. The flood in Ellicott City, Maryland, on May 27, 2018 was driven by an extreme precipitation event, topographic and land use conditions, and the city's stormwater system. Credit: Dave Dildine/WTOP direct flood risk, not only because they use historical flood patterns that do not currently apply, but also because they do not consider projections of future population growth and land use, which can put significantly more people and assets at risk (Wing et al. 2018). In addition to the most drastic flood consequences—loss of life and property—flood-related displacement, even if temporary, negatively affects communities and the economy. Floods can prevent even those people whose homes are not directly affected from going to work or school or from accessing crucial services.

Floods can also bring significant health risks to the places we live and work. Floodwater can cause the release of chemicals and pollutants from the soil and damaged structures, leading to the contamination of air and water (Perera, Sanford, and Cleetus 2012), while flooded homes become breeding grounds for various pathogens. Waterborne diseases, sewage contamination, and mold are among the many risks flooding poses to human health. Repeated flooding events have also been shown to trigger psychological and health issues such as stress, trauma, and depression, and post-traumatic stress disorder can occur among flood survivors (Stanke et al. 2012; Neria, Nandi, and Galea 2008; Verger et al. 2003).

Floods are equal-opportunity events, inundating those in the water's path regardless of wealth or ethnicity. But not everyone is affected equally. Low-income, elderly, and minority populations can be affected to a greater degree because they may have fewer resources—such as flood insurance, sufficient access to transportation, cash on hand, and the ability to relocate (Deas et al. 2017; Graham, Debucquoy, and Anguelovski 2016; Fothergill and Peek 2004).

How Can We Limit Future Floods?

As a nation, we have a long history of enduring devastating floods in both rural and urban areas. Despite the human and economic toll, we have not yet rallied the resources, policies, and coordination needed to respond adequately to the magnitude and severity of the problem today, let alone the problems sure to grow in the future.

While the federal government plays a key role in guiding flood risk management, ultimately flood risk reduction is in the hands of local and state governments, which have the authority to make land use decisions.

ROLES FOR STATES AND MUNICIPALITIES

States and municipalities should enforce and implement key flood-ready standards and risk reduction measures. These include measures to discourage development in floodplains through zoning regulations, floodplain easements, and the protection of riparian (edge of rivers) buffers and wetlands (Basche 2017). They also include moving people and buildings out of harm's way through buyout programs to ensure these places stay as open space in perpetuity so that taxpayers do not pay for repetitively flooded homes.

> ***Funding of riverine flood risk reduction programs is cost-effective and can save the nation seven dollars in future disaster costs for every one dollar invested.***

In areas surrounding floodplains, measures must be implemented to encourage rebuilding in a more resilient way by enacting more protective building standards, elevating structures several feet above the base flood elevation, and upgrading sewage and storm water systems, roads, bridges, and other types of infrastructure to accommodate an increase in water flow from heavy precipitation events.

Historically, emergency response was a state and local responsibility. Fifty years ago, Congress created the National Flood Insurance Program (NFIP). Considered a landmark piece of legislation at the time, it helped to move the nation away from engineered, structural flood control measures to a broader suite of solutions including flood insurance, mapping, flood risk reduction measures, and better floodplain management in general. While many improvements in flood policy have been made since then, they have for the most part been uncoordinated and still rely on engineered, structural approaches such as levees and dams that have altered the flow and natural habitats of river systems. They have also failed to limit development in flood-prone areas, thereby exacerbating the risk. With climate change potentially worsening flood risks, it is critical that we reform existing policies and target resources to help limit costs and harms to communities.

USING THE LATEST SCIENCE AND DATA

The nation relies on a network of government agencies, universities, nongovernment groups, and the private sector for advancing and communicating the science on extreme precipitation and riverine flooding to communities, policymakers, planners, and engineers. Congress should continue to support adequate funding for the following key agencies and programs:

- The National Oceanic and Atmospheric Administration and the National Aeronautics and Space Administration provide weather forecasting and scientific research on extreme weather events and a changing climate.
- The US Geological Survey leads the Federal Priority Stream gauges program (part of the larger National Streamflow Network), Flood Inundation Mapping program, and the 3D Elevation Program, which the nation depends on for accurate flood risk mapping and planning.
- FEMA provides flood risk mapping.
- The Centers for Disease Control and Prevention and the Environmental Protection Agency provide valuable resources for families and communities to help them stay safe and healthy before, during, and after floods.

Funding should be increased for both the stream gauge and mapping programs. Flood risk maps exist for only about one-third of the nation and many of these are out of date and limited in scope (Larson 2017). Congress and states, with federal and state agencies, could take three critical actions that would address the science and data needs:

- expand research on extreme precipitation events;
- increase the river gauge network; and
- ramp up flood mapping programs.

FEDERAL FLOOD RISK REDUCTION PROGRAMS

Based on decades of data, we know that federal funding of riverine flood risk reduction programs is cost-effective and can save the nation seven dollars in future disaster costs for every one dollar invested (NIBS 2017). Yet, each year these programs are targeted for cuts and continue to remain underfunded. Congress should support adequate funding for these essential programs and implement common sense reforms to align them with future flood risks:

- FEMA's Hazard Mitigation Grant Program, Flood Mitigation Assistance Grant Program, and Pre-Disaster Mitigation Grant Program provide funding to communities for projects that reduce risk before and after floods.
- The US Department of Housing and Urban Development's (HUD) Community Development Block Grant (CDBG) program, especially its CDBG-Disaster Recovery grants, is instrumental in helping low- and moderate-income communities—often the hardest hit by disasters—prepare, recover, and build resilience.
- The US Army Corps of Engineers' technical assistance programs, including Planning Assistance to States, the Flood Plain Management Services, the National Flood Risk Management Program, and the Silver Jackets Program, help communities plan for future flood risks.[4]
- FEMA's and HUD's voluntary home buyout programs help homeowners move to safer locations while leaving the flooded property as open space and assist communities in high-risk areas with technical assistance and grants for relocation.
- The US Department of Agriculture provides incentives and financial support to encourage farmers to adopt soil management practices that deliver flood and drought resilience.

Congress should also reform the NFIP. This vital program serves many purposes but masks the true flood risk homeowners face by offering subsidized insurance rates and providing outdated maps, most of which do not consider future conditions. It also allows for payouts for properties that have been flooded repeatedly, at taxpayers' expense (NRDC 2017).[5] The rush to rebuild in Houston, Texas, after Hurricane Harvey is a perfect example of this folly (Hunn, Handy, and Osborne 2017). Congress should undertake the following:

- Establish risk-based insurance rates that truly reflect flood risk and include affordability provisions that either help lower-income communities purchase insurance or provide grants to help lower their risk.
- Require and fund mapping based on future conditions, including population growth, land use change, and climate change.
- Provide incentives for investment in flood risk reduction measures such as elevation, preservation of open space and wetlands, and funding for voluntary home buyout programs.

It is critical that we reform existing policies and target resources to help limit costs and harms to communities.

NEW POLICIES AND TARGETED FUNDING

We need robust policy changes at all levels of government to advance science and assistance programs in a coordinated and equitable way. Widespread pressure and support from all sectors of society are needed to move our governments in this direction. Federal, state, and local governments should undertake the following:

- Plan, design, build, retrofit, and maintain infrastructure to withstand the new reality of climate change (Gibson 2017). If we do not take time now to plan for future conditions, we will spend taxpayer dollars unwisely by putting vital infrastructure that communities depend on at greater risk of flooding, which could lead to more costly and damaging consequences when a flood does happen. California's Assembly Bill 2800 provides a good state-level model with its legal framework for a Climate-Safe Infrastructure Working Group, which will develop a plan for how to design and build climate-ready infrastructure. The federal government should reinstate or establish a similar federal flood risk mitigation strategy to ensure federally funded projects are built well above elevations associated with flooding today.
- Incentivize regional flood risk planning to help consolidate funding and resources and implement flood resilience measures on a larger scale.
- Provide funding structures (such as storm water fees, green bonds, and revolving loan programs) to support innovative programs to move people and structures out of harm's way, and to expand nature-based infrastructure, and to improve flood mapping.
- Design and implement policies that incentivize good behavior. For example, a "disaster deductible" for federal aid could be structured such that it would encourage states to prioritize flood risk mitigation.
- Ensure targeted funding and resources for low-income communities, communities of color, tribal communities, and others who may be disadvantaged and face disproportionate harms from disasters.

Conclusion

Our current climate no longer replicates many past patterns. Our future climate will only stray farther from what we have come to expect and have developed our societies to withstand. To adapt, we must understand these unfolding precipitation and flooding trends, prepare for changes, and learn to be more resilient amidst them. But, vitally, we are only adaptable to a point, beyond which the damages, costs, and strain will create deep harm. We must recognize the climate risks to the US landscape that we simply cannot cope with, and we must strive to reduce changes to our climate and thus slow and—where we can—outright avoid these dangerous risks.

ENDNOTES

1 The CSSR is a key component of the Fourth National Climate Assessment (NCA).

2 We do not address the important problems of decreased streamflow and increased drought frequency and risk here.

3 It is important to note that even within a given region of the United States, there can be considerable variability in the observed trends both geographically and seasonally (Sagarika, Kalra, and Ahmad 2014).

4 *Silver Jackets* refers to teams in states throughout the country that bring together multiple state, federal, and tribal and local agencies that work with hazard mitigation, emergency management, floodplain management, and natural resources management to learn from one another and apply their knowledge to reduce the risk of flooding and other natural disasters (http://silverjackets.nfrmp.us/Home/About-The-Silver-Jackets-Program).

5 A recent study by the Natural Resources Defense Council, using data from FEMA, found that from 1978 to 2015 FEMA paid $5.5 billion to repair or rebuild 30,000 severe repetitive loss properties that have been flooded an average of five times or more. Texas, New Jersey, New York, and Florida ranked the highest in both numbers of these properties and damage costs.

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