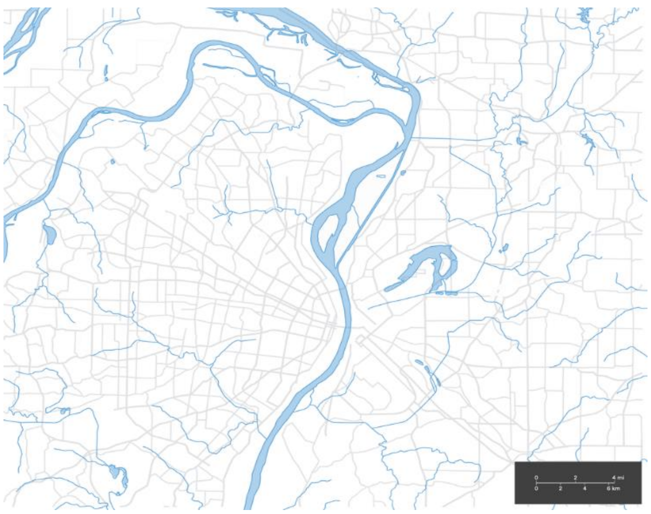
St. Louis, U.S.A.

Flooding in the Mississippi Embayment - St. Louis, Missouri

In order to understand the situation of flooding and the effects of climate change in the St. Louis region, we would have to first understand the characteristics of the Mississippi River. The Mississippi River is the largest river in North America, originating in Minnesota and ending in the Gulf of Mexico. Bodies of water from 31 contiguous states drain into the Mississippi. It is also one of the most engineered rivers in the world.

St. Louis in Missouri is situated at the near geographic center of the United States and located at the confluence of the Mississippi and Missouri Rivers. Latitudinally speaking, St. Louis is located in the middle latitude, because of which it is affected by the warm and moist air from the Gulf of Mexico, and the cold air mass originating from Canada. Therefore, naturally, St. Louis receives heavy rainfall - an average annual precipitation of about 34 inches - most of which is experienced in the spring months of March through May.



A map of rivers and lakes that criss-cross the city of St. Louis.
Source: New America
https://www.newamerica.org/in-depth/weather-eye-stories-front/st-louis-missouri/

In the recent years however, **climate change** has drastically altered the rainfall pattern, in not just St. Louis, Missouri area, but the entire Midwest. A warmer atmosphere holds more water vapor. Recent storms along the Mississippi River have been supercharged by running over a warmer ocean and through an atmosphere made wetter by global warming. This has increased both, the frequency and magnitude of floods on the Mississippi in the past 150 years.

Previously, floods in this area were correlated with global weather patterns linked to the **El Niño–Southern Oscillation in the Pacific Ocean and the Atlantic Multidecadal Oscillation**, both of which influenced when and how much rain entered the system. But these climate cycles couldn't explain the increase in the amount of precipitation. Recent data shows that the annual precipitation in the Midwest has increased by 5-10% since 1895, while the amount of rain falling in the heaviest downpours increased by 37% from 1958 – 2012 (National Climate Assessment).

https://nca2014.globalchange.gov/report/our-changing-climate/heavy-downpours-increasing

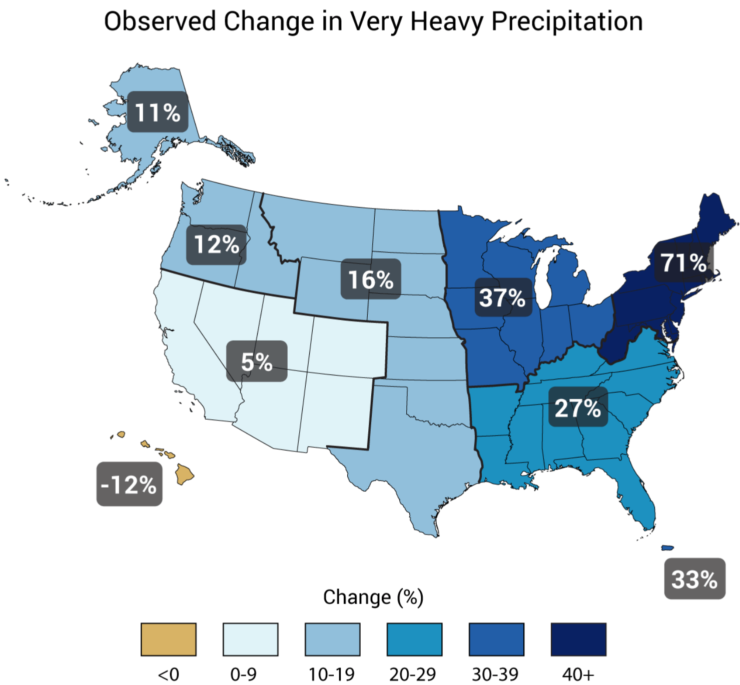


Figure 2.18: The map shows percent increases in the amount of precipitation falling in very heavy events (defined as the heaviest 1% of all daily events) from 1958 to 2012 for each region of the continental United States. These trends are larger than natural variations for the Northeast, Midwest, Puerto Rico, Southeast, Great Plains, and Alaska. The trends are not larger than natural variations for the Southwest, Hawai'i, and the Northwest. The changes shown in this figure are calculated from the beginning and end points of the trends for 1958 to 2012. (Figure source: updated from Karl et al. 2009).

According to the most recent National Climate Assessment, the region will also see higher average number of days without rainfall or snow, which could lead to agricultural droughts, reduced yields, and other economic impacts on key sectors in the future. The increased precipitation is interspersed with periods of no rain, creates what is known as a **weather whiplash effect**, which increases the risk of severe weather at both extremes (intense rain and storms and prolonged dry spells). Evidently enough, since

2005, the Mississippi River Valley has sustained successive 100, 200, and 500- year rainfall events, a 50-year drought, Hurricane Katrina, and Hurricane Isaac. As the Mississippi watershed shifts between drought and flood, climate change is exacerbating and accelerating the weather whiplash phenomenon. At St. Louis, for instance, six of the nine highest river crests recorded have happened since 1993, and four of those have occurred since 2013. The past decade has also been characterized by a series of major floods along the Missouri River.

According to the 10 cities reporting to CDP in the Mississippi River basin in 2016, the surveyed cities reported varying susceptibility to the following risks:

- ✓ 60% face river flood as a hazard;
- ✓ 50% face heat waves as a hazard;
- ✓ 30% face severe wind; 80% face flash/surface flood;
- ✓ 40% face drought; 20% face extreme winter conditions;
- ✓ 40% face extreme hot days;
- ✓ 20% face tornadoes;
- ✓ 20% face vector-borne diseases

With the exception of tornadoes, all of the above-mentioned hazards have proven to have links to climate change.

The increased frequency of heavy rain in the Mississippi River Basin is clearly due to the impact of climate change on weather. Heavier rains, combined with intensified snowpack melt on the headwaters, tributaries and mainstem of the Mississippi river, are accentuating the flood risk for basin communities. An attribution study one month after heavy rainfall battered Louisiana in August 2016, found that climate change nearly doubled the chances for the heavy downpours that caused devastating flooding across the gulf state. Average temperatures are increasing in states along both the upper and lower Mississippi, although at varying rates. Increasing heat has costly implications for agricultural yields, labor productivity, public health, energy costs, and infrastructure throughout the corridor.

These temperature trends are explored more closely below:

- ✓ Rain and flood related disasters along the Mississippi River have become persistent and systemic, incurring over $50 billion in costs since 2011.
- ✓ Furthermore, the 50-year magnitude drought in 2012 caused an estimated $31.5 billion in damages nationwide and affected at least 5 states bordering the river.
- ✓ In 2015-2016 alone, the Mississippi River Valley incurred over $13 billion in impact costs: an estimated $3 billion in damage from flooding that stretched from Grafton, IL to New Orleans, LA in the span of two months (December 2015 and most of January 2016). And in late August 2016, heavy rainfall and massive flooding caused $10 billion in damages around just the Baton Rouge area of Louisiana.
- ✓ Over the last ten years, ten or more disaster declarations have been designated in thirty states of the basin, while six states have received twenty or more.
- ✓ In 2012, disasters cut into the total revenue of the Mississippi River economy by 8.75 percent in actual losses, and more in follow-on losses. On average, over the last five years, disasters are

costing the Mississippi River economy close to 3 percent annually, with damages that carry over into successive years.

- ✓ Of the 10 cities that reported to CDP in 2016, 8 of these cities stated that they consider the effects of climate change could threaten the ability of businesses to operate successfully in their city.
- ✓ In 2016, 7 of the 10 cities of the basin surveyed by the CDP identified substantive risks to their city's water supply in the short or long term. Moreover, 47 companies reported exposure to either current or future water risks in the Mississippi River Basin severe enough to substantively change their operations, revenue or costs. Of these 47 companies, flooding was the top risk reported.

Davenport, Iowa, flooded this week after a Mississippi River barrier failed. The city is pictured here during a 2001 flood. Credit: Tannen Maury *Getty Images*

https://www.scientificamerican.com/article/rising-mississippi-river-tests-a-citys-adaptation-plan/

May 16, 2017: Several weeks after the devastating floods, some roads in St. Louis are still impassable due to high water.

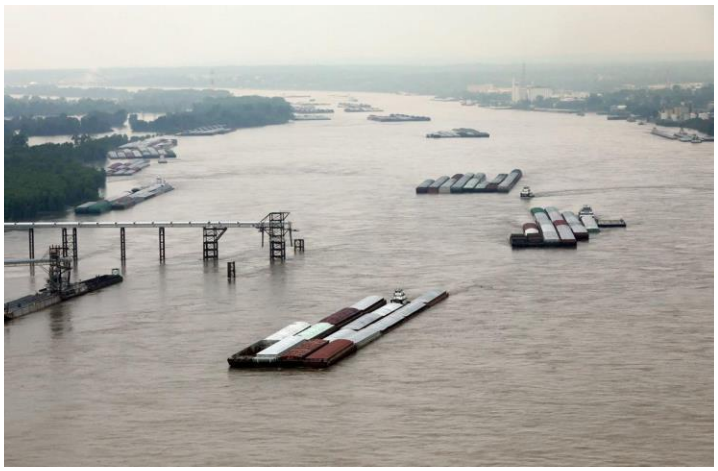
Source: Steve Zumwalt / FEMA

https://www.newamerica.org/in-depth/weather-eye-stories-front/st-louis-missouri/

Video - https://www.newamerica.org/in-depth/weather-eye-stories-front/st-louis-missouri/

The flooding that occurred this spring (2019) was outrageous, not only in terms of height of the rivers, but also for the duration spent at flood stage. A flood warning statement issued by the National Weather Service in St. Louis, MO on August 7, 2019, read as follows:

"Rainfall heavier than forecast; Could cause river levels to rise even higher than predicted." It further read, "Flood stage is 22 feet. The river is forecast to crest near 24.1 feet by early Tuesday morning."



After heavy rainfall in May 6, 2019, the Mississippi river was estimated to rise to its fourth-or-fifth highest level since records began in the 1700s. The USGS projected a crest of about 41.9 feet, which is nearly 12 feet above flood stage. The main stem of the Mississippi River has been above flood stage since March 2019, and the latest flooding in the St. Louis region added more than six inches of rain in the past week. That precipitation joined a watershed that was already saturated. "It was set up in March, of course, by snowmelt and rain, but now that snow is pretty much all in the system and getting flushed downstream," said Mark Fuchs, a senior service hydrologist for the St. Louis forecast office of the National Weather Service. "What we're seeing now is rain getting added to that base."

On May 24, 2019, the Coast Guard issued a notice closing portions of the Mississippi and Illinois rivers near St. Louis to all vessels because of extremely high water and fast-moving currents. Earlier that month the river registered another crest – seventh highest recorded in St. Louis.

HANDOUT / REUTERS: Highway 12 is seen damaged after a storm triggered historic flooding, over Niobrara River, Neb., on March 16, 2019.

https://www.stltoday.com/news/local/metro/around-st-louis-near-historic-flood-levels-expected-over-the/article_ee43ab67-b886-5037-83c6-b73b8e888790.html

http://www.city-data.com/us-cities/The-Midwest/St-Louis-Geography-and-Climate.html

https://www.weather.gov/lsx/cli_of_stl

Human Impact

Besides climate change, land use pattern, infrastructure, the construction of the levees, and other man-made navigation structures, such as wing dikes, dams, and locks, is changing the character of the river and the surrounding habitat in the St. Louis region. This human induced change is posing a threat to more than 170,000 acres of flood plain and farmland, increasing the flood risk for farmers, small towns, and cities along the banks, inundating riverside habitats and changing the flow of the river.

Illegal Levees

A series of **"Illegal" levees** are being built along both sides of the river, in the states of Illinois, Iowa and Missouri. What makes these levees illegal is that they are being built too high, or "Raised," without the required permits and approvals. The floods are more severe than they would have been without the levees, which then drives people to build more levees, driving a **"hydrologic spiral"** of flooding, levees, more flooding and higher levees.

In some areas, like Pike County, near Clarksville, levees have been overtopped and breached. Other counties are witnessing seepage. St. Charles County said on Twitter that one levee breach “displaced approximately 150 people.” According to the Mississippi analysis, Bay St. Louis, where homes have lost ninety-five million dollars in value, so far, and could lose another hundred and ten million dollars by 2033 without preventive action. Approximately 1,140 residential properties are labeled as, “High risk,” increasing to 1,237 by 2033.

There are an estimated 1,926 miles of levees across all of Missouri, according to a state hazard mitigation report, primarily built to protect agricultural land, but not up to design standards to protect people and property. In fact, five levees in Pike County, Mo., have “unacceptable” ratings, after inspections in 2016. In April, representatives with the Great Rivers Habitat Alliance, a group focused on flood plain development in the St. Louis region, wrote to members of Congress and Missouri, Illinois and U.S. Army Corps of Engineers officials to express concern about the levee situation along the Mississippi.

A new study has revealed a dramatic rise in the size and frequency of extreme floods in the past century, mostly due to **projects to straighten, channelize, and bound the river with artificial levees.** “The floods that we've had over the last century are bigger than anything we've seen in the last 500 years,” said Sam Muñoz, a former postdoctoral scholar at WHOI and the lead author of the study, published April 5, 2018, in the journal *Nature*. The research shows that in the past 150 years, the magnitude of the 100-year flood - a flood that has a 1 percent chance of occurring in any given year - has increased by about 20 percent. The research team found that about three-quarters of that elevated flood hazard can be attributed to **human modifications** of the river and its basin.

So, to what extent have human engineering altered the probability of large floods in the Mississippi? Jeff Donnelly, a paleo-climatologist at WHOI used a pioneering technique of tracking the history of hurricanes by extracting long cores of bottom sediment from lakes and marshes. By analyzing grain size and flood size for known flood events—for example, the Great Mississippi River flood of 1927—scientists could estimate the sizes of previously unknown floods represented in the sediment cores. To find out when those floods had occurred, the team used isotopes of lead, cesium, and carbon to date the coarse sediment layers.

According to another research published recently in the journal of Marine Geology, scientists have discovered that the seafloor from the Mississippi River Delta to the Gulf of Mexico is eroding. During the 20th century, the construction of thousands of dams on Mississippi River tributaries halted the flow of fine silt, clay, and other sediment from reaching the delta and seafloor to offset erosion. From the data collected from historic nautical charts, data from academic research, and the oil and gas industry as well as National Oceanic and Atmospheric Administration underwater mapping from 1764 to 2009, it was determined that the Mississippi River Delta has entered a **stage of decline.** The outlets of the Mississippi River which was previously **pro-grading** naturally for hundreds of years, has now stopped. “The underwater portions of the delta are now retreating like the land loss occurring in our landscape,” said study co-author Sam Bentley, professor and the Billy and Ann Harrison Chair in Sedimentary Geology, LSU Department of Geology and Geophysics.

The bottom line is that more levees, more wing dams, more rain, and more snowmelt a deluge of water is making its way from Minnesota southward to Illinois and beyond. With natural flood plains blocked, the water is funneled farther south, spilling out where it finds openings, often in the unprotected territory or where the levees have not been raised as high as the other side.

The regulation of the rivers is a complicated matter as the federal, state, and local agencies have to consider not just the environmental issue, but also the welfare of local residents, farmlands, ship traffic, and commerce on the river. For instance, the U.S. Army Corps of Engineers has withdrawn access to money certain levee districts used for repairs, but it does not have the authority to address levee certifications.

Adverse Impact of Human-Engineering on Flooding in the Mississippi River

The benefits of river engineering should be examined against the risks that floods pose to agriculture, infrastructure, and communities. Following is a list of adverse impacts caused due to human intervention and engineering of the Mississippi river basin.

- ✓ The construction of levees for flood protection has led to **extensive land loss**. The levees disconnect the river and an estimated 210 million tons of sediment that would naturally flow down to the delta and build the wetlands and the seafloor.

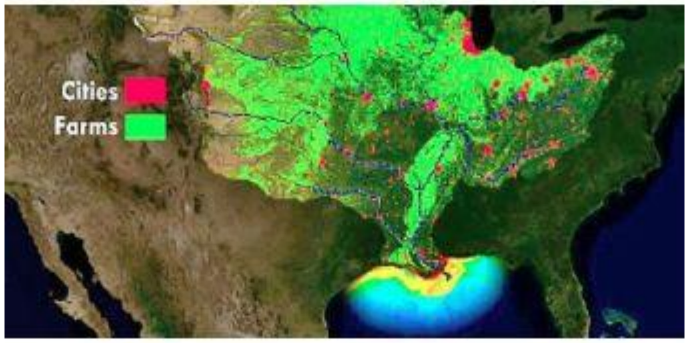
- ✓ Land loss **affects marine plants and animals**, as well as how pollution is absorbed and broken down, which affect many processes that occur from the coast to the open ocean, including marine organisms' lifecycles and underwater landslides (lead author San Diego State University Assistant Professor Jillian Maloney, who conducted this research as a post-doctoral researcher at LSU).

- ✓ During the 20th century, thousands of dams were built on Mississippi River tributaries stopping the flow of fine silt, clay and other sediment from reaching the delta and seafloor to offset erosion. Without this sediment, land in the form of wetlands and the seafloor is lost. This **threatens offshore and inland infrastructure** in the face of waves, hurricanes and surge, or flooding, from storms.

- ✓ **Hypoxic/Dead Zones**: Big floods sweep more pollutants and fertilizers from the Mississippi River into the Gulf of Mexico, causing oxygen-depleted "dead zones," which can kill fish and other marine life. The dead zone occurs cyclically every year, but scientists predict that this year's growth was one of the largest in recorded history - approximately 7,829 square miles, or roughly the size of the land mass of Massachusetts (USGS).

  The primary reason for the occurrence of a larger-than-usual dead zone this year (2019) is the abnormally high amounts of rainfall received in many parts of the Mississippi River watershed. The intense rainfall washed tons of fertilizer and sewage water out to sea, leading to a large area of polluted water. The sediment containing pollutants from fertilizers caused a spike in algal blooms developing an eight thousand mile, **"Dead Zone"** off the coast of Louisiana and Texas.

  According to the USGS estimates, the discharge in the Mississippi and the Atchafalaya Rivers was approximately 67% above the long-term average between 1980 and 2018. This abnormal river discharge is believed to have carried an outrageous 16,000 metric tons of nitrate and 25,300 metric tons of phosphorus into the Gulf of Mexico, just in the month of May 2019. The nitrate loads were estimated to be about 18% above the long-term average and phosphorus loads were 49% above the long-term average.



stated on its website www.noaa.gov.

Floods on the Mississippi River are getting more frequent and severe. But scientists warn that the infrastructure meant to protect towns and farms against flood waters is making the problem worse. The resulting floods are more severe than they would have been without the levees, which then drives people to build more levees, driving a "hydrologic spiral" of flooding, levees, more flooding and higher levees.

“When a new or larger levee is built what you're doing in many cases is taking a flood plain out there — it can be 5 or 6 miles wide — and you're forcing the water that would otherwise spread across that area to go through a narrow passageway,” states Nicholas Pinter, a geologist and the associate director of the Center for Watershed Sciences at the University of California.

As the passageway gets narrower, the water flows faster and higher. But despite 19th century warnings, levees quickly became the go-to solution for controlling the river. After the great flood of 1927, Congress required the U.S. Army Corps of Engineers to build a massive system of levees and dams on the Lower Mississippi. A study published earlier this year attempted to quantify the effect of that infrastructure on flooding. The authors examined river-adjacent sediment and tree rings going back 500 years and found that floods have become significantly more severe and frequent in the last 150 years.

Increased precipitation from climate change, combined with the effects of levees and dams, have "elevated the current flood hazard to levels that are unprecedented within the past five centuries," the authors write. “This recurring flooding is a man-made problem,” according to Bob Criss, a professor at Washington University’s Department of Earth and Planetary Sciences, speaking last month to environmental journalists. “There’s nowhere for the water to go when it rains, and the water’s getting higher and higher." Without taking the developing crest into account, three of the eight highest flood levels recorded at St. Louis have occurred since 2013, and five of those have happened since 1993.

A Flooding Conundrum

In June 2019, several temporary boilers for a dozen downtown buildings in St. Louis had lost their hot water due to flooding of the Mississippi River. Of the buildings that were inconvenienced was the City Justice Center, Busch Stadium, the Dome at America's Center, Westin St. Louis Hotel, Marriott St. Louis Grand Hotel, Hilton St. Louis at the Ballpark, and six other buildings were all affected by the outage. Similar outages had resulted in a week of closures, said Sean Hadley, the spokesman for the Metropolitan St. Louis Sewer District.

The problem was detected at the Carr Street pump station, where floodwater had mixed with rainfall from the thunderstorm, the previous day, and had overwhelmed a pipe, causing the station to fill with water. The pumping station, which pumps storm and sewer water out of the city and into the Mississippi, had to close, as there was nowhere for the water to go - The plant itself was under 10 to 12 feet of water. Water had flooded the street and the main plant for Ashley Energy, which provides steam to major downtown buildings through a 15-mile underground maze of pipes.

Ashley Energy shipped in temporary boilers from Minnesota, Illinois and Indiana to set up an impromptu station outside its riverfront facility. "Crews with the sewer district have been manning the 28 stations along the river 24 hours a day since March to monitor the river's near-historic flooding," said Hadley.

City staff said getting hot water back to the justice center, where 725 inmates were housed Monday, was the top priority. Without hot water, inmates did not have hot showers and were instead provided anti-bacterial wipes and hand sanitizer. The facility's laundry was sent to the city's other jail, the Medium Security Institution, and kitchen staff switched menus.

Richard Bradley, president of the city's Board of Public Service, managed to coordinate the overnight shipment of a mobile boiler from Chicago for the jail. Crews worked for hours trying to get the boiler running, and hoped to restore hot water there sometime Monday, according to a city spokesman.

Hot water for guests in the hotels were cut out. Westin St. Louis Hotel's general manager, Lance Misner, said the hotel arranged for the overnight shipment of a boiler, again from Chicago, and service was restored to guests early Monday. Misner said the hotel will be renting the temporary boiler for $25,000 to $30,000 a month. It was unclear who will be responsible for the cost of the replacement boilers, officials said *(*Daniel Neman of the Post-Dispatch contributed to this report).

A residential park area is overtaken by flood water from the Meremac river on 31 December 2016 in Eureka, Missouri. Photograph: Michael B Thomas/Getty Images

Personal Testimonies

Guyton, a vocal member of Neighbors of the Mississippi, a group pushing for equitable flood control measures, said about one-third of her 3,000 acres have been flooded this year (2019), and she blames the levees upstream. Without the levees blocking the floodwaters, at least some of the Mississippi River would have spilled into bottomlands and flood plains across eastern Iowa and western Illinois instead of being funneled downstream onto her land and that of her neighbors.

South of Guyton's farm, access road to Clarence Cannon National Wildlife Refuge is impassable. High water signs blocked Missouri Route 79 between Annada and Clarksville, earlier this year (2019). "No one's following the rules, and no one's making them follow the rules," said Guyton, who brought the issue to the attention of the levee district officials as well as state and federal representatives up and down the Mississippi River.

Matt Jones, a farmer, seed dealer, and crop insurance agent in Elsberry, Mo., and secretary of the Elsberry Drainage District, said, "The actions of other levee districts that raise levees during floods and do not return them to their required levels are unfairly punishing other communities, especially those on the Missouri side of the river." He further added that the "Flooded farmland is decimating crop yields and sapping farmers' livelihood."

Jon Thompson's (a 56-year-old resident of Arnold, Missouri) basement was submerged under six feet of water in just one day. "I had a 50-inch TV down there and everything," Thompson stated regretfully. "The water came through the sewers and I said to my wife: 'We've got to get out of here.' It lifted up the furniture and spun it around. The washer and drier were moving around, still connected to their hoses. That's the power of water, really." Jon Thompson is waiting on the insurance money to be paid out. "I'll stick it out a few more years here, I'll get a new drywall and TV and everything and then I'll retire and put it up for sale," he says. "I'll go and live on a mountain somewhere. I'd rather ski down than float up there."

Damon Thorne, a 44-year-old man lives in a trailer park between a freeway and the Meramac river (a tributary of the Mississippi) that experienced record flooding over the new year. "The water came around the levees and in about an hour's time it was ankle deep," Thorne says. "It was scary. We got some bags of clothes but that was it. There was three feet of water in our trailer. It destroyed our furniture, everything really." His home is completely warped, so they are temporarily staying in their landlord's trailer. They had home insurance, but it doesn't cover floods. Their county didn't supply sandbags and no volunteers are helping them out. "We felt like we were abandoned," says Damon, who doesn't work due to severe epilepsy. "We lost everything. We are trying to figure out where we go from here. How do we pick up from here? We are totally lost. "We are waiting for whatever the federal government can do. Being on a fixed income and disabled makes it hard. Right now, we are just hoping for the best and leaving it in God's hands."

Danny Brininger reads while resting on his cot at the emergency shelter opened by the American Red Cross at Arnold Baptist church. Photograph: Sid Hastings/The Guardian

Mitigation

The Missouri State Hazard Mitigation Plan includes five counties in eastern Missouri (Franklin, Jefferson, St. Charles and St. Louis Counties and the independent City of St. Louis). These five counties make up the Missouri portion of the St. Louis region. They share a common geography and climate, and hence the related risk factors which makes them unanimously vulnerable to similar natural hazards.

- ✓ Section 2.3.1. of the Missouri Hazard Mitigation Plan 2018, states that the Department of Conservation has partnered with the State Emergency Management Agency (SEMA) in developing streambank stabilization planning to help mitigate flooding problems the risk susceptible communities.

- ✓ The vulnerability analysis of state-owned facilities continued to be expanded in the 2018 State Plan. Update and the results were provided to the Office of Administration, Department of Higher Education, Department of Transportation, and Missouri Department of Conservation.

- ✓ For those facilities for which GIS data was provided, the State agencies were provided with the results indicating specific facilities potentially at risk to inundation from failure of state-regulated dams, flooding from a 100-year flood event, and levee failure;

- ✓ The five counties in eastern Missouri and the 135 municipalities within them are also members of the **East-West Gateway Council of Governments (EWG)** and are represented in regional transportation plans, (both the Long-Range Transportation Plan and the Transportation Improvement Programs); in the 2018 Water Quality plan for the region; in Homeland Security Planning through the St. Louis Area Regional Response System (STARRS), and in OneSTL, the regional plan for sustainable development.

- ✓ In 2004 and again in 2009, these five counties were part of a collaborative planning process to develop the **All Hazard Mitigation Plan**. This plan was designed to help protect public safety and prevent loss of life or injury in the event of a natural disaster. It is also designed to reduce risk to existing and future development and to prevent damage to each community's unique economic, cultural, and environmental assets. The plan will also help to improve the operational effectiveness of local governments and school districts following any natural disaster, by providing recommendations for advance preparation.

The two relevant Goals and Objectives under the Prepared Theme in OneSTL include the following:

- ✓ St. Louis Regional Hazard Mitigation Plan July 13, 2015 1-9 **Goal 1: Protect communities from known risks of natural disaster by focusing on prevention. Objectives:**

1. Reduce exposure to risks and hazards through improved disaster planning actions.

2. Increase understanding of risks and take appropriate actions to minimize risks of flooding.

3. Reduce the severity of future events through mitigation and adaptation efforts.

- ✓ **Goal 2: Strengthen capabilities for shared disaster response. Objectives**

1. Increase cooperation among first responders.

2. Promote community involvement in preparedness efforts.

In addition to the themes, goals, objectives, and strategies laid out in the OneSTL plan, EWG and the more than fifty partner organizations that were involved in that three year planning process have created a **Sustainable Solutions Toolkit** (http://www.onestl.org/toolkit) that seeks to provide practical solutions to challenges of local government in a variety of areas. Some of the toolkit elements focus on disaster mitigation practices.

Furthermore, In July 2013, the Federal Emergency Management Agency (FEMA) released its **Levee Analysis and Mapping Procedure (LAMP)** for **Non-Accredited Levees New Approach,** which outlines the approach to use for analyzing and mapping areas of risk on the landward side of non-accredited levee systems. The LAMP process specified a four-prong approach to modeling to make the final determination of the risk for these areas.

1. Conducting the Natural Valley Procedure which results in a new Zone, "D" designation

2. Conducting an interior drainage analysis inside the protected area (landward of the levee) which assumes the levee stays in place

3. Conducting an analysis of the flooding source assuming the levee stays in place (wet side of the levee)

4. Merging the risk areas and then map for each levee reach. Reaches may be mapped as one of five designations depending on the analysis results: **Sound Reach, Freeboard Deficient, Overtopping, Structural-Based Inundation, or Natural Valley**.

The State of Missouri is prone to catastrophic levee failure and/or overtopping, given the numerous levee systems constructed along the main tributaries of the Missouri River. In conjunction with the aging levee systems and lack of regular maintenance (including checking for seepage and removing trees, roots and other vegetation that can weaken a levee), the **climate change projections** suggest that precipitation may increase and occur in more extreme events, which may increase risk of flooding, putting stress on levees and increasing likelihood of levee failure.

In order to manage the floods and minimize their adverse impact on the community,

- ✓ The United States Army Corps of Engineers (USACE), has put in place **Levee Safety Program Annual Inspection Programs.**

- ✓ **State Vulnerability Overview Levees** have been constructed across the State of Missouri by public entities and private entities with varying levels of protection, inspection oversight and maintenance.

- ✓ The National Levee Safety Program Act of 2007 directed the development of a national levee safety program, in addition to the inventory and inspection of 3.139 3 Risk Assessment levees.

More importantly however, St. Louis needs a climate action plan - mitigation, and a climate adaptation plan. St. Louis is already working towards its goal of achieving a 25% reduction in greenhouse gas emissions from 2005 by 2020. St. Louis's 2010 inventory showed emissions had fallen from 2005 levels by 5.6 percent in 2010. Catherine Werner, Slay's sustainability director, noted the Rockefeller Foundation last year chose St. Louis to be part of its "100 Resilient Cities Network," which will fund a new "chief resiliency officer" in City Hall who could assist with the climate adaptation plans.

https://sema.dps.mo.gov/docs/programs/LRMF/mitigation/MO_Hazard_Mitigation_Plan2018.pdf

Adaptations

Flood Resilient construction is being used in flood risk management strategy in the St. Louis area. Flood resilient construction are designed and constructed to avoid, prevent, or reduce the damage caused when flooding takes place, and thus minimizes the impact of these actions on people and property in the event of a flood using the principles of **avoidance, water exclusion, and resilience**. They can play an important part in flood risk management strategy by reducing damage and, importantly, speeding up the recovery process.

The potential actions of flood depend on:

1. The source, depth, and velocity of flooding within a given area.

2. Flood Attributes: for instance, impacts of high velocity flooding may be dominated by hydrodynamic and debris actions, whereas groundwater flooding may be dominated by hydrostatic and buoyancy actions. Therefore, the adaptation plan should necessarily take into account the flood attributes.

3. Local construction traditions: because vernacular and contemporary architecture varies with local climate and available materials.

The approaches to avoid damage at an individual property level are categorized into three strategies:

a) Avoidance by choosing suitable locations or by designing sites or elevating buildings to avoid flooding;

b) Water exclusion, also known as dry proofing and resistance where water is prevented from entering the building by barriers and other “resistant” technology; and

c) Water entry, also known as wet proofing and resilience, where it is recognized that water will enter a building and the aim is to limit the damage and disruption from flooding.

Avoidance Technology: This technology is achieved through landscaping, drainage, and retention features and free-standing structures or barriers to prevent water reaching the building. Avoidance can also be achieved by elevation of the building itself through raising on pillars, extended foundation walls or raised earth structures, or flotation. An alternative avoidance technique is to create buildings that rise and fall with the water, either permanently floating or designed to float in flood conditions (van de Lindt et al., 2007).

Water Exclusion Strategies /Resistance and Dry Flood Proofing: are designed to keep water out of a property. Temporary measures are frequently resorted to, and sandbags and homemade flood boards are commonly used by communities to exclude water during an emergency.

Water Entry Technology/Wet Proofing/Flood Resilience/Water Acceptance: involves methods and technology designed to limit the damage once water has bypassed the building envelope and entered the occupied space.

The premise of the **Flood Resilient Construction** is based upon the following:

1. That new construction on the floodplain should be avoided where possible

2. Follow the principles of "making space for water." The evidence is underpinned by knowledge of the potential impact of flooding on buildings as outlined in Kelman and Spence (2004), an understanding of properties and limitations of construction materials, structural engineering principles, and the science of water transport and flood characteristics. Nadal et al. (2006) summarizes the state of knowledge based on a combination of theoretical and empirical evidence.

3. Construction elements, furnishings, and occupants all need to be considered from the substructure to provisions.

As Kelman and Spence (2004) observed, the main flood actions on building components are:

- Hydrostatic (lateral pressure and capillary rise)
- Hydrodynamic (velocity, waves, turbulence)
- Erosion (scour under buildings, building fabric)
- Buoyancy (lifting the building)
- Debris (items in the water colliding with the building)
- Nonphysical actions (chemical, nuclear, biological)

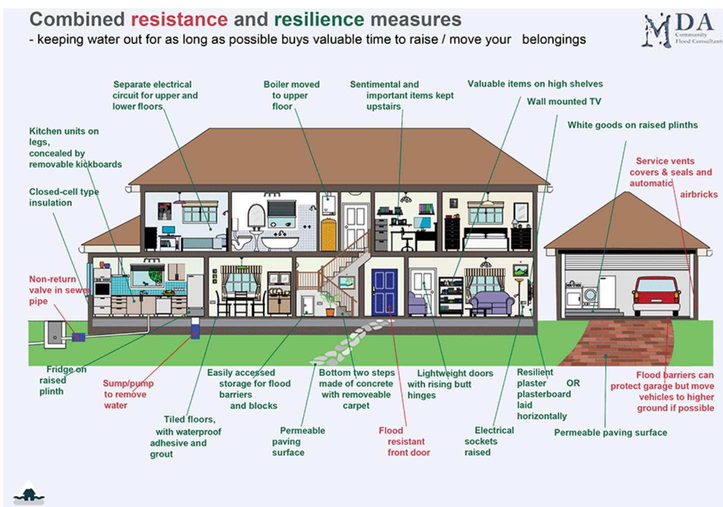


Figure 5. Graphic illustrating combined resistance and resilience measures (Dhonau & Rose, 2016).

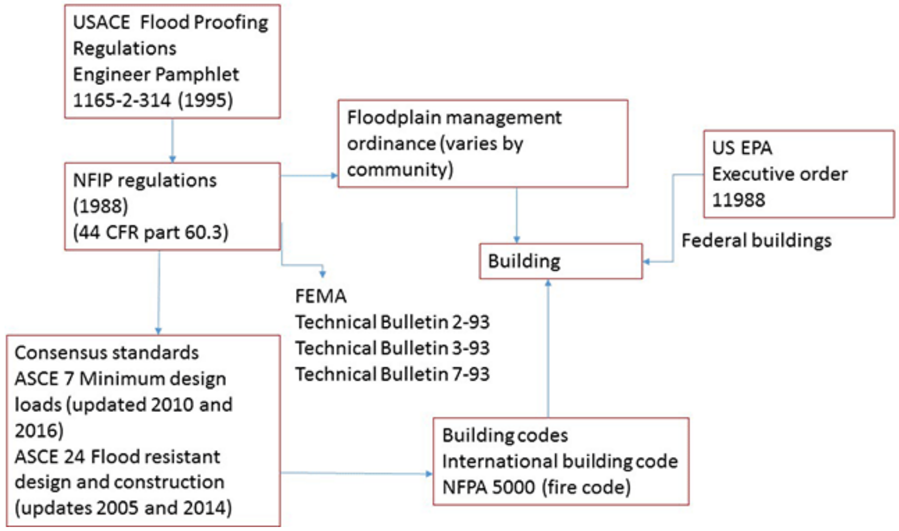


Figure 2. Development of regulation and guidance materials for resilient construction in the United States (after Perkes, 2011).

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