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Turmoil on the Mississippi River: Harnessing Green Infrastructure to Accommodate Drastically Changing Environmental Patterns

Edouard Ballett
University of Arkansas, Fayetteville

Turmoil on the Mississippi River: Harnessing Green Infrastructure to Accommodate Drastically Changing Environmental Patterns

By

Edouard Fulton Ballett

Advisor: Iana Shaheen

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Sam M. Walton College of Business
University of Arkansas
Fayetteville, Arkansas

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Abstract

The Mississippi River is one of the most important commercial waterways in the world. It connects the United States' agricultural and manufacturing centers with the rest of the country and the global supply chain while also being the economic engine for developments up and down the river. Over the past four years, the Mississippi River has experienced its worst drought and flood on record. Climate change is increasing the commonality of extreme weather events, and we must alter outdated concrete or "gray" infrastructure. Traditional river engineering of levees, locks, and dams increases the severity of river flow or lack thereof, creating problems for cargo shippers and regional economies. Nature-based and hybrid solutions are potential replacements or complements of gray infrastructure. Levee setbacks, reconnection of floodplains, wetland restoration, and utilization of flood bypasses should be emphasized on a regional scale as the Mississippi River region adjusts to rapidly changing water level patterns. The application of green infrastructure increases safety, limits financial risk, improves navigation functionality, restores river accessibility for local communities, and raises the overall environmental quality of the region.

Introduction

The Mississippi River has played a significant role in the economic development of the United States, contributing to the growth of commerce, transportation, and agriculture in the region (Severin et al., 2023). From its early use as a trade route for Native Americans to its current status as one of the most critical commercial waterways in the world, the Mississippi River has always been a vital part of the region's economic landscape (Severin et al., 2023). One of its most important roles is as a transportation and commerce hub, serving as a critical link for goods and commodities.

Today, the Mississippi River transports over 500 million tons of goods and commodities annually (Severin et al., 2023). The river's location in the heart of the United States provides access to the primary agricultural and manufacturing centers, making it an essential link in the global supply chain (Severin et al., 2023). According to the U.S. Department of the Interior (2022), by "measure of tonnage, the largest port district in the world is located along the Mississippi River delta in Louisiana" (*Commerce*). The grand stature becomes even more apparent when considering the size of the Mississippi River watershed, which includes all of its tributaries, "The Mississippi River drains an area of about 3.2 million square kilometers (1.2 million square miles) including all or parts of 32 states and two Canadian provinces, about 40% of the continental United States" (U.S. Department of the Interior, 2022, *Watershed Size*). According to the Environmental Protection Agency (2016), the Mississippi River watershed provides the daily water supply to over 50 cities and an estimated figure of over 20 million people.

Figure 1

Detailed map of the Mississippi River Watershed. Made using USGS data (Shannon1, 2016).

The river has also been crucial to the region's agricultural development. The river's fertile floodplains and delta have provided ideal conditions for growing crops such as cotton, rice, and sugarcane (Severin et al., 2023). The river basin has also played a critical role in developing the country's agricultural infrastructure, with levees and irrigation systems built to control flooding and enhance productivity (Severin et al., 2023).

> The agricultural products and the vast agribusiness industry developed in the [Mississippi River Basin] produce 92% of the nation's agricultural exports, 78% of the world's exports in feed, grains and soybeans, and most of the livestock and hogs produced nationally. 60% of all grain exported from the U.S. travels on the Mississippi River through the Port of New Orleans and the Port of South Louisiana (U.S. Department of the Interior, 2022, *Commerce*).

In addition to transportation and agriculture, the Mississippi River has significantly impacted industry and manufacturing in the region. The river provides access to raw materials such as timber, iron, and coal, fueling the country's industrial base (Severin et al., 2023). The river has also been a significant source of hydropower, with hydroelectric dams providing electricity to the region's homes and businesses (Severin et al., 2023). The river's location has made it a critical transportation link for oil and natural gas, with pipelines and refineries along its banks. The river also provides access to coal mines and power plants, making it a vital part of the country's energy infrastructure (Severin et al., 2023).

The economic impact of the Mississippi River extends beyond the United States. The river is a critical link to the global supply chain, the first step to transporting goods and commodities worldwide by boat. (Severin et al., 2023). The river's location in the heart of the country makes it an essential link between the East Coast, West Coast, and Gulf Coast ports. It remains the connective tissue of trade within the region.

Extensive engineering for water control and navigation has drastically altered the natural hydrology and riverbed of the Mississippi. Following the calamitous flood of 1927, the federal government implemented a comprehensive flood control program (Severin et al., 2023). From the Gulf of Mexico to Cape Girardeau, Missouri, "the river is virtually walled in by a vast line of main-stem levees" (Severin et al., 2023, *Flood Control*). These actions have cut-off access to floodplains and communities in the surrounding countryside (Severin et al., 2023).

Idealistically, flooding on the Mississippi is "constricted by levees, hastened out of danger zones by floodways and improved channels, dissipated down spillways into reservoirs, or starved by the impounding of tributary floods" (Severin et al., 2023, *Flood Control*). However, the system has been frequently overwhelmed recently, allowing significant flooding of farmland and riverside towns (Severin et al., 2023). For instance, the Bonnet Carrè Spillway between Baton Rouge and New Orleans opened eight times between 1931 and 2008. Since 2008, it has opened seven times (U.S. Army Corps of Engineers, 2020).

The U.S. Army Corps of Engineers is constantly dredging to ensure a consistent flow of goods. They maintain a nine-foot shipping channel from Minneapolis, MN, to Baton Rouge, LA. In the 250-mile stretch from Baton Rouge past New Orleans and down to the Gulf of Mexico, the Corps sustains a 45-foot deep channel to enable ocean-going vessels to access these ports (U.S. Department of the Interior, 2022). An ongoing project deepens this 250-mile stretch to 50 feet, matching the expanded Panama Canal and ensuring that large vessels can navigate both channels (Carse & Lewis, 2020).

Within the confines of this short paper, I seek to address the rapidly changing dynamics surrounding the Mississippi River and necessary action for the future. I was first inspired to write about the Mississippi River after reading about the supply chain calamity surrounding the 2022 Drought. Through extensive research, I discovered so much more about extreme weather caused by climate change, the history and consequences of engineering on the river, and the actions available to restore the hydrology of the Mississippi River without inhibiting its economic importance.

Understanding the Link Between Climate Change and Extreme Weather

In recent years, The navigability of the Mississippi has declined due to changing weather and precipitation patterns. To fully understand the variable water conditions of the Mississippi, it is necessary to examine how the changing climate affects hydrological cycles.

Think of an entire year of weather as a bell curve, with the hottest and coldest days on the ends and most days in the middle. A slight shift in the curve towards higher average temperatures means a more significant proportion of days would fall into hot or extremely hot, while less would be classified as extremely cold weather (Taylor, 2022; Environmental Protection Agency, 2016). Therefore, more frequent and severe heat waves occur (Taylor, 2022; Environmental Protection Agency, 2016).

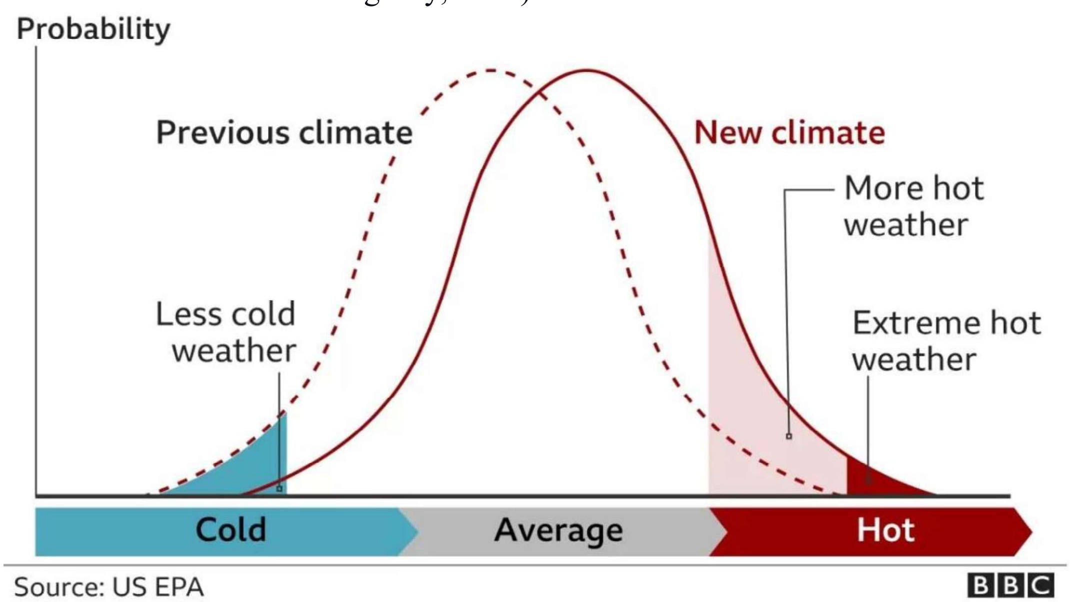

Figure 2
Bell curve of a year of weather and a shift to higher average temperatures (Taylor, 2022).

Relative to the water levels of the Mississippi River, higher average temperatures contribute to more common droughts and flooding, along with more inconsistent weather patterns. Raised temperatures increase water evaporation from water bodies and land (Environmental Protection Agency, 2016). Heat-caused water loss from plants and land contributes to rapidly drying soils which fuel drought, even without declines in precipitation (U.S. Global Change Research Program, 2014). With more evaporated moisture in the atmosphere, intense precipitation follows through severe storms and rainfall (U.S. Global Change Research Program, 2014). There are not necessarily more rainstorms, but rather an increase in the amount of rain falling within a particular storm (U.S. Global Change Research Program, 2014).

In the United States, "since 1991, the amount of rain falling in very heavy precipitation events has been significantly above average. This increase has been greatest in the Northeast, Midwest, and upper Great Plains – more than 30% above the 1901-1960 average" (U.S. Global Change Research Program, 2014, *Heavy Downpour*). As shown in image 1, the Mississippi River basin covers most of the Midwest and Upper Great Plains regions. Overall, estimations show that annual precipitation in the Mississippi River has "increased by 20% in the last 50 years" (Prida, 2021, para. 2). These trends contribute to greater flood risk on the lower Mississippi.

In addition, the cyclical changes are more drastic. During the hydrological winters of November to April, water levels further increase due to earlier snowmelt and rising precipitation (Prida, 2021). On the other hand, during hydrological summers of May to October, lowering precipitation reduces water flow, enabling long and severe drought (Prida, 2021). Essentially, an even more significant water level variance is expected on the Mississippi going forward. The trend extends beyond the Mississippi; major international inland waterways like the Mekong, Rhine, and Danube rivers are experiencing similar drought and flood, drastically hindering navigability (Prida, 2021).

The risk of a crippling disaster is significant as the severity of tropical storms and hurricanes rises due to a recorded two-degree human-caused global warming (Knutson et al., 2020).

> This phenomenon can contribute to the increase of compound high level risk in the lower Mississippi since the end of the wet season (March-July) coincides partially with the hurricane season (June-November). If an extremely wet season in the Mississippi basin coincides with the occurrence of an extreme storm surge hitting the Mississippi delta, the consequences in the region could be unprecedented. (Prida, 2021, para. 3)

Recent Extreme Weather Complications

The Mississippi River has experienced its worst drought and worst flood within the past four years. Both sides of the coin can bring shipping to a standstill and cause significant economic losses. They provide a glimpse into a future of more severe weather and the ensuing chaos from such trends.

The Flood of 2019

The 2019 Mississippi River flood was an unprecedented disaster. It was the longest-lasting flood period in recorded river history and caused significant economic damage (Prida, 2021). The leading cause was a significant increase in precipitation in the Midwest. From January to June 2019, a significant chunk of the region saw the wettest period on record, with precipitation 150-250% greater than expected (Renfro, 2019). Extreme rainfall and a rapid temperature increase in March induced early snowmelt, leading to runoff (Prida, 2021). Over those six months, "210 trillion gallons of water" flowed down the Mississippi, a "volume 64% greater than the 10-year average" (Renfro, 2019, *An Unprecedented Volume of Water*). In Baton Rouge, the Mississippi River water height remained above the flood stage for 211 days, shattering the 1927 historical record of 135 days (Prida, 2021).

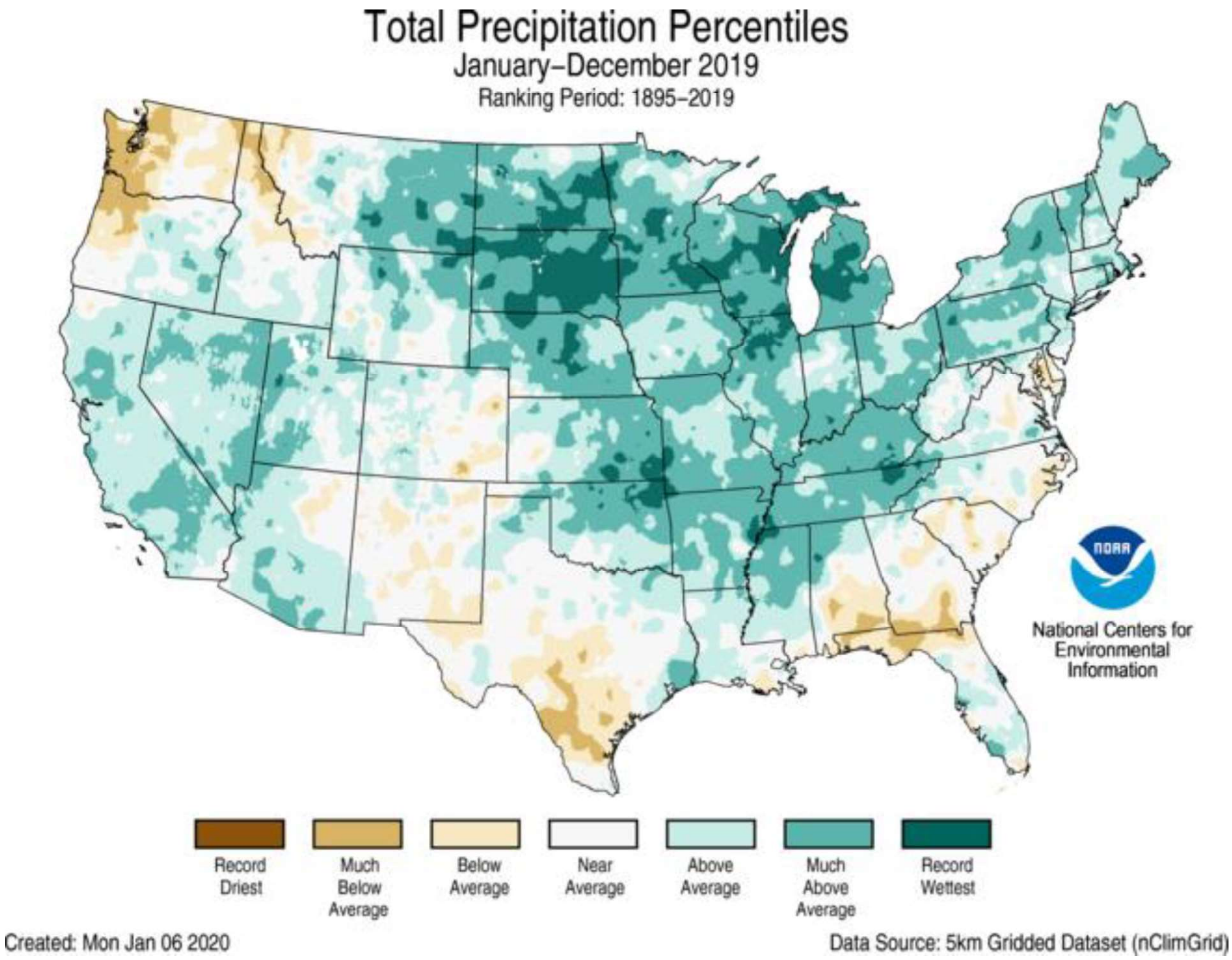

Figure 3

2019 precipitation totals (Fleming, 2020).

The economic ramifications of the 2019 flooding were disastrous. Nineteen Mississippi watershed states were damaged and incurred over $20 billion of losses (Gonzalez & Kuzma, 2020). The industries hit hardest were inland freight transportation, farming, and manufacturing. The flood prevented the harvesting of crops by farmers, halted construction projects, and brought barge traffic to a standstill for multiple months (Gonzalez & Kuzma, 2020). About $1 billion worth of grain, or 6.3 million tons, was left unshipped because of the inability to find transportation (Gonzalez & Kuzma, 2020).

Transportation is massively hindered during extreme water levels because fierce eddies and swift river flow velocities create navigation difficulties (Prida, 2021). Navigating the windy Mississippi River is complicated at the best of times. Often requiring "different ship captains with localized knowledge," but flooding creates unpredictability, complicating the problem even further (Gasparini & Yuill, 2022, *High Stage Raises Concerns*). In times of high flood stage, there is an increase in shipping accidents, occasionally resulting in deaths (Gasparini & Yuill, 2022).

Freight vessels experience extra costs if a ship is already on the river when strong currents and flooding become too treacherous to navigate. Freight companies may "need to hire tugboats to keep the vessels on berth" and pay for both additional time at a dock and captain stand-by time (Prida, 2021, para. 5). The strong currents also mean "ships at anchorage can be unmoored and drag anchors," potentially causing damage. (Gasparini & Yuill, 2022, *High Stage Raises Concerns*). For ports, available berthing for vessels to anchor becomes limited or even unusable as anchored ships need additional space between each other (Gasparini & Yuill, 2022).

Ships waiting to enter the river at its mouth also face additional fees. They may have to pay for extra time at anchorage or local piers as vessels wait for normal shipping channel conditions to resume (Prida, 2021). Even with constant dredging, silt buildup can be severe at the river mouth, limiting the possible size of a vessel coming upstream (Prida, 2021).

The lower Mississippi faces additional economic risk due to the sheer scale of goods that flow from the Gulf of Mexico to Baton Rouge. As discussed earlier, the broad width and depth of this 250-mile stretch enable ocean vessels to traverse this shipping lane. Therefore, this section is susceptible to dramatic river level changes, making transportation dangerous or completely unmanageable. Tugboats must lighten their loads during swift flow, limiting shipping capacity (Gasparini & Yuill, 2022). Journeys downstream can be quicker, but traveling upstream is slow and necessitates extra fuel. All the reasons above contributed to a 2019 commodity shipping load reduction of 25% when compared to the 10-year average (Gasparini & Yuill, 2022).

The Drought of 2022

In 2022, we saw an unprecedented drought that crippled transportation routes, bringing inland shipping to a standstill. In addition, "the 2022 flash drought occurred within a long-term trend in which annual minimum water levels on the lower Mississippi River have declined over the past century" (Lombardi et al., 2022, *Changing Flash Drought Patterns*). Typically, the lower Mississippi streamflow responds slowly to precipitation changes because water must travel great lengths from tributaries in the upper basin. However, in 2022 the change was rapid and dramatic, and the river height in Memphis dropped 20 feet in just 11 weeks (Lombardi et al., 2022).

The occurrence of drought in 2022 was most concerning, not because of its effects but due to its cause. In years prior, low water on the lower Mississippi originated from drought weather over the Ohio and Missouri River tributary regions, causing less water to flow downstream (Lombardi et al., 2022). However, soil moisture was normal over those regions in 2022; Instead, a flash drought formed directly over the Mississippi River in the central United States (Lombardi et al., 2022). Consistent, abnormally high temperatures in the region increased evaporation and rapidly reduced water flow to the lower Mississippi (Lombardi et al., 2022).

> The idea that the main stem of a large river like the Mississippi can experience low water even when its major tributaries are flowing at normal levels goes against conventional thinking about hydrologic drought. The historic drought in the Mississippi River watershed shows that climate change alters large rivers as high temperatures increase evaporation and make the soil more "thirsty." (Lombardi et al., 2022, *Changing flash drought patterns*).

With the Mississippi River dry season from May to October, water levels are typically at their lowest in October. This period is crucial for American agriculture, with the regular harvest and shipping periods for soybeans and grain falling in this timeframe (Elkin et al., 2022). In addition, corn crops are affected as nitrogen fertilizer travels upriver to the corn belt to be applied to crops in November (Elkin et al., 2022).

Limitations on navigable portions deep enough for barges are common during periods of low water. In early October, water levels permitted only one-way traffic, and a vessel queue of at least 2,000 barges and 100 tow boats developed (Plume, 2022; Lombardi et al., 2022). Harvest season shipping demand alone causes shipping costs to rise due to increased demand, but navigation problems during low water made transportation costs rise to excessive levels (Lombardi et al., 2022). Following the summer of 2022, the average shipping rate by barge escalated from approximately $11 per ton to $71 per ton by the end of October (Lombardi et al., 2022). A month later, the rate decreased to $27.25 per ton, still more than double the standard seasonal rate (Lombardi et al., 2022).

The U.S. Coast Guard restricted the number of goods shipped on an individual barge (McWhirter, 2019). They also limited the allowed depth of a particular barge and the number of barges a tow can haul to stop vessels from getting stuck (McWhirter, 2019). In times of poor navigability, there is no viable alternative for shipping agricultural goods because the quantity is immense and the profit margin is relatively low. High costs meant it was unfeasible to ship their goods to market. For many farmers across America, this meant harvesting crops and leaving them in a field with a tarp on top for months. (McWhirter, 2019)

A barge can haul 1750 tons of dry cargo, equivalent to 70 trucks. A single tow hauling 15 barges can carry 1,050 trucks worth of goods. Barges are the most sustainable and lowest-cost option for commercial shipping (McWhirter, 2019). In times of extreme water levels, rail shipping is often not a viable alternative because they are dealing with a labor shortage, capacity, and reliability issues. (Semuels, 2022)

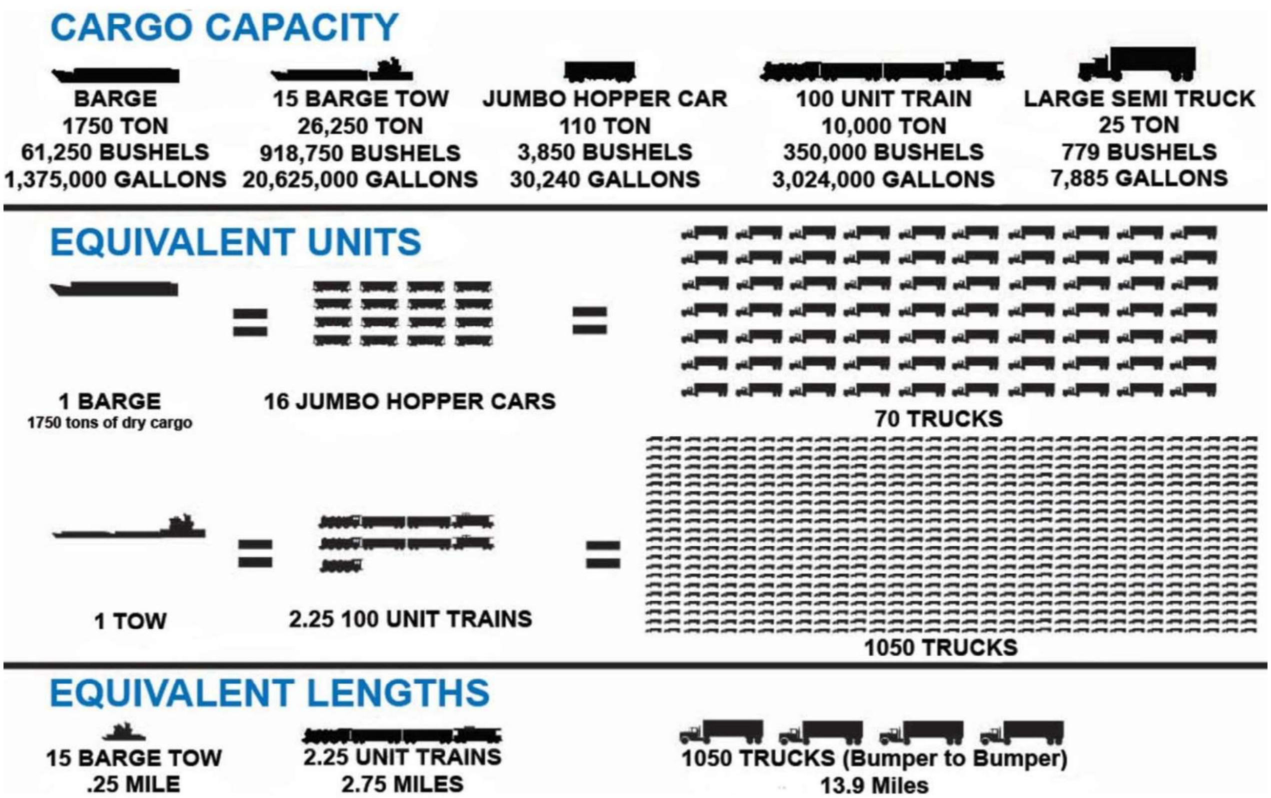

Figure 4

Cargo capacity and their equivalent units (U.S. Army Corps of Engineers, 2010).

A Highly Engineered River

We must change flood and drought management practices for the Mississippi River. Historically, river management design assumes "stationarity, or the concept that the mean and window of variability in river flow are not changing" (Gasparini & Yuill, 2022, para. 5). This idea is not accurate anymore. Changing temperatures in the United States have a ripple effect down to alterations in the precipitation patterns, increasing the severity of extreme flooding and drought tendencies experienced on the Mississippi (U.S. Global Change Research Program, 2014). Using historical water level estimates to build future water control systems is no longer feasible because it does not accurately indicate what is to come (Gasparini & Yuill, 2022).

Over the past 100 years, flood risk mitigation necessitated river engineering, still a necessary function of water control systems. However, the risk of low-water events is also drastically increasing, and the systems must adjust to the expected hydrologic extremes of the future. Past construction of levees, locks, and dams has "impounded a growing share of the river's flow upstream and decreased variations of the river's flow," unintentionally increasing the severity of low-water events (Lombardi et al., 2022, *Changing flash drought patterns*).

The Lower Mississippi exists in a highly engineered state; of the 540-kilometer stretch above the Gulf of Mexico, "483 kilometers of concrete and rock revetments… prevent channel migration and the formation of new distributary channels (Gasparini & Yuill, 2022, para. 4)." In addition, levees remain on the first 16 kilometers above the Gulf. We have bent the river to suit our economic needs. These changes have permanently altered the hydrologic cycle of the river.

With no human intervention, the Atchafalaya River would be the primary outlet of the Mississippi into the Gulf of Mexico (Rasmussen, 2017). The river has naturally changed channels in this manner about six to eight times over the past 5000 years (Rasmussen, 2017). Engineers altered the current outlet of the Mississippi River into the Gulf of Mexico to maintain shipping routes. In 1950, the U.S. Army Corps of Engineers decided that the water flow output should endure permanently, with a distribution of 30% to the Atchafalaya and 70% to the Mississippi (Gasparini & Yuill, 2022).

These decisions have had significant long-term ramifications on the deltas and natural wetlands of the Louisiana coastline. Wetlands form by the accretion of "mineral sediment and organic material" carried downstream (Younger, 2022, para. 3). Accretion creates fresh soil while combating erosion, rising sea levels, and sinking land (Younger, 2022). Human intervention has redirected the sediment flow that naturally builds wetlands through accretion (Younger, 2022). Construction of "reinforced levees and thousands of miles of canals and excavated banks have isolated many wetlands from the Mississippi River and the network of streams," which feed their growth (Younger, 2022, para. 4).

The foundation of flood protection structures on the Mississippi is Levees. They have prevented damages in the past but still inflate severe flood risk because levees increase water level height and flow speed (Gonzalez & Kuzma, 2020). A secondary effect of increased flow speed is that sediment shoots past deltas and into the Gulf of Mexico instead of depositing along the coastline. (Rasmussen, C. 2017). In addition, rapid river flow creates navigation difficulties for transportation companies (Gasparini & Yuill, 2022).

Levees also encourage human expansion and agricultural development in flood-sensitive areas because they provide a false sense of security (Gonzalez & Kuzma, 2020). More settlement in these regions increases costs when flooding strikes and covers native wetlands, which would otherwise act as floodwater depositories (Gonzalez & Kuzma, 2020). A study by the American

Society of Civil Engineers in Illinois showed that losing 1% of wetlands may increase flood volume by 7% (Gonzalez & Kuzma, 2020).

Deltas and wetlands are in danger because they cannot grow fast enough to offset the subsidence of land and rising sea levels. On a geological timescale, deltas are "young and fragile, in a delicate balance of sinking and growing" (Delta-X, *What's happening to Deltas*). Most large deltas worldwide are increasingly becoming "sediment-starved," as they are not receiving soil quickly enough to compete with sea level rise (Delta-X, *What's happening to Deltas*).

NASA research has gauged wetland loss in Louisiana at about 21 square miles per year since the 1980s (Younger, 2022). Since the 1950s, Louisiana's wetlands loss has been expansive enough to cover the state of Rhode Island (Younger, 2022). The leading cause of losses is river and coast engineering, while rising sea levels, oil and gas infrastructure, and hurricanes have also contributed (Younger, 2022). However, there is still hope for wetland recovery as some engineering projects have built new land by adding sediment. (Younger, 2022) The 2023 Louisiana Coastal Master Plan is a $50 billion project which, in part, attempts to limit the loss of land. A primary goal is utilizing sediment diversions to rebuild land (Gasparini & Yuill, 2022).

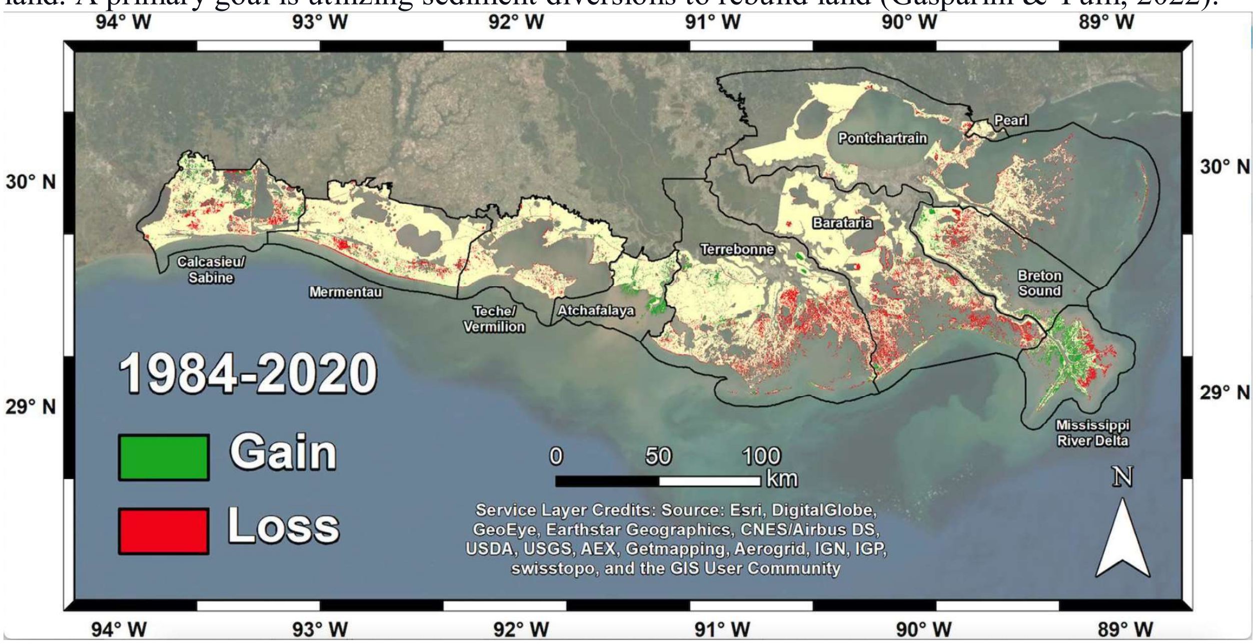

Figure 5

Map of wetlands loss on the Louisiana coastline (Younger, 2022).

Using Green Infrastructure for Effective Water Management

Moving to the future, we must change our approach to infrastructure around the Mississippi. Action must be taken at a large scale for considerable benefits to occur. Nature-based solutions are a cost-effective and mutually-beneficial option for the problems caused by extreme weather and traditional river engineering.

As discussed earlier, traditional concrete river engineering, primarily levees, makes droughts and floods more severe at a time when we expect a more significant number of these events because of climate change. (Lombardi et al., 2022; Prida, 2021; Gonzalez & Kuzma, 2020). Nature-based solutions can be cost-effective replacements or additions to concrete or gray infrastructure because they neutralize the downsides of levees (Gonzalez & Kuzma, 2020).

Effective regional river management options include levee setbacks, reconnection of floodplains, wetland restoration, and additional investment in flood bypasses (Gonzalez & Kuzma, 2020; Prida, 2021; Room for the River Programme, 2019). Many of these approaches were taken by the Netherlands, a country with a history of river management issues, in their Room for the River Program (Room for the River Programme, 2019).

Table 1

Green replacements for gray infrastructure (Ozment & Bescos, 2019).

SERVICE	GRAY INFRASTRUCTURE OPTION	GREEN INFRASTRUCTURE THAT CAN COMPLEMENT OR REPLACE
Water supply and sanitation	Reservoirs, treatment plants, pipe network	**Watersheds, wetlands**
Hydropower	Reservoirs and power plants	**Watersheds**
Coastal flood protection	Embankments, groynes, sluice gates	**Mangrove forests**
Urban flood management	Storm drains, pumps, outfalls	**Urban flood retention areas**
River flood management	Embankments, sluice gates, pump stations	**River floodplains**
Agriculture irrigation and drainage	Barrages/dams, irrigation and drainage canals	**Agricultural soils**

An economical first stage is the relocation of levees further back from a river, providing the security of a levee while limiting its adverse effects on river flow (Gonzalez & Kuzma, 2022). Levee setbacks also give room for "nature-based solutions that increase the resilience and effectiveness of flood mitigation," such as floodplains (Gonzalez & Kuzma, 2022, para. 11). Floodplains are a buffer that allows space for a river to fluctuate and expand, enabling a river to form curves which increase water storage and decrease flow speed (Gonzalez & Kuzma, 2022).

For example, the state of Washington was hit hard by flooding in 2009, forcing thousands of residents surrounding the Puyallup River to evacuate as the levees were topped (The Nature Conservancy, 2022). The state then partnered with the Nature Conservancy to work on hybrid solutions that restored green infrastructure to complement traditional gray infrastructure (The Nature Conservancy, 2022). Fantastic results came through levee setbacks and relocating residents from floodplains (The Nature Conservancy, 2022). In 2014, a similar water flow occurred, but the town remained unscathed (The Nature Conservancy, 2022). These actions also helped to rebuild the natural ecosystem and habitats of local wildlife, all while improving flood protection (The Nature Conservancy, 2022).

For farmers in flood-prone areas, sacrificing a portion of land for floodplains is worthwhile. Allowing a floodplain to do its job prevents unintentional and costly farmland flooding (Gonzalez & Kuzma, 2022). A 2009 study discovered that the reconnection of 8,000 hectares of floodplain prevents flooding on about 26,000 hectares of farmland (Gonzalez & Kuzma, 2022).

Another excellent strategy for flood mitigation by farmers is the utilization of cover crops planted to cover the soil rather than for harvest. They improve soil health, slow erosion, help to control pests, and protect against floods by holding almost three times as much water as bare soil (Gonzalez & Kuzma, 2022). They can reduce economic losses and flood damage at only $37 per acre, acting as an eco-friendly form of insurance (Gonzalez & Kuzma, 2022).

Moreover, wetland restoration is a crucial step toward limiting flood damage. Wetlands are natural storage containers that hold water during heavy rainfall or flood before gradually releasing it (Gonzalez & Kuzma, 2022). A 2013 study found that "restoration of wetlands on only 1.5% of a landscape can reduce flood peaks by up to 29%, in terms of maximum water volumes and levels." (Prida, 2021, para. 8). This illustrates the cost-effectiveness of nature-based solutions that do not require the same level of constant upkeep as concrete.

A fully-fledged alternative to levees in high-risk regions is the utilization of flood bypasses. Flood bypasses are a channel built near a river or in an undeveloped floodplain that takes in extra flood waters diverted from the main stem (Naturally Resilient Communities). The goal is to redirect water from valuable or vulnerable areas, such as a city (Naturally Resilient Communities). They can provide community greenspace, aquatic and wetland habitat, and flood mitigation without blocking a river's connectivity to its floodplain (Naturally Resilient Communities). Widespread adoption of flood bypasses as a substitute for levees would limit the river navigation problems they contribute to downstream (Naturally Resilient Communities).

Implementing a large-scale approach that includes levee setbacks, reconnection of floodplains, wetland restoration, and flood bypasses would solve problems across the board. For local communities and farmers, these solutions would significantly increase safety by mitigating flood risk and the cost of damages while improving the overall environmental quality and protecting ecosystems in the river region. Individual stakeholders, such as inland waterway cargo transport companies, are vital contributors to local economies and would also be major beneficiaries of structural changes. Emphasis on nature-based solutions can dramatically limit the adverse effects of extreme weather on river navigability. We must prioritize updates to our outdated infrastructure and utilize available solutions which will provide universal benefits.

Conclusion

The Mississippi River remains an economic engine for the United States due to its importance as a low-cost and large-scale shipping highway for many American industries and exports. The functionality of ports and adequate environmental conditions is vital to the mass of local communities and cities existing alongside the river, as well as private stakeholders such as river freight transportation companies. Nevertheless, the Mississippi River region has recently been overwhelmed as an outdated water management system struggles to curtail problems caused by rapidly changing precipitation patterns. Historically rare water levels are the new normal on the Mississippi, as precipitation extremes will worsen for the foreseeable future. The economic ramifications of such events are severe; The record drought of 2022 and flood of 2019 severely hindered regional shipping and local economies. The current system of almost exclusively gray infrastructure no longer serves its purpose sufficiently.

However, nature-based and hybrid solutions are potential replacements or complements of gray infrastructure. Large-scale prioritization of Levee setbacks, reconnection of floodplains, wetland restoration, and utilization of flood bypasses is critical. The application of green infrastructure increases safety, limits financial risk, improves navigation functionality, restores river accessibility for local communities, and raises the overall environmental quality of the Mississippi River region.

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