# A Continental-Scale Trajectory and Reckoning with Ecosystem and Water Cycle Collapse:

# From the Rocky Mountains to the Gulf of Mexico

Diagnosis, Quantification, and Nature-Based Restoration Pathways

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# EXECUTIVE SUMMARY

The terrestrial ecosystems stretching from the Rocky Mountains through the Great Plains to the Gulf of Mexico are undergoing a cascading collapse of unprecedented magnitude. Two centuries of fire suppression, the elimination of Indigenous land management, continuous livestock grazing, conversion of native grasslands to cropland, and the construction of more than eight hundred reservoirs have fundamentally disrupted the water cycle across more than 40 percent of the contiguous United States. See the graphic depiction of the primary changes in Figures 1 and 2.

The consequences are stark and quantifiable. Median river discharge has increased two hundred–four hundred times over historic levels. Soil organic carbon—the foundation of water infiltration, nutrient cycling, and biological productivity—has been depleted by an estimated 70 percent across agricultural and grazed lands. Sediment delivery to the Gulf of Mexico has fallen from five hundred million bone-dry tons per year to 120–130 million tons, fine-textured material incapable of sustaining the delta wetland system. Louisiana has lost 1,900 square miles of coastal wetlands since the 1930s, an area the size of Delaware, with losses continuing at the rate of a football field everyone hundred minutes.

The biophysical mechanisms driving this collapse are well understood. Fire suppression has allowed dense lodgepole pine monocultures to replace montane meadow grasslands, reducing surface albedo, accelerating snowmelt, eliminating deep-rooted perennial plant soil stabilization, and catalyzing soil organic carbon decomposition and erosion. Across the Great Plains, continuous grazing and tillage agriculture have stripped soils of the organic carbon that once held 12,000 to 60,000 gallons of water per acre for every one percent of soil organic carbon present. Watersheds that historically absorbed and slowly released precipitation over months to years now function as rapid surface-water conveyances, exporting floodwater while stripping topsoils through erosion and leaving remaining soils desiccated.

The evidence for recovery, however, is equally compelling. Adaptive Multi-Paddock (AMP) grazing—short-duration, high-density rotational grazing with planned recovery periods—has been demonstrated to jump start the restoration of surface to subsurface water infiltration functions within 3–5 years and increase soil organic carbon stocks by more than 13 percent relative to conventional continuous grazing. Mountain grassland restoration following logging or wildfire can jump-start measurable water-table recovery within 1–3 years and soil organic carbon improvement within 5–7 years. If AMP grazing were implemented on just 20–30 percent of Great Plains rangelands, the resulting improvements in infiltration, soil moisture retention, and base-flow stabilization would materially alter the hydrologic trajectory of the Mississippi River system and the Mississippi river delta and coastal wetlands.

This paper presents a synthesis of historic and modern ecological conditions, presents a high-level estimate of the magnitude of hydrologic and edaphic change, and identifies nature-based restoration strategies that are believed able to reverse the trajectory of ecosystem decline at

continental scale. The cost of inaction—measured in lost water resources, collapsed fisheries, vanishing coastal wetlands, intensifying floods and droughts, and a sediment-management crisis estimated to exceed many multiples of one trillion dollars—demands an immediate and strategic response.

**Figure 1. Historic Ecosystems—Mountains to Gulf**—continuous meadow and grasslands ecosystems to the Gulf of Mexico. Dominated by deep rooted perennial native herbaceous vegetation systems over the larger landscape with trees cover along rivers.

**Figure 2. Contemporary Ecosystems—Mountains to Gulf**—Heavy overstock forest cover in the mountains, to highly altered great plains converted from grassland to cropland, land development, reservoirs are filling with sediment, and gulf coastal wetlands are starved of the diverse textural types found in historic delivered sediments, and receiving excessive nutrients and decomposable suspended organic sediments.

# 1. INTRODUCTION

Massive continental changes in vegetation, soil systems, and land management have produced civilization-scale disruptions to ecosystems and the water cycle across North America. This paper summarizes a synthesis of the historic ecological conditions and the modern alterations that have transformed the hydrologic relationship between the Rocky Mountains, the Great Plains, and the Gulf of Mexico—a corridor encompassing the Mississippi River basin, which drains 43 percent of the contiguous United States and extends marginally into south-central Canada (USGS, 2023).

The transformation follows a consistent biophysical pathway: the elimination of fire-maintained perennial grasslands has triggered woody vegetation encroachment, soil organic carbon depletion, and the collapse of infiltration-driven hydrology. Watersheds that once functioned as continental-scale sponges—absorbing precipitation, recharging groundwater, and releasing water gradually over months and years—have been converted into rapid exporters of surface runoff (Apfelbaum and Haney, 2010; Teague et al., 2016). The downstream consequences include amplified flooding, chronic drought between flood events, reservoir sedimentation, Gulf of Mexico hypoxia, and the progressive disintegration of one of the most productive deltaic and grassland systems on Earth (Twilley et al., 2016; Chamberlain et al., 2018).

The magnitude of these changes has been obscured by their incremental pace and by the fragmented disciplinary lens through which individual symptoms are typically studied. Hydrologists document increased flood peaks; soil scientists measure carbon depletion; coastal geologists track land loss; fire ecologists catalog the consequences of suppression. This paper integrates these threads into a unified high-level account of continental-scale ecosystem dysfunction—and presents evidence that nature-based solutions can reverse the trajectory within years, not decades, if implemented at appropriate scales.

# 2. HISTORIC ECOLOGICAL CONDITIONS

## 2.1 Vegetation Structure

Prior to Euro-American settlement, the landscape from the Rocky Mountain alpine zones through the Great Plains to the Gulf Coast was structured and maintained by fire. Mountain vegetation was dominated by perennial, deep-rooted, diverse grasslands, with trees restricted to drainages, north- and northeast-facing slopes, and fire-protected enclaves (Donovan et al., 2024). Ponderosa pine savannas occupied the lower elevations; juniper-pinyon communities occupied intermediate elevations; scattered lodgepole pine grew at higher elevations; and limber pine, whitebark pine, Engelmann spruce, and subalpine fir existed as dispersed elements within expansive meadow systems that extended in the subalpine and alpine zone. This elevational pattern from the front range to the alpine zones was consistent across the Rockies (Brown, 1995; Apfelbaum and Haney, 2010).

This mountain grassland-meadow complex transitioned eastward and lower elevations into the shortgrass prairie, then the tallgrass prairie, interlaced with oak savanna systems. Forested and shrub zones followed major waterways emanating from the Rockies. The Mississippi River embayment—the geologic footprint of ancient marine inundation—supported extensive floodplain wetlands, oxbow lakes, and forested bottomlands (Apfelbaum, 2009). Fire, driven by both lightning and Indigenous management, routinely swept from the mountains through the Great Plains and as far as the Gulf Coast in Texas and Louisiana and the Atlantic seaboard in the Carolinas and Virginia (Donovan et al., 2024; USFS, 2023).

## 2.2 Soils and Carbon Dynamics

Mountain soils were cold and moist, conditions that suppressed decomposition and promoted the accumulation of peat and muck soils—organic deposits that often remained frozen well into the growing season at higher elevations. Below the alpine zone, the fire-maintained grasslands produced immense quantities of biomass that, through partial decomposition, generated deep reserves of soil organic carbon (SOC). Post-fire pyrolysis produced recalcitrant biochar that contributed to durable, sponge-like, mineral-associated carbon compounds. These compounds bound nutrients and water while sustaining diverse and productive communities of soil microbes and mycorrhizal fungi that further reinforced soil structural integrity and nutrient cycling (Kimble et al., 2007; Apfelbaum and Haney, 2010).

The deep-rooted perennial grasslands—with root systems extending multiple meters below the surface—accumulated SOC not only at the surface but throughout the soil profile. Historic SOC concentrations in the silt loams and clay loams of the Great Plains ranged from 5 to 12 percent by weight (Sanderman et al., 2017). This carbon-rich soil matrix functioned as a massive water-storage battery, retaining precipitation and snowmelt for slow release to groundwater and stream base flow.

## 2.3 Water Cycle Dynamics

High albedo across the mountain meadows and great plains prairies—a function of grass-dominated ground cover and open canopies—reflected solar radiation and attenuated surface heating. This reflectivity maintained cool surface conditions that prolonged snow retention and reduced evapotranspiration. Slow, sustained snowmelt infiltrated through the SOC-rich soils, recharging groundwater systems that fed a reliable, gently rising hydrograph delivering water across the entire year and even across multi-year periods (Apfelbaum and Haney, 2010). The system’s enormous storage capacity—functioning through the interaction of deep-rooted vegetation, organic carbon soil, and microbial and fungal networks—buffered precipitation variability and minimized both flood peaks and drought severity.

## 2.4 Erosion and Sediment Transport

The dense rhizosphere of perennial grasslands—a complex network of roots, mycorrhizal hyphae, and soil biota interacting with SOC-enriched colloids—slowed water movement through the soil matrix and minimized erosion throughout the system from mountains to Gulf Coast. Erosion was episodic and stochastic, associated with rare events of exceptional rainfall or snowmelt. Flash flooding in the mountains and downstream flooding in the Great Plains were correspondingly rare, usually seasonal when the ground was frozen and could not support infiltration, normally contributing to a consequence of the extended discharge hydrograph produced by this vast infiltration-driven system.

Larger erosion episodes were associated with Pleistocene glacial activity, which carved mountain valleys and transported billions of bone-dry tons of coarse sediments—cobble, gravel, sand—annually. Each glacial advance and retreat contributed to the formation of one or more delta lobes at the Mississippi River mouth, structures that extended at least sixty-six miles seaward from the present shoreline near New Orleans and developed over periods of 1,000–2,000 years. The Chandelier Islands mark the outer margin of these former delta lobes. Over the approximately 7,000 years since glaciation ceased, longshore currents and river discharge have moved former delta-lobe sediments off the continental shelf and into the deep Gulf abyss (Coleman, 1988; Penland et al., 1988). The deltas now have also eroded because of reduced diverse texture sediment loads being delivered to the delta.

### 2.5 Water, Biology, and Human Systems

Beaver, massive soil microbial communities, and deep-rooted vegetation together created a SOC storage system that enhanced soil moisture, supported both shallow and deep infiltration, and cooled and cleansed surface and infiltrating water. This complex biological-hydrologic system maintained high biodiversity, reduced nutrient, and soil loss, and minimized water export from the landscape. The ecosystem supported Indigenous hunter-gatherer communities who foraged on herds of wildlife, fish, and diverse plant resources while actively managing the landscape through fire (Apfelbaum, 2009).

## 3. MODERN CONDITIONS AND CONSEQUENCES

### 3.1 Vegetation Transformation

Since Euro-American settlement of North America, wildfire has been systematically suppressed and the Indigenous peoples whose interactions-maintained fire-dependent landscapes have been displaced. The consequences for vegetation structure have been profound and pervasive (Donovan et al., 2024; USFWS, 2024).

In the mountains, the patchy mosaic of meadows and scattered tree copses has been replaced by continuous forest cover. Foothill ponderosa pine savannas have given way to dense thickets. Juniper-pinyon woodlands have expanded into former grasslands. Most critically, the expansive south- and west-facing meadows and fire-scar grasslands across the mountain landscape are now dominated by dense, even-aged monocultures of lodgepole pine, typically 70–110 years old. These stands form closed-canopy forests with minimal light penetration to the ground layer, eliminating the perennial grass, sedge, and forb communities whose root systems historically protected soils from erosion (Woo et al., 2024; Hicke et al., 2016).

Dense needle litter covering the forest floor creates a deceptive appearance of stability. These lodgepole monocultures have dramatically accelerated soil erosion and water loss. The dark green to black canopy absorbs solar radiation—a sharp reduction in albedo—that heats the soil surface and accelerates snowmelt, even where more snow initially accumulates under tree cover (Boon, 2009). The dense forest canopy also creates homogeneity in snow accumulation patterns, concentrating snowpack in uniform areas that thaw rapidly, producing synchronized meltwater pulses that overwhelm the reduced infiltration capacity of degraded soils (Winkler et al., 2014) and also overwhelm water management infrastructure in what are now flood prone mountain valleys and Great Plain receiving watersheds.

Across the Great Plains, more than 80 percent of native grasslands have been lost to agricultural conversion, development, and woody encroachment—a rate of ecosystem destruction that makes grasslands the most imperiled terrestrial ecosystem on the planet, experiencing greater conversion rates than forests (Blair et al., 2014; USFWS, 2024). The Great Plains region has experienced the highest woody encroachment rate among all ecoregions in North America, with a 1–2 percent annual increase in woody species cover driven by the combined effects of altered fire regimes, drought, and livestock grazing (Twidwell et al., 2023). Wetlands within the mountains, foothills, Great Plains, and glacial regions have been drained. Floodplains have been converted to farmland. Unsuitable lands have been colonized by weedy woody vegetation or developed for residential and commercial uses.

## 3.2 Soil Degradation

The low albedo in lodgepole-dominated mountain forests hastens warming, runoff, erosion, and infrastructure damage while accelerating the decomposition of soil organic carbon, the very substance that provides structural stability, water-holding capacity, and infiltration function. Increased snowmelt velocity and hastened runoff dewater soils, while SOC loss reduces the moisture available for plant growth. Grazing pressure compounds the soil degradation, contributing to increased forest fire risk and fire intensity. When high-intensity fires combust the soil duff and SOC, they collapse soil structure, further reduce infiltration, and accelerate the runoff cycle from the mountains. These same degradation processes have occurred across the Great Plains beyond the mountain zone (Apfelbaum et al., 2022).

The USDA estimates that soil organic carbon across agricultural and grazed rangelands in the United States has been depleted by 70 percent on average (Sanderman et al., 2017; Lal, 2018). Soils that historically carried 5–12 percent SOC now measure 0.5–1.5 percent—a transformation that is as catastrophic for water management as it is for agricultural productivity and climate stability. The global carbon debt of 12,000 years of land use has been estimated at 133 petagrams of carbon for the top two meters of soil, with the rate of loss accelerating dramatically in the past two hundred years (Sanderman et al., 2017). In the U.S. Corn Belt alone, A-horizon soil has been completely removed from an estimated 35 percent of cultivated land (Thaler et al., 2021).

### 3.3 Hydrologic Disruption

All vegetation and soil changes converge to produce a single, devastating hydrologic outcome: the replacement of infiltration-driven base flow with surface-water runoff. The consequences include reduced base flow from groundwater, shortened time of concentration, increased runoff volumes, chronic drought risk, diminished soil moisture replenishment, reduced potable and instream water availability, and the functional elimination of reliable irrigation supply for crop production and livestock watering (Apfelbaum et al., 2012).

Native fisheries, beaver populations, and many other wildlife species that depended on stable, cool stream flows cannot persist in the altered system. Increases in soil erosion, salinity, and alkalinity contribute to downstream sedimentation, reduced floodplain productivity, and vegetation shifts that progressively undermine the productive capacity of the land for both ecological and economic uses.

### 3.4 Erosion and Coastal Consequences

Heavy soil erosion—driven by mountain vegetation conversion, agricultural cropping, continuous grazing, and accelerated snowmelt—has increased floodplain deterioration and channel degradation throughout the system. The eight hundred reservoirs constructed on tributaries and the mainstem of the Missouri River in the western United States are filling with coarse sediments. Many mainstem Missouri River reservoirs have lost 50 percent of their water storage volume since construction, while the water quality and recreational utility for which they were created continue to deteriorate (Meade and Moody, 2010).

Gulf of Mexico hypoxia—the seasonal “dead zone” driven by nutrient-laden agricultural runoff—compounds the effects of SOC depletion, declining biodiversity, increased flood severity, and damage to communities, cities, ranches, and recreational resources across the system.

## 4. QUANTIFYING THE MAGNITUDE OF CHANGE

### 4.1 River Discharge

Changes in stream discharge provide the most powerful single indicator of watershed dysfunction. Analysis of multiple rivers in Iowa, Wisconsin, and Illinois since settlement in the

1830s reveals extraordinary increases in peak discharge during flood events, with similar trends documented throughout the United States and many other regions worldwide (Apfelbaum, 2001):

**Low flows:** Increased up to three hundred times over historic peak discharge levels reflection of accelerated drainage of what were once slowly released groundwater reserves.

**Median flows:** Increased 200–four hundred times compared to historic discharge levels—documenting the systemic shift from infiltration-dominated to runoff-dominated hydrology.

**High flows:** Increased 3–5 times over historic levels—representing amplified flood peaks that exceed the capacity of constructed infrastructure.

These figures represent a fundamental inversion of the historic hydrograph. Watersheds that once delivered water slowly and reliably now produce violent flood pulses followed by rapid dewatering and drought.

## 4.2 Soil Moisture Capacity

The relationship between SOC and soil water-holding capacity is direct and quantifiable. Depending on soil texture, soils can retain between 12,000 and 60,000 gallons of water per acre for every one percent of SOC present. Each one-percent increase in SOC enables soils to hold approximately 12,000 additional gallons of water per acre (Hudson, 1994; Minasny and McBratney, 2018).

These figures are based on fine-textured soils (silt loams and clay loams) and sandy loam soils that historically carried 5–12 percent organic carbon and now carry 0.5–1.5 percent on average. The **4.5–10.5 percentage-point decline** in SOC translates to a loss of **54,000 to 630,000 gallons of water-holding capacity per acre**—a staggering hydrologic deficit that directly drives increased runoff, flooding, and drought vulnerability.

## 4.3 Sediment Budget Crisis

After glaciation, stabilized vegetation and water cycles reduced the massive glacial sediment loads to approximately five hundred million bone-dry tons of mixed-texture sediment flowing annually down the Mississippi River, with most originating from the Missouri River watershed. This load—comprising sand, gravel, cobble, silt, clay, and suspended organic matter including logs and woody debris—created a structurally competent delta system that maintained expansive Gulf coastal wetlands (Kesel, 1988; Meade and Moody, 2010).

The Gulf coastal wetlands now receive only approximately **120–130 million bone-dry tons** of sediment annually, and most is fine sediment—suspended organic materials and floatable matter from topsoil erosion—that lacks the structural diversity needed to build and maintain competent delta landforms. The 75-percent decline in sediment delivery from historic levels has been driven primarily by reservoir trapping, with lower Mississippi River sediment loads decreasing by more than 70 percent since 1850 (Mississippi River Delta Campaign, 2017).

These coastal wetlands are now subsiding and breaking apart due to saltwater intrusion, converting to open water. Louisiana has lost approximately 1,900 square miles of land since the 1930s. The sediment deficit—trapped behind approximately 800 reservoirs with virtually no sediment management plans—represents a sediment management debacle that may cost American citizens many trillion dollars or more to remediate: releasing impounded sediments, engineering delivery mechanisms, and rebuilding the Gulf coastal wetlands that support the region's tourism, commercial and sport fisheries, oyster production, and one of the most diverse and productive deltaic systems on Earth (Blum and Roberts, 2009; Kolker et al., 2023).

# 5. NATURE-BASED RESTORATION PATHWAYS

There is critically important good news. The biophysical mechanisms of restoration are well documented and can produce measurable results within years, not decades. Two major investment strategies, following nature's lead, and halting the cascading failures described above are critically important steppingstones to a restored future.

## 5.1 Adaptive Multi-Paddock Grazing

The most prevalent and destructive grazing practice across the Great Plains is continuous livestock grazing, the free roaming grazing (unmanaged), year-round presence of cattle or sheep on large, undivided pastures. This practice produces chronic overgrazing of preferred plant species, soil compaction, reduced ground cover, and progressive SOC depletion (Teague and Kreuter, 2020).

Adaptive Multi-Paddock (AMP) grazing replaces continuous grazing with a system that quickly grazes the land at high stock density, retains approximately 50 percent of standing grass biomass for cover, and provides appropriately long recovery periods—emulating the historic grazing dynamics of migratory herbivore herds (Teague et al., 2016; Apfelbaum et al., 2022). The published evidence for AMP's effectiveness is now substantial:

**Infiltration recovery:** AMP grazing consistently produces higher surface-water infiltration rates than conventional continuous grazing. Infiltration function is typically the first ecosystem response and shows recovery quickly within 3–5 years on soils with adequate baseline condition, and within double that time on severely degraded soils (Teague et al., 2011; Wang et al., 2021).

**Soil carbon sequestration:** Averaged across multiple southeastern U.S. ranch pairs, AMP management produced soil organic carbon stocks to one-meter depth that were more than 13 percent greater than paired continuous-grazing operations. AMP soils contained 25 percent more mineral-associated organic matter carbon—the most stable long-term carbon pool (Mosier et al., 2021; Apfelbaum et al., 2022).

**Vegetation and productivity:** Standing crop biomass on AMP ranches averaged more than 300 percent higher than on conventional operations, with increased plant species dominance-diversity and reduced bare ground (Apfelbaum et al., 2022).

**Soil biology:** AMP grazing enhances soil food web structure, increases bacterial and fungal biomass, and improves microbial respiration efficiency—the biological mechanisms through which soil carbon accumulates and water-holding capacity improves (Johnson et al., 2022).

**Multiple co-benefits:** AMP grazing simultaneously restores the water cycle, vegetation structure, wildlife diversity, soil health, and soil carbon—thereby addressing climate change risks, water supply deficits, and agricultural productivity with a single management investment. AMP management also supports higher livestock stocking rates and greater economic returns (Teague et al., 2016).

If AMP grazing were adopted on 20–30 percent of Great Plains rangelands, the resulting improvement in infiltration, SOC, and water retention could significantly improve water supply, flood risk, and downstream water quality. A larger adoption footprint would provide long-term confidence in the ecological and economic future of the northern Great Plains ecosystem and all downstream waterbodies, including the Gulf of Mexico.

## 5.2 Mountain Grassland Restoration

Mountain forests and eastern deciduous forests are in crisis. More than fifteen million acres of mountain pine beetle mortality have left hundreds of millions of tons of highly combustible dead and dying trees across the western United States, with additional outbreaks in Colorado ponderosa pine forests accelerating as of 2025 (Hicke et al., 2016; Colorado State Forest Service, 2025). Larger and more severe wildfires are both occurring and predicted, contributing massive smoke, haze, and caustic chemicals that harm wildlife and human health now and will exacerbate these effects in the future.

Of the approximately 155 million acres of public national forests, a substantial portion consists of overstocked western montane forests prone to wildfire and insect depredation—forests that historically were part of the mountain grassland-meadow-parkland system whose ecological and hydrologic benefits are described above. There is a significant opportunity to restore these mountain grasslands and parklands to recover the associated water-cycle and multiple ecosystem benefits including wildlife dependent on these systems.

Forest-to-grassland conversion, whether through wildfire, prescribed fire, or mechanical harvesting—produces rapid hydrologic recovery:

**Water-table recovery:** Wetting-up of the water table and rehydration of remaining soil organic matter in burned and harvested forests can occur within 1–3 years after canopy removal, driven by the immediate reduction in evaporative and evapotranspiration losses from forest cover reduction (Adams et al., 2012).

**Infiltration recovery:** Infiltration function recovers rapidly within 1–3 years as perennial grass, sedge, and forb communities reestablish root systems in the cleared landscape.

**Soil carbon rebuilding:** SOC improvements are measurable as improvements in soil health, soil carbon levels, and water-holding capacity within 5–7 years after logging or fire events (Apfelbaum and Haney, 2010).

Wildfire has been the primary mechanism of moving these forested lands back toward grassland and sparse forest conditions. However, proactive restoration—strategic thinning, prescribed fire, and reseeding with native perennial grass and forb communities—could accelerate recovery at scales sufficient to measurably improve the regional water cycle.

# 6. DISCUSSION

The synthesis presented here reveals a continental-scale system in cascading failure, driven by a coherent set of land-use changes that have disrupted the foundational ecological processes—fire, deep-rooted perennial vegetation, and soil organic carbon accumulation—upon which the North American water cycle depends. The scale of quantified change—200–400-fold increases in median river discharge, 70-percent depletion of soil organic carbon, 75-percent reduction in Gulf sediment delivery—exceeds what incremental, site-level interventions can address. The problem is continental; the solution must be commensurate.

The evidence from AMP grazing research is particularly significant because it demonstrates that the biophysical mechanisms of recovery are intact. Soils retain the capacity to rebuild organic carbon, restore infiltration, and rehydrate landscapes—but only when the management practices that caused the degradation are replaced with practices that emulate the ecological processes under which these systems evolved. The 3–5-year timeline for infiltration recovery under AMP grazing, and the 1–3-year timeline for water-table response following mountain forest-to-grassland conversion, suggest that nature-based solutions can produce measurable results within a single political or planning cycle.

The sediment crisis in the Mississippi River system illustrates the compounding nature of the problem. Reservoir sedimentation simultaneously reduces water storage capacity, traps the coarse sediments needed to sustain Gulf coastal wetlands, and eliminates the natural sediment transport processes that built and maintained the delta over millennia. Addressing this crisis requires not only watershed-scale restoration of infiltration and erosion reduction—which would slow the rate of reservoir filling—but also the development of sediment management protocols for existing reservoirs, many of which lack the infrastructure for bottom-water withdrawal or sediment flushing.

The economic case for action is compelling. The costs of inaction include accelerating flood damage, declining agricultural productivity, collapsing fisheries, vanishing coastal real estate and infrastructure, water treatment costs driven by impaired quality, and the eventual trillion-dollar sediment management liability. The costs of nature-based restoration—changes in grazing management, prescribed fire, and strategic forest thinning—are modest by comparison and generate multiple co-benefits including climate change mitigation, biodiversity recovery, and improved agricultural productivity.

# 7. CONCLUSIONS

The trajectory described in this paper—from fire-maintained grasslands and carbon-rich soils supporting infiltration-driven hydrology, to fire-suppressed forests and carbon-depleted soils producing runoff-dominated watersheds—is well documented and internally consistent across multiple lines of evidence. The consequences are already severe and will intensify without intervention.

The restoration pathways are equally clear. Adaptive multi-Paddock grazing can restore infiltration, soil carbon, vegetation diversity, and water-cycle function across hundreds of millions of acres of Great Plains rangeland within years. Mountain grassland restoration can recover hydrologic function in the headwaters that supply the Missouri and Mississippi River systems. Together, these nature-based strategies can begin to reverse the continental-scale ecosystem and water-cycle collapse that now threatens water security, food production, coastal communities, and biological diversity from the Rocky Mountains to the Gulf of Mexico.

The question is not whether restoration works. The evidence is unambiguous. The question is whether we will act at a scale commensurate with the problem—and whether we will act before the compounding costs of inaction foreclose the opportunity.

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