The West without Water

WHAT PAST FLOODS, DROUGHTS, AND OTHER CLIMATIC CLUES TELL US ABOUT TOMORROW

B. Lynn Ingram and Frances Malamud-Roam

Foreword by Sandra L. Postel

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For my loving family: Don, Daniel, Aaron, and Gene, and in memory of my father, Dr. Gerald Ingram

B. Lynn Ingram

For Anne

Frances Malamud-Roam

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FOREWORD

There is little doubt that humanity is in for turbulent times when it comes to water. Rising human demands against a finite supply are draining rivers, shrinking lakes, and depleting aquifers. In a world of seven billion people and growing, competition for water is intensifying to quench our thirst, grow our food, generate electricity, and manufacture all manner of consumer goods from cars to computers to cotton shirts.

On top of these demand-driven trends, the last century and a half of greenhouse-gas emissions and the concomitant rise in global temperatures are fundamentally altering the cycling of water between the sea, the atmosphere, and the land. Climate scientists warn of more extreme floods and droughts and of changing precipitation patterns that will generally make dry areas drier and wet areas wetter. In terms of water, the natural variability of the recent past will not be a reliable guide to the future. We have moved outside the bounds of "normal" to some new normal yet to be understood.

The recent decade of drought in the southwestern United States has thrown a spotlight on this region's vulnerability to the changes that lie ahead. From 2000 to 2009, the Colorado River exhibited the lowest ten-year-running-average flow of any ten-year period in the past century. During that time, the capacity of giant Lake Mead—which stores water for nearly 30 million people and vast areas of farmland—fell from 96 percent to 43 percent. Climate scientists at the Scripps Institution of Oceanography have estimated that, within a decade, there is a 50 percent chance that Lake Mead will drop below the reservoir's outlets.

It is sobering to realize that this current southwestern drought pales (at least so far) in comparison to the "mega droughts" that have occurred multiple times in the past—and that could occur again in the future. The

warm "medieval drought" during the middle of the twelfth century lasted two decades and was more severe and widespread than any other in the Southwest over the past 1,200 years. It almost certainly factored into the decline and ultimate collapse of the Hohokam, an enterprising people who settled and farmed in the valleys of the Salt, Gila, Verde, and other rivers of southern Arizona. The Hohokam thrived for a thousand years—from 450 to 1450—and then disappeared as a distinct culture.

Today, in our technologically sophisticated world, it is easy to believe we are immune to such an outcome. But we have not been seriously tested. For the past century and a half, humanity has enjoyed a relatively benevolent climate. During this time, we built big dams to tame the earth's rivers, diverted flows from one river basin to another, drained wetlands for farming, and built oasis cities in the desert. We have so successfully masked aridity that we have become imbued with a false sense of security about our water future.

In this engaging and enlightening book, B. Lynn Ingram and Frances Malamud-Roam peer deep into the past through the lens of paleoclimatology to assemble evidence that can inform how citizens and leaders prepare for the new climatic regimes, including more intense droughts and floods, that almost certainly lie ahead for the western United States. The insights they uncover through this climate detective work lead them to a sense of urgency about taking action now to prepare for more erratic and extreme future conditions.

We may have other lessons to learn from the past as well. In order for our modern culture to enjoy a millennium of prosperity in the West, as the Hohokam did, we may need to embrace aridity and water's tightening limits and apply ingenuity and creativity to successfully live within those limits, rather than continue to mask and deny them.

Sandra L. Postel
Director, Global Water Policy Project

PREFACE

I love a sunburnt country,
A land of sweeping plains,
Of rugged mountain ranges,
Of droughts and flooding rains.

DOROTHEA MACKELLAR,
"*My Country*"

A noise woke me in the middle of the night. I sat bolt upright in bed, my heart pounding, but heard only the sound of rain pelting the roof. Peering out my bedroom window, I saw a flashlight bobbing in the blackness of the backyard. My father, wearing a yellow raincoat, was pointing the flashlight toward the edge of our yard. The rain had been heavy on and off for weeks, soaking the ground, causing erosion, and undercutting our yard and those of our neighbors. Where once we had an ample yard, now only about fifteen feet of grass separated our house from the precipitous edge of the canyon. My father was discovering that one of our trees had vanished with the latest chunk of our property to disappear down the slope.

We lived on a steep mountain ridge in Santa Barbara, a small, beautiful city in Southern California nestled between the Santa Ynez Mountains and the Pacific Ocean, about sixty miles west of Los Angeles. By the end of that wet winter of 1969, several homes on our street had been largely destroyed. The house to our right balanced precariously on the edge of a newly formed cliff face, the former backyard entirely gone. Those neighbors, in an effort to save their home, shored up the eroding property by piling truckloads of large gray boulders onto the slope below. But nature finally won out, and they were forced to leave. The neighbors on the other side also lost most of

their backyard; only their concrete swimming pool remained, fully intact, surreally suspended over the canyon.

Although our home was spared that year, the torrential rains saturated hillsides and triggered massive landslides and mudflows all across Southern California. Roads were transformed into rivers and flat lowlands into muddy lakes. The river flows in Santa Barbara doubled their normal levels. More than 100 people were killed, and hundreds of homes were destroyed. Southern California was declared a federal disaster area, and the National Guard was brought in to help with cleanup and restoration. As an eight-year-old, I had no way of understanding these events.

Pouring rain is a common occurrence during Southern California winters, but so are sunshine and heat. This hot-weather climate extreme is of greater long-term concern, because it is the cause of perennial scarcity of freshwater in California and the Southwest. Many of my childhood summers were spent in central Arizona on my grandparent's ranch in the Sonoran Desert south of Phoenix, with more climate lessons. Central Arizona and Southern California are similar in climate—different ends of the same desert. The surreal temperature contrast between the cool of the air-conditioned houses and cars and the oven-like heat outdoors is still a vivid memory. Summer temperatures in the central Arizona desert are routinely among the hottest in the nation, commonly reaching 115–20°F, and, though I noticed the cotton and alfalfa fields, I never questioned how these crops could grow in a desert. Nor did I wonder how water could flow freely from faucets in the Arizona desert, just as it did in arid Southern California.

Occasionally, the limitations of living in a desert become more evident. I clearly remember the drought of 1976–77, which was the year that California—and much of the western United States—had virtually no rain. As a teenager, I was struck by the realization that water is a finite resource, one that can actually run out. My friends, my family, and I had always used water liberally with little thought about supply. But in 1977, suddenly every drop counted. We were prohibited from washing cars, watering lawns, and taking baths or long showers. Of course these "sacrifices" paled in comparison to the far harsher impacts we heard about on the news: farmers with less water, ski areas with no snow, and forests drying and burning.

A decade later, drought returned to California, this time one of the longest on record, lasting from 1987 to 1992. I was then a graduate student at Stanford University, ready to begin researching California's climatic past. As an adult, I wanted to understand the forces that led to the 1969 rainstorms and the 1977

"year with no rain." I had been fortunate to grow up during two decades when California experienced a dependable abundance of precipitation. In my third decade, however, we were seeing only half the normal amount of rain and snow each year. Which was the "real" California climate, I wondered. Was there such a thing as a "normal" climate for California and the West?

The goal of my graduate research was to look at how California's climate, especially its rainfall, had varied over the hundreds and thousands of years before records were kept. I focused on the past 11,000 years, the Holocene period, which extends from the end of the last ice age—when the enormous North American glaciers melted—to the present. I focused my research on the San Francisco Bay, an estuary in the heart of one of the largest population centers of the West Coast. The bay is an excellent place to search for clues about California's past climates, because at its bottom are layers of sediment containing subtle chemical signals that reflect the strengthening and weakening of the flow of California's two major rivers, the Sacramento and the San Joaquin.

San Francisco Bay and its inland delta receive river water that begins as rain and snow in locations that span almost half the state. During years with high rainfall, the rivers bring abundant water to the bay, causing the salt content of the water to decrease. During the dry years, the rivers bring less freshwater to the estuary, and the bay becomes saltier—more like the Pacific Ocean waters that meet those of the bay at the Golden Gate.

In my research, I came to focus on the chemistry of fossil shells from sediment cores taken from beneath San Francisco Bay. The chemical signals embedded in those cores allowed me to estimate how the amount of river water entering the bay had changed over many centuries. I found that the river flow fed by rainfall in California has undergone major swings over the past 5,000 years. The alternating wet and dry periods lasted decades or even centuries—much longer than the six-year drought of 1987–92. To check these findings, I worked with my colleagues Roger Byrne, Frances Malamud-Roam, and Scott Starratt on studies of marshlands surrounding San Francisco Bay to examine how these long climate swings affected the marsh ecosystems. Our studies showed that marsh vegetation comprised more species adapted to saltier water during the dry periods and more species adapted to fresher water during wet periods. And, like the sediment fossil records, these swings in the marsh ecosystems lasted decades or longer.

My family had spent a year in southeast Australia, where I later returned for two sabbaticals. The landscapes and the climate there in many ways mirror

those in the western United States, with water just as sporadic and extreme. Yet only when I was well into my research career did I realize that these places I loved—California, the American Southwest, and Australia—were vulnerable and growing more so every decade. Long periods of drought punctuated by catastrophic floods over the past millennia are a part of the climate history of Australia, just like that of the American West. These regions are also likely to share a similar future, according to climate models. As the global climate warms, the American West and Australia will become drier, with longer and deeper droughts interspersed with catastrophic floods.

As so eloquently expressed by Australian poet Dorothea Mackellar in "My Country," written in 1911 at the end of a long Australian drought, we too love our "sunburnt" land here in the western United States, despite its extreme and variable climate. Knowing more about how climate has changed in the American West, we can now anticipate what may be in store for the region, and we can begin preparing for that future today.

B. Lynn Ingram

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Introduction

Some say the world will end in fire,
Some say in ice.
From what I've tasted of desire
I hold with those who favor fire.
But if it had to perish twice,
I think I know enough of hate
To say that for destruction ice
Is also great
And would suffice.

ROBERT FROST, "*Fire and Ice*"

ONE OF ROBERT FROST'S MOST FAMOUS POEMS asks whether the world will end in fire or in ice. Although we are not expecting the world to end anytime soon, we anticipate a future that may be vastly different from the world we are experiencing today. We find ourselves in an interglacial period that could return to an ice age like the one that ended some 11,000 years ago; or, we could continue along a path of global warming. A climatologist might add the biblical element of flooding, which could accompany either extreme.

Whatever the future scenario, these questions have become urgent for the arid American West: where has the climate been, and where might it go from here? In *The West without Water,* we show how paleoclimatologists—scientists who study past climate—have painstakingly uncovered and deciphered clues about past weather and climate in the West to help us answer these questions.

The picture that emerges from this evidence is more complex than a choice between "fire" or "ice"—and more worrisome. With the help of dozens of paleoclimatologists whose work is described in this book, we find that even

the relatively ice-free and benign "normal" weather of recent millennia has been much more variable and potentially dangerous than anything we experience today. In addition, the climate now seems to be changing rapidly toward new patterns that are certain to be more challenging for human life and dwindling ecosystems.

The terms *weather* and *climate* are often used interchangeably, but there are important distinctions. Climate refers to the statistical description of weather over a given period of time and for a given region, including the weather extremes. Weather has been monitored extensively for more than a century in the West, so we have a good idea of the region's climate for this period. For example, we know that Phoenix, Arizona, is arid, with hot summers and cool winters; San Francisco, California, has cool, foggy summers and wet, mild winters. Average high temperatures in Phoenix are much different in summer (104°F) than in winter (about 65°F), but its ten inches of rain annually are more or less evenly distributed between winter and summer storms. In contrast, San Francisco has average high temperatures that vary little throughout the year, staying mostly within the narrow range of 60–70°F. The twenty inches of rain received annually falls almost entirely between November and March, and the spring and summer months in San Francisco are often foggy.

Of course, these climatic averages cover a relatively short period of time—a mere century or so. The longer timescale climate averages have not been systematically measured by humans but have been recorded in the landscape, sediments, trees, and other natural archives, as we will discuss in later chapters.

The distinctions between weather and climate often catch people off-guard, occasionally with tragic results. Mark Twain once remarked that "climate is what we expect, weather is what we get," and the Donner Party is a famous and tragic example of "getting" weather. This group of pioneers was surprised by spectacularly abundant snow that came unusually early one year. The Illinois pioneers were headed for San Francisco in the fall of 1846 but were stopped short in the Sierra Nevada near the Nevada-California border on October 20 by a mountain range blanketed by the first snowfall of the year. Statistically, the first heavy snow storms should not have arrived so early, yet the possibility is always there. The group managed to make it as far as Truckee Lake (now called Donner Lake) where another heavy snowstorm—the second of ten major snowstorms that winter—shrouded the area, rendering these unfortunate pioneers snowbound. Another attempt to cross the summit was blocked in early November when yet another major storm increased the snowpack to ten feet. Now considered one of the most

spectacular tragedies of the western migration, only 48 of the original 87 members survived, and they did so by resorting to cannibalism.

In modern parlance, the doom of the Donner Party was a result of extreme weather. Of course, during the mid-nineteenth century, just how variable and extreme the weather in the West could be was virtually unknown to pioneers entering the region. We know much more today—not just about the recent historical past but also about the longer-term climate history of the West.

Perhaps the worst climatic consequence in the twentieth century was the devastating "Dust Bowl" of the 1930s—well within living memory, yet nearly forgotten today. At its peak, this drought affected the entire western United States, from California to the Great Plains, with searing heat, roiling dust storms, and fierce winds. Along the West Coast, sparse population size, less-developed agriculture, and the buffer provided by extensive groundwater pumping meant that the effects were largely mitigated compared to the shortages and suffering such a drought would inflict today.

Looking further back, the Great Flood of 1861–62 provides an example of a climate catastrophe of biblical proportions. This flood brought quick and enduring devastation, killing thousands of people and hundreds of thousands of livestock as it submerged the entire Central Valley of California and other regions of the West under ten or more feet of water for months. But the state was relatively unpopulated at that time, and the event is virtually forgotten today.

Deadly as these recent natural assaults were, climatologists now know that they are dwarfed by ancient "megadroughts" and "megafloods" that have occurred multiple times during the Holocene, an epoch that spans 11,000 years and the entirety of recorded human civilization. Prolonged droughts, in particular—some of which lasted more than a century—brought thriving civilizations, such as the Ancestral Pueblo of the Four Corners region, to starvation, migration, and finally collapse.

Discovering and interpreting the details of recent and ancient climates is far from an easy task. The field of paleoclimatology is complex, not only because it studies conditions that vanished long ago but also because those conditions can be understood solely through multidisciplinary teamwork—including such fields as geology, chemistry, biology, hydrology, paleontology, and archaeology—using modern scientific toolkits. This book tells the story of the American West's climate detectives, scientists who work together—sharing tools, insights, and techniques—to tease out ancient clues from sediments, trees, and landscapes. This assortment of evidence allows climate scientists to piece together key features of former environments. For