SEVEN

Desert Storms

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IT HAS BEEN SAID that weather in the Sonoran Desert is a story of monotonous, cloudless days, interrupted by catastrophic exceptions. Whether catastrophic or not, those exceptions are a major part of our story here—a story of how the Sonoran Desert Region gets its rain and how this pattern of rainfall influences life in the desert, both wild and human.

PATTERNS OF RAIN

The Sonoran Desert averages only 3 to 15 inches (76–380 mm) of rain per year depending on location, with precipitation generally increasing from northwest to southeast. But, importantly, this rain falls in two rainy seasons—a winter one, December through February, and a summer one, July through early September. (In the Arizona Upland subdivision these rainy seasons bring nearly equal measures of rain.) July through August and December through January are the region's wettest months; May and June are the driest. The Arizona Upland subdivision of the Sonoran Desert (Tucson and most of south-central Arizona and the foothills of the Sierra Madre Occidental in Sonora) is our wettest desert region.

The salient feature of rainfall here is not so much its rarity, but its variability (or capriciousness, to put it in human terms). Rainfall in the Sonoran Desert is both infrequent and undependable. Sometimes rainfall over a summer will be recorded in many small showery increments, but often the rain falls in a few large storms. And while not "normal," it isn't unusual for a single storm to produce 50 percent of the rain that typically falls in an entire season, or even more. Yuma, Arizona, for example, is one of the driest places on Earth, averaging about 3 inches (76 mm) of rain a year. Yet deluges there in the past have dumped over 4 inches (102 mm) in a single day.

Why It Doesn't Rain Much in the Sonoran Desert

This area's climate is, in a word, dry. Ringed by mountains that keep rain away for much of the year, the Sonoran Desert quietly bakes. Moist air moving east from the Pacific Ocean is forced to rise over the Cascades and Sierra Nevada, cooling as it rises. Since cool air cannot retain as much water vapor as warmer air can, the excess water precipitates in those California ranges. Moisture blown in from the ocean is effectively drained, and the air that moves down the ranges' eastern slopes is usually so dry it cannot produce any more rain. This phenomenon, the *rain shadow effect*, describes such aridity on the inland side of most coastal mountain ranges. In the same way, the Rocky Mountains, Sierra Madre Occidental, and high northern Mexican Plateau keep moisture from the Great Plains and Gulf of Mexico from reaching the Sonoran Desert.

The dependability of our warm, cloudless, often windless, days is primarily the result of a North Pacific high pressure zone, and it is related to the circulation of air masses high in the Earth's atmosphere (see chapter 2 for more information). Air that heats up at the equator rises, as warm air does, and eventually moves poleward, until it cools enough to sink at roughly 30° latitude (north and south), where many of the planet's deserts lie (see map on page 12). As this air descends on the Sonoran Desert Region, it creates a very stable, warm, dry atmosphere. The rains stay away until this high pressure system weakens, or shifts northward, allowing moisture to slip into the region.

At least two things are necessary for rain: a source of moisture and a delivery system for that moisture. The Sonoran Desert's main source for both summer and winter rain is the Pacific Ocean—though different regions of that ocean provide moisture in different seasons. Moist air that makes it to the Sonoran Desert, which lies roughly between 24° and 34° latitude, arrives on the back of strong westerlies—winds that are part of a belt of eastward-moving jet stream winds that circle the earth from about 30° to 60° latitude. Independent air streams within this belt curl around and shift their flows depending on the season and other atmospheric changes. The patterns of rain change accordingly.

Summer Rains—The Big Tease

The word *monsoon* refers to a system of winds that changes seasonally, bringing wet and dry periods to a region. The word comes from the Arabic *mausim*, which literally means "seasonal," and initially referred to the famous monsoons of the Indian Subcontinent and Southeast Asia. But the Sonoran Desert also experiences monsoons, known as the North American Monsoon System (or the Mexican Monsoon System). Our summer monsoon system is driven by a low-elevation, clockwise, atmospheric circulation flow that carries warm, moisture-laden air from the Sea of Cortez and the coast of southwestern Mexico. These air currents flow north and east, joining the prevailing westerlies and moving into a low pressure area created by rising continental air warmed by the summer sun and by a northward shift of the North Pacific High. The Northern Hemisphere mid-latitude jet stream, the westerlies, shifts north in the summertime, wrapping around the northern edge of the Pacific High, which sits around 38° to 40° north latitude, allowing moist tropical air to move up and into our region.

These clockwise-moving winds circle around into the area and often reach the Sonoran Desert seeming to be southeasterly winds. This is one reason people in the past assumed that our monsoon moisture came from the Gulf of Mexico. However, meteorologists now know that most of our summer moisture comes from the Sea of Cortez and Tropical Eastern Pacific. In fact, the monsoon begins along the Pacific coast of southern Mexico in May and June, and quickly spreads northward along the western slopes of the Sierra Madre Occidental, decreasing in intensity as it moves northward; Arizona and New Mexico get only the northernmost edge of the monsoon.

Once Pacific moisture reaches southern Arizona, usually beginning in July, the increased humidity means we really begin to feel the heat. If June has proceeded as usual, the desert surface is very hot, causing the moist air

Pipe Dreams

The excitement of a summer rain reminds us that water is precious in this arid environment. Droughts are common, and desert plants and animals are adapted to water scarcity, at least up to a point. But what about the millions of people now living in the burgeoning cities of the Sonoran Desert Region? The population of the Phoenix metropolitan area increased by 45.3 percent from 1990 through 2000 (by April 2010 the population had topped 4.2 million), compared with the average U.S. rate of 13.2 percent, helping make Arizona the second-fastest-growing state in the nation. In early 2013, Tucson had a per capita water use of 130 gallons per day; Phoenix was at 184 gallons per day; and Scottsdale was sucking down a whopping 220 gallons per day. The aridity of the region and its diminishing water resources seem to impose little restraint on modern desert dwellers. There are nearly 450 golf courses in Arizona; this, despite the fact that each 18-hole course uses an average of 185 million gallons of water annually—the equivalent of 3500 single-family homes! Many are now using gray water, and there are more and more laws and policies being put in place that encourage this, but the infrastructure for public gray water distribution is expensive (it virtually always requires a separate plumbing system that pumps water uphill from low-lying treatment plants).

How can the desert supply all this water? The answer is that it can't. Rainfall replenishes only a fraction of the fossil groundwater withdrawn every year from ancient aquifers laid down thousands of years ago. The aquifer underlying central Tucson fell, on average, about 3 feet (1 m) per year over the last 60 years or so of the twentieth century; fortunately, it has risen in the central area since Tucson began using Central Arizona Project (CAP) water. To supplement depleting groundwater supplies, distant rivers, especially the Colorado River, are diverted through massive water projects to transport water into this region. Today, the Colorado River alone is controlled by 20 dams and thousands of miles of canals, levies, and dikes, and every drop of its water is managed. Tucson imports water directly from the river via the CAP canal. But the river is vastly overcommitted by the 1922 Colorado River Compact, which allocated 16.5 million acre-feet (maf) per year—15 maf/yr to the U.S. Colorado Basin States (one of which is Arizona) and the remaining 1.5 maf/yr to Mexico. However, the compact was based on river-flow data from 1910 to 1920, one of the wettest decades in the recorded history of the Colorado River, when mean flow of about 20 maf/yr occurred. Since then, the mean flow has been around 13 maf/yr. There isn't enough water to go around, and legal battles over water rights are persistent and ongoing. Except for rare flood years, the Mexican portion of the Colorado River never gets enough water to sustain its once-lush wetlands, and the delta region is now mostly dry, hard-caked earth. Once one of the richest wetlands in North America, covering 1.9 million acres, the delta today has been reduced to only a few isolated patches of moisture.

By mining fossil groundwater and importing river water from distant areas, the residents of the Sonoran Desert have buffered themselves from the reality of their arid environment. This dependence on imported and nonrenewable sources of water must eventually be addressed in planning for the long-term sustainability of our desert cities.

moving in to expand and rise. The hot air rising off the desert floor moves upward in great columns called *thermals,* which can be 3 to 5 miles (5–8 km) in diameter. Broader areas of cooler air separate the thermal columns, which is why thunderheads can be so widely scattered. The creation of thermals can be a violent business, and local updrafts can move at over 50 feet (15 m) per second. The strong convection upward is usually matched by strong adjacent downdrafts, which kick up sand and dust as they hit the land. Above, the air cools as it rises, until at about 17,000 feet (5200 m) the moisture freezes. A growing thunderhead can tower 40,000 feet (12,000 m) or more, with the whole top containing a raging snowstorm—a strange concept to a person broiling at ground level. This process is accelerated when the moisture-laden air encounters the Mogollon Rim or high mountains, such as the Sky Islands of southeastern Arizona (see chapter 3). One frequently sees thunderheads forming first around mountaintops. In a sense, these ranges "capture" moisture by forcing air upslope to higher elevations—Sky Islands are summer "rain gods" of the Sonoran Desert.

And even with all the spirited buildup, it is not at all uncommon to have a "frustrated" thunderstorm. Towering cumulus clouds spread out and sweep across valley floors, whirling skirts of wind and dust, and throwing lightning bolts. Yet all the rain can evaporate before reaching the ground. This creates one of the more awesome desert sights: *virga*, the trailing vaporous streams of rain that hang down from a thunderhead—frayed ends drying in the layer of hot air over the desert's surface.

The rain that does reach the desert floor in a summer thunderstorm typically does so with great vigor. Although the dry desert can absorb substantial amounts of water, much of the rain rolls off the hard-baked ground. Sheets of water wash across the land, filling arroyos and riverbeds in minutes, the flow carrying along sand, rocks, and plants, carving new stream channels and eroding streambanks. This runoff is a critical resource for desert life, whether it is providing a temporary pool for a desert spadefoot (*Scaphiopus* and *Spea* spp.), a cool spell and source of groundwater recharge for urban desert dwellers, or irrigation for a Tohono O'odham squash field.

Winter Rain—A More Lasting Affair

If summer monsoons are torrid affairs—unpredictable in terms of the next tempestuous rendezvous—winter storms resemble somewhat more stable relationships. While winter precipitation totals are, in fact, as variable as summer rain, the precipitation itself is more predictable, since storm tracks are typically established. For example, during the winter months, the westerlies shift south to about 35° latitude and the major storm track brings winter storms off the North Pacific to the northwestern United States and into the Great Plains region. This usually produces no more than partly cloudy skies and strong winds in the northern part of the Sonoran Desert. Occasionally, however, a trough of low pressure forms over the western United States, causing the prevailing flow to push storms farther south along the West Coast, sometimes as far as San Francisco, and then across the mountains to the Mojave and Sonoran Deserts. Meteorologists can detect the storm approaching the coast and warn desert dwellers days ahead of time that a storm has entered California and will soon reach the Sonoran Desert Region. Even the mountains can't keep all the moisture away from these low-latitude Pacific storm fronts. Although these storms are embedded in fast-moving air currents and don't usually linger more than a day or two, they are important sources of gentle, soaking rain. Once the airflow pattern is established, it tends to persist so that several storms will follow one another over the course of several weeks. This frequently also means that when it rains in Tucson, it is dry in Seattle, and vice versa. Some of the wettest winter storms swing far south over the Pacific, then make a U-turn and enter the Sonoran Desert from the south. Nonetheless, these storms originate in the northeastern Pacific Ocean.

Tropical Rain—One Heck of a Date

Another manner in which rain comes to the Sonoran Desert is by cyclones, which originate in the Tropical Eastern Pacific, usually in the early fall. These giant storms have established some of the all-time records of monthly precipitation in the Sonoran Desert Region. The Spanish word *chubasco* is frequently used by Sonoran Desert dwellers to refer to these tropical storms. (*Chubasco* is more generally defined as any extremely violent storm.) Although infrequent, these storms are memorable. And, on occasion, an early *chubasco* combines, or dovetails, with a late monsoon to create an extreme weather event.

Consider, for example, the catastrophic floods of 1983. About 10,000 people were displaced in southern Arizona alone. Water, mud, and debris damaged or destroyed nearly 3000 buildings. Many people who fled their homes were cut off from help because roads, bridges, phone lines, and electric lines were washed away. Marana and four other towns were almost completely underwater. Interstate 10, the main link between Phoenix and Tucson, was washed out at the Gila River, and twenty other main highways were closed. President Ronald Reagan declared eight Arizona counties a "major disaster area." This flooding was caused by tropical storm Octave, a *chubasco* of exceptional strength that began its life on September 23, 1983, off the coast of southern Mexico and maintained its strength until October 2. Octave reached Tucson on the tail of the monsoon season, and there was still much residual moisture in the air and ground. During Octave's visit to Tucson, the Santa Cruz, Rillito, and Gila Rivers experienced their highest crests on record.

These large storms begin offshore, and as they churn over the Baja California Peninsula, they can pick up additional energy from the warm waters of the upper Gulf of California (Sea of Cortez). In fact, the wettest years in Arizona are associated with the highest seawater temperatures in the Sea of Cortez. The Yuma area is frequently hardest hit, occasionally receiving its whole annual allotment of precipitation in a matter of hours. Even when the storm remains at sea, it can still produce heavy rains in the desert. Tropical storms are a normal part of the weather pattern, and they visit the Sonoran Desert Region several times per decade.

El Niño in the Sonoran Desert

El Niño is a band of anomalously warm ocean water that occasionally develops off the west coast of South America and can cause oceanographic and weather changes across the Pacific Ocean and elsewhere on the Earth. It is one phase of the "El Niño–Southern Oscillation" (ENSO) phenomenon, which refers to variations in the temperature of surface waters in the Tropical Eastern Pacific, and in air surface pressure in the Tropical Western Pacific. The two variations are coupled: the warm oceanic phase, El Niño, accompanies high air surface pressure in the western Pacific, while the cold phase, known as La Niña, accompanies low air surface pressure in the western Pacific. Mechanisms that cause the oscillation are not well understood, nor are they strongly predictable. An El Niño occurs when Pacific trade winds, which typically keep the ocean water circulating, weaken, allowing warm water to pool in the western Pacific. The pool of warm water drifts eastward toward South America, causing atmospheric pressure gradients along the equator to weaken and trade winds to diminish even more. Thus, changes in ocean temperatures reinforce changes in atmospheric circulation, and the two sets of changes intensify and drive each other.

One result of these "chicken-and-egg" changes is that the powerful tropical Pacific storms begin to form farther east than usual, and the jet stream over the northern Pacific Ocean is invigorated and pulled farther south. More moisture and more storms are thus carried to the southwestern United States and northern Mexico. *El Niño* events increase the likelihood and severity of winter storms in the Sonoran Desert Region. They can also increase the chance of tropical storms (*chubascos*) from the eastern Pacific. Floods have occurred more often in many Arizona rivers during El Niño events than in other years. During an El Niño, we typically see more winter days with high rainfall, while the northwestern United States typically sees fewer days with high precipitation.

Climate Change, Droughts, and Changing Vegetation Patterns

When the revision of this book began in 2013, the Sonoran Desert was in its 15th straight year of drought. *Drought* is usually defined as

Flood damage along Tucson's Rillito River, October 1983

an extended period of below-average precipitation. But ecologically, it can be viewed as a long period of diminished water availability for plants. There are two primary factors that affect a plant's ability to capture and retain water: precipitation and air temperature. Plants lose moisture from their leaves by a process called transpiration, and although they can regulate this to a certain extent, they cannot completely control it. In addition, soils lose their moisture through evaporation. This combination of plant and soil water loss is called evapotranspiration. As air temperatures increase, so do evapotranspiration rates. Thus, warming climates and decreasing precipitation both promote drought conditions that stress plants and animals. And that is just what's been happening in many places in the world for decades, especially in the Southwest. It is now known that the primary cause of the accelerated climate change since the Industrial Revolution is the increased accumulation of greenhouse gases in the atmosphere due to human activities.

A number of highly sophisticated ecological models have tracked the history and probable future of climate change, given different estimates of the level of greenhouse gas emissions for the rest of this century. All indications are that things will continue to warm, glaciers and polar ice will continue to melt, sea levels will continue to rise, the Sonoran Desert Region will continue to become hotter and drier, and natural ecosystems will continue to be stressed. In fact, the Southwest is identified in climate models as a "global hot spot," and predictions indicate a warming of 5.4°F to 10.8°F (3°C–6°C) by the end of this century.

Climate is the long-term average of day-to-day weather, and for decades now the climate of the Southwest has been warming and drying. Data from the National Weather Service show that mean annual air temperatures have increased an average of about 0.45°F (0.25°C) per decade since 1950. In fact, average daily temperatures in the Southwest for the decade from 2001 to 2010 were the highest on record since 1900, and the period since 1950 has been warmer than any period of comparable length in at least 600 years. Precipitation for the period between 1950 and 2010 also shows a statistical decrease over the last 20 years.

Plants and animals respond to these climate changes in a variety of ways. In the Sonoran Desert, many just can't take the stress and die, their population numbers dwindling. Others shift their range northward or up the sides of mountains to cooler or wetter habitats. Many plants shift their seasonal flowering patterns (in some cases disrupting the life cycles of nectar- or fruit-feeding animals), and others shift their elevational range. Many plants that live on mountain ranges, such as those on our Sky Islands, have been shown to have shifted their lower elevation boundaries (and/or the timing of their first blooms) upslope over the past few decades. Curiously, the upper elevation boundaries of mountain plants seem to be responding in a variety of ways—some species increasing their upper elevations, others decreasing them. Overall, mountain plants are experiencing elevational range compressions. Of course, the plants on the very tops of the Sky Island ranges (and presumably their associated animal communities) cannot go any higher, and it has been predicted that the subalpine conifer forests on the tops of our highest ranges (e.g., Santa Catalinas, Pinaleños, Chiricahuas) might be "pushed off the tops" of their mountain homes altogether as Southwestern climates continue to warm and dry.

PATTERNS OF LIFE

What do these dramatic weather patterns mean for life in the desert? How does wildlife cope with shifts from drought to flood within hours and then perhaps back to no rain again for months? How plants, animals, and people in the Sonoran Desert respond to the variability of rainfall is a particularly critical aspect of survival in the desert.

As we've seen, rain falls in the Sonoran Desert in a "bimodal pattern"—that is, in two seasons: scattered, intense thunderstorms in the summer, and more widespread, gentler storms in the winter. This semiannual rainfall pattern has allowed our desert life to specialize for two distinct wet periods annually, one of the reasons biodiversity is so high in the Sonoran Desert. However, these rainy times are not predictable, and a season's worth of rain can fall in a day or drizzle in over a month, or rain may not come at all. Given these conditions, survival in the desert requires finely tuned adaptations—even, as we shall see, on the part of the modern human urban dweller.

There are perhaps three things that characterize a good desert denizen: knowing how to wait, knowing how to hold on to the rain that does fall, and knowing how to get down to business when opportunities arise. Consider the patience, resourcefulness, and speedy sex of spadefoots (*Scaphiopus* and *Spea* spp.). Cued by the vibration of rain or thunder, spadefoots emerge from their interments of 10 to 11 months. Taking advantage of temporary ponds from the rain, spadefoots pursue breeding with all the intensity of creatures denied for most of the year. After months of waiting for opportunity to knock, they begin the next generation of spadefoots within a day's time. "Patience" also characterizes the Gila monster, which does absolutely nothing for nearly nine months of the year. Mornings in April, May, and June will find the large lizard seeking bird eggs and baby quail, but most of the time it waits out the hot, dry days, living off the fat stored in its plump, expandable tail.

The variability of rainfall is reflected in reproductive cycles. Many desert plants and animals do not attempt to reproduce every year but wait until sufficient rain has fallen to make the investment of energy worthwhile. Spadefoots will not emerge without a heavy enough rain to fill the temporary ponds, giving them time to mate and the tadpoles time to develop. Gambel's quail and rufous-winged sparrows will not nest unless sufficient rain has fallen to support insect life and fruit development that will in turn supply baby birds with food. Brittlebush plants bloom generously in most wet years but will forgo flowering and even fail to produce foliage in times of drought.

Many desert plants exemplify the ability to hold on to what one has. Barrel cactus, saguaro

Life-Giving Desert Oases

Riparian areas are the precious gems of the desert. These year-round streams or springs are the incubators of desert life. More than 85 percent of desert animals depend on riparian areas during some phase of their life cycle.

Sonoran Desert riparian areas are sustained by the rain that falls in the mountains and foothills and flows into the region's alluvial valleys and aquifers. As overpumping of groundwater occurs and water tables fall, riparian areas are degraded and eventually lost. Cottonwood-willow forests that once lined many rivers in the Sonoran Desert, including the Salt, Gila, Santa Cruz, and Rillito Rivers, have disappeared as groundwater pumping and surface water diversions disrupted flows and lowered the water table below the plants' root zones.

It is estimated that more than 90 percent of Arizona's riparian areas have been lost in the past century, and many of the remaining areas are imperiled by surrounding urban, agricultural, and mining development. The spectacular San Pedro riparian corridor in southeastern Arizona, for example—home or vital migration corridor to an estimated 400 species, more than 80 mammal species, and nearly 50 reptile and amphibian species, faces a bleak future because of groundwater pumping in nearby Sierra Vista and Fort Huachuca, and by burgeoning housing developments near the river. Saving the San Pedro River and the other few remaining riparian treasures will require concerted and dedicated action on a number of fronts and should be one of Arizona's highest priorities.

cactus, and succulents like agaves are well known for their ability to store gallons of life-sustaining moisture within. Saguaros grow visibly plump after a wet season. The extensive, shallow roots of these plants help them capture much of the ephemeral moisture before it evaporates. The intense competition for water when it is available is one reason desert plants are so well dispersed over the landscape—the bare ground between them is in fact permeated with roots.

People and Rain

Desert survival has required that human life also adapt to scarce and variable rainfall. For example, traditional Tohono O'odham farmers plant semiannually (e.g., tepary beans, squash, corn, melons, wheat) to correspond to the two rainy seasons, using both summer and winter crops. Their fields are designed to catch water washing across the land after storms, often channeling it to areas that have been prepared for planting. A single summer or winter rain can make or break a harvest. The Tohono O'odham also scatter their desert plots widely among several washes to maximize the chance that scattered thunderstorms will soak at least one field.

Perhaps as a reflection of their sensitivity to the vagaries of Sonoran Desert rainfall, the Tohono O'odham seem to dislike jumping to any conclusions about the weather. Linguist William Pilcher noted that the Tohono O'odham avoid any assumption that rain will fall for sure: "It is my impression that [they] abhor the idea of making definite statements. I am still in doubt as to how close a rain storm must be before one may properly say *t'o tju* (it is going to rain on us), rather than *tki' o tju:ks* (it looks like it may be going to rain on us)." Life-giving rain, on which Tohono O'odham have traditionally been utterly dependent, is not taken for granted, and when it falls, it is considered good fortune.

Many modern farmers of large-scale commercial crops, in comparison, have so divorced themselves from the natural rhythm of the desert that they actually dislike rain. Cotton, for example, is grown solely on irrigation water. To increase their yields, some farmers "stress" their plants slightly by withholding water, and the plants produce more flowers as a result. Any natural rainfall during this period is seen, therefore, as interfering with the growers' management plans.

Contemporary city dwellers, likewise, are mostly buffered from the vagaries of desert precipitation by modern technologies such as irrigation, cooling systems, and bridges. Pumped water, swimming pools, lawns, and air conditioning allow city people to live comfortably through the desert's hottest times. Is modern urban society therefore immune to the unpredictability of desert rain? In fact, the changeable nature of desert rainfall has required adaptation, even on the part of the city dweller. This is particularly evident with regard to the paradoxical hazard of arid lands—flooding. The natural desert tendency to flood is exacerbated in cities. Over paved surfaces like roads, rainwater will move more than eight times as fast as it could in a vegetated area. And in urban areas, the proportion of runoff—that is, the water that flows over the surface rather than sinking into it—is about four times that of undeveloped desert. So, not only does more runoff move much faster in a city, it has less opportunity to soak into the ground. This problem is worsened as more earth disappears under asphalt and pavement, and as more people live closer to floodplains and arroyos.

While Tohono O'odham farmers and desert spadefoots welcome floodwaters, a typical urban response has been irritation and, especially in the face of violent storms, fear for human life and safety. For decades, as cities in the region grew rapidly, the urban response to the threat of flooding was to pour concrete. Natural drainages were widened, straightened, channeled, and lined in concrete. Water that fell over a large urban area quickly flowed into concrete ditches and rushed away. Millions of dollars went toward engineering projects, including huge storm drains to accommodate the 100-year floods that inexplicably seemed to occur every decade or so.

Yet, in spite of the investments in flood control, when the big bad storms hit, such as the one causing the flood of 1983, human engineering has repeatedly met its match. In fact, the "structural" approach often serves to worsen flooding and other problems. Concrete ditches move floodwaters away fast—so fast that unlined channels downstream suffer worse erosion as they are hit with more and faster-moving water. The water quality of this runoff also presents a problem, since rain collected from streets, parking lots, and buildings carries sediments, pollutants from cars, and nutrients from fertilizers used in landscaping. Additionally, a cement-lined wash cannot serve as a recharge route to the underground aquifer, an important natural function of desert washes. And a wide cement ditch detracts from the aesthetic appeal of a neighborhood.

The Value of an Urban Wash

Over the past several decades, city dwellers have gradually realized that engineering cannot completely remove their vulnerability to the threat of floods. In addition, some people have come to view runoff from desert rains not as a nuisance to be guided away, but as a resource that can support desert wildlife and recharge underground aquifers. Engineering projects are still a major aspect of flood-control plans, but Tucson, Phoenix, Scottsdale, and other cities have begun to look to the desert's natural drainage system as part of the solution.

A newcomer may not even notice the network of arroyos around a city, or think much of the dry beds that locals call "rivers." But for desert city dwellers the arroyos are assets. Contemporary city planning has prohibited construction in floodplains and encouraged the development of extensive river park systems. These parks provide attractive recreation areas for city dwellers, and also buffers during a flood. Small, unlined washes through urban neighborhoods offer pathways and cool, green spots sheltering urban wildlife such as quail, roadrunners, javelina, and coyotes. The unlined urban washes also allow rainwater to soak into and recharge underground aquifers. City people in the desert may never respond to the arrival of the first rain of the summer monsoon with the enthusiasm of the spadefoot, but there is a sense of joy as the first drops fall. Changes in city flood-control decisions indicate an ethic of urban desert living that welcomes desert wildlife along arroyos, acknowledges vulnerability to desert storms, and seeks answers, at least in part, in the desert's natural flow. These plans are expensive, yet they enjoy real political and economic support. So when the rains come and the washes begin to run, perhaps more people are pausing to watch the arroyo vegetation turn green, breathe in the smell of wet earth, and wonder at the marvelous event of a desert storm.

ADDITIONAL READINGS

Brusca, R.C., J.F. Wiens, W.M. Meyer, J. Eble, K. Franklin, J.T. Overpeck, and W. Moore. "Dramatic Response to Climate Change in the Southwest: Robert Whittaker's 1963 Arizona Mountain Plant Transect Revisited." *Ecology and Evolution* 3, no. 10 (2013): 3307–3319.

Crimmins, T., M.A. Crimmins, and D. Bertlesen. "Onset of Summer Flowering in a 'Sky Island' Is Driven by Monsoon Moisture." *New Phytologist* 191 (2011): 468–479.

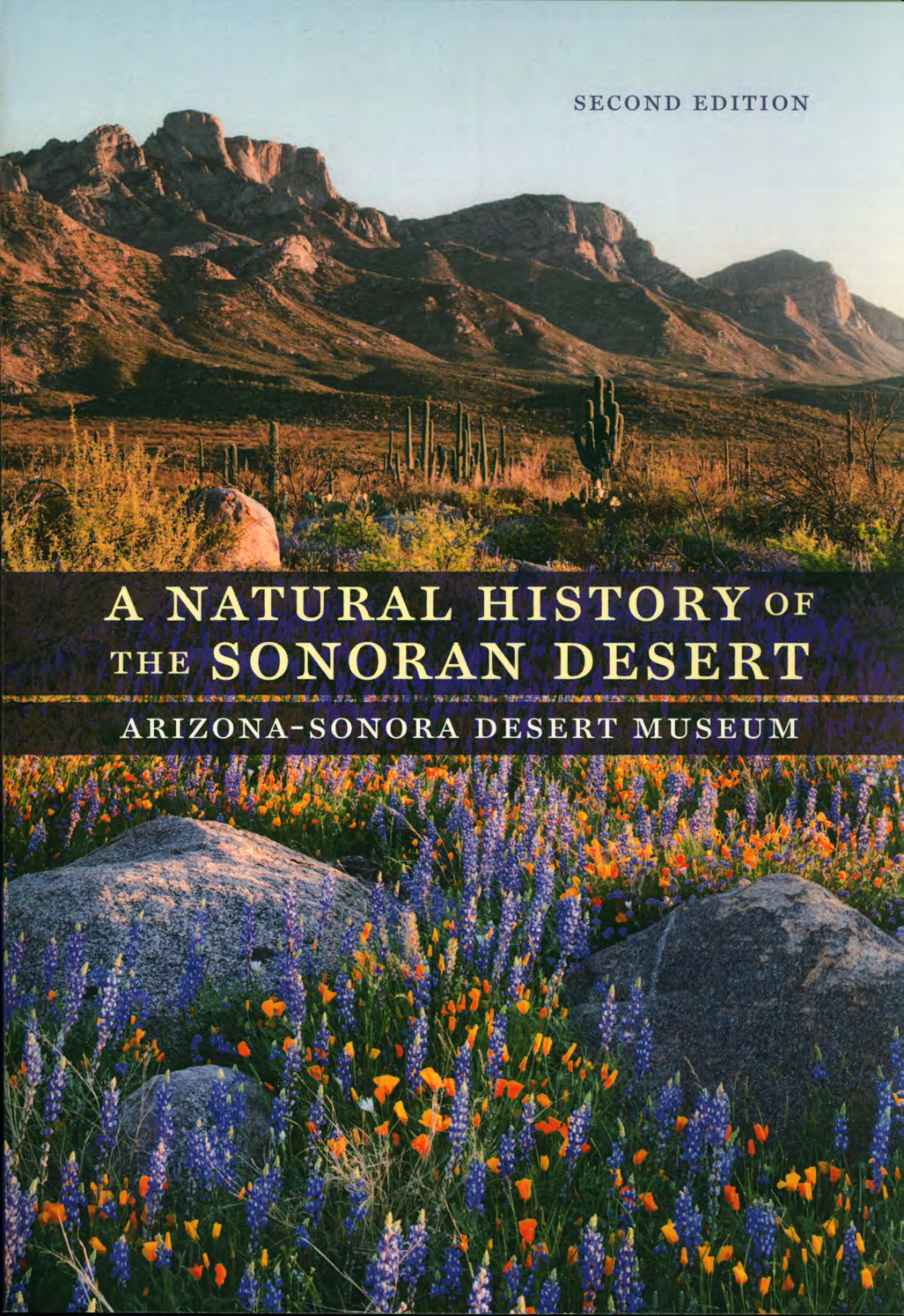
Douglas, M.W., R.A. Maddox, K. Howard, and S. Reyes. "The Mexican Monsoon." *Journal of the Climate* 6 (1993): 1665–1677.

Garfin, G., A. Jardine, R. Merideth, M. Black, and S. LeRoy, eds. *Assessment of Climate Change in the Southwest United States: A Report Prepared for the National Climate Assessment by the Southwest Climate Alliance.* Washington, DC: Island Press, 2013.

Gutzler, D.S., and T.O. Robbins. "Climate Variability and Projected Change in the Western United States: Regional Downscaling and Drought Statistics." *Climate Dynamics* 34 (2010). doi: 10.1007/s00382-010-0838-7.

Olin, George. *House in the Sun: A Natural History of the Sonoran Desert.* Tucson, AZ: Southwest Parks and Monuments Association, 1994.

Smallwood, J.B., Jr., ed. *Water in the West.* Manhattan, KS: Sunflower University Press, 1983.



SECOND EDITION

A NATURAL HISTORY OF THE SONORAN DESERT

ARIZONA-SONORA DESERT MUSEUM