CHAPTER 1

Adapting California's Water Sector to a Changing Climate

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Californians have indeed always coped with wide swings in climate, habitually forgetting one extreme as the climate veered to the other. But human-induced climate change—in part from the dumping of greenhouse gases (GHGs) and other pollutants into our atmosphere—will likely expand that variability beyond what we have experienced, bringing with it more extremes and ultimately more uncertainty. In fact, climate change has already altered our hydrology and sea levels, presenting a significant challenge to California water management.

Even in a changing climate, however, California will still be blessed with lots of water—sometimes too much—so the parable of climate change and water only descends into damnation if we fail to choose management, efficiency, and stewardship. Moreover, as climate change conveys more uncertainty, our responses could actually result in enhanced resilience. Though there is often a drought of optimism in California water management, alarmism is absolutely the wrong answer and message. Californians need not flee, nor perish, in response to climate change; with collaboration, varied options, and smart decisions, they can adapt.

The views expressed here do not necessarily reflect those of the California Department of Water Resources, the California Natural Resources Agency, or the State of California.

THE CLIMATE CONTEXT FOR CALIFORNIA'S WATER RESOURCES AND USE

Strong on climate, California is notoriously weak on weather.
—Carey McWilliams (1949)

California genuinely enjoys a Mediterranean climate, a foundation for our agricultural, tourism, and recreational economies, our relatively low residential energy demand, and our overall quality of life. Most of our precipitation—whether it is rain or snow—falls in the winter and spring. Geographically, precipitation is concentrated in the north and in the east, along the Sierra Nevada. Large parts of the rest of the state actually meet the definition of desert. For most of the year, no rain falls for months at a time, constituting California's annual drought.

As Carey McWilliams (1949) observed, the state's water demand patterns are "upside-down," both in time and space. Water falls freely from the heavens in the winter and spring, but it is primarily desired in the summer and early fall, especially for agriculture and all those green lawns in the suburbs. Most of the urban demand is located along the parched portions of the Pacific coastline, and some of the most productive and diverse farms in the world are in the arid inland areas of Central and Southern California.

To match precipitation with population (and its food and fiber), local, state, and federal governments have invested in nation-scale, inter-regional infrastructure to pipe precipitation from where it falls to where it is demanded. These interbasin projects generally transport water a very long way, from north to south and from east to west—and in the case of Southern California, in both directions. Groundwater is the state's other major water supply, though this source is often limited by contamination and overdraft.

The specter of California running out of water has spawned many a tome, but too much water is actually a far greater danger. Accordingly, governments at all levels have also constructed extensive infrastructure to defend against high water; yet there remain seven million people and over half a trillion dollars of property at risk from flooding (California Department of Water Resources 2013).

The inter-regional water transfer schemes are undoubtedly integral to California's public health, economy, and way of life. To paraphrase former House Speaker Tip O'Neill, though, all California water management is local. That is, various local and regional entities—an untidy, decentralized democracy of, really, thousands of water and wastewater utilities, irrigation districts, flood control agencies, reclamation and levee districts, cities and counties, and various other stakeholders—manage most of the water in California. That is the reality that we must recognize and leverage in responding to climate change.

THE SCIENCE OF A CHANGING WORLD

Climate data and science overwhelmingly show that Mother Earth is warming—resulting in the reduction of snow and ice, other changes in the water cycle, and the rising of the seas—and that it is "extremely likely" that human activity is the main cause of the warming since the 1950s (Intergovernmental Panel on Climate Change 2013). The fundamental findings of climate science are widely endorsed by both professional societies and academies of science around the world, including the national academy of science of every major industrialized nation. In fact, "since 2007, no scientific body of national or international standing has maintained a dissenting opinion" (California Department of Water Resources 2012).

According to the National Oceanic and Atmospheric Administration (NOAA), 2012 roasted as the warmest year on record for the continental United States, a full degree Fahrenheit warmer than the previous high—which was just in 1998. Though there are many ways to contextualize the climate science and the records broken, Seth Borenstein of the Associated Press vividly framed NOAA's finding: "The last time the world had a cooler than average year was 1976. . . . That means that more than half of the people on Earth haven't lived during a cooler than normal year for the globe."[1]

In 2012, the state of California released its Third Assessment of Climate Change, noting that average temperatures statewide had increased by 1.7 °F since 1895, and projecting a range of warming of 4.1–8.6 °F by 2100 (Moser, Ekstrom, and Franco 2012). Specific to water resources, the Third Assessment found likely increases in extreme precipitation, in a place where the climate already tends toward extremes.

CLIMATE CHANGE IMPACTS ON CALIFORNIA'S WATER

We are likely already witnessing the impacts of a changing climate on California's water—in precipitation, snowpack, rivers, and estuaries—and should not be surprised if these impacts amplify, accelerate, or abruptly adjust in the coming decades. Beyond direct hydrologic impacts, climate change may also affect water quality, water demand, hydroelectric generation, and water institutions.

Precipitation

During the twentieth century, the average amount of California's precipitation remained steady—neither more nor less (California Environmental Protection Agency 2013). But when describing water in California, "average" often means little. For instance, precipitation is about more than the absolute volume of water; details matter, such as precipitation's form, location, timing, intensity, duration, and variability. So though average volume has not changed thus far, the form of precipitation already has, with more precipitation falling as rain rather than snow (California Department of Water Resources 2014).

Snowpack

In a state where water storage—above or below ground—is a reliable source of conflict, the Sierra snowpack may be the only form of storage upon which we can all agree. The California Department of Water Resources (DWR) uses April–July runoff as a proxy for snowpack; that surrogate indicates that the snowpack provides an average of 15 million acre-feet (maf)[2] of storage per year. When it melts, this water meets 35 percent of net total agricultural and urban demand (Roos and Anderson 2006). For context, consider that all the surface storage ever constructed by humanity in the Sacramento Valley sums to 14 maf, with another 11 maf in the San Joaquin Valley (see Figure 1). So for all the storage that was ever built, in either basin, Providence provides that much for free, as snow.

Unfortunately, this form of storage—the only one with a consensus—is disappearing. The DWR (2008) estimates that approximately 10 percent of the April 1 Sierra snowpack storage has already vanished, reducing annual spring runoff on the Sacramento River by 1 maf. As a rule of thumb, for every 1 °C (1.8 °F) increase in temperature, the snowline rises by 500 feet (Roos and Anderson 2006). So, for a 3 °C (5.4 °F) temperature increase—well within projections for California by 2100—the Sierra snowline would rise by 1,500 feet, resulting in a loss of about 4–5 maf of snowpack storage. This warming also results in more rain falling on the watershed, directly running off, and leading to more intense flooding, rather than falling as snow, stored as snowpack, and running off slowly or seeping into the ground.

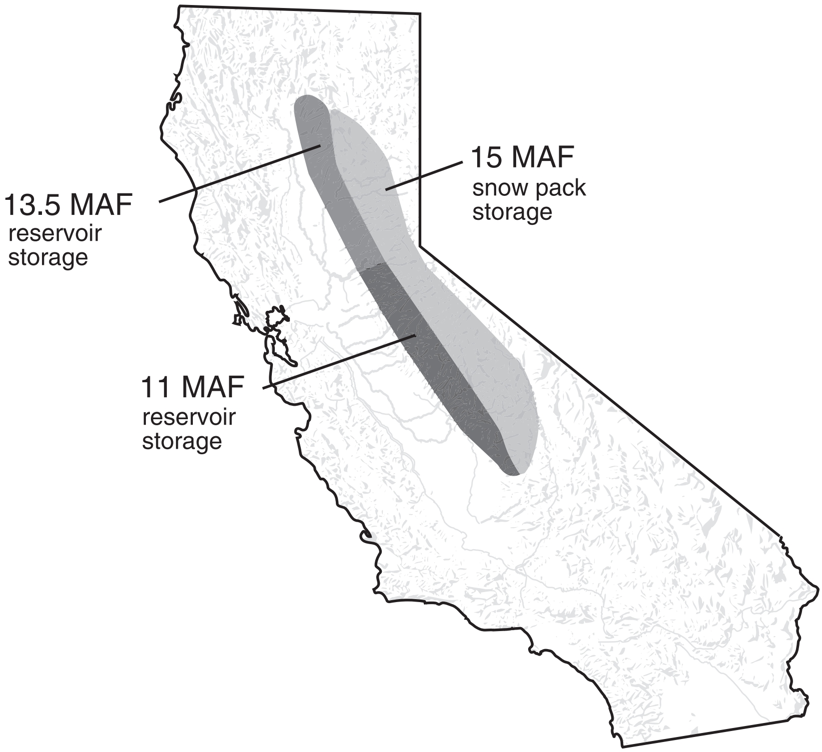

FIGURE 1.1. Climate change may significantly reduce Sierra snowpack storage, which is comparable in size to constructed storage: a moderate 3°C increase in temperature is projected to result in an increase in snow elevation of 1,500 feet. (Roos and Anderson 2006).

Hydrology

Because of its snowpack-dominated hydrology, much of California's water supply stands vulnerable to climate change. In fact, across the state, rivers are already exhibiting changes in runoff timing, reflecting changes in the snowpack (California Environmental Protection Agency 2013). As just one example, spring runoff on the Sacramento River declined from constituting approximately 45 percent of annual runoff at the beginning of the twentieth century, to about 33 percent at the century's close (California Environmental Protection Agency 2013). This trend is based upon good old-fashioned data—no computer models, no future-GHG-emission scenarios, and no other assumptions leading to layers of uncertainty about the future.

This shift in hydrology is troublesome for California's communal surface water storage system, which must meet multiple objectives: water supply, flood management, hydroelectric generation, environmental protection, and recreation. During winter, reservoirs in the Central Valley are deliberately drained to create reserve capacity, in order to intercept flood peaks and thereby protect people and places downstream. By early spring, these flood reservations are lifted, allowing water managers to harvest the spring runoff, which is necessary to carry California through the dry months of summer and early fall. However, snow now melts earlier in the year, likewise shifting runoff to earlier in the year, when often there is already too much water to manage.

The state's other major source of water, groundwater, will not be immune from the effects of climate change, either direct or indirect. For example, highly variable flow in rivers and streams may reduce groundwater recharge.[3] Further, when surface water dries up, Californians are likely to mine their aquifers, as they have historically during droughts. In this regard, agriculture and rural communities may be the most affected, through their particular dependence on groundwater.

Although there is anxiety about aridity, too much water remains the clear and present danger. During the twentieth century—again, without relying upon computers, scenarios, or assumptions—it is clear that California's rivers experienced larger flood peaks (Roos and Anderson 2006). For instance, on the American River, the four largest flood peaks on record have struck since 1950, including those in 1986 and 1997 (see Figure 2). For the operators of Folsom Dam on the American River, charged in part with the protection of the state's capital and its metropolitan region, this trend means that the hydrologic record used to design the dam (from the first half of the twentieth century) is distinctly different from the hydrology experienced during operation in the second half.

California's flood infrastructure is aging, and much of it was intended to protect farms instead of cities. Flooding immediately impacts human safety, drinking water quality, and crops, and the long recovery from flooding prolongs the misery, adding ordeals such as disease transmission, mold, housing displacement, business resumption, and mental health distress (California Natural Resources Agency 2014). The increased flood risk from climate change may fall hardest on the poor, because of where they live and their lack of resources and mobility.

In all, these hydrological impacts undermine the foundation of the state's hydraulic empires. As Maurice Roos (2005, 2), California's state hydrologist, observed: "By and large, reservoirs and water delivery

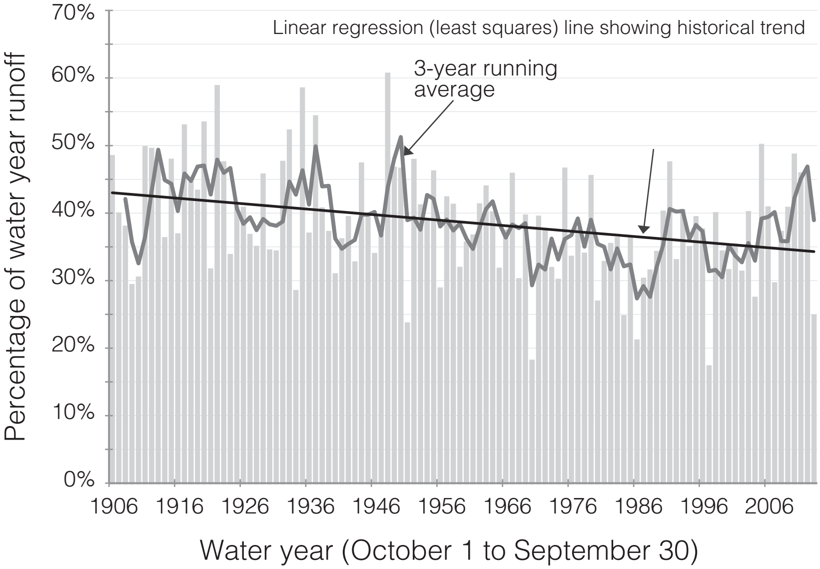

FIGURE 1.2. Spring runoff on the Sacramento River fell during the twentieth century (Roos and Anderson 2006).

systems and operating rules have been developed from historical hydrology on the assumption that the past is a good guide to the future. With global warming, that assumption may not be valid."

Water Quality

Considerable computing power has been invested in calculating the impact of climate change on water supply, while impacts to water quality—a growing concern—remain little examined. There is already an established link between heavy rainfall and waterborne disease outbreaks, and heavier runoff due to a changing climate will wash more non-point source pollution (i.e. contamination running off farms and cities) into water supplies. Conversely, climate change will probably also lead to more periods of low runoff, especially in the summer and fall, which may result in higher concentrations of some contaminants that may pass through water treatment processes, in turn affecting potability and reuse. Warmer weather will also lead to warmer water, and combined with lower summer flows, may increase the growth of algae, diminish dissolved oxygen, and generally affect aquatic habitat.

Water quality also faces the phenomenon of flood following fire, wherein summer and fall wildfires—a risk expected to increase due to climate change—scorch the earth, just in time for the early season rains, resulting in erosion and mudflows. Such runoff may deposit sediment in reservoirs, obscure water clarity with turbidity (cloudiness) that can interfere with disinfection, and cause greater wear and tear on water system equipment.

Beyond potential direct climate change impacts, water quality also serves as a good example of the potential indirect impacts of climate change, including what policy wonks call "unintended consequences," which can be as important as direct impacts. For example, the sound operation of water systems, including water treatment plants, may confront trade-offs with other climate-sensitive concerns, such as energy generation and use, fisheries, environmental water quality, and recreation.

Water Demand

Most climate change studies spotlight the supply side of water resources. However, climate change is also expected to sharpen the competition for already over-allocated water sources among the urban, agricultural, and environmental sectors. In a warmer and perhaps drier climate, water demand may rise, especially for outdoor water use, both in cities (for landscaping) and on farms (due to evaporation and plant water use).[4] Across three future scenarios of water use for the state, the *California Water Plan Update 2009* projected that in 2050, climate change may increase statewide water demand by up to 2-3 maf per year (with significant regional variability), exacerbating the potential water supply shortages from climate change (California Department of Water Resources 2010).

Water and Energy

Water demand is also the water sector's main source of GHG emissions. Water and wastewater systems use energy as an input to convey, treat, and deliver high-quality water to customers and to collect, treat, and safely reuse and dispose of wastewater, to protect both public health and the environment.[5] Though at times there is much mania about the movement of water in California and its related GHG emissions, the movement of goods and people is actually the largest source (40 percent) of the state's carbon footprint (California Air Resources Board 2014). An inconvenient truth, for many, is that the movement of water actually generates zero-GHG-emissions hydroelectricity, which is the largest source of renewable energy in California, accounting for an average of 15 percent of the state's electricity (California Air Resources Board 2014). In fact, the Assembly Bill 32 Scoping Plan—the state's strategic plan to reduce GHG emissions—depends fundamentally upon hydroelectricity to meet the state's 2020 mandate of rolling back GHG emissions to 1990 levels, by reducing emissions and also easing the integration of other, more intermittent renewable energy sources (e.g. wind and solar) into the grid.

Regrettably, climate change may limit some of the current benefits of hydroelectric generation. For example, high-elevation hydroelectric facilities may lack the storage necessary to cope with a shifting hydrology (Moser, Ekstrom, and Franco 2012). Reduced hydroelectric generation may also coincide with expected increases in summer energy demand, which may instead be met by fossil fuel–based energy generation that emits GHGs.

Real and immediate opportunities to reduce GHG emissions in the water sector primarily involve urban water users. According to a foundational California Energy Commission study (2005), the most energy-intensive part of the water sector is the end use of water (e.g. water heating), accounting for three-quarters of the electricity demand and nearly all of the natural gas demand related to water. Collectively, water customers account for 10 percent of the total energy use in the state, and urban water conservation presents the greatest opportunity to reduce the carbon footprint of water in California (California Air Resources Board 2008; California Department of Water Resources 2014).

Sea Level Rise

During the twentieth century, the tidal gauge at the Golden Gate—source of the longest continuous record of sea level in the United States—measured an incremental rise of about seven inches in sea level (California Environmental Protection Agency 2013). Sea level rise has two main components: the thermal expansion of the oceans (water expands when it warms), and the addition of water to the seas from the melting of land-based ice masses (e.g. glaciers and ice caps). In 2012, the National Research Council projected that sea levels along California's coast may rise another 5–24 inches by 2050—and the seas will hardly stop rising on that date (see Figure 3). In the near future, though, the slowly rising level of the seas is less a concern than higher storm surges and coastal flooding, due to the combination of extreme tides, winds, and rain.

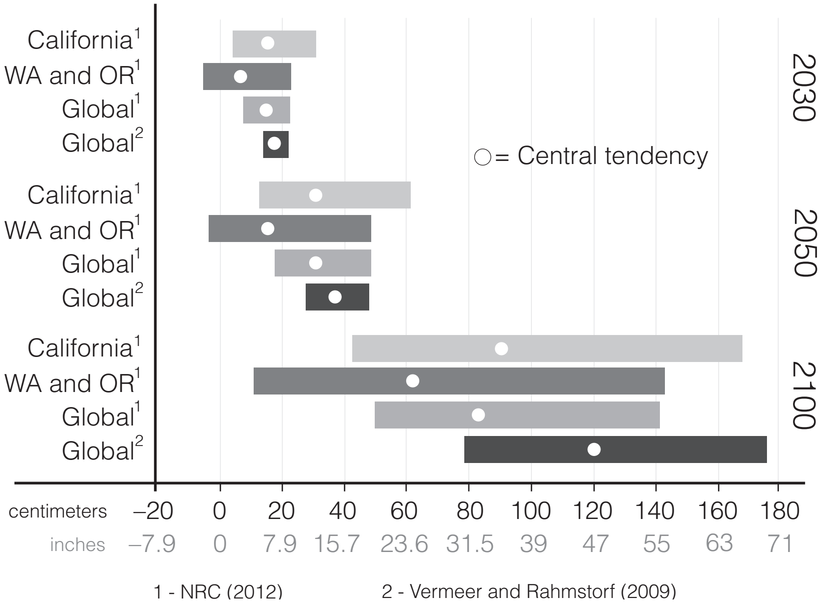

FIGURE 1.3. By 2050, the National Research Council projects approximately one foot of sea-level rise for the California coast south of Cape Mendocino (National Research Council 2012).

THE TRINITY OF WATER, CLIMATE, AND FAITH

Climate change may thus bring biblical blights like droughts, floods, and rising seas to California's water resources. Who knows? Other sectors could suffer famine, plague, and possibly some locusts. Alas, these scourges may be an appropriate judgment day for California water management, an often faith-based effort where decision-makers sometimes act more like evangelicals, defaulting to a sacrosanct set of beliefs (as in "I *believe* in dams" or "I *don't believe* in desalination") rather than rationally applying good information, science, or policy. This may be preordained for a state that named its two major rivers for the Holy Sacrament and a saint. For the general public, its daily experience with water is also largely an article of faith—it comes from the tap, always. How we generally talk about climate change completely complements this approach to water management, again, as something that you "believe in"—or not.

Despite ample observations and copious research, in all honesty we do not know exactly where climate change is going. Precipitation, in particular, remains deeply uncertain for California. Nonetheless, taking trends

An Exceptionally Vulnerable Region: The Sacramento–San Joaquin Delta

The Sacramento–San Joaquin River Delta may be the region of California most vulnerable to climate change. Part of the West Coast's largest estuary, the Delta lies at the confluence of the Sacramento and San Joaquin Rivers, which drain nearly half of California's watersheds. It is where the swamp meets the sea, a maze of rivers and sloughs—eerily similar to Southern Louisiana—with roads aptly named Netherlands and Holland, Noah and Ark. The Delta is genuinely a unique region, home to half a million people, farms and other businesses, and a distinctive culture. Along with the Suisun Marsh, the Delta covers a 1,300-square-mile natural and artificial landscape, with an urbanizing fringe. Although its ecosystem conditions have been declining for decades, it is also still home to birds, fish, and other wildlife, and especially important to the international Pacific Flyway. For the greater state, the region is also a crossroads of critical infrastructure, as Foster and Radke expound in chapter 6. Well known as a "switching yard" for California's state and federal water systems—upon which 25 million people (two-thirds of all Californians) and more than three million acres of farmland depend for water—the Delta is also vital to the state's transportation (shipping, highways, railroads) and energy systems, and thus its economy.

From flooding rivers to rising seas, climate change is affecting the Delta from literally all directions. Many of the 57 islands and tracts that compose most of the Delta have subsided below sea level—some deeply so—as a result of historic reclamation and a century of farming. Today, these islands are continuously protected by 1,100 miles of levees of varying and sometimes questionable materials, construction, and foundations. These levees are now challenged not only by subsidence on the land side but also by greater floods and rising seas on the water side. Potential impacts of climate change in the Delta include salinity intrusion, alteration of aquatic habitat, and increased risk of levee failure, with the latter threatening the inundation of communities and possibly the interruption of water exports statewide. Just as we once assumed a static climate, we have also wrongly assumed—or wished for—a static Delta.

together with studies, California seems to be in for more variability and extremes. Indeed, the preponderance of evidence indicates that, as Kathy Jacobs, director of the National Climate Assessment, once said: "Water will be the delivery mechanism for the impacts of climate change."

Though we do not know exactly the destination of this pilgrimage, we already know more than enough to act and to change the path we are on, given the long lead times required for infrastructure planning, design, and construction. Continuing the religious analogies, there will be no miracles nor forgiveness to save California's water sector in a changing climate, only Puritanical hard work. Adaptation may be costly; it may require sacrifice, and temporary and planned retreat; indeed, people, organizations, and regions may have to get along with one another. Mercifully, California is blessed with options and choices to better manage its water, even with climate change.

POLICY RESPONSES TO CLIMATE CHANGE

California is best known for—and has invested by far the most in—its mitigation response to climate change (i.e. reduction of GHG emissions and sequestration of carbon). In 2006, Governor Arnold Schwarzenegger and the California Legislature enacted AB 32, the state's Global Warming Solutions Act, which grants sweeping authority to the California Air Resources Board to reduce GHG emissions to 1990 levels. Yet, even with immediate, substantial, and vigilant global action to shrink GHG emissions, there will remain a need to adapt to climate change—that is, changes to our infrastructure, behavior, and society to cope with a changing climate or take advantage of opportunities it may present.

A water analogy may be useful here. In the world of water quality, there are *legacy pollutants*, those contaminants from previous eras of mining, farming, and manufacturing. Though the activities that caused the contamination are long gone, their consequences persist. Similarly, for climate change, there are *legacy emissions*, those GHG pollutants released since the dawn of the Industrial Era, which are already changing our climate and will continue to do so for some time. Mitigation is obviously not an option to address past emissions, and even if the world drastically reduced its carbon footprint in the first half of this century, the atmosphere would continue to warm for centuries, and the seas to rise for millennia (see figure 1.4).

ADAPTING WATER MANAGEMENT TO CLIMATE CHANGE

Adapt or perish, now as ever, is nature's inexorable imperative.
—H. G. Wells (1945, 19)

With this sobering reality in mind, in 2008, the DWR proposed a comprehensive strategy to adapt California's water sector to a changing climate, titled *Managing an Uncertain Future*. A month later, the Public Policy

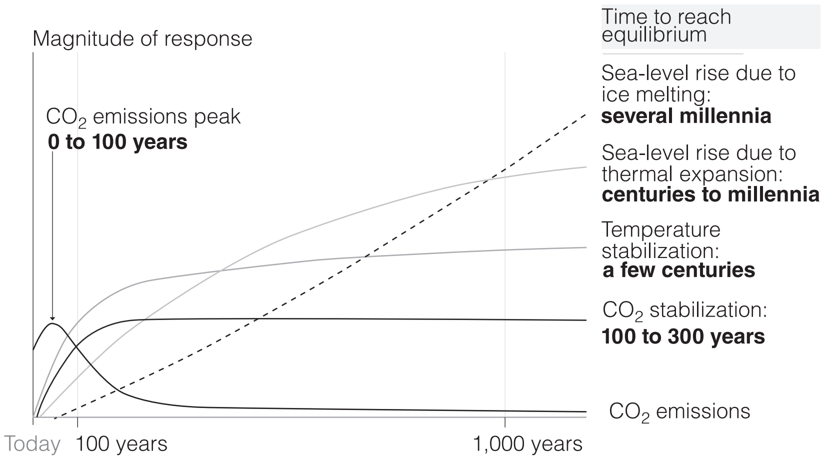

FIGURE 1.4. Even with global action to reduce GHG emissions, adaptation will still be necessary (Intergovernmental Panel on Climate Change 2001).

Institute of California issued its own report on the very same subject (written by Drs. Ellen Hanak and Jay Lund, who also provided chapter 7 of this book), covering much the same ground as the DWR's report and mirroring many of its findings. One conclusion from these analyses is that we should spend less time trying to precisely predict the future, and more on getting ready for it. As Podolak and Yarnell present (chapter 13), an adaptive management approach—iteratively studying, acting, monitoring, succeeding (and failing), learning, and sharing—generally works well for addressing complex water management predicaments, including adapting to climate change. Though there is no such thing as a no-regrets strategy—there are always opportunity and transaction costs, trade-offs, and compromise—we can take many actions now and in the near future that work across a range of possible water futures, giving us the flexibility and capacity to respond, no matter how climate change unfolds.

Regional Self-Reliance

Recognizing that local and regional entities are the principal actors in California water management, the water sector's primary tool for adapting to climate change is something called integrated regional water management (IRWM).[6] As a long-term planning process, IRWM is a strategic, statewide initiative that embraces the concept that people at the local level are best situated to know their region's priorities, capacity, and ultimately values with regard to water management. Partnerships among such stakeholders can leverage and integrate resources, take advantage of economies of scale, and produce solutions to water problems that yield multiple benefits and are sustainable.

Yes, California is one state, but in reality there are many Californias, including the North Coast, the Sierra Nevada, the Great Central Valley, and the South Coastal Plain. Different regions will be impacted differently by climate change. As noted earlier, some parts of the state are relatively wet, others dry. Some depend upon the Sierra snowpack, while others are located along the rising seas of California's 1,100-mile coastline. The impacts of sea level rise are actually regional as well, contingent upon local factors such as land movement.

Thus, a "one size fits all" approach will not work. To create more self-reliance, each region of California should develop and implement its own water management plan, reflecting a formal assessment of its climate change vulnerabilities. These regional plans should include a diverse portfolio of strategies (e.g. aggressive water conservation, storage, transfers, recycling, stormwater, desalination) appropriate for the region. Developing local supplies to meet local demands is good insurance not only for drought but also for other emergencies, such as earthquakes. Though IRWM admittedly predates the state's response to global warming, it is even more relevant in a changing climate. Fortunately, IRWM is well underway in California, with most of its land area and virtually all of its population covered by 48 IRWM regions. Moreover, many—though far from all—regional water management groups are already substantively incorporating climate change into their planning (Conrad 2012).

That said, we must concede that IRWM as strategy for adapting to climate change may have its limits. Though water problems can be less complex at smaller scales, climate projections are exceptionally uncertain at local scales and regarding extreme events. As Cantú notes (chapter 9), IRWM requires patience, trust, and ownership—qualities that are often as scarce as water in a drought. Frankly, many regions of California currently depend upon other regions for their water, a situation that is unlikely to change soon. One prominent commentator, perhaps inadvertently, once summarily dismissed a portfolio approach as "nothing heroic," a "nickel and dime" strategy (Reisner 1986).

An overemphasis on regional self-reliance also perilously perpetuates the mythology of the West, which arguably is the U.S. region most dependent upon "the state" for its development, necessitating its very own federal agency, the U.S. Bureau of Reclamation (Worster 1985).

Moreover, California itself is part of a larger region that shares the Colorado River system, which confronts its own climate change challenges. No region is a republic apart—not even California.

Thus, with IRWM, there still remains a need for continued and expanded inter-regional cooperation. Further, a role for the state and federal governments persists, specifically, to align their analysis, planning, guidelines, policies, and regulations, to support integration at the regional level. In spite of many admonitions, adapting to climate change will transpire watershed by watershed, which well fits an IRWM approach.

Statewide Integrated Water Management

California is infamous for dividing the waters. In contrast to the rest of the United States, groundwater is mostly legally separate from surface water in California, despite the clear hydrologic connection.[7] Whether it is surface or groundwater, water supply management is generally distinct from flood management—though it is often the very same water. And in both water supply and flooding, planning is often disconnected from our ecosystems, something that is "mitigated for" at the end of a water project or part of permitting therefor—although ecosystems are a critical part of the water cycle. The largest disparity of all may be that water supply, flooding, and the environment, all are often planned for and managed separately from land use, the historic and prized purview of cities and counties. On the one hand, poor land-use planning drives development into areas of little water, hardening the landscape, exacerbating water supply availability; on the other hand, it drives development into areas of too much water, putting people in harm's way.

In a changing climate, we will not have the luxury of such artificial divisions in our water planning and management. In taking an integrated approach to water management, healthy headwaters, forests, and wetlands would be protected, managed, and valued for their ability to buffer, cleanse, and store water. Rivers would be reacquainted with their floodplains, to reduce flood peaks, conserve open space, and connect habitats. An environmental stewardship ethic in water resources engineering would incorporate and support substantive ecosystem benefits in every project—equal to and as integral as any other project element. Overall, existing infrastructure can be reoperated more dynamically—and with additional storage, decision support tools, and some cooperation, surface, ground, and flood waters can be managed conjunctively. Sensible land-use planning—just integrating existing water and land-use planning and zoning—could enable more effective flood management and groundwater and habitat protection.

Inter-regional and statewide systems are also required to supply a framework of stability for regional self-reliance, facilitate water transfers and markets, and provide redundancy in the face of uncertainty. Particularly pressing statewide needs include robust flood and drought preparedness, response, and recovery planning. The dilemma in the Delta—important as a region itself and to many other regions—deserves a solution that meets both local and statewide needs.

Climate change pushes us to recognize the interrelatedness of our actions, and the need to incorporate uncertainty into our planning. Notwithstanding regional integration, we are admittedly a very long way from integrated water management at a statewide level. However, we will soon need to make real efforts in this regard if California's water sector is going to survive, much less prosper in, a changing climate.

Information and Science for Decision-Making

Making good water management decisions requires knowledge of our climate, water sources, and water uses. If the past can no longer be our sole guide to the future, then one response is to increase our situational awareness of water supply and demand in the present. For instance, the collection of real-time data on water, weather, and the environment could be better incorporated into the real-time decision-making of water operations, especially flood management (e.g. forecast-based operations). Preservation of long-term data records is also vital; without this we would have little indication of whether the climate is changing (and how), and we would lack the ability to formally evaluate the effectiveness of our responses. One initial step toward integrated water management would be the integration or coordination of existing water data collection and management systems. Whether real-time or long-term, monitoring programs represent relatively low-cost, high-value investments in adapting to climate change.

Good decision-making is also dependent upon further climate change research, even though there is unrelenting uncertainty. But that research cannot be for research's sake; climate science must focus on user needs, produce actionable findings, and be undertaken in full partnership with practitioners. And more disappointing is the state of policy analysis regarding climate change, which sadly can still be summed up as: ". . . and climate change will make things worse."

As we learn from science, we can also learn from each other, and specifically from a mistake the early East Coast settlers of the Sacramento Valley made. As Robert Kelley (1989) writes, the native peoples of the Central Valley well knew that the region regularly flooded into an inland sea—but few of the newcomers "knew or talked with the Indians." Today, this experience is valued as tribal ecological knowledge, which draws upon native peoples' cultural, spiritual, and practical connections to the land and the water.

Institutions

Climate change may precipitate trials of our water institutions as well as our infrastructure. Just as California's water management infrastructure assumes a static climate, so do many water-related regulatory processes, including water quality control plans, water rights, wastewater discharge permits, endangered species protection, reservoir operating rules, dam licensing, and flood insurance. Undeniably, most water laws and regulations are still playing catch-up with climate change science, planning, and policy. That said, some long-standing institutions have already recognized and substantively incorporated climate change, for example the state's flagship water planning process, the California Water Plan Update. Actually, there is considerable flexibility to accommodate climate change in other institutions as well—that is, if we choose to use it.

Institutions must also fill the critical need for climate literacy among the general public. The uncertainty inherent in climate change, combined with politics across the spectrum, has bred a denial of science, not unlike the reaction to the teaching of evolution nearly a century ago. In the absence of climate literacy efforts, many have turned to the gospel of talk radio for their science. Climate change presents an opportunity—again, if we choose to seize it—for institutions of all kinds to communicate fundamental scientific principles and processes, using weather and climate events as teachable moments. It is unlikely that climate change will be the only scientifically complex issue facing Californians this century, so both the bureaucracy and the academy do no service to the public by "dumbing down" the science; instead, we need to concentrate on "smarting up" the public.

The most significant institutional issue may be people. Adaptation to climate change requires professionals with an interdisciplinary skill set and a particular aptitude for translating science into action, talents not well recognized, compensated, or supported in the bureaucracy. Moreover, we should fully expect that climate change will bring more emergencies for which we will need to mobilize personnel of many talents and types, placing them in additional danger.[8]

Investment

Budgeting for California's future may be even scarier than climate change. We will have to pay to adapt, and we cannot just expect that funding will fall from the heavens like our water does (or used to). Climate change mitigation promises a "green economy" of new technologies, businesses, and jobs. In contrast, adapting to climate change may require very large, upfront, public investments—to avert catastrophe and thus even larger costs later—which will compete with equally considerable investments in other worthy societal needs like education, healthcare, and public safety. Nonetheless, the status quo is hardly free of costs, and continuing to invest in it could eventually lead to adverse financial consequences for insurance, real estate, mortgages, and local tax bases.

California water management has greatly benefitted from voter generosity with the approval of a series of water bonds over the past 40 years, and from federal largesse specifically for irrigation, flood management, and wastewater treatment. However, given the fiscal condition of our state and federal governments, compounded by the fiscal mood of the electorate, the days of such state-level generosity may be coming to a close, as for sure is the era of federal bounty. Thus, with a local and regional approach to water and climate change, so, too, may appropriately follow the responsibility for financing water management, which should result in smarter and more efficient funding decisions.

Regardless of where the money comes from, the wise use of taxpayer dollars demands that we explicitly account for climate risk in all our investments. Economics should also be used to better manage water—but in so doing, we must ensure that disadvantaged communities are not priced out of the basic human right to water and sanitation services.[9] In all, climate change is a long-term challenge to California's water resources; it deserves a long-term, stable source of funding to adapt to it.

ADAPT—FLEE IF YOU MUST—BUT PERISH IS NOT AN OPTION

Climate is our state—it is key to agriculture, energy management, recreation and tourism, our natural heritage, and our overall quality of life. For those of us in water management, climate is also our business. So, along with population growth and consumption, climate change presents one of the most significant challenges to what we do. Indeed, we ignore climate change at the risk of undermining the water sector's business model.

But if the grimmest projections of climate change come true, California will still have a lot of water—and at times, too much. Some of that water will become wastewater, which is a resource for myriad nonpotable uses. The state's aquifers hold an order of magnitude more water than the diminishing Sierra snowpack, so groundwater—if strategically and conjunctively managed with surface water, notwithstanding the inevitable holy war over how to do so—can be a fundamental adaptation option as well. With 1,100 miles of coastline—and the vast majority of California's urban demand along those shores—cities will have the option of ocean desalination, which could give inland ecosystems a break, and given its high costs, also serve as an implicit definer of reasonable water use. Most of all, regardless of where the water comes from, we must be extraordinarily efficient in its use.

When it comes to climate change in California, the state benefits from the perfect storm of innovative people, universities, businesses, and even bureaucrats. In fact, California's approach to climate change and water is already serving as a model for other states (Augustyn and Chou 2013). Political support for climate change action is strong, too—at least at the grass-roots, certainly not at the federal level. Recent polling indicates that most Californians agree that global warming is underway, it is a threat to California's future, and steps need to be taken to counter it (Public Policy Institute of California 2013). In addition, adaptation to climate change can often be incorporated into existing actions, because it also addresses other water management objectives; in fact, such an approach is especially important when other factors interact with or intensify climate change impacts. Also, the water sector can leverage a long history of formal water planning, which has resulted in an incredible system of interconnected infrastructure. Further, the water sector is well funded—water confabs involve golf courses, not bake sales—relative to other sectors like public health and biodiversity, which may continue to hurt for resources in a changing climate.

California's water sector thus has a solid foundation, and enormous potential for adaptation. With this inheritance, though, comes the danger that it will be squandered on boutique issues, like renaming, rebranding, or reorganizing resource agencies, producing "carbon-free" water, and restoring Hetch Hetchy Valley, when at the very same time many disadvantaged communities lack safe drinking water and sanitation,[10] and species are on the brink of extinction. We also do not have the luxury of limiting our options—as we have in the past—to only those we believe in; that way lays maladaptation. While the water sector needs to do its part to reduce the state's carbon footprint, as that old Berkeley bumper sticker used to say, it needs to "think globally" (mitigation) but "act locally" (adaptation). In the short term, emergency planning and response and vigorous water conservation are critical; in the long term, more actionable information, regional groundwater management, and much better land-use planning are necessary. Just as there is no average water year in California, notions of a "new normal" are flawed as well; we should be planning for change, not normal—old or new. Though exodus may be needed from some areas or at some times—and climate refugees from elsewhere may flee to California, as they did from the Dust Bowl—adaptation is clearly possible.

Responding to climate change and ensuring the sustainability of our water resources requires us to keep the faith across generations. We should be held accountable by our children for how we leave the state's water resources and world's climate for them. Thus, sustainability means that we need to stop stealing from our kids—in terms of water, climate, and money—so that they may have the basis and capacity to make their own decisions about the water and climate challenges they will inherit. As a more youthful governor Jerry Brown once said, "the world still looks to California": we must lead by example, and serve as a model for other states, future generations, and the whole world to follow.

NOTES

1. Borenstien, Seth. 2013. "World Warm Last Year, but Not Like Record US Heat." *The Big Story,* January 15, http://bigstory.ap.org/article/world-not-hot-us-2012-squeaks-top-10.

2. An acre-foot is literally what it sounds like: one acre flooded to a depth of one foot. A legacy of the agricultural origins of California's water systems, one acre-foot is almost 326,000 gallons—plenty of water for two urban families for a year.

3. Wendell and Hall (chapter 8 in this volume) provide an in-depth treatment of groundwater and its management.

4. See Christian-Smith and Heberger (chapter 5 in this volume) for a detailed description of urban water demand.

5. Wilkinson (chapter 2 in this volume) offers another, expanded view of this subject.

6. Comprehensive discussions of IRWM and integration are available nearby from Wilkinson (chapter 2), Hanak and Lund (chapter 7), and Cantú (chapter 9).

7. See Gray (chapter 4 in this volume) for more on the "antiquated separation" of groundwater and surface water law.

8. Foster and Radke (chapter 6), Cantú (chapter 9), and Podolak and Yarnell (chapter 13) also highlight the importance of people and interpersonal relationships in water resources management.

9. Hanak and Lund (chapter 7 in this volume) discuss at length the role of economics in water management.

10. Balazs and Ray (chapter 11 in this volume) say more on this frequently neglected issue.

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