Chapter 11

Agriculture and Ranching

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Executive Summary

This chapter reviews the climate factors that influence crop production and agricultural water use. It discusses (a) modeling studies that use climate-change model projections to examine effects on agricultural water allocation and (b) scenario studies that investigate economic impacts and the potential for using adaptation strategies to accommodate changing water supplies, crop yields, and pricing. The chapter concludes with sections on ranching and drought and on disaster-relief programs.

- Under warmer winter temperatures, some existing agricultural pests can persist year-round, while new pests and diseases may become established. While crops grown in some areas might not be viable economically under future climate conditions, other crops could replace them. (high confidence).
- Many important costs of climate change to agriculture will be adjustment costs. The suitability of production in an area depends not only on climate, but also on the presence of complementary infrastructure such as irrigation conveyance systems and specialized agricultural processing and handling facilities, as well

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as transportation and energy supply networks. Relocating this complementary infrastructure may be costly, especially if climate change occurs quickly. Moreover, growers in a region may be unfamiliar or inexperienced with crops suitable for the new climate. Adjustment costs can be substantial in tree-crop production, which requires large up-front capital investments and with many years between the time trees are planted and when they produce sellable output. (medium-high confidence).

- Because agriculture accounts for 79% of Southwest water withdrawals, water management and reduction of agricultural water demand are important means to adapt to climate change. Conservation strategies implemented by water managers and agricultural users tend to be more economical than developing new supplies. Options for managing demand may include addressing water pricing and markets, providing incentives to adopt water-saving irrigation technology, reusing tailwater, or shifting to less water-intensive crops. (medium-high confidence).
- The evidence supporting the widely held belief that simply improving on-farm irrigation efficiency conserves water is weak, however. Claims of water conservation are often made at the farm level. Improved application efficiency means that crops take up a higher percentage of applied water. However, this means that less water is available to recharge aquifers or serve as return flows for downstream uses. At the basin- or watershed-scale, increased application efficiency can reduce water available for these other uses. (high confidence)
- Diverse studies using mathematical programming modeling to combine economic and hydrological models have generated some consistent lessons. First, agriculture-to-urban water transfers could significantly reduce the costs of adjusting to regional water shortages. Agriculture would be the sector that alters water use the most, protecting municipal and industrial uses. Second, growers have numerous lower-cost alternatives to fallowing land as a response to drought, such as shifting crop mix, input substitution (e.g. substituting land for water), deficit irrigation, and investments in improved irrigation technologies. To facilitate transfers, additional investments in infrastructure to store and convey water would likely be required. Third, the costs of compliance with environmental regulations, especially those that protect endangered aquatic species, will represent significant adaptation costs. (high confidence)
- Irrigators also could adapt better to climate variability by increased use of water management information that is already available. The California Irrigation Management Information System (CIMIS), a weather information network for irrigation management developed and operated by the California Department of Water Resources, benefits growers via higher yields, lower water costs, and higher crop quality. CIMIS has been estimated to generate $64.7 million in benefits per year at an annual cost to the state of less than $1 million. (medium-high confidence)
- Public and private entities can more effectively deliver web-based information and decision-making tools for climate-change adaptation if they consider

constraints faced by the intended users. As of 2007, there were 29 Southwestern counties where fewer than 30% of agricultural producers had access to high-speed Internet service. Access is particularly low in the Four Corners region, which has a relatively large population of Native American farmers and ranchers. (medium-high confidence)

11.1 Distinctive Features of Southwestern Agriculture

Agriculture in the Southwest has distinctive features that influence how the sector responds to climate variability and change. First, the region accounts for more than half of the nation's production of high-value specialty crops (fruits, vegetables, and nuts). California has the most counties where specialty crops (including melons and potatoes) account for a large share of total agricultural sales (Figures 11.1). Other areas that are important in terms of specialty crops include southwestern Arizona, the San Luis Valley of Colorado, and chili- and pecan-growing areas of New Mexico (along the Rio Grande Valley).

Irrigation plays a critical role in the region. Excluding Colorado, which has significant dryland wheat production, more than 92% of the region's cropland is irrigated. Irrigated crops account for an even larger share of sales revenues. Agricultural uses of

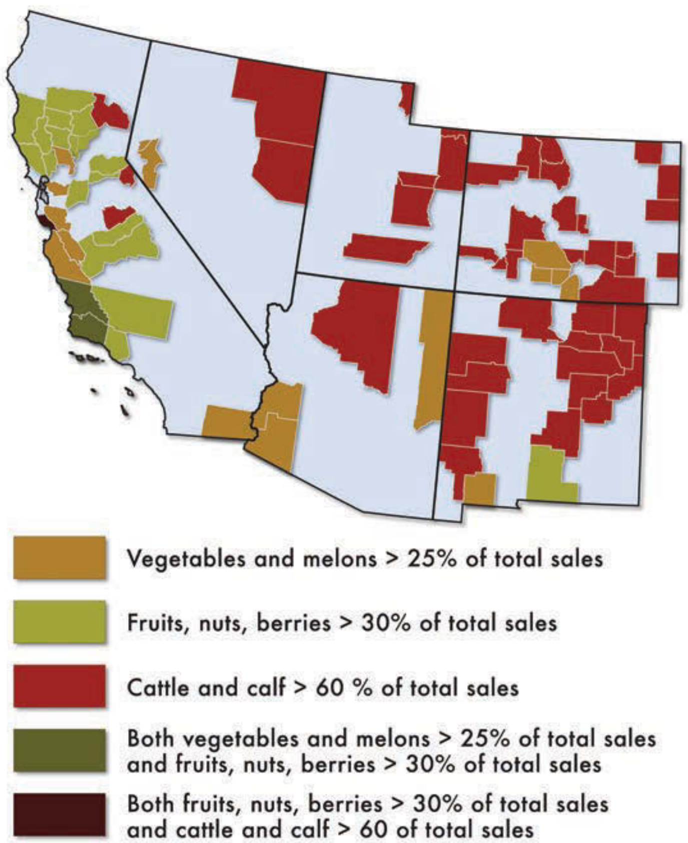

Figure 11.1 Agricultural sales by county. Source: USDA (2009, 2012).

water (for irrigation and livestock watering) account for 79% of all water withdrawals in the region. As a result, small changes in agricultural water use can have relatively large effects on the water that is available for households, industrial use, and riparian ecosystems.

The region is characterized by extensive surface water infrastructure—including dams, reservoirs, canals, pipelines, and pumping stations—managed by the U.S. Bureau of Reclamation, state water agencies, and local irrigation districts. These systems not only capture and store vast quantities of water; they also transport it over large distances, geographically "decoupling," in terms of climate-change feedbacks, many of the region's water users from its water sources. Not all agricultural areas within the region have access to this extensive surface-water network. Many locations, therefore, are highly dependent on groundwater for irrigation (Figure 11.2). Depletion of groundwater resources in these areas, as measured by increases in the average depth-to-water of wells, presents problems for irrigators, including increased costs for the energy needed to pump the water higher to reach the surface. If groundwater levels fall sufficiently, irrigators may incur additional costs to lower pumps within the well, deepen wells, or dig replacement wells. From 1994 to 2008, according to the USDA Farm and Ranch Irrigation Survey (2010), depth-to-groundwater for irrigation wells increased in all states but Nevada (Figure 11.3).

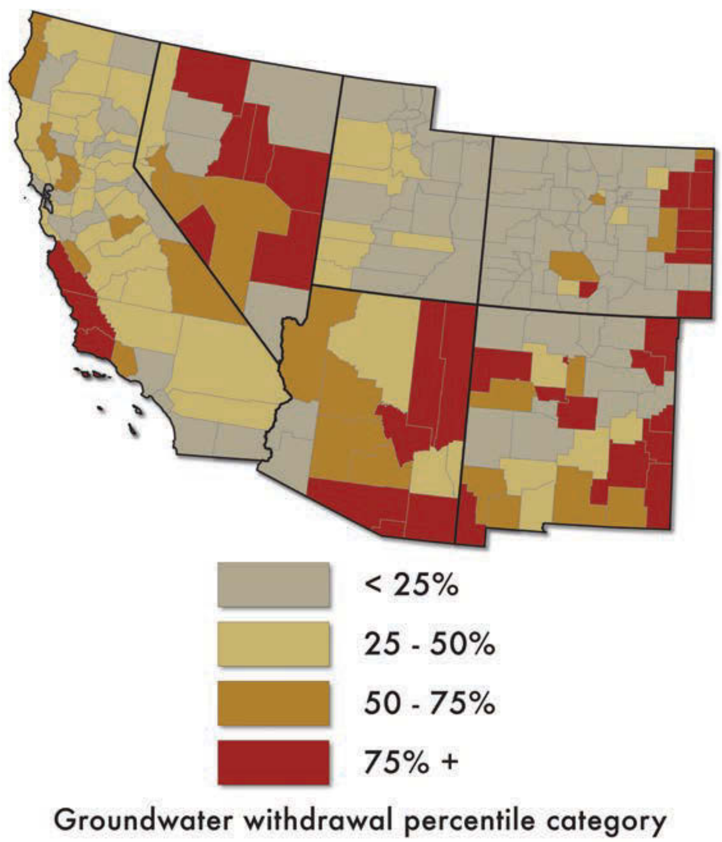

Figure 11.2 Groundwater irrigation withdrawals as a share of total irrigation withdrawals. Source: USGS (2005), Kenny et al. (2009).

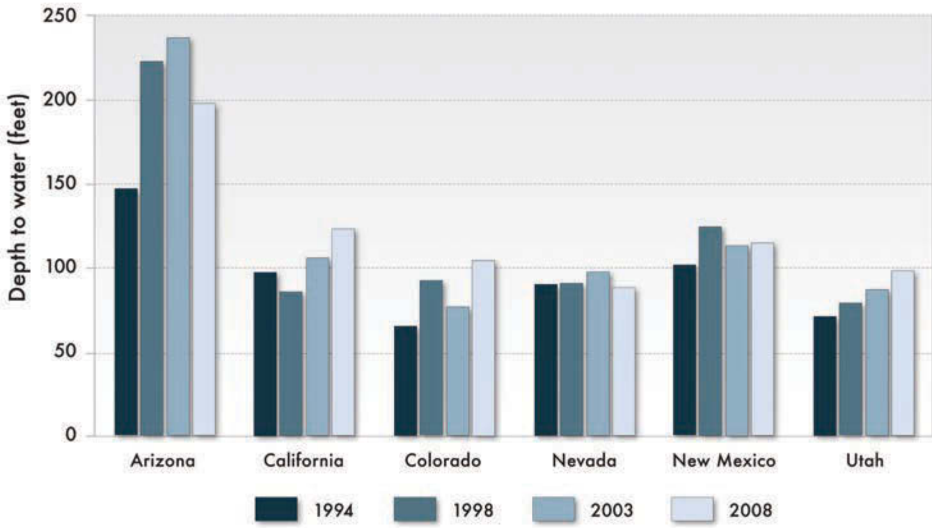

Figure 11.3 Depth to water of irrigation wells. Source: USDA (2010).

The livestock sector, especially cattle ranching and dairies, is also economically important in the region. Cattle account for most of the agricultural sales in many New Mexico and Colorado counties (Figure 11.1). Cattle ranches rely on rain-fed forage on grazing lands, making these enterprises sensitive to changes in climate. Much acreage and irrigation water is devoted to alfalfa and other hay, which provide important forage for the region's dairies as well as supplemental cattle feed.

Other major field crops include cotton in California, Arizona, and New Mexico; durum wheat in Southern California and Arizona; winter wheat in Colorado and California; and corn in eastern Colorado. An emerging challenge to crop production is the rise of glyphosate-resistant (i.e., herbicide-resistant) weeds (Price et al. 2011; CAST 2012; Norsworthy et al. 2012).

11.2 Implications for Specialty Crops

The future presents special challenges and opportunities for producers of high-value crops such as fruits, vegetables, and nuts. Demand for these crops is projected to increase over the next forty years, correlated with expected population and income growth in the United States and throughout the Pacific Rim (Howitt, Medellín-Azuara, and MacEwan 2009, 2010). Compared to field crops, demand for these high-value crops is price inelastic, meaning that demand falls little with price increases. This also means that small reductions in output lead to relatively large increases in price. Thus, price increases that accompany climate-induced losses in output can partially offset the reduced volume sold and thereby buffer producers of these crops from the effects of climate change (though there are obvious increased costs for consumers).

Climate change implies that locations best suited for production of high-value crops will change over time. Fewer frosts may make production of certain vegetables and tree crops more viable in some regions. Yet, for some stone fruits and nuts that require a minimum amount of chill time,[i] reductions in chill hours from a warming climate may reduce the profitability of production in areas where they are currently grown. In addition, many crops have threshold tolerances to high temperatures during key stages of crop development, such as pollination, while unseasonal precipitation or adverse temperatures might harm product quality during fruit development. Climate change and extreme weather are more likely to affect horticultural crops (fruits, vegetables, and ornamental plants) because they have high water content and because sales depend on good visual appearance and flavor (Backlund, Janetos, and Schimel 2008).

Under warmer winter temperatures, existing pests can persist year-round, while new pests and diseases may become established (Gutierrez et al. 2008). A study of Yolo County, California, found that warm-season crops grown there today—tomatoes, cucumbers, sweet corn, and peppers—might not be viable economically under future climate conditions. However, other crops—melon and sweet potatoes in the summer, lettuce or broccoli in the winter—could replace them (Meadows 2009; Jackson et al. 2011).

Quiggin and Horowitz (1999, 2003) note that many important costs of climate change to agriculture will be adjustment costs. The optimal location for producing specific crops will change. Established farms have infrastructure in place—for energy supply, irrigation systems, and grain storage, for example—that will be expensive to relocate, especially if climate change occurs quickly. Moreover, growers in a region may be unfamiliar or inexperienced with crops suitable for the new climate. Adjustment costs can be substantial in tree-crop production: production requires large up-front capital investments, with a stretch of years between the time trees are planted and when they produce sellable output. For example, almonds, apricots, peaches, and plums average four non-bearing years, citrus averages five to six years, while pecans average eight years (Berck and Perloff 1985). If growers reduce the number of trees as a short-term response to drought, it will reduce the region's ability to produce tree crops for many years thereafter. Another strategy—*relocating* where trees are grown—may represent a significant adjustment cost. Adjustment costs also are likely to occur when farmers change irrigation or fertilization practices or other management operations to cope with changes in resource availability, decrease greenhouse gas emissions from nitrous oxide, or to increase carbon storage in soil or the wood of trees (Hatfield et al. 2011).

11.3 On-farm Water Management

Because agriculture accounts for 79% of water withdrawals in the Southwest, methods to manage and reduce agricultural water demand are an important means to adapt to climate change (Levite, Sally, and Cour 2003; Joyce et al. 2006; Joyce et al. 2010). Local conservation strategies implemented by water managers and agricultural users tend also to be more economical than developing new supplies (Kiparsky and Gleick 2003). Options for managing demand may include addressing water pricing and markets, setting allocation limits, improving water-use efficiency, providing public and private incentives to adopt water-saving irrigation technology, reusing tailwater (excess surface water draining from an irrigated field), shifting to less water-intensive crops, and fallowing (Tanaka et al. 2006).

One way to adapt to climate-change-induced water shortages is to shift the mix of crops grown. Table 11.1 shows ranges in water application rates by crop, state, and irrigation technology in acre-feet per acre. An acre-foot is the amount of water required to cover one acre of water one foot deep. Crops in warmer Arizona tend to have higher application rates, while those in Colorado tend to have the lowest. Crops irrigated by sprinkler irrigation systems (sometimes referred to as pressurized systems) have lower application rates than those irrigated by gravity systems, which rely on flooding fields (Kallenbach, Rolston, and Horwath 2010). Sprinkler irrigation includes center-pivot, mechanical-move, hand-move, and non-moving systems (the last used mostly for perennial crops). Rather than using gravity, these systems rely on mechanically generated pressure to pump water to crops.

Table 11.1 Ranges of water application rates (acre-feet of water applied per acre) by state and irrigation technology for different crops grown in Southwestern states

	Minimum	**Median**[a]	**Maximum**
Orchards, Vineyards, Nuts	0.3 (Colorado/Drip[b])	2.7 (California/Sprinkler[b])	6.5 (Arizona/Gravity)
Alfalfa	1.6 (Colorado/Sprinkler)	3.1 (Nevada/Sprinkler)	6.4 (Arizona/Gravity)
Sugar Beets[c]	3.7 (Colorado/Sprinkler)		5.3 (Colorado/Gravity)
Cotton	2.2 (New Mexico/Sprinkler)	3.1 (California/Gravity)	4.8 (Arizona/Gravity)
Corn/silage	1.4 (Colorado/Sprinkler)	2.7 (Utah/Sprinkler)	4.7 (Arizona/Gravity)
Corn/grain	1.5 (New Mexico/Gravity)	2.1 (California/Gravity)	4.2 (Arizona/Gravity)
Other Hay	1.3 (Colorado/Sprinkler)	2.1 (New Mexico/Sprinkler)	4.2 (Arizona/Gravity)
Rice	4.1 (California/Gravity)	4.1 (California/Gravity)	4.1 (California/Gravity)
Wheat	1.3 (Colorado/Sprinkler)	2.3 (California/Gravity)	3.6 (Arizona/Gravity)
Barley	1.2 (Utah/Sprinkler)	1.7 (Colorado/Sprinkler)	3.6 (Arizona/Gravity)
Vegetables	1.7 (Colorado/Sprinkler)	2.8 (Nevada/Gravity)	3.5 (Arizona/Sprinkler)
Sorghum	0.6 (Colorado/Sprinkler)	1.7 (California/Sprinkler)	3.5 (Arizona/Gravity)

Note:

a. In cases where the median value was between two actual observations, the value of the observation with the higher application rate is reported.

b. Sprinkler irrigation includes center-pivot, mechanical-move, hand-move, and non-moving systems (the last used mostly for perennial crops). Rather than using gravity, these systems rely on mechanically generated pressure to pump water to crops. Low-flow irrigation methods, which include drip, trickle, and micro-sprinkler methods are not included in this definition of sprinkler, but treated as a separate category by USDA.

c. Only two observations.

Source: USDA (2010).

Irrigators also could adapt better to climate variability by increased use of water-management information that is already available. For example, Parker and others (2000) found the California Irrigation Management Information System (CIMIS), a weather information network for irrigation management developed and operated by the California Department of Water Resources, to be highly valuable to agriculture. The crop evapotranspiration (ET) data provided by CIMIS allows farmers to better match irrigation water applications to crop needs. This reduces risks from climate variability. Growers benefit from higher yields and lower water costs. Improved water management also increases fruit size, reduces mold, and enhances product appearance, all of which can fetch higher crop prices. They estimated that use of CIMIS reduces California's agricultural water applications by 107,300 acre-feet annually. Drought in 1989 appeared to stimulate a large increase in the number of growers and crop consultants who use CIMIS. Parker and others (2000) estimated CIMIS generated $64.7 million in benefits from higher yields and lower water costs, at an annual cost to the state of less than $1 million. CIMIS has also improved pest control and promoted use of integrated pest management techniques, which can reduce costs and improve worker safety by reducing pesticide applications.

Other Southwestern states also provide on-line databases and support tools for water management. For example, the Arizona Meteorological Network (AZMET) provides on-line, downloadable weather data and information for Arizona agriculture. Data include temperature (air and soil), humidity, solar radiation, wind (speed and direction), and precipitation as well as computed variables such as heat units (degree days), chill hours, and crop evapotranspiration. AZMET also provides ready-to-use summaries and special reports that interpret weather data such as Weekly Cotton Advisories. The Lettuce Ice Forecast Program provides temperature forecasts for the vegetable production in Yuma County. The Colorado Agricultural Meteorological Network (CoAgMet) provides daily crop-water use or evapotranspiration reports that can improve irrigation scheduling. In addition to providing raw data, the system allows users to generate customized, location-specific cropwater-use reports.

Public and private entities can more effectively deliver information or develop tools for decision making for climate-change adaptation if they consider constraints faced by the intended users. In 1996, the National Weather Service (NWS) offices discontinued issuing local agricultural weather forecasts in response to budget cuts and to avoid competing with privately supplied forecasts. The expense of privately provided forecasts may pose a barrier to some agricultural information users (Schneider and Wiener 2009). For many Southwestern farmers and ranchers, access to high-speed Internet service remains problematic. As of 2007, there were twenty-nine Southwestern counties where fewer than 30% of agricultural producers have such access (Figure 11.4). Access is particularly low in the Four Corners region of Arizona, Utah, and New Mexico, which has a relatively large population of Native American farmers and ranchers. In rural areas, radio, and television are still widely used for weather information (Schneider and Wiener 2009). Frisvold and Murugesan (2011) found that access to satellite television was a better predictor of weather information use by agricultural producers than was access to the Internet. Emphasis on encouraging commercial weather information providers may be limiting development of applications through these popular media (Schneider and Wiener 2009).

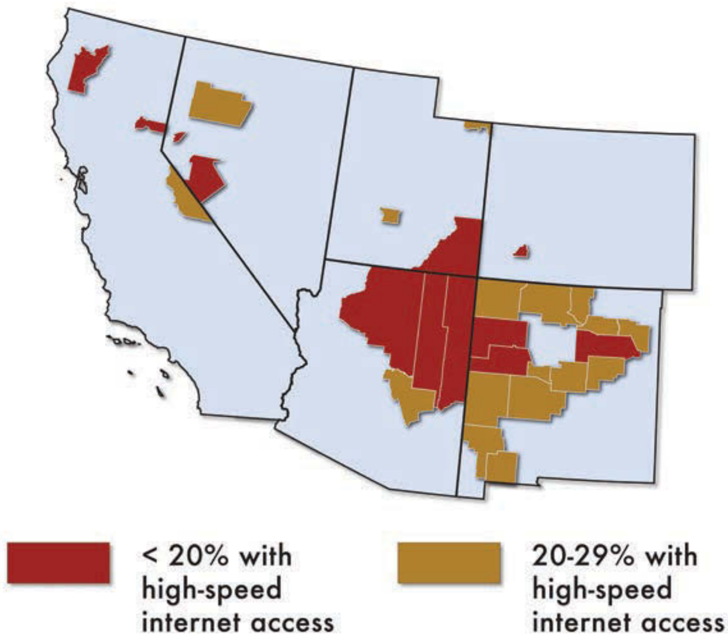

Figure 11.4 Counties in the Southwest in which agricultural producers have limited access to high-speed internet service. Source: USDA (2009, 2012).

Improving irrigation efficiency is frequently cited as a promising response to climate change or water scarcity in general (Parry et al. 1998; Wallace 2000; Ragab and Prudhomme 2002; Mendelson and Dinar 2003; Jury and Vaux 2006; Rockstrom, Lannerstad, and Falkenmark 2007). It can allow individual irrigators to save water costs and improve yields, thus increasing profits. However, improving on-farm application efficiency does not necessarily conserve water (Caswell and Zilberman 1986; Huffaker and Whittlesey 2003; Peterson and Ding 2005; Frisvold and Emerick 2008; Ward and Pulido-Velazquez 2008). Increased on-farm application efficiency means that the crop—rather than its surrounding soil— takes up a greater share of the water that is applied. However, this also means that less water returns to the system as a whole (as groundwater recharge or surface-water return flow). Other downstream irrigators (or other users) often count on this return flow or recharge for their water supplies. Similarly, reducing the water lost through the conveyance system means more of the water diverted reaches a crop, but also results in lower return flows or recharge that is no longer available to other irrigators, urban water users, or ecosystems. While fisheries and aquatic habitat depend on return flows, these "uses" typically do not hold legally recognized water rights that can contest any harm done by water transfers (Chong and Sunding 2006). Many riparian systems now depend on these return flows, which are subject to changes in managed, hydrological systems that have been altered to accommodate human water uses (Wiener et al. 2008). In some cases, minimum flow requirements have been established under the Clean Water Act and Endangered Species Act (see Ward and others [2006] and Howitt, MacEwen and Medellín-Azuara [2009] for analysis of additional costs of maintaining minimum flow requirements). However, litigation and implementation have been contentious, with variable outcomes (Moore, Mulville and Weinberg 1996; Benson 2004). Thus, what may seem a rational response to water scarcity by irrigators at the farm level, may exacerbate water scarcity problems at the basin scale. Policies to increase irrigation efficiency with the hope of freeing up water for other uses may fail to conserve water.

11.4 System-wide Water Management: Lessons from Programming Models of Water Allocation

A number of studies have used mathematical programming models to assess how different areas of the Southwest may respond to different drought, water shortage, or climate-change scenarios—which may include changes in temperature, level and type of precipitation, and the timing of mountain snowmelt and runoff into lower elevation agricultural regions (Cayan et al. 2008). To varying degrees, these studies link physical water supply and associated hydrologic information to economic models. Model solutions find the least-cost response to water shortages given system constraints. A common finding of these studies is that the agricultural sector makes large adjustments in water use, land use, and cropping patterns that allow urban and industrial water uses to remain largely unchanged.

Sustained drought in California

Harou and colleagues (2010) examined the effects of severe, sustained drought in California. Their drought simulations, based on records of ancient (paleo-) climates, assumed streamflows that are 40% to 60% of the current mean flows, with no intervening year wet enough to fully replenish reservoirs. This drought scenario is similar to the effects under "dry forms" of climate warming: those with projected reductions in precipitation. The analysis examined potential impacts to agriculture and the rest of California's economy in 2020. The model simulated allocation and storage of water to minimize costs of water scarcity and system operation. The costs in the drought scenario were borne largely by agriculture, limiting costs to the state's overall economy. The costs of water shortages were greatest in agriculture, except in Southern California where urban costs dominated. Large differences in scarcity costs across sectors and regions created incentives to transfer water from lower-valued agricultural to higher-valued urban uses, where value is determined by user willingness to pay for additional water. The study also calculated costs of maintaining required environmental flows and found these could be quite high, especially for the Sacramento-San Joaquin River Delta. Results also suggested there are large benefits to improving and expanding the conveyance infrastructure to facilitate movement of water.

Water availability and crop yields in California

Howitt, Medellín-Azuara, and MacEwan (2009, 2010) simulated the effects of changes in water availability and crop yields in California in 2050. While statewide agricultural land use and water use were projected to decline by 20% and 21% respectively, total agricultural revenues fell by less: 11%. There were large reductions in acreage of water-intensive crops and small shifts in others. In Southern California agriculture, two factors reduced negative impacts to farmers. Crop price increases accompanied production declines, while farmers also shifted to high-value crops. The greatest reductions in output were among field crops, with relatively less change among fruit and vegetable crops.

In contrast, total urban water use fell by 0.7%. Results assumed that between now and 2050, a more economical means of transferring water from Northern to Southern California will be developed. Absent climate change, growing demand for high-value specialty crops is expected to drive an increase of 40% for California's agricultural revenues by 2050. Under the dry-climate warming scenario, however, revenues are projected to grow 25% by 2050.

Effects of adaptation measures in California

Medellín-Azuara and others (2008) examined the consequences of various adaptation measures in California for 2050 in a dry-warming climate change scenario. They also made assumptions about baseline changes to water demand and land use by 2050. The model allowed water to be allocated to maximize net benefits of the state's water supply, given infrastructure and physical constraints. Water markets implicitly allowed water to flow to higher-valued urban uses. Institutional barriers to water transfers were not modeled. The simulation projected that statewide costs would rise substantially when water markets were geographically restricted. Urban water users in Southern California would purchase water from central and Northern California, while Southern California agriculture would maintain senior water rights to the state's allocation of Colorado River water. Agriculture in the Sacramento, San Joaquin, and Tulare basins would face large economic losses from reduced water availability and lower yields. Grower losses would be only partially compensated by revenues from water sales to urban areas. Rules for water storage and conjunctive management of surface and groundwater would have to change to improve management of the statewide system.

Economic and land-use projections in California

Tanaka and others (2006) combined climate scenarios for 2100 with economic and land-use projections for California. Climate scenarios were based on both wet and dry forms of climate warming. Changes in seasonal water flows ranged from a 4.6-million-acre-foot (maf) increase to a 9.4 maf decrease. Given hydrologic and conveyance constraints, water was allowed to flow from lower-valued to higher-valued uses. Dry warming scenarios presented the greatest challenges to California agriculture. Modeled simulations projected the transfer of water from Southern California agricultural users to urban users. Many of these transfers have already subsequently occurred. In the simulations, Southern California urban users also imported more water from northern agricultural areas. Agricultural water users in the Central Valley were shown to be most vulnerable to dry warming under this simulation; under the driest scenarios, their water use declined by one-third. Although in the simulation agricultural producers received some compensation from agricultural-to-urban water use transfers, transfer income was insufficient to compensate for all the costs of reduced water supplies. Agricultural producers altered irrigation technology in response to water shortages. While statewide agricultural water deliveries fell 24% and irrigated acreage fell 15%, agricultural income was reduced only 6%. Income fell less than water deliveries because farmers adapted by changing both irrigation technologies and crop mix. Farmers reduced production of lower valued crops, while maintaing production of higher valued ones.

Dry warming scenarios substantially increased the costs to agriculture (and other users) of maintaining water supplies for environmental protection. Under the driest warming scenarios, expansion of storage infrastructure yielded few benefits, while expansion of conveyance systems yielded benefits in every year.

Agriculture in Nevada's Great Basin

On a smaller geographic scale, Elbakidze (2006) examined potential impacts of climate change on agriculture in the Truckee Carson Irrigation District of Nevada's Great Basin. He considered scenarios based on two general circulation models (the Canadian and Hadley GCMs) for 2030, which projected warmer temperatures but wetter conditions and increased streamflow. The study also considered scenarios with reduced streamflow. Streamflow scenarios were examined both in isolation and combined with assumed yield increases or yield increases accompanied by price decreases. The crops included alfalfa, other hay, and irrigated pasture. In this study, agricultural returns increased with increased streamflow and decreased with decreased streamflow, but the changes were asymmetric: economic losses under reduced streamflow conditions were much larger than gains realized under increased streamflow conditions. The model assumed that existing infrastructure was sufficient to handle increased streamflow. Benefits of increased streamflow also were dependent on the growers' ability to increase their agricultural acreage.

Water transfers in Rio Grande Basin

Booker, Michelsen, and Ward (2005) examined the role of water transfers in mitigating costs of severe, sustained drought in the Upper Rio Grande Basin, stretching from southern Colorado, through New Mexico, and into West Texas. (The 1938 Rio Grande Compact governs water allocations between the three states.) Their modeling framework was not based on a specific climate-change scenario, but considered droughts that reduced basin inflows to 75% and 50% of the long-term mean. In 2002, inflows actually had fallen to 37% of mean. Under the scenario using existing institutions, surface-water allocations were not transferred between different institutional users, such as cities and irrigation districts. Agriculture accounted for the bulk of water-use reductions and economic losses. The cities of Albuquerque and El Paso did not alter consumption, but shifted to more expensive groundwater sources. Under the intra-compact trading scenarios, transfers were permitted between users *within* states. For example, trades occured between New Mexico agriculture and Albuquerque, and separately between West Texas agriculture and El Paso. Intra-compact trading would reduce economic losses from drought by 20%. Under interstate trading scenario, trades were allowed between all users in New Mexico and Texas. Under this scenario, El Paso and Albuquerque would rent water from the Middle Rio Grande Conservancy District (MRGCD) instead of pumping groundwater. The more MRGCD cut back on water use, the less Elephant Butte Irrigation District did so. Interstate water trading reduced the total economic losses from drought by one-third. The simulation results suggest *potential* gains from expanded water trading. Urban uses in Albuquerque remained unaffected, while those in El Paso fell by 1.1% at most. The researchers pointed out that there would be additional transaction costs associated with establishing and expanding water markets and for designing policy instruments to address third-party damages from transfers. They also note that there do exist institutional and legal impediments to trading water across state lines.

Severe drought in Rio Grande Basin

Ward and others (2006) also modeled impacts of severe drought in the Upper Rio Grande Basin. Increasingly severe drought scenarios were combined with minimum instream flow requirements for endangered fish protection. Agriculture again absorbed most of the shock in response to water shortages and environmental requirements, both in terms of reduced water use and economic losses. The largest absolute losses were in Colorado's San Luis Valley, where relatively high-value crops are grown.

Drought and Arizona's agriculture

The U.S. Bureau of Reclamation's Final Environmental Impact Statement for the *Colorado River Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lakes Powell and Mead* (Reclamation 2007) considered how Arizona agriculture would be affected by a shortage declaration on the Colorado River.[ii] The Final EIS analysis was not based on any explicit climate change scenarios. Baseline values were based on historical flows, but sensitivity analysis did include some drought scenarios. Other research has suggested that climate change would increase the likelihood of future shortage declarations (Christensen and Lettenmaier 2007; Seager et al. 2007; Rajagopalan et al. 2009). The study assumed the only adaptation mechanism available to agriculture is land fallowing, with crops providing the lowest returns per acre-foot of water fallowed first. Fallowing was possible for alfalfa, durum wheat, and cotton, while it was assumed that high-value specialty crops would continue to be grown. For most shortage scenarios, the bulk of shortage costs were felt in central Arizona and in Mohave County in northwest Arizona.

Reduced water supplies across the Southwest

Frisvold and Konyar (2011) simulated the impacts of reducing agricultural water supplies in Arizona, Colorado, Nevada, New Mexico, and Utah. The model did not include potential barriers to transferring water between uses, regions, or states. Nor did the model include urban sectors, but it accounted for how regional agricultural markets were linked to the broader U.S. and export markets. Possible adaptations included deficit irrigation[iii] (which may apply less water than that needed to maximize output *per acre*), changing the crop mix, and changing input mix. The costs of water shortages to irrigated agriculture using a combination of these strategies was 75% lower than under a scenario where the only adaptation mechanism was land fallowing. Similar to the Reclamation analysis cited above, results suggested that reducing cotton and alfalfa production would be most effective. Similar to the Howitt, Medellín-Azuara, and MacEwan (2009, 2010) California study results, agricultural output declined primarily for commodity crops, with little change to high-value specialty crops. Although the model treated the entire region in aggregate, the largest reductions came from crops grown in central Arizona, which holds junior water rights to Colorado River water. Crops grown in western Arizona were little affected. With high-value crops and senior rights to Colorado

River water, western Arizona would remain a national center of specialty crop production. Model results also suggested there would be relatively large losses to livestock and dairy producers from reduced supplies of alfalfa and feed grains.

Lessons from simulation studies

These mathematical programming model studies varied in many dimensions: period, geographic scope, crop coverage, hydrologic detail, and assumed climate/water shock. Taken together, however, one can draw some general lessons from their results. First, based on these simulations, agriculture would be the sector that alters its water use the most, to adapt to regional water shortages and protect municipal and industrial (M&I) uses. Agriculture would buffer urban users from water shocks, and thus serves an important insurance function. Second, although fallowing irrigated land is one response to drought, growers would have numerous lower-cost options. Third, important factors in adapting to water shortages would be the costs of complying with environmental regulations, especially those that protect endangered aquatic species. Fourth, additional investments in infrastructure to store and convey water would likely be required to reduce negative effects of dry warming or increase the benefits of wet warming. Fifth, and perhaps most importantly, water transfers would have the potential to significantly reduce the costs of adjusting to water shortages under dry warming scenarios. Agriculture-to-urban transfers would increase income for agricultural areas, partially compensating for losses from reduced water use. Currently, however, many institutional restrictions limit the transfer of water across jurisdictions, basins, or state lines. The flexibility provided by water transfers also would depend on future investment in complementary infrastructure.

11.5 Ranching Adaptations to Multi-year Drought

Southwestern cattle ranches depend on rain-fed forage grasses to feed cattle. Only a small portion of pastureland is irrigated. Drought reduces forage production on livestock grazing lands and is a major concern among ranchers (Coles and Scott 2009). In much of the region, rainfall occurs during the winter, and a rise in winter temperatures may increase forage production compared to present conditions. Climate change could offer possibilities for range improvement through the introduction of alternate forage species or of trees and shrubs that increase shade for livestock and soil fertility. Climate change may increase pasture productivity via CO_2 enrichment on plant growth and because warmer temperatures would lengthen the growing season. This should reduce the need of ranchers to store forage to feed animals over the winter. Increased temperatures are expected to increase the variability of precipitation (Izaurralde et al. 2011). Thus, a challenge for ranchers will be to manage this variability.

In the case of severe drought, ranchers can adapt by: (1) purchasing additional feed, (2) reducing herd size through selling of stock, (3) leasing additional grazing land, or (4) temporarily over-grazing lands. These adaptations are not without negative consequences. Cattle sold prematurely at lower weights fetch lower prices and sales prices during droughts can be low because many ranchers are selling simultaneously. Herd liquidation makes restocking herds in future years more expensive. Overgrazing can reduce the long-term productivity of grazing lands. All these factors may reduce both the short-term returns and longer-term debt and borrowing capacity of ranchers. Drought may also affect the price of hay, which ranchers might use for supplemental feed. However, Bastian and colleagues (2009) and Ritten, Frasier, Bastian, Paisley and colleagues (2010) suggest that irrigated hay production and statewide markets for hay reduce the risks of adverse economic impacts from drought. Costs of hay, however, can be high if pervasive drought means that it must be transported over long distances.

Ranchers face two types of risk: price risk and weather risk. They can limit their exposure to price risk through use of futures and options contracts, but to do so means that ranchers must consider price and weather risk jointly. Recent research that focuses on strategies to adapt to multi-year droughts has important implications. Such research does not directly address adaptation to particular climate-change scenarios. However, results are relevant for considering climate scenarios that project continued and prolonged drought. Important considerations for ranchers seeking to adapt to multi-year drought are (a) the length and the severity of the drought and (b) when the drought occurs in the cattle price cycle.

An example of an adaptation strategy for ranchers is to provide supplemental feeding to cattle in addition to pursuing a baseline strategy of herd liquidation (Bastian et al. 2009; Ritten, Frasier, Bastian, Paisley et al. 2010). Supplemental feeding appears to be the better long-term strategy. It allows more animals to be sold after the drought (when prices are higher) and avoids aggressive culling of herds during drought, which would have higher restocking costs. Research findings, however, suggest that there is no single "right" strategy and that the advantages of supplemental feeding depend on where a ranch is in the price cycle.

Another example of an adaptation strategy is a "flexible" rather than "conservative" approach to drought management of livestock operations (Torell, McDaniel and Koren 2011). A conservative approach would maintain low baseline stocking rates, thus requiring little sell-off in response to drought. This approach reduces adjustment costs of destocking and restocking, but does not fully utilize available forage in good years. It thus misses out on opportunities to make high returns in years with abundant forage. The flexible approach would adjust herd size to fit forage productivity and lease additional grazing land during droughts (as opposed to simply destocking). This approach allows ranchers to capitalize on good forage conditions and avoids problems of overgrazing during drought. There are costs to this approach, however. Additional grazing land with suitable forage may be scarce if drought is geographically pervasive and there are added costs of transporting livestock. High transportation costs could make the flexible approach economically unfeasible.

Ritten, Frasier, Bastian, and Gray (2010) also compared a flexible strategy to a fixed cattle-stocking strategy over a multi-year horizon and accounting for uncertainty. Optimal stocking depends on rangeland health, which varies with grazing pressure and growing season precipitation. Compared to the scenario of fixed stocking at levels recommended by the Natural Resource Conservation Service, a scenario of flexible stocking would increase average annual revenues 40%, while reducing profit variability. Over a variety of climate projections, Ritten, Frasier, Bastian and Gray found increased variability of annual precipitation to be a greater threat to ranch profitability than changes in projected average precipitation. For scenarios with more variable precipitation, average stock rates would decline but also would vary more under the flexible system. Variable precipitation could pose problems for cow/calf producers, who maintain a base herd of cows that produces calves for sale after weaning (or until they are yearlings), and so are less flexible than stocker operations. Stocker operations in contrast purchase weaned cattle in the spring to put to pasture before sale. They are more flexible because they do not need to maintain a base herd and stocker purchases can be made based on anticipated forage conditions. The cattle industry could adapt by shifting to more flexible cow-calf-yearling operations that could take better advantage of good years, while selling yearlings early to avoid damaging the range in lean years. Ritten, Bastian, and colleagues (2010) cite this as among the most profitable long-term strategies for cattle producers dealing with prolonged drought.

Torell, McDaniel, and Koren (2011) found the potential gains from this flexible strategy also depend on when drought occurs in the timing of the cattle price cycle. Potential gains from a flexible strategy are greater if forage productivity is more variable from year to year. The approach, however, entails higher costs and financial risks. Further, the approach may be more appropriate in cooler climates. In short-grass prairies, such as in New Mexico, the estimated large gains from the flexible strategy rely on perfect climate forecasts to make management decisions. In actuality, key decisions about livestock purchases depend on past conditions and the well-intended but imperfect 90-day seasonal forecasts of the National Weather Service Climate Prediction Center. Climate forecasts that are more accurate and have a longer lead-time could increase the value of a flexible grazing strategy. At present, the quality of forecasts is not sufficient to make this a preferable strategy in short-grass prairie systems. However, this example illustrates how improved climate forecasts could help ranching adapt to climate change.

11.6 Disaster Relief Programs and Climate Adaptation

Agricultural producers may take a variety of actions to reduce risks from drought, flood, and other weather-related events. They can diversify the mix of the crops they grow, adopt irrigation and pest control practices to protect yields, enter into forward or futures contracts,[iv] or make use of weather or other data to time operations to reduce risk. Increasingly, farmers have diversified their household incomes by relying on both farm and non-farm jobs. Disaster relief programs affect producer incentives for managing risks because they alter the costs and benefits of these and other risk-reducing measures.

Congress has traditionally provided regular disaster payments to growers on an ad hoc basis in response to natural disasters and weather extremes that lowered crop yields or forage production. Ad hoc payments have been criticized because of their expense and because they maintain economic incentives to continue production in areas susceptible to agronomic risks. The Federal Crop Insurance Act of 1980 and subsequent legislation attempted to establish crop insurance, rather than disaster payments, as the main vehicle for managing farm risk. While the number of producers covered under federally subsidized crop insurance has risen, ad hoc disaster payments have continued, averaging about $1 billion annually.

The most recent Farm Bill (2008) established several new disaster relief programs also intended to replace ad hoc payments. The largest program was the Supplemental Revenue Assistance Payments Program (SURE), which pays producers for crop revenue losses from natural disaster or adverse weather. It compensates producers for a portion of their losses not eligible for payments under crop-insurance policies (Shields 2010). A producer can become eligible for payments if a disaster is declared in that producer's county or a contiguous county. Eligible producers need show only a 10% yield loss on one crop to qualify for payments. Outside of designated counties, producers must show a 50% loss of a crop. The SURE program has proved to be complex to administer in part because of how it interacts with crop insurance payments. Payments are often delayed for a year or more after actual losses.

Some researchers have raised concerns that the program encourages more risky behavior by producers (Barnaby 2008; Schnitkey 2010; Shields 2010; Smith and Watts 2010). Small changes in yield, even one bushel per acre, can mean the difference between receiving large payments or no payments. This makes it difficult for producers to determine year to year if they will be eligible or for program payments. It also makes it difficult for administrators to gauge whether producers are actively trying to avoid yield losses. Payments are more likely to be triggered if producers raise a single crop in a county that has high yield risk than if they grow a more diversified mix of crops. In some cases, producers may receive higher revenues by simply allowing their crops to fail (Smith and Watts 2010). Figure 11.5 shows the counties that received two-thirds of SURE payments disbursed in the Southwestern states to date. Fourteen counties, primarily in dryland wheat producing areas, account for most of the payments. Most are counties with payments triggered every year.

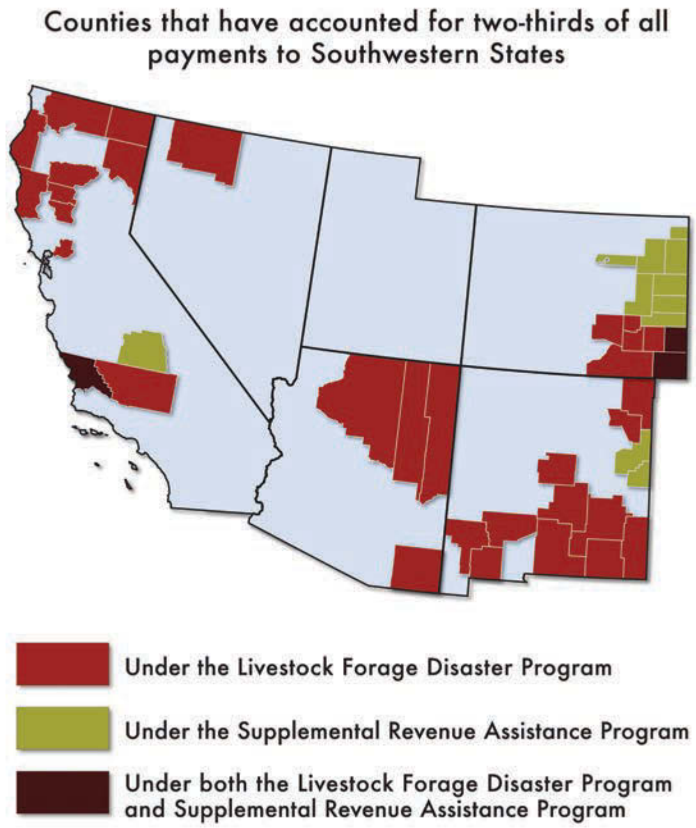

Figure 11.5 Counties that have accounted for two-thirds of all payments disbursed to Southwestern States under the Livestock Forage Disaster Program (LFP) and the Supplemental Revenue Assistance (SURE) Program. Source: USDA (n.d.).

Another disaster relief program established under the 2008 Farm Bill was the Livestock Forage Disaster Program (LFP). The program compensates livestock producers for losses related to drought or fires on grazing lands. For drought compensation, producers must have livestock in counties rated by the U.S. Drought Monitor[v] (Svoboda et al. 2002) as having severe, extreme, or exceptional drought. Payment levels rise with the length and severity of drought. Producers may also qualify if they normally graze livestock on federal lands where federal agencies have banned grazing because of occurrence of fire. LFP has certain advantages over SURE from a risk-management perspective. First, payments are determined by the Drought Monitor rather than disaster designations, which do not necessarily follow clear, severity-related guidelines. Second, because the Drought Monitor releases information weekly, processing and payment of claims is much faster. Third, and perhaps most importantly, payments based on county-level drought or fire conditions mean that payment levels are relatively independent of producer decisions. Thus, there is much less reward for producers failing to limit risk. Figure 11.5 also shows counties that have received two-thirds of all LFP payments disbursed to the Southwestern states to date. It illustrates where drought and fire risks and livestock forage production intersect.

Lobell, Torney, and Field (2011) examined data on federal crop insurance indemnity payments and disaster payments in California from 1993 to 2007. Grapes accounted for the largest number of indemnity claims, followed closely by wheat. Tree crops and grapes accounted for 75% of all indemnity payments. Excess moisture was the most common cause of both insurance and disaster payments, followed by cold spells, then heat waves. The effect of climate change on these payments remains difficult to predict. Less frequent cold extremes would tend to reduce payments, while heat waves would tend to increase them. There remains a high degree of variability in projections of precipitation intensity, flooding risk, and other hydrological risks (Lobell, Torney, and Field 2011). Given the economic significance of damage from wet events, better projections of these extreme events are important.

The Southwest region is characterized by irrigation-dependent production of high-value specialty crops that are vulnerable to excess moisture, followed by cold, then heat. The region also is characterized by ranching and dryland wheat production, both of which are sensitive to fluctuations in precipitation. In both areas, improved projections of precipitation will be crucial for agricultural adaptation. Another key area of uncertainty is knowledge about when improvements in irrigation efficiency actually reduce consumptive use of water on a basin-wide scale and when it actually increases consumptive water use. Finally, many of the costs of climate change to agricultural producers are adjustment costs. Effects of climate change on both tree-crop and livestock production will be long-lived, with short-term shocks having repercussions over several years of tree and animal production cycles.

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Endnotes

i Chill time is the accumulation of hours between 32°F–45°F (0°C–7°C) during bud dormancy (Aron 1983; Baldocchi and Wong 2008).

ii This would be declared by the Secretary of the Interior in response to specific conditions agreed upon by the seven states participating in the Colorado River Compact: the six Southwestern states considered in this report and Wyoming.

iii Rather than emphasizing maximizing yield (crop output per acre), deficit irrigation focuses more on achieving greater output per unit of water applied (Fereres and Soriano 2007). The strategy can involve some sacrifice of yield, but can use less water.

iv Both forward and futures contracts are agreements to buy and sell an asset at a specified time and price in the future, with both terms agreed upon today. Futures contracts are standardized contracts traded on commodity exchanges, while forward contracts are bilateral agreements between two parties.

v See http://droughtmonitor.unl.edu/.