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# Simple Approaches to Examine Economic Impacts of Water Reallocations from Agriculture

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**Abstract:** Facing an anticipated shortage declaration on the Colorado River and reductions in surface water for agricultural use, rural stakeholder groups are concerned about how water cutbacks will affect their local economies. Local farm groups and county governments often lack the analytical tools to measure such impacts. While one can learn much from large-scale hydro-economic models, data, cost, and time limitations have been barriers to such model development. This article introduces three basic modeling approaches, using relatively low-cost and accessible data, to examine local economic impacts of water reallocations from agriculture. An empirical application estimates the effect of agricultural water reductions to Pinal County, Arizona, the county that would be most affected by a Colorado River Shortage Declaration. Water cutbacks to agriculture are modeled using two variants of a "rationing" model, which assumes that farmers will fallow their acres that generate the lowest gross returns (Rationing Model I) or the lowest net returns (Rationing Model II) per acre-foot of water. Rationing models have modest data requirements given that crop and region specific data are available. Building off these simpler rationing models, an input-output (I-O) model provides more detailed information about the impacts on different rural stakeholder groups as well as the impacts to non-agricultural sectors and the local tax base. Given imminent water cutbacks, access to low-cost data and information that are easy to interpret is essential for effective community dialogue.

**Keywords:** *Pinal County, Arizona; Colorado River; shortage; agricultural water use*

The states of the Colorado River Basin (Arizona, California, Colorado, Nevada, New Mexico, Utah, and Wyoming) face growing challenges of balancing increasing water demands with limited and possibly declining supplies. The region's population is projected to grow by 12 million people (about 19%) over the next 20 years (University of Virginia 2018), increasing demands for municipal and industrial (M&I) water uses. On the supply side, the region faces a number of challenges. First, water supplies are over-allocated. The 1922 Colorado River Compact allocated (i.e., gave the legal rights to) 16.5 million acre-feet (maf) of water per year between the Basin States and Mexico, based on annual runoff estimates at the time of the Compact. Longer-term streamflow records, however, suggest average runoff of only 15 maf/year (Garrick et al. 2008). Tree ring reconstructions place the figure even lower, between 13.5 and 14.7 maf/year (Stockton and Jacoby 1976; Woodhouse et al. 2006; Meko et al. 2007). Second, few potential sites for dam projects for large-scale water storage remain in the West, while projects face greater scrutiny over their environmental impacts. Although there is renewed interest in "auxiliary projects" to increase storage capacity at existing dam sites (Perry and Praskievicz 2017), these are at best a partial solution. In addition, climate change is projected to further reduce Colorado River runoff (Overpeck and Udall 2010) and increase agricultural demands for water (USBOR 2012).

With limited (and possibly shrinking) water supplies and growing water demands, water planners expect large reductions in agricultural use will occur to balance Basin water supplies and demands. The Bureau of Reclamation's (BOR) *Colorado River Basin Water Supply and Demand Study* (USBOR 2012) projects Colorado River agricultural water use to fall by 0.3 to 0.6 maf/year, depending on the scenario, with the bulk of these reductions occurring in Arizona. Agricultural water use from all sources in the Basin is projected to fall between 0.7 and 3 maf/year (depending on scenario). The BOR scenarios assume, "[t]he overall decrease is almost entirely due to a reduction in irrigated acreage, as per-acre delivery shows slight increases across all scenarios" (p. C-29). A survey of state and regional modeling studies of western state adjustments to water shortages (Frisvold et al. 2013) found that "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" (p. 231). In December 2017, the BOR Commissioner Brenda Burman called on the seven Basin States to develop Drought Contingency Plans (DCPs) in response to persistent drought and declining regional water supplies stored in Lake Powell and Lake Mead. Although states have yet to precisely allocate cutbacks across sectors, their tentative plans require agriculture to account for the bulk of water use cutbacks.

Rural stakeholder groups are concerned about how agricultural water cutbacks will affect their local economies in terms of lost agricultural production, farm income, and jobs, as well as broader economy-wide impacts on non-farm sectors and the local tax base. Yet, local farm groups and county governments often lack the analytical tools to measure such impacts. While one can learn much from large-scale state and regional hydro-economic models, these suffer from several drawbacks. They have significant data requirements, which can make them expensive and time-consuming to develop. Furthermore, state- or water basin-level models based on broader averages across larger geographies may not fit specific, local farming conditions well. California has invested considerable resources to develop modeling capacity at multiple geographical scales (see Sunding et al. 1994, 2002; Harou et al. 2009; Howitt et al. 2014; Medellin-Azuara et al. 2015). Yet, other states have followed suit to only a limited extent, perhaps because of the large budget and expertise required. This article introduces more basic modeling techniques to examine local economic impacts of water reallocations from agriculture. It begins with simple "back of the envelope" methods that have low data requirements, providing results that are easy to interpret by non-economists. It then builds up to a more complex input-output (I-O) model. I-O models are an extension of simpler methods and can be the basis of more sophisticated models, such as computable general equilibrium (CGE) models (Berck et al. 1991; Seung et al. 1997, 1999; Goodman 2000). In contrast to CGE models, local planners often employ (or are familiar with) I-O modeling methods.

The empirical application for this article estimates economic impacts of agricultural water reductions to Pinal County, Arizona. Previous BOR analysis identified Pinal as the county that would be most affected by surface water cutbacks to Central Arizona agriculture triggered by a Colorado River Shortage Declaration (USBOR 2007). Pinal County agriculture has also been at the center of debate and negotiations over the Arizona DCP.

The article proceeds as follows. Section 2 provides basic information about the role of agriculture in the Pinal County economy. Section 3 discusses the structure, assumptions, and data requirements of three modeling approaches. These include two variants of a "rationing" model of water cutbacks. Rationing models have the benefit of easy interpretation and very modest data requirements. The third modeling approach is an I-O model whose assumptions about agricultural production technology, cropping patterns, and short-run economic responses build off those of the simpler rationing models. The I-O model provides more detailed information about the impacts on different rural stakeholder groups (e.g., farmers, farm workers). It also provides information about how contractions in agricultural production affect non-agricultural sectors. Section 4 introduces a water supply shock – a 300,000 acre-foot (AF) reduction – in surface water supplies to Pinal County agriculture. This hypothetical shock is comparable to water reductions under earlier BOR shortage scenarios and reductions envisioned under the Arizona DCP. Section 5 discusses the importance of modeling assumptions and the final section closes by discussing limitations of the three modeling approaches and identifying areas of future research to better assess impacts of water cutbacks.

## Pinal County Study Area

Pinal County in Central Arizona is bordered to the north and south by urban counties, Maricopa (metropolitan Phoenix) and Pima (metropolitan Tucson) (Figure 1). Archeological evidence suggests that irrigated agriculture in Central Arizona started as early as 600 AD when the native population, the Hohokam, began construction of a network of large canals near the Salt and Gila Rivers to irrigate their crops (Howard no date; Lahmers and Eden 2018). Today, important agricultural goods in Pinal County include cotton, milk, cattle, alfalfa, and other livestock feed and forage. With about two-thirds to three-quarters of Pinal County's annual agricultural sales derived from livestock and their products (USDOC BEA multiple years), the county is a leading producer of cattle and calves and milk from cows. According to the 2017 Census of Agriculture, Pinal County accounted for 44% and 31% of Arizona's cattle and milk sales, respectively, ranking it in the top 2% and top 1% of U.S. counties with cattle and milk sales (USDA NASS 2019).

Pinal County is an especially important source of milk for the large urban centers of Phoenix (Maricopa County) and Tucson (Pima County). In 2017, the county accounted for just 6% of the state's total population (AOEO 2019) but 31% of the state's milk sales. Dairy product manufacturing accounts for 18% of county manufacturing jobs (USDOL BLS 2017). Annual wages per employee are $13,754 per year higher in the dairy manufacturing sector ($66,830 per employee per year) compared to the county average for all manufacturing jobs ($53,076) (USDOL BLS 2017). About 96% of the cattle and calves sold in the county originated from 25 farms, which each have more than 500 head. This reflects the presence of a number of large feedlots in the county (AZDA 2018).

The importance of livestock and dairy production is reflected in Pinal County crop production, where the county ranks in the top 2%, top 3%, and top 6% of counties nationwide for hay and haylage, corn silage, and barley acreage, respectively. The

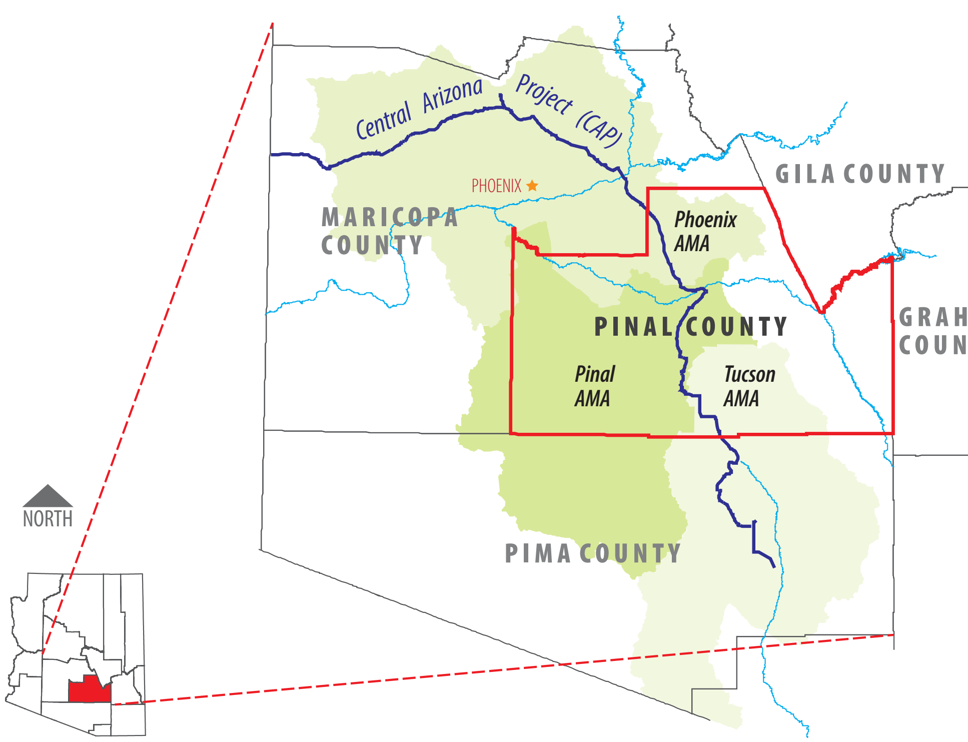



**Figure 1.** Map of Pinal County.

county also ranks in the top 1% of U.S. counties for "other crops and hay" sales, where alfalfa sales dominate (USDA NASS 2019). Meanwhile, in 2017, cotton and cottonseed were the county's top crop in terms of sales, ranking Pinal County in the top 2% of all U.S. counties in cotton and cottonseed sales. Wheat production in the county is primarily durum wheat, a market class of wheat utilized around the world for pasta making (Duval et al. 2016).

With average annual precipitation in Pinal County ranging from only 8 to 10 inches per year, the availability of irrigation water is of utmost importance to crop production (ADWR 2010, 220). Groundwater and surface water from the Colorado River, transported by the Central Arizona Project (CAP) canal, are the primary sources of water for irrigation in Pinal County. Most of Pinal County falls within an Active Management Area (AMA), an area designated by the state through the 1980 Groundwater Management Act to manage, preserve, and protect groundwater supplies. In fact, Pinal County falls within three of the five AMAs in the state, with approximately 42% of county land within the Pinal AMA, 15% within the Phoenix AMA, and 13% within the Tucson AMA. The remaining 29% of land in Pinal County does not fall within an AMA (Figure 1).

Pinal County agriculture is a large water user. Based on data from 2001 to 2005, approximately 96% of the average annual water demand in the Pinal AMA (the largest proportion of Pinal County land) was for agricultural use. In the same period, average annual demand for agricultural irrigation water in the Pinal AMA was supplied through groundwater (439,600 AF or 45%) and from non-groundwater supplies, including surface water, CAP, effluent, spill water, or tailings water (534,900 AF or 55%) (ADWR 2010).

In Pinal County, CAP water plays an important role. CAP water is divided into priority pools, with high priority pools allocated to M&I and Indian water users, and lower priority pools for non-Indian agricultural (NIA) users and the "Ag Pool." The Ag Pool (Agricultural Settlement Pool), created in 2004, offered a pool of excess CAP water (subject to availability) to agricultural water users in Central Arizona at energy-only rates through 2030 (CAP 2016). The Ag Pool supplies a large portion of irrigated agriculture in Central Arizona, most of which is used by non-Indian agriculture and would be the first to be cut in the event of a shortage on the Colorado River (CAP 2016; Lahmers and Eden 2018).

Persistent drought conditions and warming temperatures have increased the likelihood of a shortage on the Colorado River. In 2007, the Lower Basin States (Arizona, California, and Nevada) enacted a shortage sharing agreement, which determined how they would allocate water in the event of a shortage on the Colorado River. They established a tiered system where mandatory cutbacks would occur if Lake Mead dropped to pre-determined elevations. A Tier 1 shortage would be declared on the river if Lake Mead falls to 1,075 feet. The BOR projects that a Tier 1 shortage could occur in 2020, where the state of Arizona, with a low priority water entitlement, would lose 320,000 AF (ADWR and CAP 2018; USBOR 2018) (Figure 2). A Tier 2 shortage would be triggered when Lake Mead reaches 1,050 feet and a Tier 3 shortage would be triggered when Lake Mead reaches 1,025 feet. The BOR projected that a Tier 3 shortage could occur as early as 2023 and would result in a reduction of 480,000 AF for the state of Arizona (ADWR and CAP 2018; USBOR 2018; Western Resource Advocates 2019) (Figure 2).

With Arizona having a low priority water entitlement among other Basin States and many Pinal County and other Central Arizona farmers relying on the Ag Pool and NIA water allocations, farmers in Pinal County would be the first to be affected by a shortage declaration on the Colorado River.

## Modeling Economic Impacts of Water Cutbacks

We begin by presenting two versions of a "rationing model," then illustrate how an I-O model is an extension of the rationing model approach.

### Rationing Models

Rationing models are based on the "putty-clay" production function approach to modeling production relationships (Houthakker 1955; Johanson 1972; Hochman and Zilberman 1978; Moffitt et al. 1978). In economics, a production

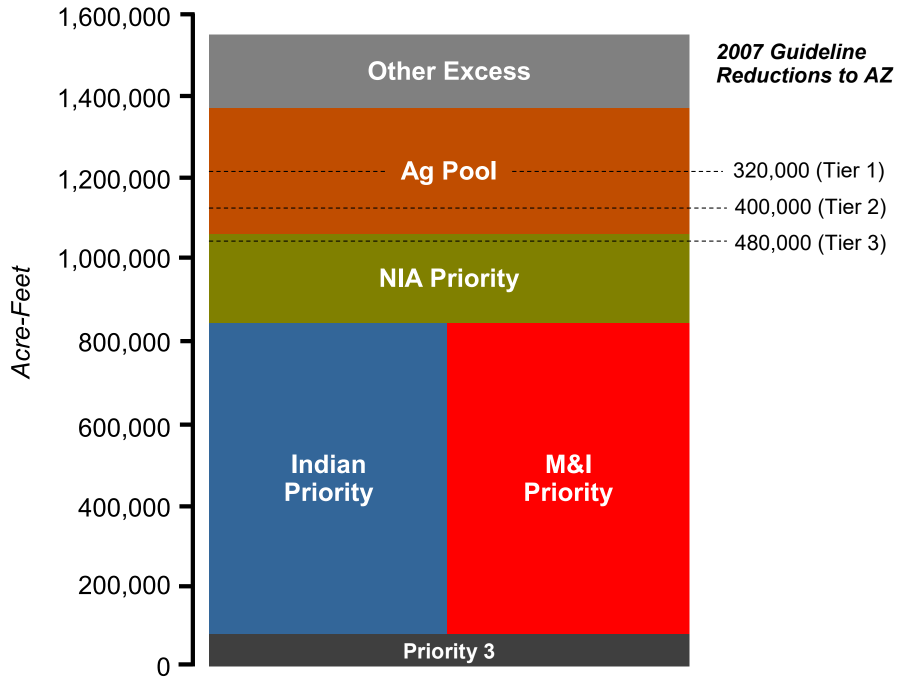



**Figure 2.** Projected impacts to Arizona CAP water allocations due to Colorado River Tier 1, 2, and 3 shortages. Source: Adapted from ADWR and CAP 2018.

function is just a mathematical representation of how much output can be produced as a function of the mix and levels of inputs used. Prior to making investments in new capital equipment and technology or entering into marketing contracts, producers have a certain degree of flexibility in which production processes and practices they can employ. This is the "putty" (flexible) aspect of production relationships. Once producers commit, however, to fixed capital investments in often highly specialized equipment, or to plant particular crops of particular seed varieties, or to enter into marketing agreements with particular buyers, etc., their production decisions are highly limited by these prior choices. This is the hardened "clay" (inflexible) aspect of the production process. So while in the longer-term, producers can choose technologies that use different mixes of inputs, in the short-run they may not be able to substitute between inputs and their ratio of output to inputs will be fixed (Moffitt et al. 1978). Dale and Dixon (1998) argue that the types of responses farmers make to water cutbacks depend on the time frame one considers. Some changes, such as fallowing crops, can be made rapidly. Others, such as shifting cropping (and marketing) patterns or investing in new irrigation technology may be more gradual.

Several studies have applied the putty-clay approach to examine reallocations of water from agricultural production. Based on this approach, Sunding et al. (2002) argue, "[a]t each location, farmers have invested substantial resources in production infrastructure, including equipment for harvesting, packing, and irrigation. As a result, crop mix choices are largely predetermined in the short-run and appropriate for an individual location" (p. 218). Regarding Pinal County, alfalfa production supports large feedlot and dairy industries that in turn supply the Phoenix and Tucson metropolitan areas with a combined population of 5.7 million. In many cases, dairies are also engaged in feed and forage production, much of which cannot be imported economically from outside the region, so their scope to switch away from these crops is limited. For other major Pinal County crops, such as cotton and wheat, producers harvest them using expensive, specialized equipment, so substitution between crops would require large capital investments.

Sunding et al. (2002) appeal to other research on water productivity (Letey et al. 1985; Letey and Dinar 1986) to further argue, "[a]gronomic evidence suggests … a crop should either be irrigated with a certain amount of water, the 'water requirement,' or not irrigated at all[.] […] [W]ater supply reductions […] are likely to be met in the short-run with the only response available to growers: reducing the amount of land cultivated while retaining the existing production technology on the land remaining in production" (p. 219).

Thus, a number of studies have assumed that farmers will respond to water shortages in the short-run by fallowing their crops (Sunding et al. 1994, 2002; Dale and Dixon 1998; USBOR 2007; Frisvold and Konyar 2012). The empirical analysis for Pinal County corresponds to a situation where farmers do not have much time to adjust and therefore represents short-run response to a water cutback. Which crop acreage is fallowed though? Here is where the rationing model gets its name. In an area facing water cutbacks, crops are ranked by gross revenue per AF of water (Rationing Model I) or by net income (profit) per AF of water (Rationing Model II). To adjust to the water shortfall, farmers will fallow acres of the crop that generate the least gross or net returns per AF of water first. If fallowing the acreage of the least valuable crop (per AF of water) is not sufficient to meet the water constraint, farmers move on to the crop with the next lowest returns per AF of water. Farmers continue to fallow crops with higher and higher returns per AF until their water use adjusts to their new, lower supplies.

Rationing Model I assumes growers will respond to water cutbacks by fallowing acreage of crops with the lowest gross revenues per AF of water first, then move on to fallowing crops of increasingly larger revenues per AF, until the water cutback is met. Economic losses are measured in terms of lost gross revenues. This approach has the advantages of having quite modest data requirements, being easy to calculate by non-economists, and providing an impact measure (reduced sales revenues) that is readily understandable by decision-makers. Gross revenues and acreage for major crops are usually available from the USDA, state agricultural departments, or irrigation districts. If one knows water use per acre for crops, it is then straightforward to calculate gross revenues per AF: Revenues per AF of water = [Gross Revenues/Acres] / [Water Use/Acres]. Sunding et al. (1994) argue that a rationing model based on gross revenues rather than profits may be preferable because gross revenues include net revenues plus production costs, especially labor. They note that many field workers in California agriculture may have limited opportunities for alternative employment in other industries so that the lost production "expense" of wages represents lost income to the agricultural labor force in areas facing water cutbacks. Many production expenses, however, are non-labor variable inputs, such as fuel, fertilizer, and pesticides. Fallowing land reduces farm expenditures on these items, so one might question whether reducing such costs constitutes a loss.

Rationing Model II ranks crops by profits per AF of water, fallowing the least profitable crop per AF of water first (Dale and Dixon 1998; USBOR 2007; Frisvold and Konyar 2012). This approach requires data on costs of production in addition to the basic data needed for Rationing Model I. Production costs are often available at the county or state level from crop enterprise budgets published by state Cooperative Extension Service. These budgets are generally crop and region specific, but may not be updated regularly. Production expense data are also available from USDA, Economic Research Service Commodity Cost and Returns data and from the USDA *Census of Agriculture* that is published every five years. USDA budgets are updated more regularly, but may not reflect local production costs for specific crops. These data report labor expenses separately from non-labor expenses. Rationing Model II accounts for the fact that fallowing reduces both gross revenues and expenses. It also measures on-farm income losses from fallowed acreage. Therefore, it provides measures of short-term income losses to two stakeholder groups: farmers and farm workers. Given that data are available, up-to-date, and representative of the production practices in the region, data requirements are still modest and results are easy to calculate and interpret.

Again, Rationing Model II considers short-term responses to surface water shortages. In the longer term, growers could make capital investments, such as developing groundwater resources. In the short-run, however, the existing technology infrastructure may be viewed as a sunk cost that does not affect immediate choices. Because the rationing models implicitly assume individual crops have a constant profitability per acre of land and per AF of water, one obtains the extreme, “corner solutions” common in linear programming. If marginal profitability varies for crops, one may have some crops with lower average profitability continue to be produced. The rationing approach, however, can provide a useful indication of which crops will face relatively larger contractions. For example, Frisvold and Konyar (2012) applied both a water rationing model and a quadratic programming model to examine large-scale water reductions across the Southwestern U.S. The rationing model suggested all cotton, barley, and apple acreage would be taken out of production to meet the water cutback constraint. Meanwhile, the quadratic programming model estimated that cuts to these crops would be less severe (and that production of other crops would also decline). Nonetheless, the three crops identified in the rationing model also had the largest percentage change reductions in production in the programming model. In a study of California grower response to drought, Dale and Dixon (1998) estimated that under a rationing model 100% of the acreage fallowed would be field crops. Using a more sophisticated programming model, field crops accounted for 98% of the acreage reduction, while vegetables accounted for 2%.

**Input-Output Models**

Wassily Leontief was awarded the Nobel Prize in economics for developing I-O models as a means of examining how different sectors in the economy are linked and how changes in demand in one sector affect demands in other sectors (Leontief 1936). The underlying assumptions about technology in I-O models match those of the rationing models. Inputs are used in fixed proportions in production processes, reflecting no input substitution in the short-run. There are fixed ratios of inputs to outputs and prices are fixed in the models. The fixed-price assumption may be reasonable if one is considering smaller regional scales where producers and consumers can be viewed as price-takers. Across small regions, prices may be determined primarily by international or national markets. The fixed price assumption may be less tenable for larger geographical scales (where price-endogenous mathematical programming or CGE models may be more appropriate).

While I-O models share assumptions about technology and prices with rationing models, they consider linkages between different economic sectors in detail. A key feature of I-O models is their capacity to capture indirect and induced multiplier effects. When producers within a local economy buy inputs, they generate additional rounds of spending in that local economy. Input suppliers themselves require inputs, and so on. Initial spending on inputs generates subsequent rounds of input purchases. The effects of these backward linkages in the economy are called indirect multiplier effects. Induced multiplier effects occur when business owners spend their profits and workers spend their salaries on consumer goods and services in the local economy. This demand for goods creates subsequent additional demands for goods and services in the local economy. While some inputs are produced locally, others are “imported” from outside the local area. Spending on goods from outside the area – called “leakage” – represents money leaving the local economy. With each round of local spending, more money leaks out of the local economy, such that the indirect and induced multiplier effects on demand diminish with each round and eventually cease.

Constructing I-O models is substantially more difficult than applying the rationing model approach. First, I-O models require substantial amounts of data on input use, prices, I-O relationships, and spending patterns across multiple sectors of an economy. Once constructed, economic expertise is needed to avoid large errors in model application and interpretation (Coughlin and Mandelbaum 1991; Beattie and Leones 1993; Loomis and Helfand 2001). Today, there are a number of combined database-modeling platforms available to conduct regional economic analyses. Among the most popular are the IMPLAN model (originally produced by the USDA/Forest Service but now supported by a private firm) (IMPLAN 2017), the REMI model supported by Regional Economic Models, and the U.S. Department of Commerce’s RIMS II model (Rickman and Schwer 1995). The present study relies on the IMPLAN modeling platform and data for Pinal County.

IMPLAN reports several effects not accounted for in the rationing models. It measures impacts on the number of jobs in each sector. It measures not only direct impacts on the sectors experiencing change – in our case the Pinal County farms fallowing land – but also effects on other sectors of the Pinal County economy via indirect and induced multiplier effects. IMPLAN also reports effects on value added, which is the local equivalent of Gross Domestic Product (GDP) at the national level. Value added measures the value created by an industry over and above the costs of inputs. At the county level, value added combines net farm income, profits in other industries, employee compensation, and tax revenues. It is thus a summation of economic effects on various stakeholders (farmers, other business owners, farm labor, other labor, and county and state agencies concerned about effects on tax revenues). An understanding of these effects can inform compensation programs that can be used as a strategy to mitigate the economic impacts of fallowing. In California, payments have been made to farmers to fallow land and transfer water to higher-value uses (Akhbari and Smith 2016). Colby et al. (2007) note compensation can not only help avoid conflict, but also offset third party impacts within the local economy. They state that often "[t]he parties most affected by proposed transfers generally are not those who have water to sell, but rather are suppliers of inputs and labor (farm workers) to growers and post-harvest processing enterprises (such as cotton gins)" (p. 10).

Rationing model and I-O approaches complement each other. While direct effects on farming sectors of a water cutback should be similar across models, the I-O model provides more information on jobs, sectors linked to agriculture, and effects on the local tax base. One may use data from Rationing Model II to better calibrate the base IMPLAN model to local production conditions. IMPLAN's I-O coefficients rely on embedded assumptions about input cost shares based on national averages. For agricultural production especially, local production coefficients can be quite different from national averages. Using localized data from Cooperative Extension Service crop enterprise budgets, USDA county-level data, or both, one can more accurately characterize local production technology.

## Hypothetical Agricultural Water Reductions in Pinal County, Arizona

To evaluate economic impacts of agricultural reductions from a Colorado River Shortage Declaration, the BOR followed a rationing model approach to select crops to model water supply shocks in their I-O analysis (USBOR 2007). Crops were ranked from lowest to highest in terms of profits per AF of water and crop acreage with the lowest profits per AF would be fallowed. These acreage reductions were then entered as output reductions in IMPLAN. For Pinal County, the study estimated that the first crop that would drop out of production would be wheat, followed by cotton, then alfalfa hay. One scenario the study considered was the effect of a 400,000 AF cutback to Arizona agriculture in 2017. The BOR did not report how much water would be taken away from each Arizona county, but about two-thirds of the job losses and 70% of the income losses occurred in Pinal County. Recall that under a Tier 1 Colorado River shortage (if Lake Mead's elevation falls below 1,075 feet), Arizona's CAP would lose 320,000 AF of surface water, primarily used by Central Arizona agriculture. Under a Tier 2 shortage (Lake Mead elevation 1,050 feet) the cutback would be 400,000 AF.

The present analysis considers the impact of a hypothetical 300,000 AF reduction in Pinal County's agricultural surface water supplies for the calendar year 2017. Under the recently approved Arizona DCP, Arizona would lose 192,000 AF if Lake Mead falls below 1,090 feet and 592,000 AF if Lake Mead falls below 1,075 feet (McGinnis 2019).

Using readily available, county-level data on acreage and yield and state-level commodity price and water application rate data (USDA NASS 2014, 2017), Rationing Model I identifies wheat as the crop with the lowest gross revenues per AF (Table 1), therefore wheat acreage will be fallowed first. Even if 100% of wheat acreage is fallowed, that does not reduce water use by 300,000 AF, so alfalfa acreage is fallowed next. In 2017 alfalfa gross revenues per AF were slightly lower than for cotton. According to Rationing Model I, 100% of county wheat acreage and 62% of county alfalfa acreage is fallowed (Table 3). Under Rationing

**Table 1.** Gross revenues per acre-foot of water for major Pinal County crops, 2017.

| | Wheat | Alfalfa | Cotton/Cottonseed | |
|---|---|---|---|---|
| AZ water application rate, gravity (2014) | 3.3 acre-feet/acre | 5.5 acre-feet/acre | 4.6 acre-feet/acre | |
| Pinal County average yield (2017) | 103.9 bushels/acre | 8.45 tons/acre | 1,434 lbs./acre | 1.07 tons/acre |
| AZ average price (2017) | $7.06/bushel | $172/ton | $0.73/lb. | $183/ton |
| Gross revenues/AF | $222.28 | $264.25 | $269.15 | |

Note: Calculations by authors.
Source: USDA NASS 2014; USDA NASS 2017.

**Table 2.** Net returns per acre-foot of water for major Pinal County crops, 2017.

| | Wheat | Alfalfa | Cotton/Cottonseed |
|---|---|---|---|
| AZ water application rate, gravity (2014) | 3.3 acre-feet/acre | 5.5 acre-feet/acre | 4.6 acre-feet/acre |
| Gross revenues/Acre | $733.53 | $1,453.40 | $1,238.10 |
| Cash costs/Acre | $534.35 | $941.81 | $1,201.66 |
| Net returns/AF | $60.36 | $93.02 | $7.92 |

Note: Calculations by authors.
Source: University of Arizona Cooperative Extension 2011; USDA NASS 2014; USDA NASS 2017.

Model II, when costs of production are taken into account, cotton becomes the first crop fallowed as it is the crop with the lowest net returns per AF in 2017 (Table 2). Cotton acreage in Pinal County in 2017 is sufficient to reduce water use by 300,000 AF, and is therefore the only crop fallowed. According to Rationing Model II, approximately 75% of county cotton acreage is fallowed (Table 3). The I-O model builds upon Rationing Model II to examine the impacts of land fallowing on the Pinal County economy. Using estimated reductions in labor and non-labor cotton production expenses from Rationing Model II, the effects of farmers and farm workers earning and spending less of their income on consumer goods and services and farmers purchasing fewer inputs are modeled. These are modeled in IMPLAN through a labor income change and customized cotton industry spending pattern. The cotton industry spending pattern was calibrated using local, inflation-adjusted data from Cooperative Extension crop enterprise budgets and the USDA Prices Paid Index (University of Arizona Cooperative Extension 2011; USDA NASS 2017) to better capture the magnitude and distribution of impacts among Pinal County sectors that supply farm inputs. Of particular importance was the input cost share for irrigation water, where Arizona's production coefficient was calculated higher than national average IMPLAN production coefficients (which are inclusive of dryland agriculture).

**Table 3.** Effects of 300,000 acre-foot water reductions to Pinal County agriculture, 2017. (Numbers reported are losses. Dollar values are in millions.)

| | Rationing Model I | Rationing Model II | Input-Output Model |
|---|---|---|---|
| *First Crop Fallowed* | Wheat | Cotton | Cotton |
| Acreage Fallowed | 19,300 | 65,217 | 65,217 |
| % of Pinal County Acreage in Crop | 100% | 75% | 75% |
| *Second Crop Fallowed* | Alfalfa | | |
| Acreage Fallowed | 42,965 | | |
| % of Pinal County Acreage in Crop | 62% | | |
| **Direct On-Farm Effects:** | | | |
| *Gross Revenues (Total)* | $76.6 | $80.7 | $80.7 |
| Wheat | $14.2 | $0.0 | $0.0 |
| Cotton | $0.0 | $80.7 | $80.7 |
| Alfalfa | $62.4 | $0.0 | $0.0 |
| *Production Expenses (Total)* | | $78.4 | |
| Labor Expenses | | $9.5 | |
| Non-Labor Expenses | | $68.8 | $68.8 |
| *On-Farm Income* | | $11.9 | $11.9 |
| [a] Farmer Income | | $2.4 | $2.4 |
| Farm Worker Income | | $9.5 | $9.5 |
| [b] *Farm Jobs* | | | 209 |
| **Indirect & Induced Effects:** | | | |
| *Value Added* | | | $18.8 |
| [c] Business-Owner Income | | | $8.8 |
| Employee Income | | | $9.0 |
| Net Taxes | | | $1.1 |
| *Jobs* | | | 239 |
| **Total Effects:** | | | |
| *Value Added* | | | $30.7 |
| Farmer and Business-Owner Income | | | $11.1 |
| Farm Worker and Non-Farm Employee Income | | | $18.5 |
| Net Taxes | | | $1.1 |
| *Total Jobs* | | | 448 |

Note: Calculations by authors. Figures may not add due to rounding.
Source: University of Arizona Cooperative Extension 2011; USDA NASS 2014; IMPLAN 2017; USDA NASS 2017.
[a] Farmer Income = Gross Revenues - Production Expenses
[b] Farm Jobs = On-farm hired workers (does not include proprietors)
[c] Business-Owner Income = Proprietors Income + Other Property Type Income

**Comparing Model Results**

Under Rationing Model I, wheat and alfalfa acreage are fallowed to reduce water use by 300,000 AF. Total gross revenue reductions in 2017 are an estimated $76.6 million, with $14.2 million less in wheat sales and $62.4 million less in alfalfa sales (Table 3).

Rationing Model II builds upon Rationing Model I and incorporates more detailed, regional information about costs of production in Pinal County and selects crops to fallow based on net income per AF instead of gross revenues per AF. Rationing Model II identifies cotton as the crop to be fallowed in 2017 and estimates total gross cotton revenue reductions of $80.7 million. While gross revenue reductions between Rationing Model I and Rationing Model II are similar, Rationing Model II identifies a different crop to be fallowed. It also accounts for the fact that while fallowing reduces gross revenues by $80.7 million, it also reduces total production expenses by $78.4 million (Table 3). Reduced production expenses come in the form of reduced costs for labor ($9.5 million) as well as reduced costs for production inputs and operation ($68.8 million). Accounting for both revenue reductions and reduced costs associated with fallowing, net income losses to farmers are an estimated $2.4 million (Table 3). Rationing Model II improves upon Rationing Model I by providing estimates of the impacts of crop fallowing on farmer and farm worker income. While the farmer realizes reduced labor costs of $9.5 million, farm workers, conversely, realize $9.5 million less in wages and compensation. Under the Rationing Model II approach, short-term income losses are more severe for farm workers than for farmers.

The I-O model builds upon Rationing Model II to examine the impacts of fallowing on the broader Pinal County economy. Given results from Rationing Model II, direct losses to farmers and farm workers are an estimated $11.9 million in income. Using average wage data for cotton farming in Pinal County from the U.S. Department of Labor Bureau of Labor Statistics (2017) and the IMPLAN (2017) conversion rate to income (wages, salaries, and benefits), cotton farm worker income losses of $9.5 million would be equivalent to 209 farm jobs (Table 3). The I-O model also accounts for effects on other sectors of the Pinal County economy that result from farmers purchasing fewer inputs (indirect effects) and farmers and farm workers earning and spending less income on consumer goods and services (induced effects). Impacts to Pinal County due to indirect and induced multiplier effects are an estimated $17.8 million less in income in non-agricultural sectors and $1.1 million less in tax revenues, for a total value added impact of $18.8 million and 239 fewer jobs. Income losses of $17.8 million in non-agricultural sectors are higher than on-farm income losses of $11.9 million.

This distribution of impacts raises questions for compensation programs that aim to mitigate the economic losses of fallowing. While financial compensation paid to farmers will help mitigate farmers' losses, it is unlikely that they would reach farm workers or workers in other sectors, possibly leading to disparate impacts on Pinal County residents. A limitation of the I-O model, however, is that it captures immediate, short-run effects. Over time, job and income losses will diminish as some displaced labor will find work in other sectors in Pinal County, mitigating the impacts. Other workers, however, may move out of Pinal County seeking employment elsewhere.

The total economic impacts (direct, indirect, and induced) of a 300,000 AF water reduction to Pinal County agriculture in 2017 are an estimated $30.7 million in reduced value added and 448 fewer jobs (Table 3). Hired workers, for both agriculture and non-agriculture, have income losses of $18.5 million and business-owners (including farmers) have income losses of $11.1 million. Reduced sales in non-agricultural industries, from fewer inputs purchased and fewer farm workers purchasing household goods and services, also reduce tax revenues. Net tax revenue impacts are an estimated loss of $1.1 million.

Comparing results across the three models (Table 3), consider the gross revenue impacts – the main impacts from Rationing Model I. Losses in gross revenues are not particularly close approximations of reduced farm profits (that would be called producer surplus in standard welfare economics). Nor are losses in revenues close to income losses to business-owners (farm and non-farm) and workers (farm and non-farm). Thus, Rationing Model I greatly overstates losses in terms of economic welfare measures or payoff-to-interest-group measures. Furthermore, direct on-farm income losses are lower than income losses in non-agricultural sectors.

Perhaps a more useful way to present the results above is by presenting the losses per AF of water reduced (Howe and Goemans 2003). Using this metric to describe losses allows for a better understanding of the value of water for all aspects of agricultural production. For example, on a per AF basis, direct reductions to farmer income from fallowing cotton acreage equivalent to a 300,000 AF water reduction amount to about $8 per AF (Table 4). Considering the wider impacts to the Pinal County economy (total including multiplier effects), regional value added losses amount to about $102 per AF.

Estimates of losses per AF can provide important information to water planners, agricultural stakeholder groups, county governments, and the general public about the value that would be required to mitigate the economic losses of fallowing. In other words, if farmers were to be compensated for fallowing cotton acreage of this magnitude, compensation would need to be at least $8 per AF to offset farmer income losses. At the regional level, compensation would need to be at least $102 per AF to offset county valued added losses.

While designing compensation schemes for non-farm losses from fallowing can be daunting, such schemes are not without precedent. A water transfer agreement between the Metropolitan Water District (MWD) in Southern California and the Palo Verde Irrigation and Drainage District established a Mitigation Plan and Community Improvement Board to address job losses resulting from a rotational land fallowing program (Taylor and MacIlroy 2015). MWD provided funds for a $6 million endowment to the Palo Verde Valley Community Improvement Fund. The Fund has loaned $6.25 million to local businesses and provided $1.2 in grants to non-profit organizations (PVVCIF 2019). To qualify for loans, borrowers must demonstrate how loans will be used to maintain existing jobs or create new ones. Grants target workforce development. In another case, as part of a water transfer agreement between Imperial Irrigation District and the San Diego County Water Authority, a Local Entity was established to compensate farm input and service providers losing sales from land fallowing. Since 2003, the Local Entity has distributed $14.5 million to these businesses while a competitive grants program supporting local economic development projects has awarded $2.9 million to Imperial County organizations (IID 2019).

## Sensitivity Analysis: Importance of Modeling Assumptions

An important consideration for examining the impacts of fallowing on farmers, farm workers, and the local economy is how price, yield, and acreage assumptions affect model results. Farm-level decisions to plant acreage are, in part, in response to expected prices, costs, and returns. In some instances, fallowing might occur regardless of water supply cutbacks, or the incentives to fallow one crop versus another might shift. Regional economic impacts attributable to shortage depend partially on the net change in acreage resulting from water cutbacks. Whereas in this analysis, based on 2017 data, cotton is assumed to be fallowed, there may be years where fallowing wheat or alfalfa could be more advantageous to producers, with different implications for the regional economy.

With this in mind, this study presents a comparison of the crops fallowed using the Rationing Model I and Rationing Model II approaches based on production data for 2015, 2016, and 2017 (Figure 3). When crops are ranked and fallowed by the lowest gross revenues per AF (Rationing Model I), wheat and alfalfa acreage are fallowed in two of the three years, with wheat acreage fallowed first in 2016 and 2017. In 2015, wheat acreage is not fallowed in part due to relatively high wheat prices. When crops are ranked and fallowed by the lowest net income (profit) per AF (Rationing Model II), cotton acreage is fallowed first in all three years. While cotton acreage accounts for all fallowed agricultural land in 2016 and 2017, in 2015 there was not enough cotton acreage in Pinal County to meet the 300,000 AF water cutback. In that year, both cotton and alfalfa acreage are fallowed. While total revenue losses are relatively consistent under the Rationing Model II approach, on-farm income losses, in particular farmer income losses, vary

**Table 4.** Effects of 300,000 acre-foot water reductions to Pinal County agriculture, 2017. (Numbers reported are losses per acre-foot of water reduced.)

| | **Input-Output Model Results** |
|---|---|
| **Direct On-Farm Effects:** | |
| *Gross Revenues* | $269.15 |
| *Production Expenses* | $261.23 |
| Labor Expenses | $31.77 |
| Non-Labor Expenses | $229.46 |
| *On-Farm Income* | $39.69 |
| [a] Farmer Income | $7.92 |
| Farm Worker Income | $31.77 |
| **Indirect & Induced Effects:** | |
| *Value Added* | $62.79 |
| [b] Business-Owner Income | $29.18 |
| Employee Income | $30.02 |
| Net Taxes | $3.58 |
| **Total Effects:** | |
| *Value Added* | $102.48 |
| Farmer and Business-Owner Income | $37.10 |
| Farm Worker and Non-Farm Employee Income | $61.79 |
| Net Taxes | $3.58 |

Note: Calculations by authors. Figures may not add due to rounding.
Source: University of Arizona Cooperative Extension 2011; USDA NASS 2014; IMPLAN 2017; USDA NASS 2017.
[a] Farmer Income = Gross Revenues – Production Expenses
[b] Business-Owner Income = Proprietors Income + Other Property Type Income

significantly from year to year, ranging from $2.4 million to more than $10.0 million (Figure 4). Income losses to farmers per AF of water reduced range from $7.92/AF at 2017 prices, to $20.89/AF at 2016 prices, to $35.82/AF at 2015 prices. Lost income to farm workers range from $31.77/AF at 2017 prices, to $31.19/AF at 2016 prices, to $31.80/AF at 2015 prices. The BOR's analysis of fallowing losses in response to a Colorado River Shortage Declaration (USBOR 2007) did not consider effects of changes in crop prices or yields. Results presented here suggest that the annual costs of fallowing to farmers can fluctuate significantly from year to year.

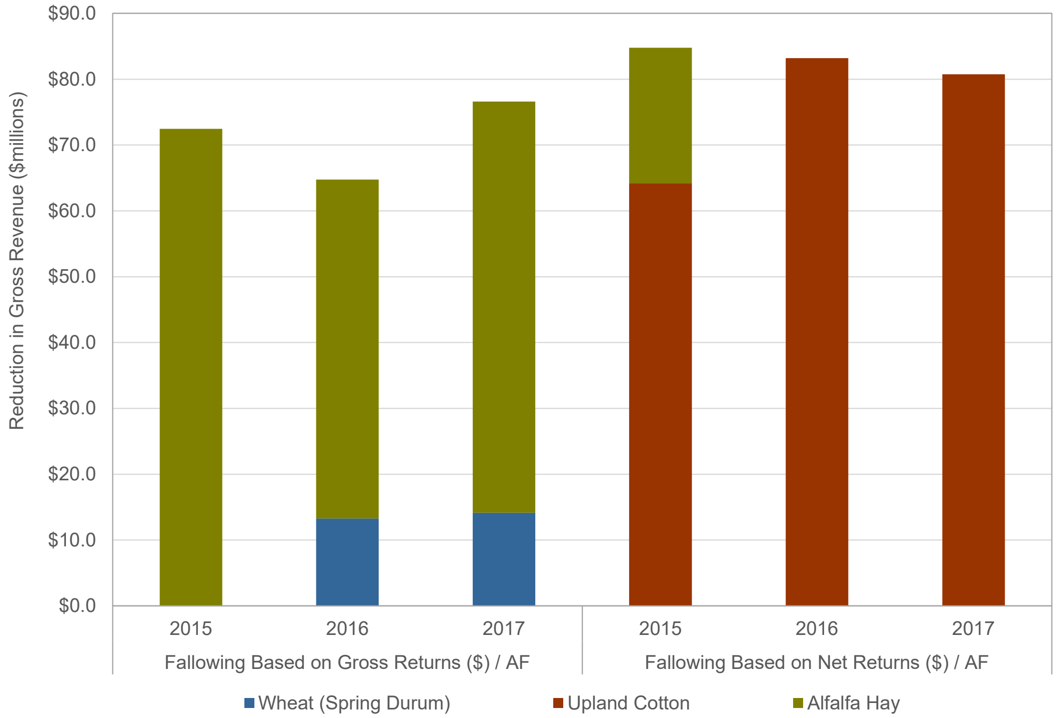
## Limitations, Future Research, and Conclusions

One limitation of this analysis is that, although intuitive, fallowing all crop acreage in order of gross revenues per AF or net returns per AF does not account for the realities and complexities of farm-level planting decisions and the resulting incentives to fallow or not fallow crop acreage. Farmers often grow multiple crops and planting decisions are made in light of this multi-crop system, capital investments, and crop commodity payments, among other factors. As mentioned previously, in some instances, fallowing might occur regardless of water supply cutbacks, or the incentives to fallow one crop over another might shift. These shifts in crop production can have different implications for the regional economy.

An extension of this is the potential for impacts on regional livestock feed markets in the case of large-scale alfalfa fallowing. In addition to potential price effects impacting dairy producers, there could be downstream effects to dairy manufacturers, retailers, and consumers of dairy products resulting from any major increases in feed prices. While this model assumes that for small regions, prices are determined primarily by international or national markets, the markets for particular livestock feed crops such as alfalfa or corn silage are typically regional due to high transportation costs. The fixed price assumption may underestimate negative impacts to users of livestock feed crops within the region and those indirectly impacted, as well as any potential positive impacts to alfalfa producers that do not fallow and receive higher prices due to reduced regional supplies.

Farmers can also respond to a water cutback by making planting decisions at the extensive and intensive margins. The simplest case, as modeled here, is to adjust total production by reducing crop acreage. Farmers could also adjust at the extensive margin by shifting some of their acreage to a less-water-intensive crop, thereby using less water and maintaining profits from that acreage. Finally, farmers could adjust at the intensive margin and utilize a practice called deficit irrigation. Deficit irrigation reduces irrigation water use by limiting irrigation to certain times during plant development, meanwhile maintaining a sustainable level of crop water stress and yield reductions. This practice allows farmers to continue growing their customary crops, albeit at lower yields, therefore mitigating full revenue losses resulting from crop fallowing (Colby et al. 2014). Some crops are more amenable to deficit irrigation than others, but if the timing is selected correctly, deficit irrigation is feasible for cotton, wheat, and alfalfa acreage (Kirda 2002; Ottman and Putnam 2017).

Finally, a major assumption of this analysis is that farmers elect to fallow their fields as opposed to shifting to groundwater irrigation. Shifting to groundwater pumping is a viable strategy for many Pinal County producers to offset reductions in surface water deliveries, either in the short- or medium-term. That said, investing in or recommissioning wells and pumps, as well as operating them, changes cost structures for producers, and once again may affect the returns of different crops relative to one another. In the case that producers do shift to groundwater, regional economic impacts could be moderated, and in fact, investment in wells and associated infrastructure could inject money into the local economy, particularly if producers receive outside funds to support well development. In the long term, however, there may be serious implications of this strategy on groundwater supplies, and producers relying on groundwater may be forced to dig deeper wells, incur infrastructure damages due to land subsidence, and future aquifer storage capacity may be impacted. Future research could examine farmers' decisions to fallow or transition to groundwater pumping in the face of irrigation




Sources: Calculations by authors; University of Arizona Cooperative Extension 2011; USDA NASS 2014; USDA NASS 2017.

**Figure 3.** Individual crop and total gross revenue losses under different rationing rules and year prices.


Sources: Calculations by authors; University of Arizona Cooperative Extension 2011; USDA NASS 2014; USDA NASS 2017.

**Figure 4.** On-farm income effects under Rationing Model II and different year prices.

water cutbacks in order to assess short-, medium-, and long-term impacts of large-scale irrigation water supply reductions.

Data, cost, and time limitations coupled with the complexities of farmers' responses to changes in agricultural water supplies pose challenges to estimating the local economic impacts of water reallocations from agriculture. More sophisticated models that account for uncertainty, capital investment, and farmers' adjustments to water cutbacks (such as substituting between inputs, shifting crops, practicing deficit irrigation, or investing in groundwater pumping infrastructure) are available and demonstrate that the costs of water reductions can be quite a bit smaller than estimated by rationing or I-O models. However, many county governments and local farm groups do not have the access or expertise to utilize the models. Although there are limitations to the models illustrated in this study, they can provide a useful starting point for community discussion, particularly when farmers have limited time or scope to adjust technologically to water shortages. This study demonstrates how these models can be used to address basic policy questions when faced with water shortages. First, how might growers respond in the short-run to a specific cutback in water supplies? Second, how would reductions in agricultural production affect non-agricultural industries in the local area? We argue that the approaches demonstrated here are useful methods to obtain rapid and low-cost answers to such specific questions.

Though the information we draw on for these models is low-cost and relatively easy to implement, it bears mentioning that access to timely, region-specific, accurate, and publicly available data is of critical importance to this type of analysis. Even basic modeling techniques require quality data and, when that data is not available, the potential for misallocation of resources increases. Continued or increased financial support for the systematic collection of agricultural data will be critical as water resources become scarcer.

Using relatively low-cost, publicly available data, water planners in Arizona and other states within the Colorado River Basin can use the basic modeling techniques presented in this article to derive rough estimates and provide a range of the potential economic impacts of fallowing for their region, including secondary impacts to the local economy. These approaches also allow for consideration of the distributional impacts, including income losses to farm workers and other non-farm business-owners and workers. A greater understanding of these potential disparate impacts can help inform strategies to mitigate and offset direct and indirect economic losses due to fallowing, helping to alleviate resistance at the local level. With limited water supplies, growing water demands, and an anticipated and imminent shortage declaration on the Colorado River, information that is expedient and easy to interpret is essential and provides a useful starting point for community discourse.

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