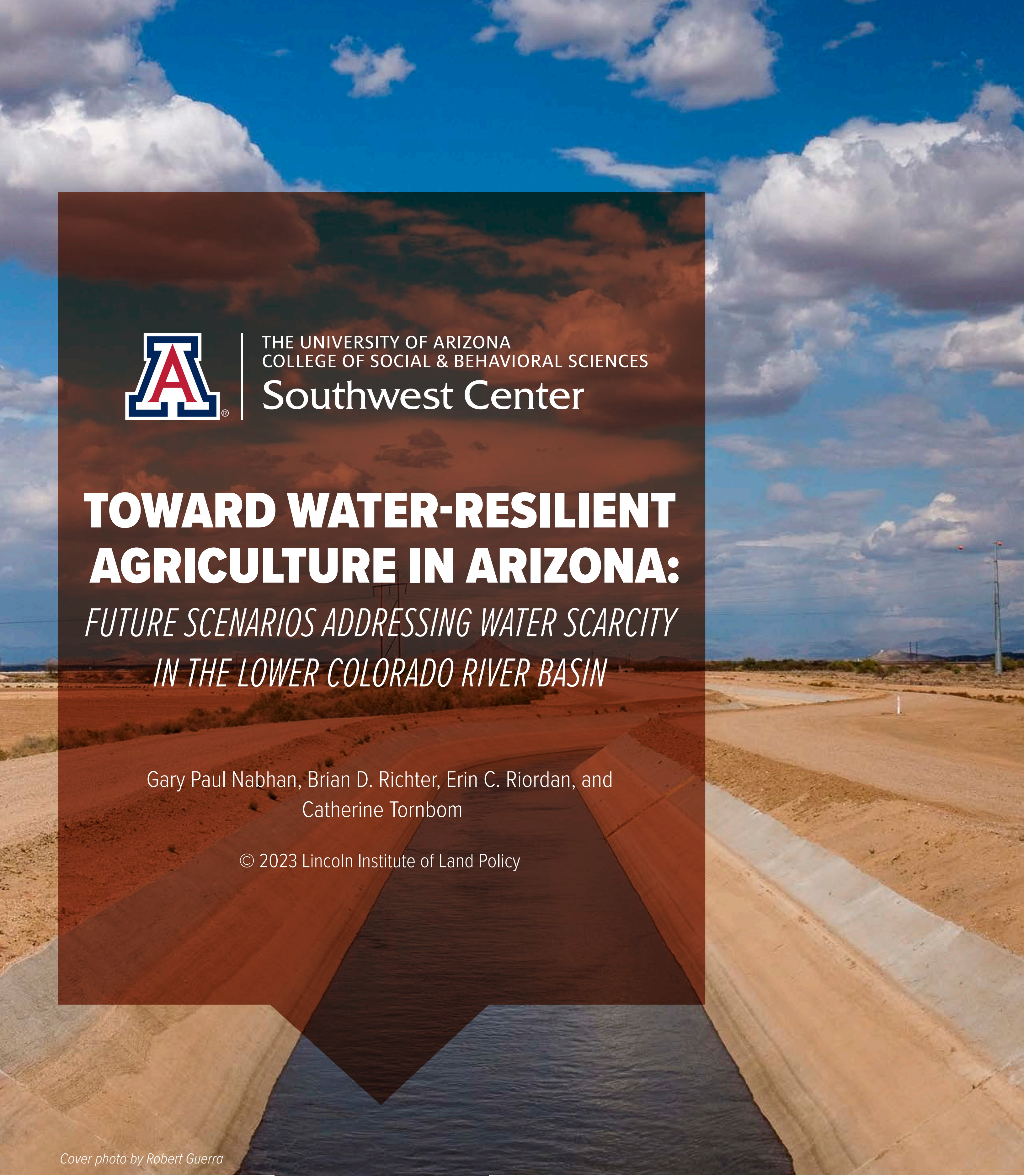

THE UNIVERSITY OF ARIZONA
COLLEGE OF SOCIAL & BEHAVIORAL SCIENCES
Southwest Center

TOWARD WATER-RESILIENT AGRICULTURE IN ARIZONA:

FUTURE SCENARIOS ADDRESSING WATER SCARCITY IN THE LOWER COLORADO RIVER BASIN

Gary Paul Nabhan, Brian D. Richter, Erin C. Riordan, and Catherine Tornbom

Cover photo by Robert Guerra

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For further in-state discussion of the paper with Arizona participants, contact Gary Pasul Nabhan at gpnabhan@arizona.edu to gain help reaching, inviting or dialoguing with them in person or by zoom.

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Solutions in a Time of Scarcity

Pinal County sluice gate with adjacent fallowed fields. Photo by Gary Nabhan.

Abstract

Arizona farms dependent on irrigation allocations from the Lower Colorado River are facing their worst water crisis in history. Climate change has reduced surface water available for irrigating crops, while increasing evapotranspiration rates. Beginning in January 2022 and running through at least December 2023, water rationing mandated by the federal government has reduced Arizona's allocation from the Colorado River by up to 592,000-acre-feet, a 21 percent reduction in water supply. These reductions are primarily impacting agricultural users in Pinal, Maricopa, and Pima counties dependent on Colorado River water for irrigation. Facing the prospect of even more severe shortages in coming decades due to climate change, farmers will need to adapt, using a variety of strategies and practices. To help facilitate dialogue about potential adaptations, the University of Arizona's Southwest Center conducted a farmer-focused questionnaire survey followed by an in-person retreat. The Center sent out 100 questionnaires to farmers, ranchers, water policy experts, agroecologists, food systems analysts, conservation agriculture scholars and farmland preservation professionals in August 2022. In September 2022, the Center hosted a retreat for 13 participants at Biosphere 2 to 1) develop scenarios for water-resilient agriculture; 2) identify factors that would assist or resist their adoption; 3) suggest case studies of on-farm climate adaptation; and 4) identify gaps in knowledge. This report also outlines sources of technical, legal, and financial support available to help farmers adapt to an evolving climate and water availability in Arizona.

Keywords: agriculture, Arizona, climate change, Colorado River Basin, drought, irrigation, resilience, scenario planning, water, water scarcity

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TOWARD WATER-RESILIENT AGRICULTURE IN ARIZONA:

FUTURE SCENARIOS ADDRESSING WATER SCARCITY IN THE LOWER COLORADO RIVER BASIN

EXECUTIVE SUMMARY

This report is intended to help Arizona farmers and ranchers who depend on irrigation allocations from the Lower Colorado River deal with the state's worst water crisis in history. Long-term climate change has reduced and will continue to lessen the quantity and reliability of surface water available for irrigating crops. Beginning in January 2022 and running through at least December 2023, water rationing mandated by the federal government has reduced Arizona's allocation from the Colorado River by up to 592,000-acre-feet, a 21 percent reduction in water supply. These reductions are primarily impacting private and tribal farms in Pinal, Maricopa, and Pima Counties dependent on surface water for irrigation.

At the same time, declining aquifers, rising temperatures, increasing evapotranspiration rates, and salinization of soils are exacerbating the water scarcity dilemma for many Arizona farmers and ranchers, whether or not they depend on irrigation allocations from the Lower Colorado River. These water challenges make it increasingly difficult to grow the same crops, or use the same irrigation practices that have come to dominate agriculture in the Desert Southwest since the construction of dams and installation of high-capacity wells beginning more than a century ago. Facing the prospect of even more severe water shortages in coming decades due to climate change, many farmers will need assistance to adapt to these impending conditions most cost-effectively, while still producing a year-round food supply.

To facilitate dialogue about potential adaptations, the University of Arizona's Southwest Center conducted a farmer-focused questionnaire survey followed by an in-person retreat. In August 2022, the Center sent out 100 questionnaires to farmers, ranchers, water policy experts, agroecologists, food systems analysts, conservation agriculture scholars, and farmland preservation professionals. The Center then hosted a retreat for 13 participants at Biosphere 2 in September 2022 with support from the Babbitt Center of the Lincoln Institute and the W.K. Kellogg

Water Certainty for the Colorado River Basin. *Compensating farmers to use less water while staying productive, adjusting allocations on a rolling basis based on hydrological conditions, and a basin-wide, limited market for agricultural water users that facilitates movement of water to areas of optimal agricultural production while compensating farmers giving up water used for low margin crops.*

- More sustainable water supply for high-value agricultural production
- Funding stream for agricultural water efficiencies
- Resilient rural economies that would otherwise be devastated by fallowing of cropland
- Improved water security for the 40 million people who depend on the Colorado River system

Holistic Agriculture and Watershed Management. *Considering hydrologic and landscape connections between watershed uplands and lowlands while incentivizing on-farm transitions to more sustainable, regenerative-centered agricultural practices.*

- Improved watershed health and balanced ecosystem function
- Improved air and water quality
- Managed flood waters and well-maintained working landscapes
- Economic benefits to both rural communities and big cities
- More local, nutrient-dense food choices for consumers

Restored biocultural value on fallowed farmland. *Establishing vegetation cover on fallowed agricultural lands through low water agricultural practices (e.g., desert agroforestry, agrivoltaics) or habitat restoration.*

- Mitigate lost land value and rural livelihoods while safeguarding future agricultural potential
- Vegetation cover reduces dust and improves air and water quality
- Job creation supports rural economies
- Diversified farmer revenue streams (agrivoltaics, desert agroforestry)
- Habitat for wildlife and improved ecosystem function (habitat restoration)

Endowment at the University of Arizona.
Retreat participants explored innovative solutions to water scarcity and uncertainty that could benefit Arizona farmers, ranchers, farmworkers, and consumers while balancing environmental water needs. During the retreat, participants: 1) developed scenarios for water-resilient agriculture; 2) identified factors that would assist or resist their adoption; 3) suggested case studies of on-farm climate adaptation; and 4) identified gaps in knowledge.

This report highlights three possible scenarios to restore health, productivity, and resilience to Arizona's lands, waters, and communities that can be implemented at the scale of individual field, entire farm scape, rural community, watershed, or entire Colorado River basin. This report also outlines sources of technical, legal, and financial support available to help farmers adapt to an evolving climate and water availability in Arizona.

In general, farmers will require assistance in transitioning to reduce the costs of water and energy inputs to crop production, but will also need assistance in marketing their harvests or the value-added products derived from them to increase their income per acre. Fortunately, in December 2022 the University of Arizona and three non-profits received a $4.7 million grant from the USDA that will help farmers throughout the state to more rapidly implement climate-friendly solutions that can reduce their input costs, while helping promote value-added products in markets to enhance their income. Additionally, University of Arizona President Robbins announced the formation of the Presidential Advisory Commission on the Future of Agriculture and Food Production in a Drying Climate, charged with suggesting actions to bring the varied and many resources of the university to bear on keeping agriculture productive even in the face of less water.

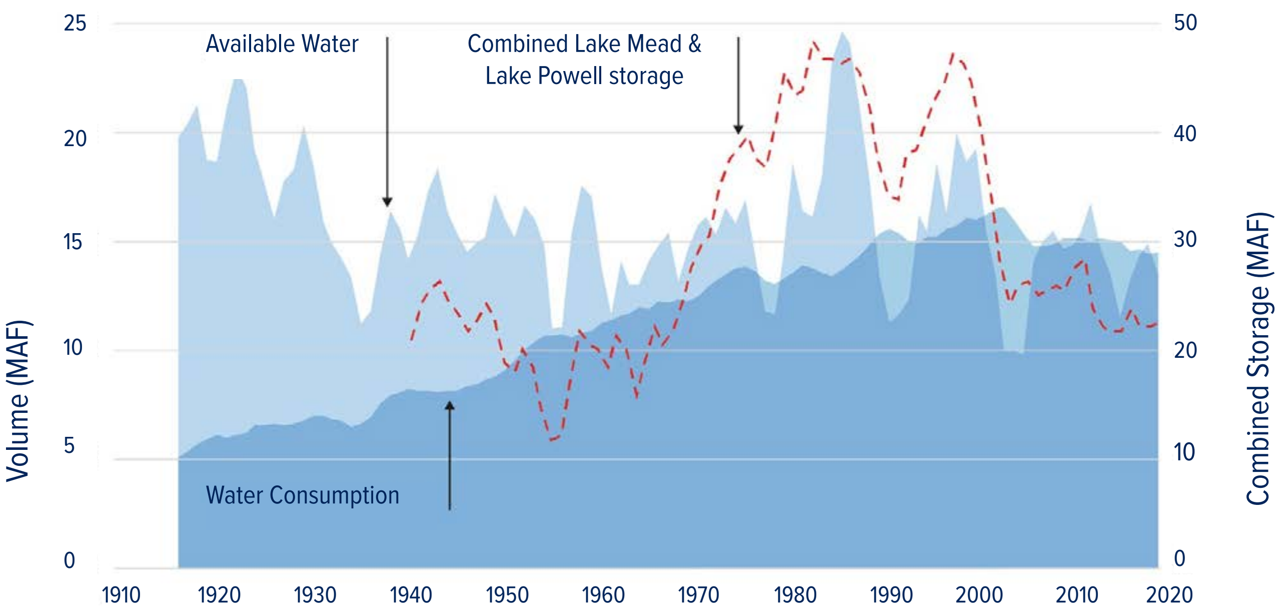
INTRODUCTION

At the end of 1999, Lake Mead and Lake Powell on the Colorado River—the two largest water-storage reservoirs in America—were both nearly full. But the new millennium brought an abrupt shift in climate and the past 22 years are now recognized as the driest 'mega-drought' in at least 1,200 years (Williams, Cook, and Smerdon 2022).

The natural annual replenishment of the river from snow melt and rain has, in recent decades, been 20 percent lower than the past century's average. Unfortunately, use of the river for urban and agricultural water supplies and other purposes has not decreased to a commensurate degree. In 18 of the last 23 years, the volume of water consumed has exceeded the river's natural replenishment (Fig. 1). This repeated overuse has been accommodated by depleting the water stored in Lake Mead and Lake Powell, which stood three-quarters empty at the end of 2022.

In an effort to stabilize reservoir levels, water managers in state and federal agencies have imposed a schedule of mandatory curtailments of water deliveries from Lake Mead that become more severe with lower reservoir levels. In 2022, Arizona's allocation of river water was decreased by 18 percent (512,000-acre-feet or AF), but Lake Mead continued to shrink. In 2023, Arizona will lose 21 percent of its allocation (592,000 AF) (Krol 2022), primarily affecting agriculture, which uses over 70 percent of the state's water supply (ADWR 2022).

Figure 1. Colorado River flows and consumptive use in million acre-feet (MAF). *Data Source: U.S.Bureau of Reclamation*



In Pinal County, where rationing of Colorado River water allocations has been the most severe, irrigated farms suffered an 87% reduction in surface water allotments from one year to the next through 2022. In 2023, through negotiated agreements, Pinal County farmers will receive just 5% of what they were allotted in 2021, but that has forced many of them to rely almost exclusively on groundwater pumping for their irrigation needs.

The economic impact of these water cutbacks will be profound. Farmers in several counties—Pinal, Maricopa, and Pima—have already lost a considerable portion of their surface water allocations. For Pinal County, a 300,000 AF cutback in 2023 could require fallowing or retiring between 54,000 and 71,000 acres, depending on the mix of crops on the acreage, leading to potential losses of up to $66.7 million in gross farm-gate sales and $104 million in the county economy as a whole (Bickel, Duval, and Frisvold 2018; based on 2016 data). Farmers in Pinal County have already fallowed about 57,000 acres—25 percent of the county's 228,000 irrigable field acres—and have taken steps to leave more than half their total irrigated field acreage (roughly 117,000 acres) unplanted in 2023 (Paul Orme cited by Allhands 2022). As many as 1,000 rural jobs have already been lost in the county (Nabhan 2021). As farm equipment, fertilizer, and pesticide sales in Central Arizona lose a significant part of their markets, the longer-term costs to the Arizona economy will be far greater (Samar 2019).

Climate warming is increasing rates of evaporation, transpiration, and salinization on farmland, all of which require increased water use to maintain yields. When faced with shortages from surface water sources, farmers often turn toward increased groundwater pumping. However, groundwater levels across the state are declining (Ferris and Porter 2021). Simply shifting to already-depleted aquifers for costly pumping of groundwater has its own challenges and will not ensure a viable or sustainable agricultural future for the region.

Many farmers will need to (or have begun to) reduce their water use. This may include temporarily fallowing croplands; permanently retiring farmlands and selling them to land developers or other interested parties; shifting agricultural practices, crop mixtures, densities, or planting or harvesting times to reduce irrigation applications; improving irrigation technologies and efficiencies; improving soil health; developing other revenue streams for income off the same land, such as through installation of solar farms; relying more heavily on government subsidies, crop insurance, or other forms of disaster relief and transition support; or some combination of the above and other responses.

This report highlights several possible scenarios to enhance water-resilience of Arizona agriculture at the scales of 1) field, orchard, or pasture; 2) entire farm-scape properties; 3) rural farm community; and 4) watershed, region, or state. It explores on-ground solutions to restore health, productivity, and resilience to Arizona's lands, waters, and communities.

PROFILE OF ARIZONA AGRICULTURE

Wintertime lettuce farming with furrow irrigation in Yuma County provides the US consumers with a large portion of their cool season sale greens. Photo by Brian D. Richter

Agriculture has been an important aspect of Arizona's cultural identity for thousands of years. The earliest documented crop production in the U.S. was found in the Tucson Basin, with maize remains dated 5,000–5,500 years before present (da Fonseca et al. 2015). Not long after the introduction of maize and other crops, evidence of irrigation technologies appears. Buried irrigation canals in the Tucson Basin indicate that 3,200 years ago, Indigenous agriculturalists were augmenting the supply of water available for irrigating seed crops (Vint and Nials 2015).

Today, traditional Indigenous agriculture of maize and a dozen other native crops continues on reservation lands using a variety of soil and water conservation techniques (e.g., rainfed agriculture) that have proven effective over time (Wall and Masayesva 2004; Johnson 2022). While these low-input farming methods produce yields that may be considered low compared to industrial farm standards, their yield stability and sustainability are a model of agricultural resilience.

Arizona's agricultural trajectory radically changed with the pumping of fossil groundwater using fossil fuels, beginning between 1900 and 1910, and the delivery of surface water from far-distant rivers and reservoirs whose construction was funded through the National Reclamation Act of 1902. Water storage and diversion dams were built on the Colorado, Gila, and Salt Rivers: Laguna Diversion Dam (1905); Roosevelt Dam (1911); Ashurst-Hayden Dam (1922); Coolidge Dam (1927); Hoover Dam (1936); Parker Dam (1934); and Glen Canyon Dam (1963).

These taxpayer-funded reservoirs ushered in water-intensive, highly mechanized field production. Arizona farmers of some crops have since benefited from a variety of subsidies that reduce their production costs and guarantee income during times of drought, heat waves, and other natural disasters. From 1995 to 2020, Arizona farmers received $1.5 billion dollars in commodities subsidies, nearly $741 million in crop insurance indemnities, and $394 million in crop insurance premiums (EWG 2022).

Since the 1960's, Arizona's irrigation farmers have grown significant proportions of the nation's supply of winter lettuce, alfalfa, durum wheat (for pasta), and pecans. Arizona is also one of the nation's leading producers of cantaloupes, chili peppers, dates, honeydew melons, spring onions, and pistachios (AZDA 2018). The commodities produced on farms and ranches are one part of the larger Arizona agribusiness system that in 2014 contributed $4.3 billion to Arizona's total Gross State Product (GSP) and as much as $23.3 billion when including indirect and multiplier effects (Bickel, Duval, and Frisvold 2017).

Arizona's economy can be said to run on water. More than 70 percent of the state's water supply goes to irrigated agriculture, with the remainder going to municipal (22 percent) and industrial (6 percent) uses (ADWR 2022). The state's water supply is provided by four main sources: groundwater (41 percent), Colorado River (36 percent), in-state rivers (18 percent), and reclaimed water (5 percent). Half of the state's Colorado River supply goes to irrigated agriculture, particularly in Yuma, Pinal, and Maricopa counties (see Table 1). Overall, Arizona agriculture uses the highest volume of water per unit area of arable land in any state, averaging 4.7 AF of surface water and groundwater applied per acre, in part due to the prevailing aridity where fields are located (NASS 2019).

However, farmers and ranchers are now facing the prospect of much-lessened water availability. Colorado River flows have declined by approximately 20 percent since 2000, with the ongoing 22–year mega-drought documented as the worst in the last 1,200 years (Williams, Cook, and Smerdon 2022). This trend of decreasing irrigation supplies is expected to continue, as climate scientists now project that Colorado River flows will decrease by 20–35 percent from pre-2000 averages (Udall and Overpeck 2017), with large implications for farm water availability and Arizona's economy. In 2020, agriculture cash receipts totaled only $3.85 billion, the lowest level since 2010 (Dewalt 2020).

There is some hopeful news nonetheless. Farmers in the Lower Colorado River region, including the Imperial Irrigation District in California, were able to increase their farm revenues by 30 percent over recent decades (2000–2019) even while their total water use decreased by 18 percent (Richter *et al.* in review). Yuma area farmers have been able to reduce irrigation water use by 18 percent over the past 50 years, while significantly increasing output (YCAWC 2015). This suggests that it may be possible to sustain the livelihoods of farmers in this region even while water availability declines.

One big wildcard for farming in the Lower Colorado River region is the potential effects of federally-funded crop fallowing for the purpose of stabilizing reservoir levels at Lake Mead. The federal Inflation Reduction Act of 2022 designated $4 billion for water conservation actions in the Colorado River Basin, which is being used to compensate farmers willing to fallow for 1–3 years (USDOI 2022). The implications of this fallowing program—which could involve hundreds of thousands of acres—remains to be seen.

Despite the serious federal and private investment in agriculture, there has been little effort to pass farmland preservation legislation to ensure that the most productive lands are protected from development or from water conservation programs that incentivize farm fallowing. Even with the prosperity that has been derived from high-value farmlands over many decades, Arizona continues to be ranked by the American Farmland Trust in the lowest tier of state policy responses for protecting farmland from development, promoting farm viability, or facilitating transfer of land to other farmers (Corral 2022).

Table 1: County profiles of agricultural water sources for irrigated croplands. *Data Source: Duval, Bickel, and Frisvold (2020) based on the 2017 USDA Census of Agriculture and 2015 water use estimates from the U.S. Geological Survey.*

	Cropland Acres (% irrigated)	**Agricultural Water Use (acre-feet)**		**No. Reservations with Irrigated Cropland**
		Surface Water	Ground Water	
Maricopa	187,467 (95%)	273,483	1,013,641	4 (76,952 acres cropland)*
Pima	29,192 (99%)	35,878	57,340	2 (>8,603 acres cropland)*
Pinal	235,185 (98%)	640,532	395,523	4 (>49,719 acres cropland)*
Yuma	193,823 (94%)	1,084,143	120,203	2 (74779 acres cropland)*
County Total	645,667 (96%)	2,034,036	1,56,707	
State Total	1,286,648 (96%)	2,819,156	2,117,061	

* Tribal Communities in two or more counties do not split irrigated acreage by county, so double counting may occur.

Sidebar: *Reflections on the Significance of Tribal Water Rights in Arizona*

Heather Whiteman Runs Him, Associate Clinical Professor and Director of the Tribal Justice Clinic at Rogers College of Law, University of Arizona.

Indigenous lands retained by the Tribal nations in Arizona encompass 27.7 percent—nearly a third—of the land area within the state's boundaries, the highest percentage of any state in the nation. Indigenous farmers also make up a significant percentage of agricultural water users in the state. Established through the terms of negotiated settlements with Tribal nations and decisions by courts of law, the amount of decreed water rights held by 14 of the 22 federally recognized Tribal nations in Arizona is substantial.

Importantly, nine Tribes have yet to complete determination of their water rights, which could be considerable in quantity and impact. Tribal nations already hold rights to the greater portion of Arizona's allocation under the Colorado River Compact. The importance of hearing, honoring, and respecting the rights of tribal nations to water has never been more apparent and pressing.

The legal framework underlying the rights of Tribal nations to water is well established. In 1908, the United States Supreme Court issued its decision in the case Winters v. United States, 207 U.S. 564 (1908), ruling that the establishment of an Indian reservation impliedly also reserved a sufficient amount of water to meet the purposes of the reservation—in that case, agriculture and domestic settlements.

Since that time, the Winters doctrine—as it's become known—has been examined and applied to uphold the rights of Tribal nations, and the rights of their individual members or citizens, to protect their rights to increasingly scarce and precious water resources.

Under the Winters doctrine, tribal reserved rights to water have a priority date of the establishment of the reservation. This means they are first in line for fulfillment over later-in-time uses and claimants. As a matter of law, tribal reserved water rights are not lost due to non-use. Even if a right has not been put to beneficial use, it remains valid and enforceable, having vested at the time it was established.

This is incredibly important given the history of abuse and theft of tribal lands and resources, and the historic underfunding of water infrastructure by the federal government and other interests on and around Indian reservations. In many cases, these abusive or neglectful practices effectively prevented Indian Tribes and individuals from putting their water to beneficial use.

In the Arizona v. California litigation, challenges to tribal water rights were asserted by the states and other non-Indian stakeholders. However, the Court approved the Special Master's 1960 Report including the determination that all Indian reservations, whether established pursuant to a treaty, an act of Congress, or by an executive order, have an implied right to sufficient water to fulfill the purposes for which they were established or set aside—rights which would have to be satisfied from the State's Colorado River Compact allocation.

The Court has also ruled that the appropriate standard for quantifying the rights associated with the reservations would be through a determination of the practicably irrigable acreage on each respective reservation. However, in 2001 the Arizona Supreme Court altered that quantification standard for Arizona Indian Tribes when it ruled in the Gila adjudication that a more appropriate and equitable standard for quantification should be the amount of water sufficient to establish and support a homeland for the Tribe.

This standard is viewed by some as providing flexibility to encompass more varied water uses beyond agriculture, potentially resulting in greater amounts of water awarded to Tribal nations. It also could result in water being dedicated to a wider variety of non consumptive uses, including habitat preservation and restoration, ceremonial, and religious water uses.

Through the McCarran Amendment, passed in 1952, Congress agreed to allow state water adjudication forums to determine federal water rights, and the Supreme Court has held that this included the water rights held by Indian Tribes associated with their lands reserved and held in trust by the federal government.

State courts have not always ruled fairly on conflicts involving the rights and resources of Indian people, so their exercise of jurisdiction over Indian water rights can be a cause for concern. This extension of state power over Indian water rights has caused some Tribes to hesitate to litigate their water rights in courts that are seen as potentially hostile, and which may also be located far from tribal land bases and populations, and thus difficult to access.

Due to the increased uncertainty, delay, and expense associated with litigation, many Tribal nations have instead sought to negotiate settlements between themselves, the United States, state governments, and other stakeholders. The federal government's official policy is that negotiated settlements are the preferred path to quantify and establish tribal water rights. It has developed policies and guidelines that govern its process of engagement with Tribal nations, state governments, and other relevant stakeholders in crafting negotiated settlements.

These settlements often include funding for infrastructure and development of water resources that was long withheld from Tribal nations. In exchange, the settlements usually require Tribal nations to waive potential future claims for additional water resources, for past abuses or neglect of tribal water rights and resources, and related legal issues.

This path is seen by many as preferable to litigation, as it lessens the risks associated with litigating in an unfamiliar and potentially unfriendly forum, and also includes financial resources to put water to beneficial use—something that litigation does not generally provide as a potential result. However, the negotiated settlement process is not without its own delays and risks, as the national political climate can make federal congressional approval of these settlements difficult.

The key to understanding the potential impact of the water rights of the Tribal nations in Arizona is communication and respect: For too long, the Tribes were excluded from key decision-making processes, including the crafting and establishment of drought response requirements and procedures on the Lower Colorado River Basin.

In recent years, Tribal leaders and tribal water users have increasingly asserted their role in managing the rivers and the waters that they and their ancestors have managed and relied on for millennia. The Tribes have strong legal rights to the water they need to support their lands and life ways. They also have strong moral and spiritual traditions of respect and sustainability which underlie every decision made about the most critical resource in the desert landscape—water. The roles of Tribal nations in identifying viable paths toward a more secure and sustainable water future for all Arizonans cannot be disregarded and, if respected and supported, hold the potential to benefit us all.

SCENARIO PLANNING PROCESS

The Babbitt Center for Land and Water Policy contracted with the Southwest Center of the University of Arizona to engage stakeholders in a scenario planning exercise to explore a broad range of options to address and mitigate the effects of climate uncertainty and reduced water availability on agriculture in the Colorado River basin. In August 2022, the University of Arizona Southwest Center sent out 100 questionnaires to farmers, ranchers, water policy experts, agroecologists, food systems analysts, conservation agriculture scholars and farmland preservation activists. Thirty-one were returned fully or partially completed.

Twenty-six candidates were then invited to attend a 3-day scenario planning retreat based on their responses to the questionnaire. Candidates were selected to reflect a broad range of professions, viewpoints, and expertise. Thirteen were able participate, including professionals in urban and organic farming, regenerative agriculture (Rodale Institute 2017), alfalfa and grass hay production, orchard production, hydrology, soil science, agro-ecology, range management, water harvesting, conservation agriculture, farmland preservation, water law, water policy, economic development, and food systems. They included professionals of African, Asian-American, Arab-American, Mexican-American, and European-American heritage, who now live, have lived, and work in seven counties in Arizona. Two additional guests attended evening sessions to engage in focused dialogues on two topics: Tribal water law (Heather Whiteman Runs Him, Associate Clinical Professor and Director of Tribal Justice Clinic at Rogers College of Law, University of Arizona) and Arizona agricultural legislation (Tim Dunn, Arizona State Representative and farmer).

The retreat was held from September 11–13, 2022 at Biosphere 2, a University of Arizona facility in Oracle, Arizona. Catherine Tornbom, of the School of Government and Public Policy of the University of Arizona designed the scenario-building process, facilitated the meeting, and documented the recommendations. At the outset, participants identified a collective purpose: *to engage in dialogue to explore innovative solutions to the water crisis in the binational Colorado River Basin, focusing on Arizona agriculture.* They were prompted to keep the following focus question in mind during the scenario planning process: What are collaborative-based solutions to water for Arizona agriculture? The rational objectives of the retreat were to:

- Develop a set of values and guidelines for long-term collaboration
- Brainstorm up to 12 scenarios in response to the crisis
- Choose five of those scenarios to explain in more detail
- Identify barriers that prevent successful solutions from being developed

In addition, experiential objectives provided a foundation for open and respectful discourse:

- Create a safe and invigorating space for authentic collaboration
- Respect and honor the diverse voices in the room
- Move outside familiar paradigms with courage and confidence to open the door to innovation
- Stay focused on what we want the farming future to be
- Actively engage with curiosity and openness to each other and the process
- Assume good intentions and check our assumptions about each other and ourselves
- Attune to those not at the table who most need our care in providing tangible solutions

The retreat was structured into five sessions.

Session 1: Collaboration Workshop

Objective: Identify key values and elements for highly successful collaboration.
Process: Individual brainstorming, paired sharing, and group engagement.

Session 2: Questionnaire Themes

Objective: Identify key themes from pre-retreat survey questions to inform scenario building.
Process: Each of three groups reviewed responses and developed themes on a question from the questionnaire.

Session 3: Scenario Building

Objective: Develop future scenarios addressing the problem of Arizona's agricultural water needs.
Process: A group exercise developed criteria for evaluating scenarios and participants developed individual scenarios. Each participant shared their scenario addressing the criteria developed by the group. The entire group then clustered scenarios by similar intent. The resulting groupings were further developed with participants working in groups.

Session 4: Obstacles Workshop

Objective: Brainstorm factors that will assist and resist the achievement of the scenarios.
Process: Each small group discussed and decided on three to five things that assist or resist the successful implementation of their scenarios. Each group then reported their findings.

Session 5: Next Steps

Objective: Identify next steps, individually and as a group.
Process: Conducted as a group dialog and final activity of the retreat.

KEY ELEMENTS OF COLLABORATION

Participants agreed upon a unifying intention for collaboration: to make Arizona agriculture more resilient in the face of uncertainty through long-term sustainable water use. They then identified key values for successful collaboration in each of three realms: values that are important to the citizens of Arizona, values that are important to professional colleagues, and personal values (**Appendix A**). Three core themes emerged from this exercise: transparency, inclusivity of all who impact and are impacted by solutions, and action. Such values will be necessary to promote community-based solutions which are both socially acceptable and technologically feasible.

Participants also identified 10 key elements for successful collaboration:

- Clear vision with a concerted strategy towards achieving solutions
- Achieving common desired outcomes and values with respect, trust, and open minds
- Structured process for shared decision-making
- Inclusion of diverse community engagement through conservation and collaboration
- Collaborative adaptive management for unexpected opportunities and challenges
- Iterative engagement with larger audiences
- Support by sufficient resources
- Utilizing expertise in relevant fields to build a strong knowledge base
- Be proponents of action
- The right people are engaged in the collaboration

QUESTIONNAIRE THEMES

The pre-retreat questionnaire focused on climate impacts on food and food security, food and water equity, and barriers to climate change adaptation. Prior to the retreat, word clouds were created to visually represent questionnaire responses and provide insight into patterns and trends (**Fig. 2**). During the retreat, participants broke into groups to identify themes in the responses to each of three questions (see below). Participants evaluated, ranked, and organized responses into groups with similar intent (**Appendix B**).

Question 1. In what ways might weather-related disasters, temperature shifts, or changes in other human and natural resources affect food, and energy security within the region? (**Fig. 2 a, b**).

Responses fell into three major themes:

- Food availability and afford-ability
- New pressures affecting crop selection
- Harsher workplace conditions reduce labor availability

Question 2. What values, capabilities or rights need to be better protected to assure a more viable, equitable or resilient food and water future for farmers, farmworkers, and eaters in our region, particularly with respect to those whose voices and needs are often left out of the discussion? (**Fig. 2 c, d**).

Responses fell into six major themes, with overlaps and convergences among themes. For instance, equity and access have strong but not exclusive overlaps with Indigenous water issues.

- Environment
- Agriculture/producer
- Agriculture/consumer
- Equity and access
- Indigenous
- Municipal management

Question 3. What barriers do we need to address that keep farmers from modifying current operations or adopting new practices and technologies to deal with water scarcity and other challenges? (**Fig. 2 e, f**).

Responses fell into five major themes:

- Policy incentives misaligned
- Uncertainty and high cost of entry for new markets
- Cost of retooling to transition
- Lack of an adaptation pipeline (people, education, technology transfer)
- Cultural and behavioral resistance to change

SCENARIOS

Scenario Building Exercise

During the scenario building process, participants responded individually to the prompt: *What are future scenarios that solve the problem of Arizona's agricultural and other water needs?* Each participant identified an idea to solve a specific problem within this scope, outlined steps for its achievement, and described how it would benefit Arizonans. The resulting 13 scenarios addressed a range of solutions, from on-farm practices to water policy, ranging in geographic scope from farm or ranch to state or region, including the multi-state Colorado River Basin.

Working as a group, participants clustered scenarios by similar intent, resulting in three groupings:

Group 1: Water certainty for the Colorado River Basin

- "Save the River" voluntary compensated agriculture water reduction program
- Securing Arizona's water future through updated limits on extractions
- Water sharing (reallocation) by and for agriculture across the Colorado River Basin

Figure 2. Questionnaire themes. Word cloud of responses where larger words appeared more frequently in responses (**a,c,e**) and group exercise (**b,d,f**).

Group 2: Holistic agriculture and watershed management

- Vertical integrated solution: partnerships across producers to steward farmland as part of the watershed/subwatershed and ecosystem
- Crop shifting and regenerative agriculture to conserve river and ground water
- Farmer-driven, collaborative sub-basin transition planning to learn to live with less water
- Upland flood management to improve rural watershed health
- Modernized irrigation water management that benefits agriculture and the environment
- Navajo and Hopi assert water rights for local agriculture and food sovereignty

Group 3: Restoring Biocultural Value on Fallowed Farmland

- Creating urban agriculture forestry in urban corridors
- Habitat restoration on fallowed farmland to reduce land degradation
- Co-location of renewable energy generation, shade-grown crop production, and water harvesting on marginal agricultural lands in Pinal, Maricopa, and Yuma counties
- Implementing desert agroforestry to save water, sequester carbon, and generate novel value-added products and jobs

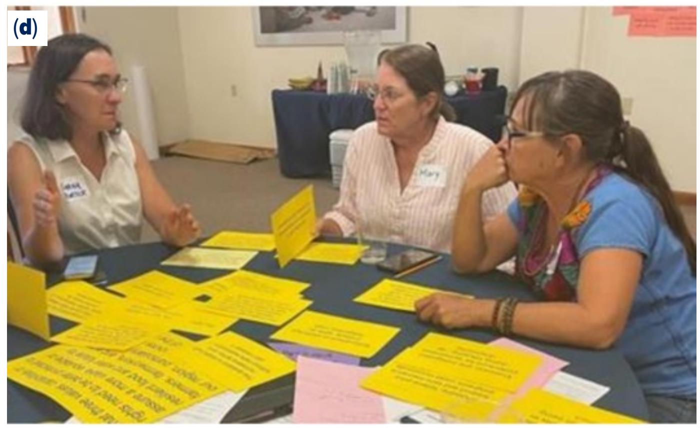
(**a**)

(**b**)

In what ways might weather-related disasters, temperature shifts, or changes in other human and natural resources affect food, and energy security within the region?

(**c**)

(**d**)



What values, capabilities or rights need to be better protected to assure a more viable, equitable or resilient food and water future for farmers, farm workers, and eaters in our region, particularly with respect to those with voices and needs are often left out of the discussion?

(**e**)

(**f**)

What barriers do we need to address that keep farmers from modifying current operations or adopting new practices and technologies to deal with water scarcity and other challenges?

Groups worked through an exploratory scenario planning process to develop three detailed scenarios, with the hope that a fourth subgroup of Native Americans could later elaborate a complementary scenario from their own perspectives. During this process, participants developed the following criteria to assess scenarios:

- Feasibility
- Scale of impact
- Breadth of impact
- Type and volume of impact
- Most urgent
- Legality
- Environmental impact
- Policy barriers
- Longevity
- Cost
- Cultural, political equity and justice impact

> *"It seems to me that addressing this crisis requires not only reckoning with the scale of the problem, but also recognizing how fundamental misunderstandings of our surroundings have been built into our systems. What would it mean for us to re-think our food system infrastructures with the explicit assumption of climatic variability? How would assuming unpredictability, as opposed to trying to achieve stability, help in redesigning water allocation and distribution, food production and transport networks, or producer or consumer subsidies and risk-buffering mechanisms? These are the kinds of questions which, to my mind, may help us move forward."* ***- Alder Keleman Saxena, Northern Arizona University Social Scientist of Conservation Agriculture***

Group Scenario: Water Certainty for the Colorado River Basin

Problem: *Water overuse, imbalance, and inefficient use with respect to the Colorado River Basin system.* Over-allocation, prolonged drought, and climate change have imperiled the Colorado River system, which provides water to some 40 million people and 5 million acres of farmland. Agriculture is responsible for around 75% of the consumptive use of Colorado River water. Efforts to prevent Colorado River reservoirs from crashing have proved insufficient, and water users are preparing for unprecedented cuts in the coming months.

Continued water uncertainty and reduced availability will impact:

- Colorado River water users
- $1.4 trillion of annual economic activity and 16 million jobs supported by the Colorado River system
- National and global food security
- Western electric power users
- The Colorado River ecosystem, including the iconic Grand Canyon and habitat for endangered fish, birds, and other species

Rules related to entitlements to use Colorado River water inhibit the movement of water to higher value

Reservoirs built decades ago on Colorado River are at lowest level since dam construction. Photo by Robert Guerra.

agricultural areas and perpetuate water use in places where farming is suboptimal, or of low marginal value. In particular, the Colorado River Compact and Law of the River prevent water sharing or re-allocations between the Upper and Lower Basins and between water users of different states. Effective solutions will require participation by all Colorado River water users, including high priority water rights holders.

Solution: *A basin-wide market where agricultural water users can reallocate water amongst themselves for compensation.* A limited market mechanism facilitates movement of water to areas of optimal agricultural production while compensating those farmers giving up water used for low margin crops. Agricultural water exchanges would be time limited and restricted to Colorado River agricultural uses, where the party yielding water cannot replace it with groundwater or other surface water. To make such a market work, a cap on allocations to the Upper and Lower Basins will be essential.

A three-part plan for achieving optimal allocation amongst agricultural users would:

1. Conserve 1 million acre-feet per year for four years by compensating all lower basin on-river farmers for reducing water orders by one acre-foot per acre voluntarily,
2. Adjust operating guidelines or state allocations to align deliveries with actual supply on recurring 5-year time periods (through consultation), and
3. Establish a basin-wide water market limited to agricultural water users.

Benefits to Arizona: This scenario ensures a more sustainable water supply for high-value agricultural production and creates a funding stream for agricultural water efficiencies. For example, investment in new technologies and/or adjusting cropping practices, irrigation methods, and crop selection to use less water. This benefits rural economies that would otherwise be devastated by the fallowing of cropland. Perhaps most importantly, a viable Colorado River system benefits all who depend on it, not just mainstream Colorado River producers.

Over 40 million people in two countries, seven states, and 30 Native American tribes currently rely on the Colorado River for their food, water, and energy. In addition, commerce and industry, a multi-billion-dollar recreation and tourism economy, sensitive ecosystems, and endangered species all depend on the Colorado River.

> *"The declining availability of water due to climate change, along with the reality that irrigated farmland consumes 70–80% of water supplies, suggests that we must find ways to use substantially less water for irrigation. With proper foresight and planning, we can create opportunities rather than impacts for farmers."* ***- Brian Richter, President of Sustainable Waters***

Implementation Challenges: Each aspect of this proposal will be contentious and difficult to negotiate. Because there is great disparity in the volume of water used in the Upper versus Lower Basin, any constraints or caps on water use in the Upper Basin will be strongly resisted. The Upper Basin will also resist any proposal for trading water from the Upper to the Lower Basin due to fears that this reduces local economic productivity and erodes the culture of rural farming communities once their water supplies are exported. Given reluctance to see any land go out of production, farmers throughout the basin are likely to be more receptive to measures that keep land in production but require less water consumption, such as crop shifting.

Group Scenario: Holistic Agriculture and Watershed Management

Problem: *Conventional agriculture is unsustainable in its high water consumption and is contributing to land degradation in the arid West.* The current Colorado River water crisis has highlighted the need for a paradigm shift from highly consumptive conventional agricultural water use to more holistic, watershed-scale management of water resources. Problems of conventional agriculture include depleted natural resources within the watershed, high water-consuming crops, soil erosion, poor water infiltration capacity due to poor soil structure and beneficial microbial characteristics, heavy reliance on inputs, and a focus on near-term productivity at the cost of long-term balance of ecosystem services and watershed-scale stewardship.

Solution: *Holistic management of watershed resources to support a more sustainable, regenerative Arizona agriculture ecosystem.* This approach considers the hydrologic and landscape connections between watershed uplands that support grazing and lowlands that support cropland agriculture. It incentivizes on-farm transitions to more sustainable, regenerative-centered agricultural practices. A multi-pronged plan for achievement would:

- Convene basin-specific dialogues and actions that address water realities and agricultural transitions
- Incentivize partnerships among producers to mitigate soil erosion problems and improve water retention and water cycle within watersheds
- Incentivize practices involving green infrastructure (e.g., gabions, check dams, berms) that convert rangeland surface runoff to infiltration
- Incentivize transition from high-water consumption and low value crops to low-water consumption and high value crops
- Incentivize growing climate appropriate, desert adapted native and heritage plants (e.g., White Sonora wheat)
- Incentivize regenerative agricultural practices that reduce soil erosion, improve soil health, and enhance ecosystem services while building additional economic gains for farmers. Regenerative practices include no-till or low-till cover crops, organic, biodiversity, and livestock mob grazing.

- Promote vertically integrated solutions and partnerships among ranchers, farmers, and feedlots (e.g., intensively managed rotational grazing on cropland during non-cash crop season with ranchers' herd)
- Increase funding for regenerative agricultural practices in 2023 U.S. Farm Bill (e.g., Kiss the Ground Regenerate America Campaign; NRCD Regenerative Agriculture: Farm Policy for the 21st Century)
- Create public funding for market development of low-water consumption crops

Benefit to Arizona: Producers benefit from long-term investments in sustainable and regenerative agriculture, watershed health, and balanced ecosystem function. At the same time, rural communities benefit from well-maintained working landscapes while municipalities benefit from managed flood waters. Economic benefits extend to big cities, which thrive when rural communities thrive. Consumers benefit from more local, nutrient-dense food choices that offer multiple health benefits. All benefit from more water in the Colorado River System, as well as from improved water and air quality and enhanced ecosystem services linked to regenerative agricultural practices.

> *"Water conservation needs to be addressed in all sectors, not just agriculture. Consumers need to vote with their fork and wallet for farmers to adopt better practices. Farmers need to cover the soil surface so soil erosion can be mitigated, which enhances soil water holding capacity and reduces evaporation. Policy makers should address locally sourced food and discourage growing commodities that send our water resources elsewhere. It is not just a water crisis. It is a crisis of the entire ecosystem function."* ***- Yadi Wang, Kiss the Ground Regenerate America Campaign Farm Leadership Council, Tucson, Arizona***

Group Scenario: Restoring Biocultural Value on Fallowed Farmland

Problem: *Reduced and less reliable water supplies will force an increasing acreage of irrigated, arable farmland to be fallowed or permanently retired, damaging rural economies and causing widespread land degradation.* Across Arizona, as many as 150,000 acres of farmland irrigated by Colorado River water may be retired in the coming years due to water shortages and climate change. If left fallow, these brittle landscapes will be vulnerable to soil erosion, infestation by invasive plants like tumbleweed, and hazardous dust storms. If developed, continued water demands on these lands will stress dwindling water resources. There is currently no state or federal budget to restore vegetation cover on lands taken out of crop production.

Solution: *Reestablish vegetation cover through low water agricultural practices (e.g., desert agroforestry, agrivoltaics) or habitat restoration, in order to help restore biocultural value to fallowed agricultural lands and provide economic opportunities for rural communities.* Low-input agrisystems, such as desert agroforestry and agrivoltaics, provide farmers options to keep agricultural lands in production and generate diversified revenue streams while using less water. In a desert agroforestry system, winter vegetables are alley cropped between arid-adapted tree crops (e.g., mesquite) in fields edged with hardier desert crops (e.g., agave, prickly pear) (Nabhan et al. 2020). Multiple harvests on the same acreage increases crop value per acre by while reducing water use and increasing yield stability. Agrivoltaic systems co-locate renewable energy generation, high-value shade-grown crops (e.g. vegetables and spices), and water harvesting. Shading by photovoltaic (PV) panels provides multiple additive and synergistic benefits, including reduced water use, reduced plant drought stress, greater food production, and reduced PV panel heat stress (Barron-Gafford et al. 2019). Habitat restoration on stressed agricultural lands that would otherwise be permanently retired recovers biodiversity and creates multiple co-benefits during transitions to sustainability (Bryant et al. 2020). Each of these examples would use as little as 1 to 1.5-AF-per-acre of water, compared to the average 4.5-AF-per-acre of water for conventionally grown crops in Arizona (**Appendix C**). Habitat restoration would use even less water once native desert vegetation is established.

Implementing these solutions requires funding for research, development, planning, prototypes, and scaling-up. Receptive current landowners and land trusts, skill and training, and private business interest are needed to jumpstart the process. Achievement would require:

- Research to identify landowners and understand which financial incentives are attractive to different owners (farmers versus developers) and geospatial analyses to identify most appropriate and highest value land use (restoration, agrivoltaics, agroforestry)
- Small-scale pilot projects (5- to 10-acre) to evaluate start-up and maintenance costs and benefits of restoration, agroforestry, and agrivoltaic systems using less than 1.5-AF-per-acre-per-year
- Detailed, evidence-based restoration strategies
- Funding and incentives to implement agroforestry and agrivoltaic systems, transition to low-water regenerative agricultural practices and crops, and restore habitat
- Adaptation pipeline to establish and invest in desert-adapted crops and native seed suppliers, equipment, farmer training, skilled labor, etc.
- Skilled restoration practitioners and land managers

Benefit to Arizona: Revitalizing fallowed lands to economic and biocultural value provides numerous benefits to Arizona's land and people. Each of the above low-water uses mitigates losses of land value, rural livelihoods, and ecosystem services while safeguarding the future agricultural potential of arable lands. Each creates jobs in multiple professions and sectors in rural communities that are currently losing jobs. Establishing ground cover, either through desert-adapted agrisystems or habitat restoration, mitigates health and environmental threats associated with fallowing. Benefits include improved water and air quality. Improved soil health and increased soil water holding capacity leads to further reductions in water use while increasing groundwater recharge. Agrivoltaic systems diversify farmer revenue streams—renewable energy generated from photovoltaics can power on-farm energy use or be sold into grids to supplement high-value, shade-grown crop sales. Habitat restoration creates wildlife corridors and sustains ecosystem services. Benefits would extend to neighboring farmland—pollinator and beneficial insect habitat in and between extant fields enhances crop yields. Wild foraging on restored lands supports Indigenous cultural uses and restaurant or medicinal plant trade.

> *"In deserts, water use and energy use are hitched at the hip. The most effective shift for slowing farm debt and climate change would be to reduce on-farm fossil fuel costs in pumping water. Artesian springs and their vulnerable aquifers need to be protected into perpetuity to make them available for future generations of farmers and on-farm wildlife. Protecting farmers' livelihoods and protecting the landscape, its beneficial wildlife and renewable water resources are not either/or choices. One supports the other."* ***- Gary Paul Nabhan, Orchard Keeper and Research Scientist, Patagonia Arizona.***

Next Steps

A number of next steps arose out of the retreat. Foremost was the need to engage the right people in order to develop and implement effective solutions. This could involve convening Colorado River experts to assess water shortages and other climate-driven impacts on farmers, farmworkers, and habitat restoration for endangered fish and wildlife. Mexican and Native American perspectives are critical to the scenario and drought planning process. To this end, we are considering hosting further dialogues between Native American farmers and Indian water law experts to clarify common ground and difference in perspectives on culturally-acceptable and economically-viable future scenarios. Among retreat participants, there was interest to further develop group scenarios, including research into what related efforts may already be in progress. Additional next steps being considered are: developing proposals to collectively initiate some of the proposed innovations; exploring and publicizing how new disaster relief qualification guidelines now favor farmers switching to alternative water-efficient crops without former disincentives; and disseminating the report findings (e.g., through farmers' forum gatherings and briefings to major news media).

OBSTACLES TO ADAPTATION

While the collaborative effort outlined in this report will hopefully be one of many initiatives that are *assisting forces* in achieving scenarios of value to all water users, we recognize that there are also *resisting forces* that might prevent success (**Appendix D**). Many factors—political, economic, behavioral, environmental—can impede or disrupt efforts to transition to a more resilient agricultural future, even when there is sincere will and long-term economic incentives. Barrier-busting proposals to create novel opportunities, such as those presented in the report, not only require political and managerial will from farmers themselves, but buy-in from water districts, federal agencies, farmers organizations, and dominant players in markets.

Highlighted below are four kinds of impediments that need to be overcome, recognizing that an incentive for one user group (e.g., more crop insurance payments for irrigation farmers) may be seen as a disincentive for another (e.g., water conservation to ensure water for endangered species).

Barriers to New Water Technologies

Open-canal flood irrigation of annual crops remains widespread in Arizona, despite recognition of its low efficiency (70–75 percent) compared to sprinkler (80–85 percent) and subsurface micro-irrigation (90–95 percent) (Samar 2019). In a decade-old farm and ranch survey compiled by the USDA (NASS 2014), Arizona farmers cited five major barriers to improving irrigation efficiencies on farms that remain valid today:

- landlords will not share costs with farmer/leasee;
- improvements will not cover the cost of installation;
- farmers cannot finance improvements;
- farmers will not be farming long enough for return on investment; and
- uncertainty about the water.

Infrastructure can impede transitioning, such as limited sites where head gates and outlets are located on a farm. On-farm spatial arrangements often need to be reworked to allow for drip or sprinklers. A farmer leasing irrigable land over the short term (three to five years) is unlikely to invest in infrastructural changes that have a longer payback time than the lease duration. Uncertainty about what crops will be affordably grown in the future keeps some farmers from transitioning to another irrigation technology that will only work for specific crops.

Funding programs from the USDA and NRCS (**Appendix E**) can help farmers transition to new irrigation management strategies. Recent high-tech practices are maximizing irrigation efficiencies, such as irrigation scheduling by drone, airplane, or satellite imagery combined with digital soil moisture sensors and lap-top or smartphone decision support tools that optimize the timing of water deliveries (USGAO 2019). However, additional incentives, policy changes, or water management controls (such as reducing head gate delivery volumes) may be necessary to ensure that improved water efficiency translates to water conservation. Often, the resulting water savings are used to increase yields, switch to thirstier crops, or irrigate more land (USGAO 2019), rather than reducing water use.

Barriers to Shifting Crops

The potential water savings and higher cash value of arid-adapted crops such as agaves, chia, guayule, heirloom grains, or prickly pear, are impeded by lacking or poor consumer markets and the cost of needing to invest in new farming, harvesting, sorting, cleaning, milling, and packaging equipment. In addition, perennial crops require several years in the ground to produce harvest-able and sale-able yields. More daunting is the risk of losing crop insurance indemnities by switching away from a crop for which farmers have several or many years of yield records. Both disaster relief and crop insurance payouts are predicated on the capability of demonstrating a certain percentage of decline from average yields over time for the same crop. Farmers who rely upon crop insurance indemnities to break even may be averse to losing federal subsidies to avoid further debt.

Some scientists and farmers, nevertheless, see increasing heat and water scarcity as an opportunity to grow novel, arid-adapted crops (Kleinwachter and Selmar 2015). It is also possible to substantially reduce irrigation requirements simply by changing the mixture or proportion of crops already being grown in a farming district (Richter *et al.* in review). For instance, in the Lower Colorado farming districts, a shift toward replacing a portion of cattle-feed crops (alfalfa and other grass hay) with sugar beets—which are already being grown in the area—can sustain overall farmer revenues while reducing water consumption by more than 20 percent. It remains to be seen whether such a paradoxical strategy based on good science can be translated to the extent that farmers can embrace and adopt it.

> *"Oatman Flats Ranch is the first farm in the Southwestern United States to achieve Regenerative Organic Certified® status. Although we are still early in our journey, we are seeing success regenerating our 665 acre farm and conserving significant volumes of water by focusing on regenerative farming practices and drought-tolerant and heritage crops like White Sonora wheat, agave and mesquite. The practices and crops are sound, but in order to succeed as a region we must develop large-scale markets for regenerative and heritage crops at prices that meet or exceed the prices of customary crops such as alfalfa."* ***- J. Dax Hansen, Founder of Oatman Farms, Gila Bend, Arizona***

Innovating Out of Sync with Neighbors

Community-level barriers that limit adoption of efficient irrigation technologies across a water district or watershed include lack of collective capital to adopt and maintain new technologies, and relative lack of up-to-date information about such technologies and the cost/benefit ratios (USGAO 2019). Some communities of desert farmers rely on their neighbors to grow the same crops or use the same irrigation technologies so that they can share the same pool of suppliers, plumbers, mechanics, mills, and processing plants located in or near their locality. When one farm is hit with a flood, or other natural disaster, neighbors regularly step in to offer use of equipment and know-how to help the afflicted farming family repair their infrastructure and recover their crops. However, if a critical mass of farmers in the same community choose to not share the same crops, technologies, or ethics of reciprocity, the entire support system risks collapse. To repeat an oft-cited proverb, “it takes a village.” There are well-documented examples in the arid West of farmers banding together to adopt a new crop that they collectively market with great success that could be applied in Arizona (Carlisle 2016).

Innovating without Political Leveraging

The U.S. Government Accountability Office (2019) has concluded that federal policymakers should consider bills that

- Promote the use of more efficient irrigation technology and practices, such as irrigation scheduling, and
- Promote the use of precision agriculture technologies, such as soil moisture sensors and weather stations.

To be most effective, policy needs to be combined with agreements between farmers, water providers, and cities that consistently enable and encourage water savings, not just during optimal years. On several occasions, the Arizona Legislature temporarily waived groundwater pumping restrictions during severe drought, potentially setting back water security even further. Such agreements could include incentives to farmers for conserving water.

The majority of Arizona farmers have far less collective capacity to leverage political and policy support for long-term assistance than at any other point in Arizona history. Currently, there are remarkably few (three to five) farmers in the Arizona state legislature, and state senate, or in other pivotal positions in the state government. Nearly all the Arizona delegation to the U.S. Congress and U.S. Senate lack first-hand farm and ranch experience, and few Arizonans are offered political appointments in the U.S. Department of Agriculture.

Further, the Arizona Farm Bureau has few paying and participating members (other than purchasers of insurance) that are Native Americans or women of color. The Arizona Department of Agriculture lags nearly every other state in adequately representing African-, Asian-, Mexican-, and Native American farmers and farmworkers on its governor-appointed Advisory Council that sets and reviews policies and expenditures, and its other boards (Nabhan and Glennon 2016). That would be regarded as a civil rights issue but not a state economic issue in earlier eras. Today it is both, because minority farmers and farmworkers are an ever-increasing portion of new farmers in Arizona across all scales of farms and ranches.

According to the Environmental Working Group, the $2.1 billion of farm subsidies paid to Arizona farmers between 1995 and 2020 have been directed to just 4% of Arizona farms (EWG 2022). We fear that because most Arizona farmers lack political leverage to obtain such federal support, most disaster relief and transitioning grants will also go to less than 5% of Arizona’s farms, when in a more politically responsive environment, that assistance might otherwise be spread to help those with greatest need.

The following five case studies are based on current in-the-field efforts that demonstrate the viability of scenarios proposed during the retreat. Although these examples may not be viable at all scales of farming, they showcase solutions that are disproportionately significant for future water-resilience relative to their current scale.

Case Study 1: Saving Water by Growing and Malting Barley for Craft Beers

If Arizona farmers want to shift their mix of crops toward varieties that consume less water per acre, their farm operations must absorb the costs of transitioning to different ways of planting, managing, harvesting, and marketing their sale able yields.

Along the Verde River tributary of the Colorado River, the late Kevin Hauser of Hauser and Hauser farms navigated through difficult terrain with a unique collaboration of The Nature Conservancy (TNC) and the Verde Natural Resource Conservation District (NRCD). Their collective idea was to begin growing barley on the Hauser's Shield Ranch in Camp Verde, Arizona—seeding just 15 acres in 2015—to see if it would help restore flows in the Verde.

For years, Chip Norton of the Verde NRCD had been working on ways that TNC's river conservation programs could help rather than hurt Verde Valley's farmers, who rely heavily on river water. The Verde's springs and stream flows had been declining for decades, and housing developments were encroaching upon Verde Valley's open spaces and water resources.

The consensus among diverse stakeholders was to phase out the production of water-intensive summer crops like alfalfa for drought-hardy winter barley. But Chip Norton had determined that there was a good reason that farmers had previously not initiated such water-saving innovations: "There was the missing piece for the farmer wanting to do the switch: He had to have a market, and that meant we had to have a local malting facility," Norton said. "And now we've done that, and we're selling malt to brewers throughout Arizona."

Arizona Wilderness Brewery (AWB), which focuses on the preservation of Arizona's wilderness areas, is a major contributor to the success of the Sinagua Malt crop-shifting and market-creation initiative. AWB proudly publicizes their commitment to using only Sinagua malt in their beers and championing water-savings. Collectively, they've crafted messages about the links between agriculture and water conservation that delight many Arizonans: "*Save water, drink beer. Drink beer, save water*," and "*Drink like you care*."

Realizing that farmers needed both means and markets to cut irrigation volumes so that ecologically important river flows could be restored in the Verde, Chip Norton decided to become the president and principal shareholder of a new barley malting house named Sinagua Malt. He began to collaborate with farmers like the late Kevin Hauser—and continues with sons Ben and Zach Hauser—as they shifted away from growing water-intensive alfalfa and finessed the production of malt barley. The Copeland two-row malting barley that Sinagua Malt promotes requires 20 percent less water for saleable yields compared to the average Arizona field crop, and well under half that of many alfalfa hayfields (Sinagua Malt 2022).

This barley variety is excellent for malting, and because there are few malting houses that serve Arizona microbreweries, the establishment of Sinagua Malt helps solve two problems at once. Chip Norton began building out the Sinagua Malt house in Camp Verde in 2016, and the first sale-able batch of malt was distributed to craft beer brewers in the state in May 2018. In 2019, Sinagua Malt was formally recognized as a Certified Sustainable Business by the Sustainability Alliance, and 433 acres had been planted with barley in the Verde Watershed (Chanler 2019).

By the beginning of 2020, Sinagua Malt and its growers had saved a cumulative 425 million gallons of water merely by shifting from more water-intensive crops to barley cultivars that require only 3–3.5 AF per season. But there was another reward from this work as well. Fifteen micro-breweries in and around Arizona have now used Sinagua malt in their seasonal recipes, and two home brew supply stores carry the base malt for the pleasure of home brewers interested in the Verde Valley's terroir. They also broadcast the water savings embedded in their beers.

Case Study 2: Balancing Climate-Friendly Native Crops with Commodity Crops

Many Arizonans have heard of Ramona and Terry Button's award-winning native food products—from tepary beans to corn pinoles. For decades, their Ramona Farms has produced these foods on Gila River Indian lands, both for their own Akimel O'odham relatives and for other desert food enthusiasts (Looker 1995). Nevertheless, few of their customers realize just how diversified Ramona Farms is, and how it has become a model for other climate-friendly farms.

> *"You cannot fully understand how to grow a desert crop like tepary beans after one or two years or know how and when to irrigate and harvest them in Pinal County,"* ***Terry said.*** *"It has taken me over forty years to get irrigation timing and volume right so that we can use less water."*

In the past, the Buttons and other tepary growers have used up to 1.75-acre-feet per acre for a harvest-able crop of these drought- and heat-tolerant legumes. Currently, Terry and his foreman Danny Mark can apply just one acre-foot or less, and still gain a sale-able, quality bean crop on 100 acres each year.

The Buttons and their business partners also grow Pima sixty-day flour corn, five other corns, three kinds of wheat, barley, oats, two kinds of cotton, alfalfa, and Bermuda grass hay, and occasionally garbanzo beans.

Although most durum wheat growers in the Grand Canyon state use 3.1–3.45-acre-feet per acre for this winter crop, Terry and Danny have been skilled enough to get that down to 2–3-acre-feet per acre. Terry grows his other grain varieties on even less irrigation by carefully timing the plantings in mid-January to early February.
When asked how that diversity of crops helps keep their 4000–7000 acres of owned and leased fields economically viable, Terry offered a surprising answer:

“I would not have the slack to grow as much of these native crops if we did not also have commodity crops that I can sell into national or foreign markets. We just couldn’t pull off the time and investment in these heritage crops if we did not have steady revenue streams from the cash crops that have a far bigger market demand.”

That pragmatism in the face of uncertainty is what made Ramona Farms become the largest producer of Indigenous crops in the Colorado River watershed. In 1974, the Buttons started growing just barley and alfalfa on the Gila River land allotment that Ramona’s mother Margaret had previously cultivated. They then diversified.

Today, a total of 240 acres of Ramona Farms production goes into organic vegetable and legume production. While that is less than 6 percent of the Button’s owned or leased acreage in any given year, it is the acreage from which they gain most of their acclaim!

Ramona and Terry were inducted into the Arizona Farm and Ranch Hall of Fame in 2017 but have not yet rested on their laurels. With their daughter Velvet, they regularly distribute 18 kinds of Native American heritage food products to 100 chefs in Arizona (Kelly 2019).

On occasion, the Buttons have weighed on federal policies to help farmers better manage scarce water, as they did in the U.S. Capitol in 1990. They spoke at a Senate hearing to gain CAP water access for Indian farmers; it was offered at $55 an acre-foot at that time (Murphee 2019).

By 2020, the price of CAP water for Gila River Indian Community farmers had risen $200 an acre-foot, and whatever CAP water remains available is likely to rise in cost at least 3 percent each year. And yet, despite these rising costs, Ramona Farms has stayed “ahead of the curve” while it celebrates and revitalizes the O’odham agricultural heritage.

Case Study 3: High-Tech Climate-Smart Efforts to Save the River

Paul Brierley of the Yuma Center of Excellence for Desert Agriculture (YCEDA) has worked with dozens of Arizona farmers on a plan to “save” the Colorado River by compensating farmers for reducing their water usage by one acre-foot of water per acre that they farm. The goal, leaving an additional one million acre-feed annually in Lake Mead. This is not a fallowing program or transfer of water rights, but an attempt by agriculture to help avoid the system crashing, and impacting everyone in the Southwest, during exceptional drought. Farmers would continue to farm, but with an income source to pay for efficiency practices and upgrades.

By October of 2022, this proposal had garnered enough national attention that it was integrated into the federal Inflation Reduction Act. While operational details are not yet available, the Act provided $4 billion in drought mitigation funding to pay for such activities as reimbursing farmers, cities, and Native Nations for drawing less water from the drought-stricken Colorado River. Should the proposal proceed in its current form, farmers and other willing applicants will be temporarily giving up at least 20 percent of their current water use per acre, in return for compensation, to help achieve the targeted water savings.

Technologies and practices that can achieve these water savings include sophisticated soil moisture tracking and high-tech monitoring of crop water use over a growing season, laser leveling of fields for more efficient water retention, or mobile apps, drones, satellites, and the computerized analyses of complex weather data maps in “real time.” These technologies offer decision support tools for desert farmers who must inevitably make tougher and costlier choices than they did in the past in order to stay productive with less water available for their crops. Practices could include soil amendments to enhance soil health and moisture retention.

But even as the YCEDA is scoping new options for the future of desert farming, it is revisiting and learning valuable lessons from the farming of the past. Over the past five decades, Yuma area farmers came to use 18 percent less irrigation water than was used on the same fields 50 years ago, while significantly increasing output (YCAWC 2015).

One of Brierley's goals is to keep the prime croplands in the Lower Colorado River Basin economically viable by helping farmers adopt emerging best practices and technologies. There are farmers who tell Brierley "We are doing everything as well as can possibly be done," but he suggests to them that there is always more they can accomplish in terms of conserving water and enhancing crop yields. Brierley tells farmers that when we look at our current state of irrigation technologies and imagine what innovations might exist a half century from now, the differences will amaze us!

Case Study 4: Going with Heritage Grains to Best Utilize Our Rain

In 2011, as Jeff and Emma Zimmerman began reviving the mystique of the historic Hayden Flour Mill in Arizona, they learned that they needn't look too far for heritage grains to promote. At least four kinds of wheat and several barleys were introduced to the Sonoran Desert well before Padre Kino's missions or water-run flour mills arose. Some had been lost for good, but others "had gone into hiding."

Two of those Old-World grains—White Sonora wheat and Pima Club wheat—were steady staples in desert communities for centuries before their decline around the time of World War II. Fortunately, plant explorers preserved the last remaining coffee cans of these heritage grains before they fell out of commercial cultivation.

Even though the seeds were saved, there was little infrastructure or obvious market left to support their processing. These historic grains did not rebound quickly as organic veggies and heirloom fruits did when the local food movement spread across the nation.

Nevertheless, the Zimmermans steadily scaled up their milling facilities.

They also built partnerships with farmers, grain scientists, historians, chefs, brewers, and bakers, including two renowned artisan bakers—Don Guerra of Barrio Breads and Marco Bianco of Pane Bianco. Their collaborations have increased grain production from just 10 acres of the initial White Sonora planting, to 400 acres by 2022 and another 400 that will be added on reservation lands in 2023. The acreage already in White Sonora includes croplands stewarded by two Pinal County farmers—Brent Sandstrom and Noah Hiscox. Noah is also exploring strategies that could reduce water applications per acre by 20 percent.

All along, Emma and Jeff had kept their eyes on that ultimate prize: reducing Arizona agriculture's water use. If planted in late December through early February, White Sonora can produce good yields on just twenty inches (1.66-acre-feet) of application. In a 2022 interview with Brianna Plaza, Emma described why she has focused on that prize:

> *"What we've done from Day One is keep climate change in mind, but more specifically, water usage in Arizona. We're seeing the trend of mismanagement of our water resources, and thinking of the future, [so] we need to feed ourselves with foods that require less water. Water is such a complicated issue [in] building a resilient local food system, [but it] is really important to our future."*

Other sources have suggested that by providing White Sonora with half the irrigation water that other wheat varieties receive, a farmer may save as much as 1.7-acre-feet per acre while reducing harvesting losses due to "lodging"—the bending over of wheat stalks that makes harvesting their grain difficult.

The successes of the Zimmermans comes from their protracted attention to the possibilities of partnering for "win-win" innovations. These alliances have already generated an unprecedented market for heritage grains in the desert borderlands. They have joined forces with the legendary Masienda to create a tortilla flour with 50 percent heritage corn and 50 percent heritage wheat, and with Chris Bianco on branded pizza flour blends. These blends have attracted over 750 "super fans" nationally who regularly bake at home with their flours.

Oftentimes, desert farmers have been willing to transition to the production of low water use crops but are unable to find markets to pay for the crop products at a price that can keep farmers and millers both out of debt. Through their generosity and perspicacity, Emma and Jeff Zimmerman—along with James Beard Award-winning baker Don Guerra and many others—have stimulated a growth in heritage grain utilization that is enough for Arizona farmers to suffer less risk and enjoy more gain. We might conclude that water is best conserved by a cohesive food chain (Zimmerman 2022).

Case Study 5: Sowing Your Wild Oats or Wheat To Regenerate a Desert Farm

Halfway between Casa Grande and Yuma in Arizona, a historic farm in the desert is being restored and rejuvenated by pioneer J. Dax Hansen, who has begun charting out a future that is rooted in healthy soil. Oatman Flats Ranch, the four-generation family farm that Dax is revitalizing is in Maricopa County, a desert landscape where agriculture production relies heavily on pumping precious groundwater.

Despite growing tensions over water between farmers and housing developers in Maricopa County, Hansen is committed to a model of regenerative agriculture that he hopes will dampen rather than heighten the conflict. He is endeavoring to do so in one of the hottest, driest, and saltiest arid landscapes where agriculture still occurs in the U.S.

His goal is to push the boundary of regenerative farming practices first developed in more temperate climes to conserve hundreds of millions of gallons of water in the aquifer beneath his family farm and up and down the Lower Gila River. One of his strategies is to enhance the soil water-holding capacity and the biological health of his fields with the planting of heat- and drought-adapted crops that require less water, such as White Sonora wheat.

So far, so good. In the first two years of production as the only Regenerative Organic Certified® farm in the Southwest, Oatman Flats Ranch more than a million pounds of low water heritage wheat and distributed more than 12,000 packages of Oatman Farms baking mixes in ways that saved 9,259,932 gallons of water compared to what would be used growing alfalfa in similar conditions.

Yadi Wang, who works on the farm management team at Oatman Flats Ranch, unpacks how they came to that figure:

> *"From our data, we have found that with every pound of grain we grow, we conserve approximately 700 gallons of water compared to growing alfalfa in our region. What that means is that with the approximately half a million pounds of grains harvested annually, we may save up to 350 million gallons of water a year. This figure includes growing cover crops that help add biodiversity, prevent soil erosion, and mitigate floods during non-cash crop season."*

Hansen is successfully developing markets for Oatman Farms' Regenerative Organic Certified® heritage wheat and baking mixes. Their premium mixes are found on local grocery store shelves and on Amazon.com. Moreover, Oatman Farms has been featured in chef Chris Bianco's 2022 Chef's Table Pizza Netflix episode, and their products are on the menus of Arizona restaurants like Arizona Wilderness Brewery and Chompie's focused on regenerative agriculture and saving Arizona's wilderness and rivers.

Although Oatman Farms' first product line focuses on heritage grains, Hansen is working with accredited agroecologists to plant and evaluate over a dozen varieties of mesquite, palo verdes, ironwoods, agave, and prickly pear cactus as well. The former three are deep-rooted nitrogen-fixing legume trees, while the last two are succulent perennials that yield more edible biomass on a fraction of water than corn or sorghum. In many ways, Dax has built a private experimental farm that will create sustainable and profitable business models that other family farmers can emulate.

CONCLUSIONS: PLANNING FOR UNCERTAINTY, EMBRACING INNOVATION

By December 2020 diminishing water levels in Lake Mead were exposing geological and archaeological strata not seen since dam was first completed. Photo by Brian Richter

Traveling through Arizona's farm country in the summer and fall of 2022, it is clear that times are changing. Glancing out the window of a car or truck, any attentive observer can view dramatic actions and poignant images that deviate from business as usual.

One can witness hundreds of thousands of pounds of PVC pipes being installed for low-level sprinkler systems on chili farms in Pinal County. One can see "For Sale" signs in several counties that indicate how fast farms are being put up for purchase by developers. One can hear of farmers who had to sell a significant portion of their acreage to solar energy companies to save the rest of their fields; they are now surrounded by thousands of solar photovoltaic panels that generate their own heat island effects. One can observe farmers trying out new crops, from guayule and mesquite, to gourds and spices. And one can glance out over thousands of acres where tumbleweeds are the only cover left on fallowed land until a family can decide upon a possible option for the future.

Yet one outcome of this tragic restructuring of Arizona water allocations is that we can now say the phrase "water crisis" aloud without villainizing any single party or multiple parties, so that we can get on with solving the many technical, economic, environmental, administrative, and political problems that now lay clearly before all of us. We simply can't fix a problem if we don't acknowledge it and correctly name it (**Appendix F**). We need both innovation and collaboration to further shape water-proof scenarios that will help "float the boat" down a river that deserves saving just as much as Arizona's 4000-year agricultural legacy deserves saving.

While help may be on the way from federal, state, and philanthropic sources, those participating in our workshop are wary of short-term disaster relief and crop insurance funds dominating the mix of support available to farmers who wish to transition to other crops, irrigation technologies or strategies. They would prefer to see an increasing proportion of available funds go to "adaptation" rather than "mitigation" that fails to move the needle toward a more climate-resilient agriculture and food system in Arizona.

That said, this exercise has demonstrated that there are many interesting pilot projects (**see Case Studies**) that would indeed move the needle, if there were commensurate investments in their expansion. There are viable solutions at hand, or at least in the innovation labs and experimental farms that await ground-truthing.

At the same time, there are several key issues that our survey and retreat of experts could not adequately address, but will be problems that need immediate solutions:

1. Under-representation of Native Nations in Arizona and the Colorado River Basin in negotiations to chart a post-Tier 2 water future for Arizona agriculture.
2. Maintaining adequate environmental flows in rivers and to assure legally protected endangered species in the U.S. and Mexico are not further compromised by habitat desiccation and fragmentation.
3. Failure of current funding mechanisms to cover the costs for re-vegetating upwards of 150,000 acres of cropland that is being temporarily fallowed or permanently retired in Arizona; such funds are urgently needed to stave off dust bowls in several counties.
4. Paucity of training centers to help transitioning farmers in their consideration of novel crops, irrigation technologies, regenerative practices, agroforestry systems, or agrivoltaic options for the future.
5. Tighter controls on uncapping and deepening pre-1980 drilled wells in Arizona's AMAs, and stronger fines against attempts by developers or farmers to drill clandestine wells.
6. Assistance to farmworkers now being displaced due to the effects of Tier 2 water rationing, or put at risk by increasing dangerous heat and dehydration conditions in remaining farmlands.
7. Fully addressing Mexico's water needs not only for their farmers on the Colorado River delta, but for the many endangered wildlife dependent on freshwater flows continuing south of the border.
8. Grappling with the inexorable growth of urban and ex-urban housing developments, many of which will indefinitely use more water per acre than irrigated field agriculture.
9. Dilemma of some farmers' current dependence on crop insurance payouts that have served as a disincentive to transitioning to true adaptation to the new climate normal.
10. Disproportionately high levels of use of Colorado River water to grow alfalfa and grass hay to feed livestock for meat and dairy production.

In general, farmers will require assistance in transitioning to reduce the costs of water and energy inputs to crop production, but will also need assistance in marketing their harvests or the value-added products derived from them to increase their income per acre. Fortunately, in December 2022 the University of Arizona and three non-profits received a $4.7 million grant from the USDA that will help farmers throughout the state to more rapidly implement climate-friendly solutions that can reduce their input costs, while helping promote value-added products in markets to enhance their income. Additionally, University of Arizona President Robbins announced the formation of the Presidential Advisory Commission on the Future of Agriculture and Food Production in a Drying Climate, charged with suggesting actions to bring the varied and many resources of the university to bear on keeping agriculture productive even in the face of less water.

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Women from Mexico comprise a growing proportion of farm workers harvesting irrigated crops in southern Arizona and California, where they regularly face the risks of dehydration and heat stress. Photo by Gary Nabhan

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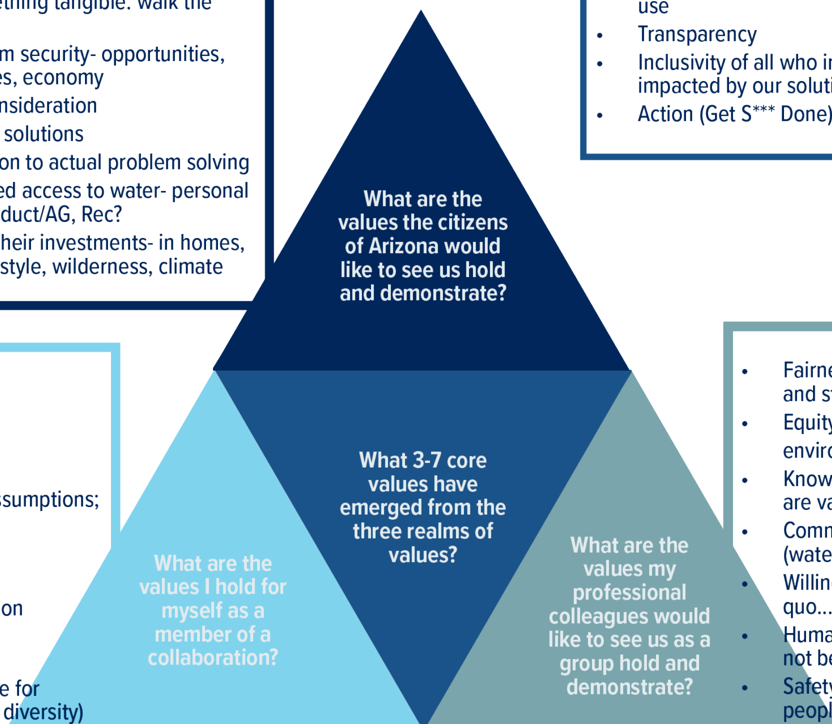
APPENDIX A. VALUES OF A HIGHLY SUCCESSFUL COLLABORATION IDENTIFIED BY PARTICIPANTS

- Respect for historical and geographical context
- Prosperity from water security
- Help society
- Equity and accessibility
- Actionable and accessible solutions
- Spend public money wisely (an how it was meant to be spent)
- Do something tangible: walk the taco!
- Long term security- opportunities, resources, economy
- Local consideration
- Realistic solutions
- Dedication to actual problem solving
- Continued access to water- personal food product/AG, Rec?
- Protect their investments- in homes, jobs, lifestyle, wilderness, climate

Core Values

- Making Arizona agriculture more resilient in the face of uncertainty through long-term sustainable water use
- Transparency
- Inclusivity of all who impact and are impacted by our solutions
- Action (Get S*** Done)



- Commitment
- Real-world perspective
- Help society
- Pleasure
- Willingness to question assumptions; skepticism
- Sustainability with equity
- Cooperations
- Define and achieve common grounds- cooperation
- Intellectual humility
- Spiritual commitment: care for "creation" (e.g. biological diversity)
- Deference to 1st Nations rights and/or those "left out"
- Genuine (authentic) (not disingenuous)
- Help society; help family farmers; preserve and regenerate historical landmarks
- Respectful of other views- openness

- Fairness- ask others what they need and strive to create win-win models
- Equity- farmers, consumer, environment
- Knowledge (our recommendations are valid)
- Commitment to sustainable future (water sustainability)
- Willingness to challenge status quo...(with holistic solutions)
- Humanity finding solutions that will not be the next problem
- Safety (engr. perspective), (health for people and environment)
- Creativity- innovating to effectuate positive change
- Cooperation
- Informed by science and need
- Don't normalize making the same mistakes all over again
- True engagement (not tokenism)
- Jargon-free unsoiled communication = straight talk

APPENDIX B. QUESTIONNAIRE RESPONSES

Group One Question: In addition to aggravating water scarcity or potential conflicts in water allocation, what three ways might weather-related disasters, temperature shifts, or changes in other human and natural resources affect our food, and energy security within our region?			
• Extreme conditions endanger farmworker health • Threat of fires and flooding may negatively impact production of food crops locally • Failing infrastructure will not be able to cope with extreme rain/flooding	• Food trade policies need to encourage more appropriate crops that are for local U.S. • Increasing dairy and beef production is misappropriating scarce water to detriment of other food crops • Temperature shifts and water reductions influence growing season and force changes in crop selection • Extended intense droughts will make growing even the desert adapted crops impossible	• Wider equity gap • Higher food prices because won't be able to buy locally • The climate instability on a global scale has tremendously impacted food security of people around the world. The Arizona water issues will impact farmers life, but 95% of agricultural products are exported elsewhere and we rely on imports (probably 95% imports) to fulfill consumer market need • Combination of rising gas prices and lower yields elsewhere magnify problems of importing food from elsewhere • Small family farms unable to afford rising input and production costs; farms consolidate to corporate ownership or sell to development • Loss of farmland and thus crops	• Mass migration from unlivable urban areas into still livable rural areas • Water reductions impact salinity management • Groundwater depletion is leading to drying of shallower wells and threatening food security • Rising land/property values may make it difficult for existing community gardens to maintain/expand • Breakdown of infrastructure due to flooding or erosion • Almost anything could happen. There is a multitude of scenarios, good and bad • In an extreme, dystopian conflicts to control food or water

Group Two Question: What three values, capabilities or rights need to be better protected to assure a more viable, equitable or resilient food and water future for farmers, farmworkers, and eaters in our region, particularly with respect to those whose voices and needs are often left out of the discussion?

Themes:

Environment	Ag/Producer	Ag/Consumer	Equity & Access	Indigenous	Municipal Mgt
• The inherent right of water to flow where it wants to flow, rather than being dammed The inherent right of "non-human" entities like clouds, rain, mountains, flowers, and pollinators to speak and be heard • Biodiversity • Soil ecosystem	• Tax preferences for keeping lands in production could potentially be changed to include preferences for groundwater savings • Regular conferences for discussion of trends & opportunities in farm- land transformation (with subsidies to enable attendance/ engagement) • Incentives (and removal of disincentives) for producers to sell regionally • Economic and immigration protections for farmworkers during fallowing/ ag downsizing • Possibly, federal price support and farm insurance programs could incorporate water sustainability principles	• Access to healthy, affordable, regionally produced foods • Supply chains could be improved and secured to ensure that they are resilient in the face of various disruptions. As agriculture is diminished in Arizona and the Southwest, Arizona cities will rely more heavily on food imported from out-of-state	• The right to clean drinking water • The right for poorer communities to access water • Equity • Equity needs to be built into the water distribution infrastructure. I'm not sure exactly how to do this but if this is a collective governance/ common property issue, it seems important for the infrastructure to allow for decision-making about equitable access to actually be implemented • More listening to the folks on the ground and less political influence by paid lobbyist	• Compensation for tribes that cannot fully utilize water rights, dedication of unused water to environment • The inherent right of indigenous peoples like the Hopis to practice and to readjust their cultural relationships to water on their own lands and other public and private lands • Full adjudication of all native water rights • Water security/ sovereignty as a basic human right – esp. on the Navajo nation. (Not sure how to implement this but the disparity is shocking) • Enforcement of intellectual property rights for Indigenous crops	• Tiered Pricing for water consumption in Phoenix/Tucson • Discounts for people who have low-irrigation landscaping

Group Three Question: What are three barriers we need to address that keep farmers from modifying current or adopting new practices and technologies to deal with water scarcity and other challenges (energy prices for pumping, labor shortages or vulnerability to heat, supply chain issues, etc.)

Themes: Policy Incentive Misaligned	New Market Uncertainty & Cost of Entry	Cost of Retooling to Transition as Barrier	Lack of Adaptation Pipeline	Cultural and Behavioral Resistance to Change
• Crop insurance impedes shifts to alternative crops; need transition to less-vulnerable crops • Possibly, federal price support and farm insurance programs could incorporate water sustainability principles • Tax preferences for keeping lands in production could potentially be changed to include preferences for groundwater savings • Incentives (interest free loan, easy payment for conservation practices and good practice insurance discount) • The USDA market formula quantity and efficiency needs to be changes • Misaligned specialty crop program with Arizona's needs for water efficient specialty crops	• Supply chains could be improved and secured to ensure that they are resilient in the face of various disruptions. As agriculture is diminished in Arizona and the Southwest, Arizona cities will rely more heavily on food imported from out-of-state • Poor market for new/ alternative crops • Demonstration of crop viability and profitability for alternative crops • Price of commodities and consumer demands • Cost of infrastructure and technology to pilot new crops • Uncertain or unstable markets for new/ niche crops • Establishment of markets (and price guarantees?) for alternative crops	• Less relying on inputs • Expenses • Cost of infrastructure required to shift to new crops/ regenerative practices • The cost of new technology • Path dependency – too many sunk costs in other technologies • Technology is scary	• Lack of publicity about farmers who are changing their ways to meet the new realities • Knowledge barriers (what tools are available?) • Lack of public education to address farmers concerns • Lack of young people who are engaged in farming as a means of earning a living	• Ignorance and lack of education • Cost/risk barriers to trying new things. (Why invest a lot of money if it may not work/many not raise profit margin?) • Long-standing practice/ cultural heritage • Failure to adapt to change. This is the way "my Daddy did it."

APPENDIX C. CONSUMPTIVE WATER USE OF ARIZONA CROPS.

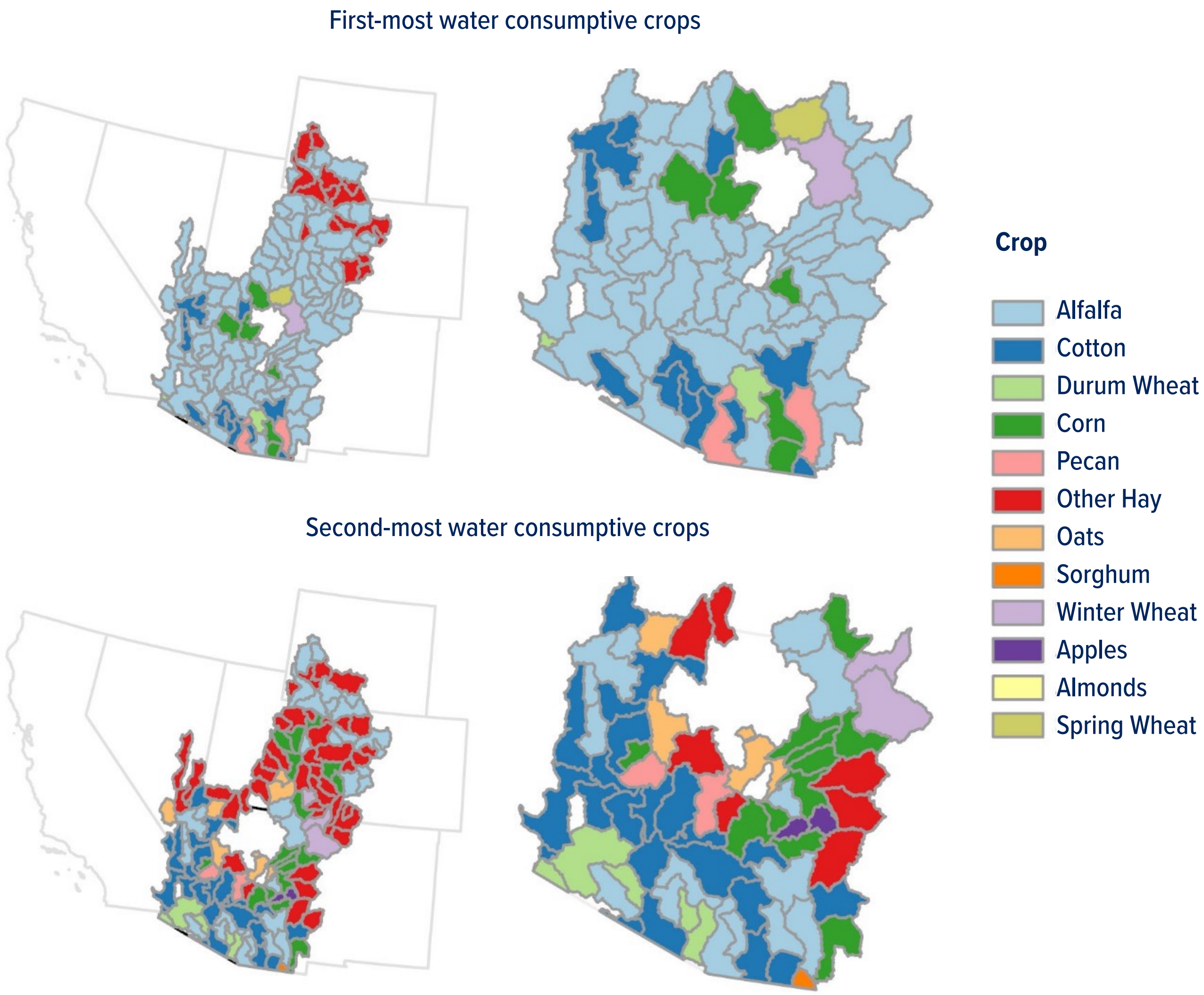
Table C1. Acre-feet of water applied per acre for Arizona crops.

Crop	Water applied (acre-feet /acre)			Reference
	Avg	Low	High	
Alfalfa	5.4			Frisvold 2015
Barley and Durum wheat	3.1			Frisvold 2015
Beans, common dry	2.2			Frisvold 2015
Beans, tepary		0.5	1.75	Burgess 1983; Looker 1995
Broccoli		1.88	2.83	Acker et al. 2008
Cabbage		2.08	3.5	Acker et al. 2008
Cantaloupe melon		1.67	3.33	Acker et al. 2008
Cauliflower		2.08	3.08	Acker et al. 2008
Chile pepper		1.82	4.5	Acker et al. 2008
Corn for grain	3			Frisvold 2015
Corn for silage	4.1			Frisvold 2015
Cotton	4.5			Frisvold 2015
Dry onion		1.94	2.75	Acker et al. 2008
Guayule		2.5	4	Badzinski 2022; Elshikha et al. 2021; Evancho and Hullinger 2021
Head lettuce		3.42	4.29	Acker et al. 2008
Honeydew melon		1.86	3.33	Acker et al. 2008
Leaf lettuce		3.42	4.29	Acker et al. 2008
Pecans		2	7	Skaggs and Samani 2005
Potato		2.03	5	Acker et al. 2008
Romaine lettuce		3.42	4.29	Acker et al. 2008
Sorghum	3.3			Frisvold 2015
Spinach		1.25	3	Acker et al. 2008
Watermelon		1.86	4.17	Acker et al. 2008

Table C2. Average total water consumption in Arizona by crop (2000-2019). *Data source: Richter et al. (in review).*

Crop	Crop Water Consumption (acre-feet/yr)
Alfalfa	499,233
Cotton	389,801
Durum Wheat	129,299
Corn	55,949
Barley	51,938
Pecan	32,560
Other Hay	28,227
Oats	19,967
Sorghum	17,439
Winter Wheat	11,751
Oranges	7,408
Dry Beans	3,657
Potato	2,127
Spring Wheat	1,978
Grapes	661
Apples	526
Almonds	526
Sugarbeet	430
Sweet Corn	405
Canola	173
Peas	142
Sunflower	21
Soybean	11
Tomato	1
Sugarcane	<1

Figure C3.Most water consumptive irrigated crops in Arizona. *Data source: Richter et al. (in review).*



APPENDIX D. ACHIEVING SOLUTIONS: ASSISTING AND RESISTING FACTORS

Result of group brainstorming in response to the prompt: What will help us achieve and prevent us from achieving scenarios?

Assisting Forces: *What helps us achieve our scenarios?*

- Scale of crisis is "all options on the table"
- Alternate funding sources (land trusts, Slow Money, RSF Social Finance) are more & more common
- AZ's status as StrikeForce USDA state should [increase] access to $ through Farm Bill & Inflation Reduction Act
- Farmers are probably more open to considering options than ever before
- Policy makers with Ag background
- Current water crisis (public support)
- Funding to implement solution
- Large Water Community with a lot of experience
- System thinking of economic savings of improving nutrition and health benefits of how agriculture system should be
- Bipartisan issue
- Enormous youth momentum for energizing social & environmental sustainability
- Some expertise

Resisting Forces: *What prevents us from achieving scenarios?*

- Urban-rural competition
- Urban-rural divide prevents many consumers & politicians from empathy with farmers, re: the urgency and severity
- Acceptance of facts
- Opposition from farmers and others
- Federal Bureaucracy
- Historic tensions between Ag & tribes
- Language gets coded as partisan
- Ease & scale/speed of dis- and mis-information
- Perception of bias/liberal
- Push-back from policy makers who have agenda or interest to protect
- Limited public understanding of water complexities
- Infighting among Ag
- $$$
- Data gaps
- Tunnel vision
- Limited Funding

APPENDIX E. FARMER RESOURCES

Arizona Water Infrastructure Finance Authority (WIFA) As outlined in Arizona Senate Bill 1740, $1 billion or more dollars of state funds will be made available from 2022 to 2027 by the Water Infrastructure Finance Authority (WIFA, an existing agency whose authority was expanded) via appropriations, grants, loans, municipal bonds. WIFA funding initiatives will include:

- Long-term water augmentation fund, $670 million (new)
- Water supply development fund, $220 million (expanded scope)
- Water conservation grant fund, $200 million (new)
- Basin supply + demand assessments to be performed by ADWR, $3.5 million (new)
- Drinking Water State Revolving Fund (existing)
- Clean Water State Revolving Fund (existing), and
- AZ Water Protection Fund and Water Management Assistance Program will continue to operate as normal, separate from the WIFA initiatives.

American Farmland Trust (AFT) Founded in 1980, AFT created the conservation agriculture movement, which speaks for the land—and for the people—who grow our food. They have three priorities: protecting agricultural land, promoting environmentally sound farming practices, and keeping farmers on the land. Today, because of AFT, millions of acres of farmland that otherwise would have been developed remain in farming, and tens of thousands of farmers and ranchers have adopted better farming practices. AFT currently has micro-loans and is applying for an upcoming grant that could further help producers with funding for land access and other capital needs. https://farmland.org/

Coalition for Farmland Preservation (CFP) Convened and managed by Local First Arizona, the CPF works to keep Maricopa County farmers farming by securing and locating land for local farmers who are vulnerable to development or have recently been displaced. The CFP is developing a multi-pronged approach to preserving Maricopa farmland as a model that can then be replicated in other counties statewide. The Coalition is also building a comprehensive approach to urban farmland preservation through conservation easements, policies, planning, public awareness campaigns, incentives, and creative partnerships. The Coalition assists farmers and ranchers throughout the state with technical assistance, finding funding and resources, and increasing consumer support through the use of the GoodFoodFinder online food resource hub and directory. https://www.goodfoodfinderaz.com/coalition-for-farmland-preservation

USDA National Institute of Food and Agriculture (NIFA) NIFA provides important financial support for climate change adaptation through the Agriculture and Food Research Initiative program to the Desert Research Institute and its Native Waters on Arid Lands project. https://www.nifa.usda.gov/

Arizona Department of Water Resources (ADWR). This agency oversees Statewide Planning and Rural Water Studies. The Rural Water Studies fund was established to assist Rural Arizona Watershed partnerships and watershed groups with the funding of projects and studies pertaining to the understanding, planning, management, and enhancement of water supplies in rural Arizona. Funding is authorized annually by the State Legislature. Requests for funding are reviewed by the Department when funds are available. Watershed partnerships and/or watershed groups include local stakeholders and representatives of resource and regulatory agencies that are active in rural areas. https://new.azwater.gov/rural-programs

The Central Arizona Land Trust (CALT) serves as the administrator of the City of Phoenix Farmland Preservation program as approved by the Phoenix City Council. CALT is the subrecipient to place conservation easements on up to three farms with willing landowners. https://www.centralazlandtrust.org/save-our-farms/save-our-farms

USDA NRCS Agricultural Conservation Easement Program (ACEP) helps landowners, land trusts, and other entities protect, restore, and enhance wetlands, grasslands, and working farms and ranches through conservation easements. Under the Agricultural Land Easements component, NRCS helps American Indian Tribes, state and local governments and non-governmental organizations protect working agricultural lands and limit non-agricultural uses of the land: https://www.nrcs.usda.gov/programs-initiatives/acep-agricultural-conservation-easement-program

USDA Farm Service Agency (FSA) Natural Disaster Area Relief FSA's mission is to help ensure the success of Arizona's farmers and ranchers through various progams and technical assistance, including being eligible for natural disaster relief from droughts, fires, floods and heat waves. A new Secretarial natural disaster designation allows the United States Department of Agriculture (USDA) Farm Service Agency (FSA) to extend much-needed emergency credit to producers recovering from natural disasters through emergency loans. https://www.fsa.usda.gov/state-offices/Arizona/index

USDA Organic and Transitional Education Certification Program (OTECP) and Organic Certification Cost Share Program (OCCSP) help producers and handlers cover the cost of organic certification, along with other related expenses. https://www.farmers.gov/pandemic-assistance/otecp
https://www.fsa.usda.gov/programs-and-services/occsp/index

Arizona Community Land Trust Farm and Garden Land Protection Program The Arizona Community Land Trust (AzCLT) holds and protects land for the larger community, providing long-term access to land for community gardens and agriculture, and other community initiatives. https://www.arizonacommunitylandtrust.org/

Arizona Land and Water Trust Desert Rivers Program. The Arizona Land and Water Trust understands the critical role that farmers and ranchers play in the stewardship of our desert waters. Leveraging funding from private and public partners, the Trust offers landowners the opportunity—and financial incentive—to support their local river or stream. Completely voluntary, market-based water transactions provide landowners with the flexibility to choose how to use their water, and where and when to conserve that water, in any given season. Launched in 2007, the Desert Rivers Program was established to restore desert streams and rivers in the Upper Gila, Lower San Pedro and Upper Santa Cruz watersheds. https://www.alwt.org/desert-rivers-program-2/

APPENDIX F. CONTRIBUTORS TO THE WATER CRISIS: RECONCILING THE DIVERSITY OF PERCEPTIONS & OPINIONS

Although the primary goal of this report is to offer scenarios and solutions to Arizona's looming water crisis, we would be remiss if we did not address the problems that led up to this crisis. Proposed solutions that misread or poorly address the core or ultimate causes are bound to fall short. To fully address these contributing factors, we use the framework adopted by Carse (2020) and others that categorizes types of droughts. Their schema recognizes that hydrological droughts may ultimately be the geophysical cause of a crisis, but primary or secondary contributing factors include edaphic droughts created by salinization or depletion of soil moisture holding capacity, as well as infrastructural and political droughts that may exacerbate them:

> *"First, droughts, like other natural disasters, are not environmental manifestations of how infrastructures become intertwined with the more-than-human world through the accretion of sociotechnical decisions and, crucially, of how water shortage in a given region can be influenced by the built national and transnational networks that circulate liquid from one place to another. Second, infrastructures can naturalize some water uses in ways that shape the emphases of drought response and the capacities of various publics to make claims. Sometimes this infrastructural invisibility is an outcome of a given community's distance in time or space from the mundane organizational work that allows large, complex systems to operate. Sometimes it is an outcome of concerted efforts to manage environmental and political variability, dependency, and vulnerability".* ***- (Carse 2020)***

From our compilation and analyses of prevailing views, the following eight issues remain widely cited and, in some cases, hotly debated as causal factors contributing to the current crisis.

Overallocation of Colorado River water. A century ago, Colorado River Compact allocations were based on a miscalculation of one key variable: the total volume of water that the river could supply to human uses. Disregarding recommendations the U.S. Geological Survey (USGS) scientists and engineers, political officials and business boosters asserted that the river could provide 20 million AF to users in seven U.S. states and Mexico. USGS scientist E.C. La Rue suggested that the water flow in the Colorado River was closer to 15 million AF (Kuhn and Fleck 2021). Scientists now estimate the recent average flow in this highly variable system to be only about 12 million AF. That miscalculation has not only led to chronic overallocation of Colorado River water for direct human uses like deliveries for irrigated agriculture and for potable water consumption in urban households (Jones 2022). It has also limited the water left in the river for endangered fish and wildlife and for ecosystem services such as water purification by wetland vegetation.

Climate Change. Long-term climate change driven by human activities—not an isolated, temporary drought—is considered by many to be the ultimate driver of flow declines in the Colorado River since 2000. Consumptive uses of the river have not been reduced to a level commensurate with these declines in water supply. Recurring annual deficits between supply and consumptive use had led to a need to remove water stored in Lake Mead and Lake Powell, which have now been depleted by three-fourths. The misreading of current water scarcity as the effects of "just one more drought" has set Arizona back in formulating and mobilizing solutions to help farmers and cities with this crisis.

Water-consumptive crops. Scientists have documented that half of the Colorado River's water is still being used to produce some of the most water-consumptive crops like alfalfa and grass for hay (Richter et al. 2020). Beef and dairy consumption is a leading driver of both water shortages and the endangerment of native fish in the Colorado River and its tributaries (Richter 2020). Arizona farmers continue to opt for growing crops like cotton, corn, and alfalfa which require large volumes of irrigated water, largely because they will not be immediately eligible for crop insurance indemnities if they switch to crops using lower volumes of water. Even after the announcement of Tier 1 rationing, alfalfa production acreage in Arizona increased by 7 percent (Dewalt 2022).

Farm subsidies. Some economists claim that the genuine interest from policy makers in assisting farmers has led to subsidies that suppress innovation and drought adaptation rather than promoting them. Crop insurance payments as drought relief to farmers will not be enough to bail them out of deep trouble, in fact they may aggravate conditions rather than relieving them (Miao 2022). Between 1995 and 2020, Arizona farmers received more than $740 million in crop insurance indemnity payments, according to the Environmental Working Group (EWG 2022). Even as the federal government promised billions of dollars to help farmers in the drought-stricken Colorado River Basin in late September 2022 as part of the federal Inflation Reduction Act, political scientist Elizabeth Koebele warned that such a knee-jerk emergency response "is not really a long-term measure, and the money is not there to do this into perpetuity" (Hager 2022).

Tribal Water Rights. Some claim that the increasing tendency of Tribal governments to assert and use their long-standing water rights has begun to pinch allocations to non-Indian farmers. Indigenous water allocations—which predate virtually all other water rights due to their seniority dates—is a concept poorly understood by non-Indigenous populations. It is clear that Indigenous Tribal water rights have been altogether overlooked, misunderstood or dismissed (Fonseca 2021, Heather Whiteman-Runs-Him, see insert). Their rights and needs have been chronically under addressed, and funds required to address these needs were often held back or redirected at the state level. Today, failure to fully engage Tribes in forging solutions could stalemate or put at risk the allocation negotiations which must be completed by the end of 2025. Even though 10 river Tribes have raised their voices regarding the river's future, not all Indian Nation leaders have been invited (or have come) to the table to negotiate with other water users of the Colorado River (Krol 2022). Some Indian water law scholars project that if all Arizona tribes were to settle their water rights cases and receive formal allocations, the total volume due them might be greater than the current allocation that Arizona is being granted through Tier 1 rationing edicts.

Rural–urban divide. Both farmers and city dwellers claim they are in a zero-sum game of winners and losers. While many scholars feel this dualistic framework is fraught with problems, few doubt that competition for scarce water is a contributing factor to the crisis. The flaws in this zero-sum game assumption are many, but include:

- Farmers have often sold their land to housing developers rather than to farmland preservation land trusts. Few are aware that exurban residents on former farmland may use 3–3.5 AF in perpetuity for each acre of homes or condominiums, compared to an average use of 4.5 AF per acre for irrigated crops in southern Arizona. Whereas retired farmland can be fallowed in times of drought, then renovated for later crop production, it is doubtful that walls, asphalt, and concrete will ever be removed to "daylight" arable lands in the future; and
- Demographers note that the per capita declines in water use within the city limits of Phoenix and Tucson—while laudable—are essentially negated by the influx of new urban immigrants to Arizona's metro areas, especially in developments on the urban fringes where use of water often remains unrestricted except by pricing. At the same time, city dwellers claim that farmers access federally subsidized water far more cheaply than urban developments do.

Groundwater depletion. Hydrologists lament the lack of understanding that surface water and groundwater reserves are oftentimes interconnected hydrologically. Excessive pumping of shallow groundwater can capture and deplete river flows. But surface and groundwater are also connected in the practice of irrigation, meaning that when surface water supplies are meager, farmers tend to pump groundwater more heavily. The failure to recognize the inter-relatedness of surface and groundwater has led to a reluctance to prevent more well drilling and aquifer pumping each time access to surface water for irrigating crops has become scarce. Ethicists argue that the over-extraction of a shared and finite resource is short-sighted—whether done in the name of agricultural productivity or urban water security—that it only places farmers and metro dwellers at further risk.

Environmental water needs. Conservationists argue that policymakers have long underestimated the fundamental needs to provide base levels of water flows that provide critical habitat for endangered species, ecosystem services, and non-consumptive river recreation. They claim that this oversight has forced the federal government to issue mandates that could have been avoided if proactive planning and recognition of the need for maintaining proper river flows had been accomplished decades ago.

This list of presumed contributors to the water crisis in Arizona and the rest of the Colorado River shows the complexity of the problem. At the same time, it confirms that hydrological drought driven by climate change is not the only trigger of the water scarcity facing Arizona farmers and city dwellers nearby. Therefore, water shortages cannot merely be remedied by a technological fix or a one-time payout to farmers, but need integrated solutions involving input from and to multiple public sectors. The repeated failure of both federal and state to make tough decisions in the face of the mounting crisis has become obvious. No single factor alone can save the river in time to assure future water and food security. All stakeholders must take off their blinders, tighten their belts, strive to innovate, and pledge to genuinely collaborate.

THE UNIVERSITY OF ARIZONA

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