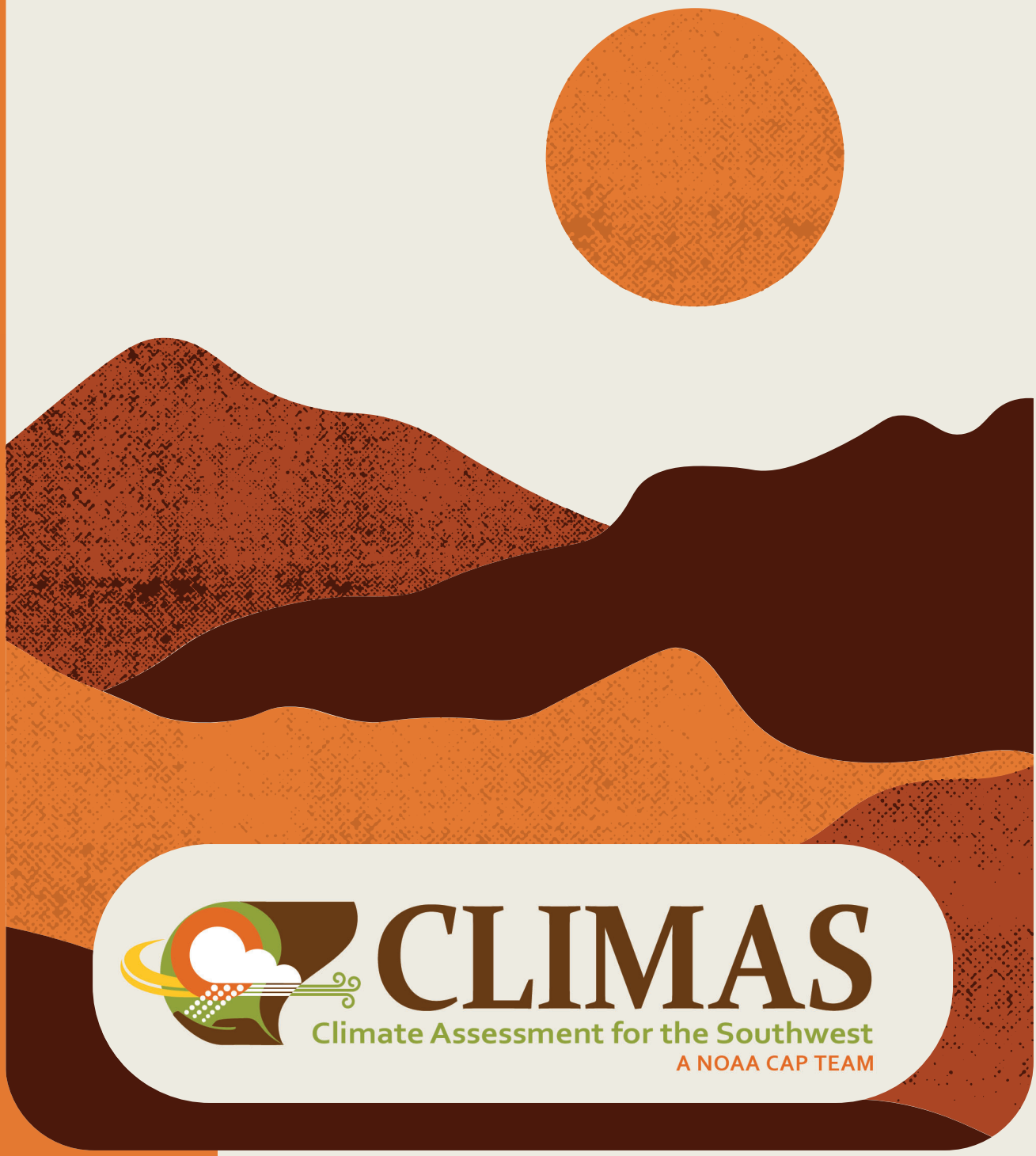

# CLIMAS

Climate Assessment for the Southwest

A NOAA CAP TEAM

## COLLABORATIVELY ASSESSING CRITICAL SOCIAL-ECOLOGICAL SYSTEM BUFFERS TO HELP BUILD REGIONAL CLIMATE RESILIENCE

FINAL REPORT: SEPTEMBER 1, 2017 – AUGUST 31, 2024

CLIMAS
Climate Assessment for the Southwest
A NOAA CAP TEAM

Climate Adaptation Partnerships
Formerly RISA

THE UNIVERSITY OF ARIZONA

NM STATE UNIVERSITY

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Photo: Melissa Merrick

# What is CLIMAS?

The Climate Assessment for the Southwest (CLIMAS) is a NOAA-funded program that connects researchers and professionals at the University of Arizona, New Mexico State University, and the Inter Tribal Council of Arizona to partners from the private sector, academia, and local, state, federal, and tribal governments. Since 1998, CLIMAS has brought the best available scientific knowledge to weather and climate-related challenges in the Southwest. CLIMAS is funded by the NOAA Climate Adaptation Partnerships (CAP) Program (formerly known as Regional Integrated Sciences and Assessments, or RISA).

**The work highlighted in this report focuses on the outcomes of 17 CLIMAS projects and CLIMAS communication, training, and outreach efforts supported by the National Oceanic and Atmospheric Administration's Climate Program Office through Grant #NA17OAR4310288.** This funding cycle originally ran from 2017-2022. CLIMAS was granted a no-cost extension for 2022-2023 and again in 2023-2024 to continue projects that experienced disruptions from the COVID-19 pandemic.

# CLIMAS Focus Areas

CLIMAS research focused on several key themes concerning climate in the Southwest during this grant cycle:

**Water Resources**: Understanding impacts of climate change on water availability, streamflow, and drought in the region.

**Urban Heat**: Investigating the urban heat island effect, its impact on public health, and planning strategies to deal with extreme heat.

**Drought Monitoring and Land Management**: Evaluating drought indices, improving drought monitoring, and informing wildfire management strategies.

**Agriculture and Food Systems**: Assessing climate-related risks to agriculture and food systems and developing local strategies for adaptation and resilience.

**Climate and Health**: Examining links between climate change and human health, including extreme heat, exposure to mosquito vectors, and dust storms.

**Indigenous Collaboration**: Building awareness of ethical engagement practices with Indigenous Peoples in climate research while respecting Indigenous Knowledge and data sovereignty.

**Outreach and Education**: Communicating climate science to various audiences, providing educational resources and training, applying knowledge to community initiatives, resource management, and planning.

**Decision Support and Climate Services**: Creating climate services, tools, and resources to support decision-making, such as tailored analyses and data, and guidance on adaptation strategies.

# CLIMAS Team during the reporting period

## *Principal Investigators*

**Daniel Ferguson:** Director, Climate Assessment for the Southwest (CLIMAS); Associate Professor, Department of Environmental Science; Associate Professor, Arizona Institute for Resilience; Univ. of Arizona

**Heidi Brown:** Associate Professor, Public Health, Univ. of Arizona

**Michael Crimmins:** Professor & Extension Specialist – Climate Science; Environmental Science, Univ. of Arizona

**Connie Woodhouse:** Regents Professor Emerita, Geography, Development, & Environment, Univ. of Arizona

**George Frisvold:** Professor, Agricultural and Resource Economics, Univ. of Arizona

## *Co-Principal Investigators*

**Stephanie Russo Carroll:** Associate Professor, Public Health Policy and Management; Associate Director, Native Nations Institute, Univ. of Arizona

**Bonnie Colby:** Professor, Agricultural and Resource Economics, Univ. of Arizona

**David DuBois:** New Mexico State Climatologist; Assistant Professor, New Mexico State Univ.

**Ladd Keith:** Associate Professor, Landscape Architecture & Planning, Univ. of Arizona

**Ben McMahan:** Assistant Research Professor, Arizona Institute for Resilience, Bureau of Applied Research in Anthropology, Univ. of Arizona

**Alison Meadow:** Associate Research Professor, Research, Innovation, and Impact (RII) – Societal Impact, Univ. of Arizona

**Gigi Owen:** Assistant Research Scientist, Arizona Institute for Resilience, Univ. of Arizona

**Jeremy Weiss:** Climate and Geospatial Extension Scientist, School of Natural Resources and the Environment, Univ. of Arizona

## *Senior Personnel*

**Erika Austhof:** Research Specialist, Public Health, Univ. of Arizona

**Christina Greene:** Assistant Research Scientist, Arizona Institute for Resilience, Univ. of Arizona

**Sarah Leroy**: Research Staff, AZ Institutes for Resilient Environments & Societies, Univ. of Arizona

**Mitch McClaran:** Professor, School of Natural Resources and the Environment, Univ. of Arizona

**Trevor McKellar:** Research Scientist, Arizona Institute for Resilience, Univ. of Arizona

**Craig Rasmussen:** Professor, Soil Water & Environmental Science, Univ. of Arizona

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**Rachel Rosenbaum**: Research Professional, Arizona Institute for Resilience, Univ. of Arizona

**Marcel Schaap**: Associate Professor, Soil, Water and Environmental Science, Univ. of Arizona

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**Ramon Driesen:** Bureau of Applied Research in Anthropology, Univ. of Arizona

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**Stan Engle:** Plant & Environmental Sciences, New Mexico State Univ.

**Ty Ferré**: Hydrology & Atmospheric Sciences, Univ. of Arizona

**Andrea Gerlak**: School of Geography, Development and the Environment, Univ. of Arizona

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**Rey Granillo:** Development and Information Technology, Univ. of Arizona

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*Plant and Environmental Sciences*: Tye Bell, Jonathan Consford, Natalie Franco, Jaylen Fuentes, Jace LeBlanc, Zahra Ghodsi Zadeh

**Undergraduate Student Researchers – University of Arizona**

*College of Engineering:* Mansur Bolaji Olaitan

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*Department of Mathematics*: Dharma Hoy

*Department of Nutritional Sciences*: Tommey Jodie

*Mel & Enid Zuckerman College of Public Health*: Kaleb Lee Arnold, Taylor Rae Ellsworth

*School of Animal and Comparative Biomedical Sciences:* Daniel Acosta

**Environment & Society Fellows – University of Arizona**

*Arid Lands Resource Science:* Marie-Blanche Roudaut, Simone Williams

*Art and Visual Culture Education:* Rachel Zollinger

*Center for Latin American Studies:* Jake Dean

*Environmental Science:* JoRee LaFrance, Alma Morales, Norma Villagomez-Márquez

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*Mel and Enid Zuckerman School of Public Health:* Emily Cooksey

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*School of Natural Resources:* Lea Schram von Haupt, Stephanie Doerries

*Soil and Water Science:* Kunal Palawat

# CLIMAS – Role in the Southwest

Through innovative research, knowledge co-production, and collaboration, the CLIMAS team helps strengthen the Southwest's resilience to climate variability and change. During this funding cycle, CLIMAS accomplished this in the following ways:

**Increasing scientific knowledge:** CLIMAS researchers brought the best available science and research methodology to address important climate questions—such as the impacts of drought on agriculture, the risks of extreme heat in urban areas, and effective strategies for climate adaptation—faced by people, governments, businesses, and other organizations in the Southwest. To ensure the usefulness of these findings, CLIMAS tailored its research outputs to meet the needs of its partners.

**Informing decision-making:** Knowledge generated through CLIMAS research informed decision-making across a range of scales – from individual households, to local and state governments, to federal programs. CLIMAS research also informed decisions related across sectors such as water resource management, public health, urban heat governance, land management, and climate adaptation planning.

**Developing new tools and information resources:** CLIMAS produced a variety of tools and resources to support climate adaptation and decision-making, such as monsoon visualizations, wildfire data tools, data repositories, economic analyses, and urban heat maps.

**Strengthening partnerships:** Collaboration and knowledge sharing were central to CLIMAS projects, fostering new and stronger relationships between researchers, community partners, stakeholders, and decision-makers.

**Training the adaptation workforce:** CLIMAS provided training and research opportunities for students and early career scholars in use-inspired and collaborative research, contributing to a growing pool of climate researchers and professionals.

**Securing additional funding and resources**: CLIMAS projects directly supported communities in securing funding for climate-related initiatives, such as water projects, green infrastructure, and local workshops. CLIMAS investigators leveraged their research to obtain additional funding, expanding research into new topics, geographic regions, and partnerships.

# CLIMAS by the Numbers

## ACTIVITIES AND OUTPUTS BY THE NUMBERS

*Presentations Given to Stakeholder & Academic Audiences:* **468**

*Academic Articles Published*: **116**

*Reports Produced for Partners and Stakeholders*: **102**

*CLIMAS-related Master's Theses and PhD Dissertations*: **17**

*Climate Briefs Disseminated*: **198**

*Podcasts Recorded*: **63**

*Workshops, Seminars, & Trainings Facilitated*: **76**

*Appearances in the Media*: **327**

*Advisory Roles Served*: **88**

*Online Tools Developed*: **17**

*Environment & Society Graduate Fellows Funded:* **18**

## SOCIETAL IMPACTS BY THE NUMBERS

Evidence of CLIMAS impact in the region was collected through annual reports, interviews with project teams (2019 and 2022), and interviews with societal partners (2022 or 2024). During the reporting period, the CLIMAS team had the following types of societal impact:


31 Conceptual Impacts - raised awareness or understanding of an issue


52 Capacity Building Impacts - new skills, resources, or increased ability to do something


35 Connectivity Impacts - new or strengthened relationships


35 Instrumental Impacts - direct applications to policies, decisions, or actions


1 Socio-Environmental Impact - changes to social or environmental systems

# Research Findings and Applications

The following section highlights research findings from the reporting period and the impact of these findings for project partners, the CLIMAS team, and the end-users of research information.

## The Influence of Climate on Lower Colorado Streamflow Variability: Present, Past, and Future

**Investigators:** Connie Woodhouse, Dan Ferguson

**Research Focus:** Warming temperatures have an increasingly important effect on streamflow and surface water supplies. In the three major tributaries of the Lower Colorado River Basin (LCRB) – the Salt, Verde, and Gila Rivers – temperature may play a more significant role in mediating how much precipitation ends up as streamflow. However, before this project, studies had not yet investigated the impact of temperatures on streamflow in this basin. The initial project focused on understanding the role of temperature on streamflow in the LCRB. Another focus investigated the role of the monsoon's contribution to streamflow in the LCRB, and how warming temperatures may affect the monsoon's contribution.

**Research Findings:**

*Temperature and Streamflow:* Unlike the Upper Colorado River, the upper Gila River and major Gila River tributaries do not yet reflect significant declines in annual streamflow, despite warming trends (Figure1).

While statistically significant trends in annual streamflow are not evident, decreases in autumn and spring streamflow reflect warming temperatures and some decreases in spring precipitation.

Given relationships between observed climate and streamflow, current trends in hydroclimate, and projections for the future, it would be reasonable to expect declines in Gila River water supplies in the coming decades.

*Monsoon Influence:* Annual streamflow is dominated by cool-season precipitation, but the monsoon influence is discernable as well. The monsoon is variable across the basin and complicated by an inverse relationship with cool-season precipitation in the Salt and Verde River basins. Major multiyear streamflow droughts in the Salt and Verde River basins are often accompanied by wet monsoons, suggesting that monsoon precipitation may partially offset the impacts of a dry cool-season.

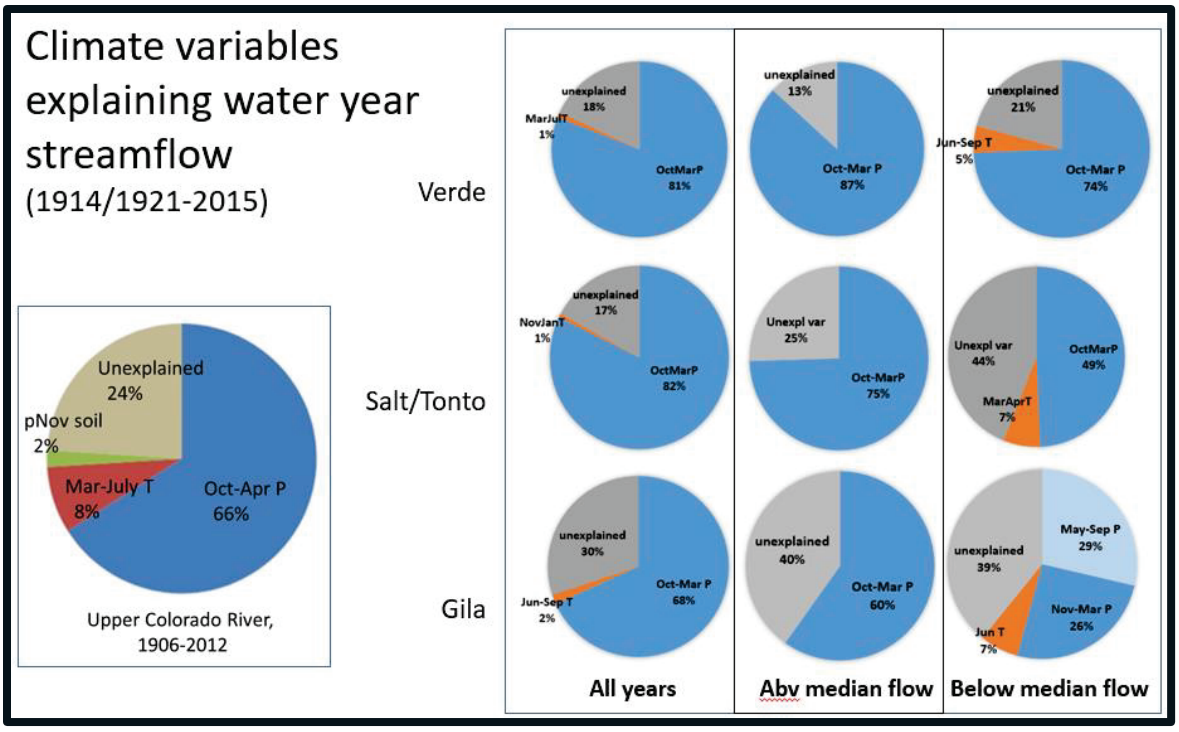


Figure 1. Climate variables explaining water year streamflow for the Verde, Salt/Tonto, and Gila River basins, with comparison to the Upper Colorado River basin.

## Research Impact

**Generating scientific results for water resource management:** This project produced meaningful scientific findings that were useful for decision-makers in the Lower Colorado River Basin (LCRB). Through collaboration with regional resource managers, the CLIMAS team developed a research agenda that addressed their concerns about the roles of temperature and monsoon patterns on water resources in the Salt, Gila, and Verde River basins.

***On the need for peer-reviewed research:***

Connie's research suggests results that we were expecting, but there wasn't a lot of peer reviewed literature to support it before this project. The way we communicate to the U.S. Bureau of Reclamation and to customers about water resiliency projects is heavily informed by this CLIMAS research.

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Bo Svoma, Salt River Project

**Understanding climate impact on water availability**: This research resulted in online fact sheets and peer-reviewed publications that clarified the roles of temperature and the monsoon on streamflow and surface water availability.

**Value of peer-reviewed research**: This project equipped end-users – notably Salt River Project and Flagstaff Water – with quantitative data and peer-reviewed research that supported their observations, enabling them to communicate more confidently with their constituents, agencies, and customers about climate and water resources.

**Related Publications:**

Woodhouse, C.A., B. Udall. 2022. Upper Gila, Salt and Verde Rivers: Arid Land Rivers in a Changing Climate. *Earth Interactions* 1:1-14. https://doi.org/10.1175/EI-D-21-0014.1

Lower Colorado River Basin Fact Sheets – One fact sheet for each of the Gila, Salt/Tonto, and Verde River basins were developed regarding a) streamflow and climate relationships, b) trends in key climatic variables, and c) the role of climate during multi-year droughts.

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## Improved Understanding of Climate Variability and Change Relevant to Orchards and Vineyards in Arizona and New Mexico

**Investigators:** Jeremy Weiss, Mike Crimmins, George Frisvold, Alison Meadow

**Research Focus:** Orchards and vineyards are particularly sensitive to temperature and are increasingly important to rural economies of the Southwest. However, growers of these high-value perennial fruit and nut crops have limited climate information to support critical decisions about selecting sites and cultivars. This research focused on understanding the impact of climate change on winegrape growing in Arizona and New Mexico, with a particular emphasis on vine phenology (growth stages). Researchers investigated how climate change, especially rising temperatures, might affect winegrape cultivation and vine development. The project also focused on assessing how well current winegrape varieties might adapt to projected warmer climate conditions.

**Selected Scientific Findings:**

*Climate impact on winegrapes:* Vine phenology – the timing of growth stages – is how weather and climate connect to the vineyard. Warmer conditions are causing the vines to progress through their growth stages earlier than usual, meaning events like budburst (when the buds open) and flowering are happening sooner. Changes in the timing of growth phases increases the risk of damage from late spring frosts, can affect the harvest, and the quality of the grapes.

*Bud break modeling:* Incorporating information about how fast grapevines lose their cold hardiness (de-acclimation kinetics), improves the accuracy of bud break models, especially in warmer climates.

*Impact on quality:* In white grape varieties, the duration of heat and cold exposure, as well as how extreme those temperatures are, influence sugar content (Brix) and the level of acidity (TA). Both measures are crucial for determining the flavor and balance of wine.

*Growing winegrapes in the Southwest:* Two of three American Viticultural Areas in Arizona and two of three in New Mexico are at the warm end of the winegrape growing spectrum. Excessive heat in these areas can cause negative impacts to plant physiology, fruit quality, composition.

**Summary of Impact:**

**Supporting adaptation in viticulture**: Through this project winegrape growers gained better understandings of how climate change affects their vineyards, specifically through

changes in vine phenology, or timing of growth stages. Growers incorporated climate and weather information into their decisions, such as the timing of irrigation.

**Building a network for information sharing and support:** The project fostered new relationships between researchers and growers, creating a stronger network for information sharing and support.

**Providing tailored resources:** Activities and resources like workshops, reports, and a monthly newsletter were specifically designed to meet expressed needs of local growers.

**Related Publication:** Improved Understanding of Climate Variability and Change Relevant to Orchards and Vineyards in Arizona and New Mexico. 2018. *Report Series*. Presented historical data analyses of temperature conditions relevant to orchards and vineyards as starting points for discussing project activities.

## U.S.D.A. Livestock Forage Disaster Program and Ranching in the Southwest U.S.

**Investigators:** Mike Crimmins, Christina Greene, Dan Ferguson, George Frisvold

**Research Focus:** The 2014 Farm Bill permanently authorized the U.S. Department of Agriculture's Livestock Forage Program, which compensates livestock producers who suffer grazing losses caused by drought and wildfire. The Livestock Forage Program bases payment eligibility on drought status categories of the U.S. Drought Monitor. Yet, Drought Monitor status assignments do not accurately capture the timescales of climate variability that drive forage production and drought impacts across Arizona and New Mexico. The current system may understate the extent of losses and need for compensation of Southwest ranchers. This study evaluated how the current application of the Drought Monitor in the Livestock Forage Program addresses drought and wildfire risks faced by Arizona and New Mexico ranchers. The research also explored who is excluded from receiving program payments based on how the drought status categories for the Drought Monitor are developed.

**Selected Scientific Findings:**

*Discrepancies in monitoring:* Researchers discovered a divergence between drought conditions as determined by the technical experts who develop the Drought Monitor and the ranchers and producers experiencing drought firsthand. These discrepancies are likely due to technical experts' reliance on quantitative data over qualitative observational data and the lack of quantitative data collection points (e.g., monitoring stations) in the Southwest.

*Incorporating local knowledge:* The Drought Monitor could better reflect drought conditions in the Southwest by incorporating local knowledge and qualitative observations of drought conditions on the ground. This improved drought monitoring product would provide more accurate triggers for the Livestock Forage Program payments for Southwest ranchers. However, the Drought Monitor has no incentive to change the mechanisms that

trigger Livestock Forage Program payments, and ranchers typically complain when they feel there is a discrepancy and are not receiving payments.

**Summary of Impact**

**Improving understanding of drought monitoring:** Findings resulted in a deeper and more nuanced understanding of regional drought monitoring. It improved research interview participants' knowledge about how the Drought Monitor is created and how it connects to Livestock Foraging Program payments.

**Strengthening partnerships:** The project strengthened relationships between CLIMAS researchers and key partners in drought monitoring and land management across Arizona and New Mexico, leading to valuable connections for future collaborations and promoting a more integrated and dynamic approach to drought research.

**Supporting policy discussions:** The final project report aimed to provide a better picture of what drought monitoring in Arizona looks like in Arizona and can inform policy discussions around the use of the Drought Monitor and Livestock Foraging Program.

**Related Publication:** Greene, C., M. Crimmins. 2024. Perceptions and Experiences with Drought and the Livestock Forage Disaster Program in Arizona. Climate Assessment for the Southwest – University of Arizona, Tucson, AZ.

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## Sectoral Impacts of Drought and Climate Change

**Investigators:** George Frisvold, Ashley Bickel, Dari Duval

**Research Focus:** To effectively address the impacts of drought on Arizona's rural economies, government agencies, businesses, and natural resource managers need a clear understanding of how drought affects these communities. This knowledge is essential for informed decision-making and the development of drought mitigation and response plans. In response to numerous stakeholder requests, this project examined the impacts of drought on climate sensitive sectors in the Southwest, focusing on agriculture and outdoor recreation.

**Selected Scientific Findings:**

*Regarding drought and agriculture:* In Arizona, short-term drought has little effect on crop yields, because most croplands are irrigated. Longer-term drought that results in reduced irrigation water supply, will cause farmers to cut back acreage. However, yields on remaining planted acres stay relatively stable. Drought effects on irrigated crops in Arizona are different than those on rainfed crops in the Plains and Midwest.

*Regarding drought and outdoor recreation:* The effect of drought on outdoor recreation depends on the length of the drought measure. Short-term drought (measured by one-month Standard Precipitation Index (SPI)) is associated with more recreation visits, while longer-term drought (measured by 24-month SPI) is associated with fewer visits. People may avoid outdoor recreation in especially rainy months (short-term effect). Longer-term drought can reduce streamflow, water in seeps in springs, and wildlife viewing

opportunities, while increasing wildfire-related park closures. Figure 1 below shows the effect of changes in SPI (1-month) and SPI (24-month) on visits to Arizona state parks.

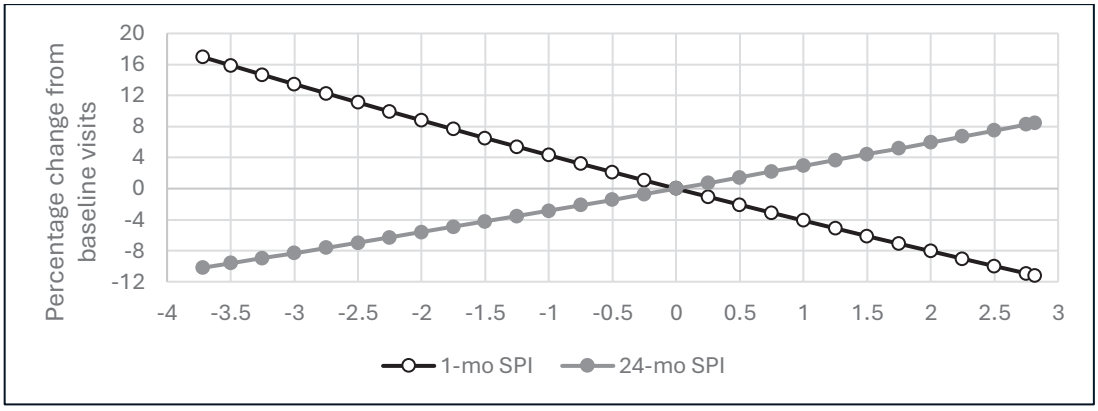


*Figure 1*. Percentage change in visits to Arizona state parks from baseline visits with changes in SPI (1-mo) and SPI (24-mo).

*Regarding economy and outdoor recreation:* Arizona residents generate an estimated $8.3 billion in annual economic activity around non-motorized trail use. Trail users travel furthest to access areas that are more heavily forested, have cooler average maximum and minimum temperatures, and have steeper and more varied slopes.

## Summary of Impact

**Increasing understanding on the economic impacts of drought:** This project provided valuable insights regarding the economic impacts of drought in Arizona, particularly for agricultural and outdoor recreation sectors. A main finding regarding Arizona agriculture is that crops are highly irrigation-dependent, meaning that drought's primary effect is not on crop yields but on planted acreage. A main finding for tourism and outdoor recreation shows an increase in recreational visits during periods of short-term drought, but a decrease in visits over periods of longer-term drought.

**Communicating drought impacts**: CLIMAS researchers directly addressed Arizona stakeholder requests for information by providing findings in presentations and publicly accessible reports.

## Related Publications:

Bickel, A.K., D. Duval, G. Frisvold. 2021. Drought and Agriculture in Arizona. Final Report to the Arizona Department of Water Resources. University of Arizona Cooperative Extension,

Duval, D., A.K. Bickel, G. Frisvold. 2021. Effects of Reservoir Levels on Arizona National Recreation Area Visitation, Visitor Spending, and Local Economies. *JAWRA – Journal of the American Water Resources Association*. https://doi.org/10.1111/1752-1688.12962

Duval, D., G. Frisvold, A.K. Bickel. 2020. The economic value of trails: A travel cost method study. Final Technical Report to the Arizona Parks Board. Department of Agricultural and Resource Economics, University of Arizona.

## Evaluating Existing & Developing New Drought Indices Using Modeled Soil Moisture Time Series

**Investigators:** Mike Crimmins, Dan Ferguson

**Research Focus:** Several drought indices exist, but there is little understanding about how to use them to make decisions about drought in various contexts. A system is needed to help people choose the right drought index at the right timescale and use it effectively to address their specific needs. This project assessed the effectiveness of two common drought indices, the Standardized Precipitation Index (SPI) and the Standardized Precipitation Evapotranspiration Index (SPEI), by comparing them to past soil moisture conditions. Researchers used HYDRUS-1D, a soil water model, to simulate how water moves through soil over long periods (over 50 years) at a daily resolution. Historical soil water profile climatologies – detailed pictures of soil moisture changes due to varying climate conditions – were developed for locations in Arizona, New Mexico, and California.

The initial project study area focused on the Las Cienegas National Conservation Area (LCNCA), in partnership with The Nature Conservancy. The study area was then extended to include semi-arid lands from southern New Mexico to southern California.

### Selected Scientific Findings

*Effectiveness of drought indices:* Multiscalar drought indices like the Standardized Precipitation Index (SPI) and Standardized Precipitation Evapotranspiration Index (SPEI) correlate highly with soil moisture variability at various depths and across soil types. Both can serve as reasonable proxies for soil moisture drought, allowing index users to better track drought development on their lands.

*Variables that impact effectiveness:* The SPI and SPEI are most effective at tracking changes in soil moisture when the timescale of the drought index is adjusted to the depth of soil being monitored. For example, shorter timescales (1-3 months) track changes in shallow (~10cm) soil moisture variability, while longer timescales (9-12 months) track changes in deeper soil moisture (~30 to 50 cm). Correlations were consistent across low desert areas of the Southwest U.S but varied by soil type, with indices better matching drought conditions in soils with higher clay content. Overall, the SPI captured drought development in soils slightly better than the SPEI. This was attributed to the inclusion of potential and not actual evapotranspiration in the SPEI calculation.

*Optimizing drought indices for use:* Drought events at different soil depths are strongly related to seasonal patterns in precipitation. Drought indices can be optimized to follow these patterns by varying the timescale length during different calendar months (i.e. using shorter timescales during the rainy seasons and longer timescales during the dry seasons).

*Adjusting for soil type:* Accuracy can be further improved by considering the type of soil (sand soil, for example, requires short timescales to track changes). SPI better represented soil water availability in soils of the semi-arid Southwest.

***On using drought indices:***

Without soil moisture data, people use drought indices as proxies for estimating soil moisture. The focus of my dissertation was to understand if that worked. And the answer is yes. But people can also use drought indices at different timescales - one month, two months, three months, etc. Depending on the depth of soil moisture, the timescale length will change. So, a main outcome of this work is being able to effectively communicate this connection, like "If you want to get an idea of what soil moisture looks like at 30 cm, use a 6-month SPI timescale." That's valuable information for land managers, especially if they're trying to look at a specific type of crop or a specific type of vegetation on their landscape that might be changing. How and when it rains will impact when land managers might start seeing anomalies in their soil moisture.

–

*Trevor McKellar, CLIMAS*

## Summary of Impact

**Developing climate services for drought management:** This project supported the development of new climate services and educational resources to help land managers better understand and manage drought in the U.S. Southwest. Researchers explored relationships between common drought indices and soil moisture and discovered ways that land managers could more effectively monitor drought conditions at various depths.

**Increasing understanding and use of drought indices:** End users improved understanding of how different drought indices work, and how to choose the right one, at the right timescale, for their land management decisions.

**Building partnerships through collaboration:** The project tracked drought on rangelands across southern Arizona, New Mexico, and California, constituting millions of acres of grazing lands. By co-developing this project with land managers and presenting research findings to other end users, researchers have improved the utility of existing drought monitoring indices across the Southwest.

## Related Publications


McKellar, T.T. 2017. Evaluating How Representative Simple Multiscalar Drought Indices are of Modeled Soil Moisture Across the Desert Southwest United States. Master's Thesis. University of Arizona, Dept. of Soil, Water, and Environmental Science.

McKellar, T.T., M.A. Crimmins, M.G. Schaap, C. Rasmussen. 2023. Defining the multiscalar index timescale—Soil water depth continuum for the southwestern United States. *Journal of Geophysical Research: Atmospheres* 128:e2023JD039348. https://doi.org/10.1029/2023JD039348

McKellar, T.T., M.A. Crimmins. The Relationships Between Multiscalar Index Timescale and Soil Water Availability for the Southwestern United States *Journal of Agriculture and Forest Meteorology*, in Review.

## Impacts of climate extremes to interstate and local trucking industry across NM and AZ

**Investigators:** Dave DuBois

**Research Focus:** Transportation along U.S. highways forms a basis for the national economy, moves goods from place to place, and connects communities. Dust storms – caused by convective thunderstorms, wind, and exacerbated by drought – creates hazardous driving conditions. This issue is of particular concern near the Lordsburg playa, a dry lakebed in southwestern New Mexico.

This project aimed to understand dust events in southwestern New Mexico and use that information to inform driver education and dust storm early warning systems. Observation systems were developed to characterize and document the climatic and visual conditions that exist during dust storms.

### Selected Scientific Findings:

*Visibility:* Visual and instrumental data supported the hypothesis that commercial trucks have better visibility in dust storms than passenger vehicles, due to the seat height and view of drivers. However, dust concentration can differ at various heights, so visibility does not *always* improve with increased seat height.

*Dust concentration patterns:* Generally, there are higher concentrations of dust closer to the ground (1 meter) than higher up (3 meters). Gravity pulls dust particles downwards, making it harder for them to stay suspended in the air at greater heights. But wind and air currents also affect dust concentration. Dispersion - how wind and air spread dust particles – can sometimes lead to higher dust concentrations at 3 meters than at 1 meter.

*Effect of air conditions on dust:* Observations of dust emissions in southwestern NM show complexity and the importance of vertical motion and convection in the dispersion of dust plumes. Turbulent updrafts of air, caused by unstable air conditions due to uneven heating and wind patterns, can lift dust particles to higher elevations.

*Effect of thunderstorms:* Convective dust events, triggered by thunderstorms, can occur quickly without much warning and can cause a lot of damage. Summertime convection often occurs over the Gila or Chiricahua Mountains and can spark growth of storms by upslope forced convection.

*Using dust early warning systems:* Early warning dust forecast systems could potentially minimize the number of vehicle accidents and associated fatalities on New Mexico highways. However, driver behavior is also important. Education about driving during dust storms is also necessary to increase driver safety.

*Using machine learning to classify dust storms:* A system developed through this project used machine learning with time-lapse camera images to classify dust storms by analyzing characteristics like hue, saturation, and value bands. The system proved highly effective, achieving 97% accuracy and 94% precision in classifying dust storms.

### Summary of Impact

**Improving understanding of dust storms:** Regional drought conditions combined with thunderstorms and wind events create dust storms that reduce driver visibility and make

driving hazardous. This project increased understanding about dust storms in the Southwest which informed develop a dust storm warning system now in use by NOAA-NWS offices in El Paso, TX and Phoenix, AZ.

**Strengthening connections:** The project fostered collaboration between researchers, state transportation managers, and NOAA-NWS offices, strengthening connections and facilitating ongoing efforts to address dust storm challenges.

**Informing warning systems, training, and dust mitigation:** Findings informed New Mexico Department of Transportation's driver safety campaigns and installation of new road signs and driver warning systems. New Mexico State University and trucking companies incorporated project materials into driver training programs. Time-lapse imagery provided valuable insights into how native grasses can reduce dust emissions, contributing to knowledge about effective mitigation strategies.

### Related Publications

DuBois, D. 2022. Dust Mitigation Monitoring Project, Final Report. Prepared for the Research Bureau New Mexico Department of Transportation, Albuquerque, NM.

Fuentes, J. 2019. Using time-lapse footage to estimate mineral dust concentrations at heights correlating to passenger and commercial vehicles. MS Thesis. New Mexico State University.

Gutierrez, J. 2020. Automated detection of dust storms from ground-based weather station imagery using neural network classification. MS Thesis. New Mexico State University

## Southwest Tribal Data Summit: Partnering with Southwest Indigenous Communities to Identify Data

**Investigators:** Stephanie Russo Carroll, Dan Ferguson, Sarah Leroy

**Research Focus:** Indigenous communities use data, information, and knowledge to make decisions about climate resilience. However, the way that data is collected, stored, and managed has implications for tribal sovereignty. The lack of Indigenous control over Indigenous data has resulted in: limited environmental data for tribal lands; data that do not reflect community values and needs; insufficient support for Indigenous rights for environmental self-determination; and extractive climate research practices that provide little direct benefit for Indigenous communities.

Climate and environmental science researchers who want to engage with Indigenous communities often have little knowledge of settler colonialism and its ongoing impact or the harm caused by extractive research practices. Researchers need to adopt a responsible and ethical approach to research involving Indigenous communities that acknowledges past harms and prioritizes collaboration and mutual benefit.

This project focused on convening Indigenous scholars, students, and practitioners to discuss Indigenous data sovereignty, tribal data governance, and Indigenous Knowledge about climate resilience in the Southwest.

***On the need for Indigenous data sovereignty:***

The very nexus of all our projects' research is focused around the lack of Indigenous control of Indigenous data. That's resulted in data that don't meet the needs or the goals of Indigenous peoples. In this case it's mostly with respect to climate, but also, broadly all of the other relevant data that you'd need. Either because the data are not available, there are access issues, or the wrong outcomes or things are monitored, that kind of stuff.

–

*Stephanie Russo Carroll, CLIMAS*

### Summary of Impact

**Strengthening collaboration:** This project brought together Indigenous scholars, students, and professionals around Indigenous data sovereignty and Indigenous Knowledge on climate and the environment in the Southwest.

**Advancing understanding of Indigenous data sovereignty**: A 2018 summit convened by CLIMAS and the Native Nations Institute focused on defining and building shared knowledge around Indigenous data sovereignty and developing a network of people doing Indigenous community-driven climate resilience work. That summit prompted a second convening in 2019, leading to more informed discussions and collaborations around Indigenous Knowledge, data governance, and climate resilience.

**Supporting Indigenous-led research:** Discussions and outcomes from this work have enabled early career Indigenous scholars to conduct research and advocate for policies that support Indigenous data sovereignty.

**Impact on CLIMAS program**: This work influenced CLIMAS program operations by offering training opportunities for CLIMAS investigators on Indigenous data sovereignty, research governance, and ethical principles for working with Indigenous communities.

**Related Publication:** David-Chavez, D., D.B. Ferguson, A. Curley, T. Lane, S. Yazzie, S. Leroy, S.R. Carroll. 2019. Policy Brief: Supporting Tribal Data Governance for Indigenous Community Climate Resilience. Tucson: Native Nations Institute and the Climate Assessment for the Southwest, University of Arizona. This brief summarizes the 2018 workshop and identified next steps for tribes, universities, federal agencies, and others who want to learn more about tribal interests and needs related to Indigenous data sovereignty in Arizona.

## An Assessment of Drought and Climate Vulnerability and Resilience in the Rio Grande Basin in New Mexico

**Investigators:** Christina Greene, Dave Dubois, Dan Ferguson

**Research Focus:** The 2018 New Mexico Drought Plan identified the need for in-depth assessments of drought and climate vulnerabilities to inform drought planning across the state. This project assessed drought and climate vulnerabilities and resilience in areas of

concern identified by the New Mexico Drought Monitoring Working Group, including water, economy, fire, recreation, health, agriculture, and the environment.

### Selected Scientific Findings:

*Need for investment*: Opportunities for strengthening drought monitoring in New Mexico include greater investments in physical drought data as well as investments in community engagement.

*Drought-related inequities:* Drought impacts are not evenly distributed across society. Certain communities, often those already marginalized, experience more severe impacts, such as disparities in agricultural losses, water insecurity, and wildfire exposure.

*Improving drought monitoring:* Current climate services often fail to capture the unequal ways in which people experience drought. There is a need for community engagement that is designed to build trust between drought researchers, agencies, and local communities, which will support drought monitoring that is better aligned with drought decision-making.

*Integrating local knowledge:* Drought data and information often do not match the scale at which people make decisions. Integrating place-based knowledge can better support local decision-making, which involves recognizing and valuing different forms of expertise, including those from communities directly impacted by drought.

### Summary of Impact

**Network expansion:** This project expanded CLIMAS's network of collaborators and stakeholders in New Mexico by connecting with the NM Drought Monitoring Working Group, state officials, and experts from multiple sectors including water, economy, fire, recreation, health, agriculture, and the environment.

**Shaping future CLIMAS research:** Drought research priorities that emerged from this project shaped new CLIMAS projects in the region by applying an equity focus to wildfire and aridity in the Southwest. This approach involves understanding how social and economic inequities frame people’s experiences with drought, aridity, and changing climate in the Southwest.

**Disseminating findings:** The peer-reviewed publication generated from this project on equity and drought monitoring garnered interest from the Southwest Fire Science Consortium. They subsequently condensed the findings into a handout for their constituents to disseminate the project's key takeaways on the links between drought and wildfire to a wider audience.

# Societal Impacts & Accomplishments

The following section highlights selected societal impacts of CLIMAS projects during the reporting period. Impacts are categorized by:

- **Connectivity Impacts** – new or strengthened relationships
- **Conceptual Impacts** – raised awareness or understanding of an issue
- **Capacity Building Impacts** – new skills, resources, or increased ability to do something
- **Instrumental Impacts** – direct applications to policies, decisions, or actions
- **Socio-environmental Impacts** – changes to social or environmental systems

## Community Climate Profiles to Support Adaptation Planning

**Investigators:** Alison Meadow, Jeremy Weiss, Ladd Keith

**Project Focus:** Climate change adaptation planning requires decision makers to envision the future of their communities, and make well-grounded assumptions about economic, demographic, and cultural trends that are likely to affect that vision. However, many communities do not have the technical resources to compile and analyze climate data and research findings, making this information inaccessible. This project addressed the lack of access to climate change information by producing climate profiles for communities to support their adaptation planning efforts. The CLIMAS team sought to work with communities that had a usable outcome for climate information.

***On connecting with CLIMAS:***

Our community was very under-informed about climate change. I called up Dan Ferguson and he introduced me to Alison Meadow and this project. It was a perfect fit. We went down to the University to discuss our situation. They came up to the Highlands to get familiarity with what was happening here. Alison would call from time to time, and we would chat about things that helped her to ensure that the report was focused on us. We've been very pleased with what came out of it. And it was a lot of fun, it was just an enjoyable time to put the profile together.

-

*Rich Markham, The Highlands at Dove Mountain*

### Societal Impacts by Category

***Instrumental:***

- City of Flagstaff, AZ directly integrated profile information into the city's Climate Adaptation and Action Plan, which was adopted by City council in 2018. The Plan won an Arizona Planning Association Award.
- Pueblo of Laguna, NM integrated their profile into their vulnerability assessment process, which is part of a larger effort by the Pueblo to develop a climate change adaptation plan.
- Arizona Land and Water Trust used the profile of the Upper Santa Cruz Watershed to inform plans to incorporate climate adaptation into their

conservation easements, which are legal agreements between the land trust and landowners regarding future use and conservation of working lands in Arizona. This organization protects over 2.7 million acres of land through its conservation easements.

- The Highlands at Dove Mountain used their profile to inform their Five-Year Trends Planning effort and develop community priorities for action, such as desert landscaping, sustainable golf course management, and greater awareness of physical and mental health impacts of climate change on older adults.
- Consultants used the Highlands at Dove Mountain profile – done at the scale of Pima County – to develop the City of Tucson's Climate Action and Adaptation Plan. The profile report was a major source of climate science for Tucson's plan.

***On tailoring the profile:***

One thing that's very important is defining the boundaries for a downscaled analysis. Like in the case of Pueblo of Laguna, was It the tribal territory, like the land that they own, or was it their traditional use area? And then what's the sweet spot in terms of the size and the validity of the climate projections? That was one of the conversations that we had with the community and with CLIMAS – where does it make sense to draw these boundaries, so that it's valid and also gives the community a sense of ownership over the information. If we just downscaled the analysis for the county using county boundaries, that wouldn't have resonated.

-

***Sascha Petersen, Adaptation International***

***On co-development:***

One of the things we focus on is the community process and building capacity at the local level. Alison came out to Pueblo of Laguna for some early scoping meetings, when we were talking with the tribe about where climate impacts have already happened, what are the things they care about that are already being affected or that they're worried about being affected. That allowed us to collaboratively refine what products CLIMAS could provide.

-

***Sascha Petersen, Adaptation International***

***Connectivity:***

- Word of mouth connections increased interest in Climate Profiles. For example, Prescott, AZ contacted CLIMAS to develop a profile for their region because they heard about it from partners in Flagstaff and Sedona.
- After the profile process, Dove Mountain residents collaborated with CLIMAS researchers to develop and teach classes for their community.
- Through the Pueblo of Laguna profile, CLIMAS formed a solid partnership with Adaptation International that led to additional collaboration on other projects.

- CLIMAS collaborated with several partners on new funding proposals which extended stakeholder engagement on issues of climate resilience and adaptation.
- In December 2019, The Highlands at Dove Mountain was approved for membership in the Firewise USA Program, following a recommendation from Alison Meadow. This program teaches communities how to adapt to living with wildfire and encourages neighbors to work together and take action to prevent losses. Residents from The Highlands, including members of the Architectural Landscape, Infrastructure and Common Area Committees, will prepare an Action Plan—a prioritized list of fire risk reduction projects/investments as well as suggested homeowner actions and education activities.

***Capacity Building:***

- Profile reports were used by communities to apply for funding to do adaptation work. For example, the Town of Oro Valley's Office of Emergency Management cited the profile to apply for funding from FEMA to enhance the town's preparedness for climate and weather-related events. Although that funding application was not successful, they were encouraged to apply to another program.
- Arizona Land and Water Trust used the Upper Santa Cruz Watershed profile in a successful grant application from the Land Trust Alliance's Land and Climate Program.

***On use of the profile:***

This climate profile became central to a grant we received from the Land Trust Alliance's Land and Climate Program, and together these opportunities have motivated … our involvement with groups like the Southwest Climate Hub. We're eager to share the profile with our landowner partners and other stakeholders in the Upper Santa Cruz Watershed and believe it will provide practical guideposts to encourage climate-adaptive land management across the region. The Trust is very grateful that CLIMAS was able to take on this project, and we hope we're able to work together again in the future.

–

Bailey Kennett, Arizona Land and Water Trust

## Tools and Weather/Climate Information Used by Wildland Fire Managers in the Southwest United States

**Investigators:** George Frisvold, Dan Ferguson, Mike Crimmins, Chuck Maxwell (U.S. Fish and Wildlife Service; Predictive Services Southwest Coordination Center)

**Research Focus:** Wildland fire management in the U.S. is complicated, expensive, and requires a substantial amount of scientific data and information across a huge range of temporal and spatial scales. Although state and federal agencies as well as academic research groups have devoted substantial resources to develop data products, forecasts,

outlooks, and decision support tools for wildland fire management, relatively little is known about how these tools have been used to inform wildland fire management decisions.

This study initially focused on two related research questions: 1) How do weather and climate products and tools inform wildland fire management decisions in the Southwest? 2) How are existing decision support systems used by wildland fire managers in the Southwest? As the project evolved, it took a transdisciplinary research approach by adding wildland fire meteorologist and regional wildfire expert Chuck Maxwell to the team. The team added a new project focus to develop operational weather and climate information products for the Southwest wildland fire management community.

***On engagement of the wildfire community:***

I saw this project as an opportunity to learn some stuff, do it comprehensively, and get all the people I knew [in the wildfire community] to engage. Getting that engagement was huge and CLIMAS gave fire managers a much wider forum to participate. I think that's part of why we got good engagement. We were able to give them a voice, which helped get the southwest wildfire community to move things forward.

–

Chuck Maxwell, Predictive Services, Southwest Coordination Center

### Societal Impacts by Category

***Connectivity:***

- This project strengthened a collaborative partnership between CLIMAS researchers and Chuck Maxwell who has strong connections with the western fire and land management community. This partnership facilitated two-way communication, allowing researchers to quickly connect with fire managers, understand their needs, and collaboratively develop targeted tools and resources to improve wildfire management on the ground.
- The transdisciplinary nature of this team, which included an economist, a social scientist, a climatologist, and a wildland fire meteorologist/government liaison, pushed the research in new directions. The CLIMAS wildfire research agenda has evolved and will continue to expand beyond this initial project.

***Capacity Building:***

- An early career scholar, Trevor McKellar, gained experience in developing climate service decision support tools while helping develop the Burn Period Tracker.
- The National Interagency Fire Center is developing training materials using historical Burn Period plots developed through this project. This agency requested an Archive of the Burn Period Tracker for training and research purposes.

***Instrumental:***

- The SBPT is used by fire managers daily, throughout the year, across Arizona and New Mexico. It is used in operational decision making regarding the execution of prescribed fires and wildland fire management planning.
- Information from the SBPT is referenced during regional and national wildfire briefings.
- The Burn Period Tracker is linked as a key resource on the Fuels/Fire Danger page of the Southwest Coordination Center website, which was accessed over 1400 times in 2023.

***On use of a decision support tool:***

A highlight of this project for me was being able to use things like the burn period tracker right away, operationally, to brief my fire managers who had informed the development of the tool. The tracker is built right into our operations, especially regarding the summertime monsoon and moisture conditions. We've been having fires now over the summer, during times that we did not in past decades, and the burn period tracker seems to resolve that very well.

–

Chuck Maxwell, Predictive Services, Southwest Coordination Center

## Building Regional Food System Resilience in Southern Arizona

**Investigators:** Gigi Owen, Shelby Thompson (Pima County Food Alliance)

**Research Focus:** The COVID-19 pandemic exposed deep-rooted inequities in how people access, produce, and distribute food. To create more equitable food systems, policies and programs should be shaped by the communities they serve.

This project focused on a) analyzing how economic, climatic, and societal risk interact within the local food system over time; b) building partnerships between small local businesses, business development agencies, food policy organizations, and researchers; and c) developing a coordinated strategic plan for building local food system resilience.

### Societal Impacts by Category

***Connectivity:***

- This project brought together more than 100 individuals representing multiple organizations across southern Arizona's food system. Spaces forged during focus groups, community meetings, and networking events allowed individuals to connect and learn from one another.
- PCFA connected the research team to multiple community partners, food system organizations, and local farmers and food producers.

- The relationship building component of this work helped support an instrumental policy outcome. Local relationships are critical to building in-roads for change at the local level.
- The Food Bank of Southern Arizona and the Pima County Health Department contacted the research team to conduct additional related research projects.

***Capacity Building:***

- Pinnacle Prevention, a nonprofit organization, used State of the Tucson Food System report and research findings in their conversations with Arizona legislators in support of local food system policy.
- This project led to creation of the Food Systems Research Lab, a rotating team of interdisciplinary researchers and students. The lab supported 9 graduate and 2 undergraduate students who received training and experience in community-based research. They participated in research development, partner meetings, data collection and analysis, presenting findings, and community event planning.

***On the value of local information:***

*We've already shared your report findings in our conversations with legislators! To have this level of hyperlocal information is just priceless, we cannot thank you enough.*

—

*Adrienne Udarbe, Pinnacle Prevention*

***On community support:***

*Being able to work with somebody who is funded to do work like this was really crucial to the success of the project and to getting PCFA to where it's at now. I don't think that PCFA would exist if it wasn't for CLIMAS, and [Gigi Owen] specifically and all the work she's done on this project. My main takeaway is just a lot of gratitude for all the energy and work that's been put into it*

—

*Shelby Thompson, Pima County Food Alliance*

- Gigi Owen and Shelby Thompson (PCFA) co-wrote a funding proposal from the Community Food Bank of Southern Arizona to revitalize the food policy council. The grant was awarded in 2022.
- CLIMAS invited PCFA members to collaborate using technical resources unavailable to them as a community organization, such as a Teams channel, Zoom meetings, and Box to aid in regular communication and information management.
- The research team helped PCFA design and develop a new website. Students working in the lab provided written content and photos.
- The team helped PCFA create and manage a new list-serv through participant sign ups from focus groups, interviews, and public events. Students developed list-serv content and sent out periodic newsletters.

***Instrumental:***

- PCFA used findings from reports developed in May 2024 to inform its organizational structure; to develop its mission, vision, and roles in the community moving forward; and to set priorities for events and working groups.
- Gigi Owen presented research results to Tucson Mayor and Council in support of a reduced water rate for small-scale urban farmers (invited by Pima County Food Alliance, Community Food Bank of Southern AZ, and Tucson Ward 3). The mechanism of how this reduced rate would function and how it would be monitored and implemented went under development. In November 2023, results were cited again by the Community Food Bank of Southern AZ to support a 1-year pilot project for the water rate program, which was approved by Mayor and Council. The policy aims to improve local economic livelihood, reduce water consumption, and increase food security. CLIMAS will continue to monitor progress on this water rate to measure those outcomes.

***On partnership:***

*CLIMAS brings expertise that I don't have. It allowed this project to flourish in a way that just wouldn't have been possible otherwise. And it was a real partnership as opposed to an extractive research project. As somebody who has been at the grassroots level in the community for a long time, I was able to provide connections and help deepen relationships. But I didn't have all the knowledge and expertise around research. Gigi helped us develop fantastic discussion guides for our focus groups and to understand how to ask questions that would result in what we wanted to know from community members. If we hadn't had that partnership, it wouldn't have happened with the same level of precision and thoroughness. And we had a lot of fun, which is not something you always get to experience on a project.*

—

*Shelby Thompson, Pima County Food Alliance*

## Identifying Gaps in Stakeholder Needs Regarding the Climate-Health Connection

**CLIMAS Investigators:** Heidi Brown, Erika Austhof, Ladd Keith, Daniel Ferguson

**Research Focus:** Communities need to be prepared for health impacts related to climate change and extreme events. Academic researchers working on climate and health issues can serve regional stakeholders actively working on climate and health adaptation planning. This project aimed to build research and practitioner partnerships and connect academic research to climate and health planning efforts in Arizona. In 2009, the Center for Disease Control (CDC) engaged 16 states and 2 cities to implement a 5-step program Building Resilience Against Climate Effects (BRACE) to help communities prepare for the

health effects of climate change. As BRACE ended, the CDC supported monitoring and evaluation of the efforts developed under BRACE through a new program called Climate and Health Adaptation Monitoring Program (CHAMP). To support these monitoring and evaluation efforts, CLIMAS researchers mapped an Arizona network of climate and health advocates, identified gaps in stakeholder needs regarding the climate-health connection, and developed strategies and partnerships to better support these efforts.

## Societal Impacts by Category

***Conceptual:***

- Research findings helped frame climate knowledge and risks in the context of healthcare. Research findings highlighted that healthcare providers are highly trusted on issues of climate, which supports opportunities for health services to implement climate education initiatives.

***Connectivity:***

- The established partnership between CLIMAS and ADHS allowed for heat resilience work to move forward in Pima and Maricopa Counties while county health departments focused on COVID-19 mitigation efforts.

***On collaborative partnership:***

There's a reliance on academic partnerships when health departments don't have the staff available to do the work. The partnership [between CLIMAS and ADHS] was really helpful…because ADHS had someone to rely on when they couldn't move [an initiative] forward.

–

*Matt Roach, Arizona Department of Health Services*

***On new BRACE grant:***

There are only 11 awards in the country, and many of the States that were previous grantees did not get one. [Heidi Brown] is funded for an even larger amount and the goal of this new grant is to implement two interventions focused on heat and strategic plans, particularly working with Maricopa and Pima Counties and building a [heat] compendium.

-

*Matt Roach, Arizona Department of Health Services*

- This project directly led to the expansion of heat-related research and outreach with CLIMAS PI, Ladd Keith, and the expansion of the health portfolio within CLIMAS.

***Capacity Building:***

- Sustained engagement between CLIMAS Investigators and ADHS paved the way for a long-standing partnership and strengthened the connection between health and climate change for Pima, Maricopa, and Pinal County.
- New funding was acquired in 2021 through an additional Building Resilience Against Climate Effects (BRACE) grant from the U.S. Centers for

Disease Control ($2 million, 2022-2026) with ADHS and Pima and Maricopa County Departments of Health.

***Instrumental:***

- CLIMAS research directly informed the Arizona's Climate and Health Adaptation Plan (2017) and its addendum (2018), which were prepared for the CDC's Climate-Ready States and Cities Initiative.
- Maps of cooling centers in Tucson, produced in connection with this project, were used by the Pima Association of Governments, Tucson Pima Collaboration to End Homelessness, and Chicanos Por La Causa, to inform strategies to help populations that experience high exposure to heat stress Pima County, including homeless populations and people without cooling systems in their homes.
- AZ Governor Katie Hobbs proclaimed Arizona Heat Awareness Week from May 6 to May 10, to increase awareness of extreme heat. Activities during this week focus on heat health and precautions.

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## Visualization & Analysis Tools for the North American Monsoon – Integrating Citizen Science Data and Observations

**Investigators:** Ben McMahan, Mike Crimmins

**Research Focus:** Monsoon precipitation is difficult to forecast and analyze. Daily and seasonal precipitation are commonly used, but other sources of data, such as citizen science monitoring, could be used to make a higher resolution and more accurate monsoon assessment framework. Tucson has dozens of observations collected by these networks, along with datasets based on radar and weather models. A central monsoon data repository forms a dense network of observations, facilitating innovative visualizations, and offering an unparalleled high-resolution view of regional precipitation patterns.

### Societal Impacts by Category

***Connectivity:***

- A presentation at the Pima County Hazard Mitigation Workshop led to additional collaborative opportunities with the Pima County Flood Control Office and the Oro Valley Police Department. Both were interested in using the aggregated data as decision support for prioritizing post-monsoon cleanup and recovery.

***Conceptual:***

- This project provided more detailed and nuanced understanding of the monsoon across Tucson, and other regions in southern Arizona. Aggregated data from multiple datasets provided an improved visualization of precipitation patterns across the metropolitan area of Tucson.

***Capacity Building:***

- This project led to the formation of the AIRES Research Computing Working Group, co-led by Rey Granillo & Ben McMahan. This working group supported three graduate students, three early career researchers, and two undergrad students. They contributed to project design, revised data aggregation and visualization techniques, and brainstormed additional data analysis and proposal development opportunities.
- The replicable framework for data assimilation and aggregation developed by this project can be applied by others in any location with multiple and overlapping data sets. Researchers collaborated with NWS Phoenix office to apply this framework in Maricopa County, using the 2020 monsoon as a testbed.
- Researchers expanded data coverage to rural areas (Pinal County and Mojave County) based on requests to build out the dataset and to create a system (API) that gathers and organizes data from the Arizona Department of Water Resources that is not otherwise available.
- The monsoon visualizer has been used as a training tool for NOAA-NWS forecasters.
- The protocol for developing, cleaning, and organizing data for the Aggregated Precipitation Database for Southern AZ served as a prototype for database development at larger scales. Conversations with colleagues in New Mexico and Texas increased their capacity to apply a similar process in the Las Cruces, El Paso, and Ciudad Juarez region.

***On technical capacity:***

We're currently migrating our website to a new content management system, which provides a better end product, as opposed to our old monsoon tracker which is 10 -20 years old. So that's a good thing. But one major disadvantage is that there's very little programming that we can do on the back end to add the data sets we need to help track the monsoon. That's where CLIMAS gets involved and it's a big, key component of this. They have their own internal servers where they can bring in data and repackage it in a way that's actually useful, that we technically can't do. They bring a lot of technical expertise that we just don't have and we aren't going to be able to mimic.

-

*Tom Dang, National Weather Service Tucson*

***Instrumental:***

- The Monsoon Visualizer provides near real time overviews of precipitation and has been used to aid in flood control, monsoon recovery, and forecasting monsoon events.
- The National Weather Service's Monsoon webpage cites and links to the Monsoon Visualizer, the Southwest U.S. Summer Monsoon Season Precipitation Mapping Tool,

and Monsoon Season Station Summaries. Their monsoon tracker integrates station data with CLIMAS-developed maps and data for daily and seasonal monsoon tracking.

## Evaluating the Use of Urban Heat Island and Heat Increase Modeling in Land Use and Planning Decision-Making

**Investigators:** Ladd Keith, Ben McMahan**,** Sarah Meerow (Arizona State University)

**Research Focus:** The impacts of the urban heat island (UHI) and extreme heat events are well documented, including increased public health issues, stresses on urban ecology, and energy usage to mitigate higher temperatures. Increased urban heat is of particular concern to cities in the Southwest because it counteracts the cooling that otherwise normally occurs at night. While mapping and modeling have become more sophisticated, there is still a gap between the use of heat maps and models to inform urban planning and design strategies to mitigate urban heat. This research focused on understanding how UHI maps and models could be used for decision-making and planning.

### Societal Impacts by Category

***Conceptual:***

- A nationwide survey of planners established baseline knowledge on the rapidly emerging topic of urban heat governance in the U.S. This work was cited by the Urban Institute in their Centering Equity to Address Extreme Heat report.
- This project informed federal discussions about developing and funding heat and health programs, including discussions about NIHHIS - National Integrated Heat Health Information System.
- Several media outlets reported on research findings from this project and the need for better extreme heat planning and governance in the U.S.
- The definition of heat governance conceptualized in a paper from this project is displayed in a call-out box for the NOAA/NIHHIS Maturity Model for Heat Governance.

***Connectivity:***

- The Extreme Heat Network (now the Heat Resilience Initiative) launched through this project is a community of research and practice that sends out a monthly newsletter, organizes seminar series, and has worked to expand heat networking globally.

***On future partnership:***

It's awesome having Ladd as a resource in our region. I look for ways we can work with him and ways in which we can share our work to help further his goals. I know his means are different in that you know it's more policy and that side of things, but the use of this information sparks discussion and new projects.

-

*Josh Pope, Pima Association of Governments*

- Ladd Keith has served in advisory roles for the New York City Mayor's Office of Resiliency and the Urban Design Forum. Keith also has served as an expert reviewer for the Urban Land Institute's report *Scorched: Extreme heat and real estate*.
- Long-standing partnerships were established with heat-related researchers at Arizona State University.

***On university partnership:***

From a public sector perspective, it was good working with [CLIMAS]. Ladd helped add some formality to the partnership, which helped my leadership feel more comfortable. I was very upfront with Ladd about how my leadership is anxious about us saying, "It's getting hotter here, and your efforts aren't cooling anything over here." So, working with the university and us being able to point to a collaboration on that was helpful. Ladd was quick to point out that no one else was doing this work, so there's not a lot [of other research] to compare this to.

-

*Josh Pope, Pima Association of Governments*

- Ladd Keith's 2022 appointment on the Global Heat Health Information Network's (GHHIN) Management Committee is a direct result of CLIMAS and the NOAA partnerships built through this project.

***Capacity Building:***

- Ladd Keith finished his dissertation work on assessing climate action planning in the U.S. Southwest in 2019 and has since launched an impactful research career, as an Associate Professor in the College of Architecture, Planning and Landscape Architecture at the University of Arizona.
- Graduate students received training on qualitative interview techniques and coding analysis through this project. Erika Schmidt presented research findings at the Climate Prediction Applications Science Workshop.
- New York City's Office of Resiliency used results from this research to acquire grant funding to implement urban heat mitigation strategies.

***Instrumental:***

- Preliminary results were reported to NOAA's Climate Program Office and informed development of a new national funding opportunity for five communities to monitor, understand, and respond to local heat risk.
- Provided information utilized in the ULI Scorched: Extreme Heat & Real Estate report.
- Trust for Public Land served as an informal project advisor. They used findings from the project to inform data use guides they produce.
- The Pima Association of Governments revised their resiliency planning map from a green infrastructure-focused map. Using technical assistance from this CLIMAS project, they now have a layer for heat impacts and cooling centers on their Resiliency Planning Maps.

## Planning for a Sustainable Future with an Electric Utility: Emissions Reductions and Cumulative Carbon Budgets

**Investigators:** Ben McMahan, Andrea Gerlak, William Holmgren

**Research Focus:** Public utilities are under considerable pressure to respond to public demand for carbon reductions but lack the mechanisms to evaluate resource portfolio decisions objectively. The project examined different combinations of energy sources (like solar, wind, natural gas, and coal) that TEP could use to generate electricity. Research focused on analyzing carbon reduction strategies for TEP's resource portfolio and assessed the implications that different portfolio decisions might have on things like carbon emissions, global warming, and air quality.

> ***On academic expertise:***
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> It was really helpful for all the other stakeholders to hear what Ben and Andrea had to say. They were there all the time, at least one of them, and they would speak up when people had just general questions and discussions. They were the experts in the room. That was like another layer of value that they brought beyond the analysis.
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> *Lee Alter, Tucson Electric Power*

### Societal Impacts by Category

***Connectivity:***

- This project extended from a prior partnership to develop plausible, climate-driven carbon reduction scenarios for Tucson Electric Power

***Capacity Building:***

- To offer transparency and encourage wider collaboration, researchers made this project's data and methodology fully accessible through an open-source GitHub repository. Anyone can reproduce the analysis to verify findings, offer changes, or update it with new data. Members of TEP's Advisory Council recognize the value of the open-source nature of the repository and have referenced it in their own work.

***Instrumental:***

- TEP's 2020 Integrated Resource Plan demonstrates a significant commitment to reducing carbon emissions in terms of timing and intensity. It adopted an aggressive timeline for carbon reduction. The plan uses a more transparent and data-driven approach to justify its strategies compared to plans from other utilities.
- Researchers created a transparent and reusable framework for evaluating carbon budgets across various sectors. This data infrastructure allows any organization with emissions and warming targets to better understand their carbon budgets. By working closely with TEP, researchers tailored this tool to meet their specific needs, enabling them to contextualize their energy decisions and how those decisions might scale to a global context.
- Despite constraints due to prior investments in carbon-intensive generating sources, through this project TEP was able to explore various energy portfolio scenarios and their impact on warming and emissions, emphasizing the importance of timing in

***On use of findings:***

It was very helpful to learn that we were close to where we had to be in terms of our carbon commitment. It also was helpful to see how that stacked up against other utilities. All the rest of our stakeholders and rate payers, whoever read the IRP, would see that we're on the right path, both compared to other leaders in the in the industry and in terms of the science. This was a big down payment on ultimately where we needed to go. It helped our credibility in terms of goal setting.

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*Lee Alter, Tucson Electric Power*

reducing carbon emissions. This analysis demonstrated to regional stakeholders that while immediate elimination of all carbon-based fuels may not be feasible, a rapid phase-out of coal-fired power plants would significantly reduce cumulative carbon emissions. This strategy allows for a transition period where natural gas serves as a "bridge fuel" on the path towards 100% clean and renewable energy.

- TEP incorporated cumulative emissions assessments in its Integrated Resource Plan, which is presented to the Arizona Corporation Commission. Project recommendations and analysis were directly integrated into this document. The data repository was published on TEP's Integrated Resource Plan web page.

***Conceptual & Capacity Building:***

- This project provided TEP with a more comprehensive understanding of the impact of their energy choices. Initially the project focused on setting emissions reduction targets, but it shifted toward a cumulative emissions analysis**.** Instead of just measuring reductions from a baseline, the project analyzed the total accumulated emissions of different energy portfolios. This approach provided a clearer picture of long-term environmental consequences.
- By linking emissions data with climate models, TEP was able to directly assess the warming impact of their portfolio decisions. This highlights the importance of early and continuous emissions reductions beyond setting percentage-based targets.
- While TEP was already moving toward renewables and low carbon fuels because of their low cost, the metric to describe cumulative impact of early reductions may have helped them justify their earlier reductions.
- Feedback from TEP stated that CLIMAS' participation in the Salt River Project advisory committee improved climate knowledge and how climate overlapped with other challenges. This increased knowledge enhanced committee members' capacity to discuss issues around a clean energy transition with more peers and colleagues.

***On environmental & societal impact:***

The most significant outcome is the closure of coal plants, which have an ecological impact locally and globally. And while the ecological effects are really nuanced, these closures will also have a huge social impact up at Springerville and Eagar and Holbrook, where these coal plants are located. All these things stem from our decisions which stem in part from the work that CLIMAS did.

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*Lee Alter, Tucson Electric Power*

***Socio-environmental:***

- TEP is closing Units 1 and 2 at the coal-fired Springerville Generating Station, one in 2027 and one in 2032. These closures aim to help TEP reduce its carbon emissions to 80% below 2005 levels by 2035. Another utility, Arizona Public Service, is closing the Cholla Power Plant near Holbrook in spring 2025. These utilities have set up training and education programs for these employees and communities to help them transition to new careers. They are also offering a combined total of $1 million in funding assistance for impacted communities.

## Community-based responses to climate-related water challenges

**CLIMAS Investigators:** Bonnie Colby

**Research Focus:** Rural communities in the Southwest face increasing water scarcity due to climate change. Information about risks to their local water supplies and tailored assessments of adaptation and mitigation strategies is needed for watershed management and planning. This project aimed to develop a replicable method for co-producing resilient, water-related community climate adaptation and mitigation strategies. Research focused on identifying the drivers of water-related risks and evaluating the feasibility of adaptation and mitigation options as identified through a collaborative process in each of three communities. Options included investing in built infrastructure, adopting incentive-based risk-sharing agreements, and investigating watershed ecosystem services.

### Societal Impacts by Category

***Capacity Building:***

- The online data hub gathered local water and climate data for three communities in Arizona. Regional drought planning data and research can be difficult to find and interpret. The data hubs enhanced community partners' capacity to use and engage with these data sources.
- Four graduate students gained research experience through this project. After graduation they continued related work at Resources for the Future, Salt River Project, Montgomery and Associates, and Arizona Municipal Water Users Association.

- The project provided three rural communities in AZ with drought response planning consulting services that were otherwise cost prohibitive. Consultant fees for development of planning studies for communities can range from $20,000 - $100,000.
- The online database and other project research were cited in a successful funding application from the Town of Superior to the Bureau of Reclamation WaterSMART Cooperative Watershed Management Program for $245,000, to prioritize community water projects.
- The online database was cited in a successful funding application to the Water Infrastructure Finance Authority of Arizona's Water Conservation Grant Fund for $140,000, to install green infrastructure and host community workshops.

***Instrumental:***

- This project developed Community Drought Preparedness and Response Plans for the three listed communities.
- Three community groups applied new and emerging data from this project to develop Watershed Management Plans for their regions, including the Santa Cruz Watershed Collaborative (Benson and Patagonia, AZ), Cobre Valley Watershed Partnership (Globe, AZ), and the Aravaipa Watershed Conservation Alliance (Superior and Queen Creek, AZ).

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## A Colorado River Shortage Declaration: Planning, Responses, and Consequences

**CLIMAS Investigators:** George Frisvold

**Research Focus:** Lake Mead's water levels are declining due to prolonged drought. In response, the Bureau of Reclamation asked Colorado Basin States to develop new drought contingency plans to reduce water usage from Lake Mead. Arizona's Drought Contingency Plan calls for significant reductions in surface water supplies for irrigated agriculture in Pinal County. While this action may lead to short-term cost savings, it may also reduce the sustainability of agricultural production in Central Arizona, causing negative economic impacts in other sectors. Reduced water supply may also negatively affect tourism industries at Lake Powell and Lake Mead. The economic effects of a Tier-1 Colorado River shortage declaration will likely concentrate in rural communities, but little is known about which communities and sectors will be affected and how. This project explored the effects of reduced surface water supplies on (a) crop production in Pinal County, (b) spillover economic effects to Arizona dairy production, (c) spillover economic effects to non-agricultural sectors in Pinal County, and (d) recreational demand around Lakes Mead and Powell.

> ***On policy impact:***
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> You might be talking about a policy in your research, but if policy makers are not calling you up, then you're not having that direct policy influence. When they do, you must be able to respond quickly.
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>
> *George Frisvold, CLIMAS*

## Societal Impacts by Category

***Conceptual:***

- AZ State Senator Kirsten Engel consulted George Frisvold about the effect of technology requirements on water conservation in response to legislative debates over the Drought Contingency Plan.
- Local irrigation districts in Pinal County and the Arizona Department of Agriculture requested the analyses conducted by this project. The final project report was shared on the Arizona Farm Bureau's and Pinal County's websites for public access. Nine news outlets reported research findings in January and February 2019.
- The Colorado River management division at the Arizona Department of Water Resources requested a copy of a presentation that shared new findings from this research. They wanted to use findings to inform Colorado River negotiations with different states.

> ***On use of findings:***
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> I asked George to summarize his study findings so we could add them to the 2022 Arizona Drought Preparedness annual report. This report is not only intended for the public and general audiences, but it's also sent to the Governor's office. It is our way of keeping the Governor's office up to date about everything drought that we do in the state. That's one way that we shared information from this project with leadership and policymakers.
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> *Nemesis Ortiz-Declet, Arizona Department of Water Resources*

**Capacity Building:**

- The Arizona Department of Water Resources requested a summary of research findings to include in their 2022 Arizona Drought Preparedness annual report. ADWR uses the report to update the public and the Governor's office on their drought-related work.
- This project trained three graduate students on economic analysis, resulting in three M.S. theses. The project provided continued support for two early career scholars.

***Instrumental:***

- The Arizona Municipal Water Users Association developed a briefing memo using study results to inform their positions on the state's Drought Contingency Plan.

- Negotiations over Arizona's 2018-2019 Drought Contingency Plan negotiations were contentious. Urban water providers and agricultural interests disagreed on issues like the costs of water cutbacks on Pinal County agriculture and appropriate mitigation measures. Both urban and agricultural sides relied on research findings from this project in their negotiations.
- Economic impact estimates from the study were used in testimony over mitigation funds for Pinal County agriculture.

***On use of findings:***

Presentations from this research provided a way to have new and reliable information based on research, that policymakers could use when they talk about the Colorado River situation, and negotiations with different States

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*Nemesis Ortiz-Declet, Arizona Department of Water Resources*

## Is Adaptation Maladaptation? An assessment of mosquitoes and water harvesting

**CLIMAS Investigators:** Heidi Brown, Ladd Keith

**Research Focus:** As society adapts to climate change, it is important to ensure that adaptations do not create new problems. Green infrastructure that diverts stormwater to rainwater harvesting basins can inadvertently create new habitats for mosquitoes, especially if the infrastructure falls into disrepair or is improperly designed. Increased mosquito populations can lead to increased incidence of vector-borne disease in humans, like West Nile virus. This project focused on evaluating the effectiveness of green stormwater infrastructure sites in Tucson, AZ. In 2018, researchers sampled 28 selected sites after rain events, including basins, curb cuts, and bioswales to test if they created breeding habitat for mosquitoes.

### Societal Impacts by Category

***Connectivity:***

- CLIMAS researchers strengthened existing relationships with Tucson Water and Pima County Vector Control. Tucson Water has suggested Brown and Keith to work on other City of Tucson research needs related to green infrastructure, heat, and public health.

***Conceptual:***

- Findings from this study confirmed that Pima County's well-maintained

***On supporting city climate action:***

I was very happy that Heidi and Ladd offered to do a study about green stormwater infrastructure and mosquitos. We tend not to be very good about collecting metrics on how our basins are performing, so bringing that data to table is great.

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*Irene Ogata, Tucson Water*

green infrastructure practices were not generating new mosquito populations. One basin that that had standing water did yield larvae. These findings were shared with societal partners. Tucson Water used these findings to understand green stormwater infrastructure performance and effectiveness.

***Capacity Building:***

- Five undergraduate students and 1 graduate student from different academic backgrounds worked on this interdisciplinary project and gained experience conducting community-based scientific research.

# Appendix A: Key Partnerships

| NOAA programs | |
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| National Integrated Drought Information System | Sectoral Impacts of Drought and Climate Change - end user, funder |
| National Weather Service | USDA Livestock Forage Disaster Program and Ranching - end user |
| National Weather Service, Albuquerque | Impacts of Climate Extremes to Interstate and Local Trucking Industry - end user |
| National Weather Service, El Paso | Impacts of Climate Extremes to Interstate and Local Trucking Industry - end user |
| National Weather Service, Phoenix | Impacts of Climate Extremes to Interstate and Local Trucking Industry - end user; Visualization & Analysis Tools for the North American Monsoon – Integrating Citizen Science Data and Observations - end user |
| National Weather Service, Regional Climate Services | Visualization & Analysis Tools for the North American Monsoon – Integrating Citizen Science Data and Observations - end user |
| National Weather Service, Santa Teresa | Impacts of Climate Extremes to Interstate and Local Trucking Industry - end user |
| National Weather Service, Tucson | Visualization & Analysis Tools for the North American Monsoon – Integrating Citizen Science Data and Observations - key partner, end user |
| **Federal Agencies** | |
| US Bureau of Indian Affairs | Tools and Weather/Climate Information Used by Wildland Fire Managers - end user |
| US Bureau of Land Management | Evaluating Existing & Developing New Drought Indices Using Modeled Soil Moisture Time Series - end user; Tools and Weather/Climate Information Used by Wildland Fire Managers - end user |
| US Bureau of Land Management, Las Cruces | Impacts of Climate Extremes to Interstate and Local Trucking Industry - end user |
| US Bureau of Reclamation | Colorado River Shortage Declaration: Planning, Responses, and Consequences - end user; Sectoral Impacts of Drought and Climate Change - end user |
| US Drought Monitor | USDA Livestock Forage Disaster Program and Ranching; Evaluating Existing & Developing New Drought Indices Using Modeled Soil Moisture Time Series - end user |

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| USDA Agricultural Research Service | Evaluating Existing & Developing New Drought Indices Using Modeled Soil Moisture Time Series - key partner, end user |
| USDA Farm Services Agency | USDA Livestock Forage Disaster Program and Ranching - end user |
| USDA Natural Resources Conservation Service | USDA Livestock Forage Disaster Program and Ranching - end user; Evaluating Existing & Developing New Drought Indices Using Modeled Soil Moisture Time Series - key partner, end user |
| US Fish & Wildlife Service | Tools and Weather/Climate Information Used by Wildland Fire Managers - research partner; end user |
| US Forest Service | Tools and Weather/Climate Information Used by Wildland Fire Managers - end user; Influence of Climate on Lower Colorado Streamflow Variability: Present, Past, and Future - end user; Evaluating Existing & Developing New Drought Indices Using Modeled Soil Moisture Time Series - end user |
| US National Park Service | Tools and Weather/Climate Information Used by Wildland Fire Managers - end user |
| State, Local, & Tribal Governments | |
| AZ Department of Agriculture | Colorado River Shortage Declaration: Planning, Responses, and Consequences - end user |
| AZ Department of Forestry and Fire Management | Tools and Weather/Climate Information Used by Wildland Fire Managers - end user |
| AZ Department of Health Services | Identifying gaps in stakeholder needs regarding the climate-health connection - research partner and end user |
| AZ Department of Transportation | Impacts of Climate Extremes to Interstate and Local Trucking Industry - end user |
| AZ Department of Water Resources | Community-based responses to climate-related water challenges - end user; Colorado River Shortage Declaration: Planning, Responses, and Consequences - end user; Sectoral Impacts of Drought and Climate Change - end user, funder |
| AZ House of Representatives, Ag & Water Committee | Sectoral Impacts of Drought and Climate Change - end user |
| AZ Governor's Drought Task Force | Evaluating Existing & Developing New Drought Indices Using Modeled Soil Moisture Time Series - end user |
| Central Arizona Irrigation and Drainage District | Colorado River Shortage Declaration: Planning, Responses, and Consequences - end user, funder |
| Central Arizona Project | Influence of Climate on Lower Colorado Streamflow Variability: Present, Past, and Future - key partner, end user; Community- |

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| | based responses to climate-related water challenges - end user; Sectoral Impacts of Drought and Climate Change - end user |
| City of Benson, AZ | Community-based responses to climate-related water challenges - end user |
| City of Flagstaff, AZ | Community Climate Profiles to Support Adaptation Planning - end user |
| City of Globe, AZ | Community-based responses to climate-related water challenges - end user |
| City of Prescott, AZ | Community Climate Profiles to Support Adaptation Planning - end user |
| City of Sedona, AZ | Community Climate Profiles to Support Adaptation Planning - end user |
| City of Tucson, AZ | Building Regional Food System Resilience in Southern Arizona - end user |
| Flagstaff Water Services | Influence of Climate on Lower Colorado Streamflow Variability: Present, Past, and Future - key partner, end user |
| Gila River Indian Community, AZ | Community Climate Profiles to Support Adaptation Planning - end user |
| Graham County, AZ | Sectoral Impacts of Drought and Climate Change - end user |
| Greenlee County, AZ | Sectoral Impacts of Drought and Climate Change - end user |
| Maricopa County Health Department | Identifying gaps in stakeholder needs regarding the climate-health connection - end user |
| Maricopa County Implementation and Monitoring Strategies | Identifying gaps in stakeholder needs regarding the climate-health connection - end user |
| Maricopa Stanfield Irrigation & Drainage District | Colorado River Shortage Declaration: Planning, Responses, and Consequences - end user, funder |
| NM Department of Transportation | Impacts of Climate Extremes to Interstate and Local Trucking Industry - end user, funder |
| NM Drought Monitoring Working Group | Assessment of Drought and Climate Vulnerability and Resilience in the Rio Grande Basin - end user, key partner |
| NM Forestry Division | Tools and Weather/Climate Information Used by Wildland Fire Managers - end user |
| Office of the AZ Governor | Colorado River Shortage Declaration: Planning, Responses, and Consequences - end user |
| Oro Valley, AZ – Office of Emergency Management | Community Climate Profiles to Support Adaptation Planning - key partner, end user |

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| Oro Valley Police Department | Visualization & Analysis Tools for the North American Monsoon – Integrating Citizen Science Data and Observations - end user |
| Pima Association of Governments | Evaluating the Use of Urban Heat Island and Heat Increase Modeling in Land Use and Planning Decision-Making - end user |
| Pima County Health Department | Identifying gaps in stakeholder needs regarding the climate-health connection - end user |
| Pima County Natural Resources Division | Visualization & Analysis Tools for the North American Monsoon – Integrating Citizen Science Data and Observations - end user |
| Pima County Office of Emergency Management | Visualization & Analysis Tools for the North American Monsoon – Integrating Citizen Science Data and Observations - end user |
| Pima County Vector Control | Is Adaptation Maladaptation? An assessment of mosquitoes and water harvesting - key partner, end user |
| Pinal County Extension Office | Colorado River Shortage Declaration: Planning, Responses, and Consequences - end user |
| Pinal County Health Department | Identifying gaps in stakeholder needs regarding the climate-health connection - end user |
| Predictive Services Southwest Coordination Center | Tools and Weather/Climate Information Used by Wildland Fire Manag research partner, end user |
| Pueblo of Laguna, NM | Community Climate Profiles to Support Adaptation Planning - key partner, end user |
| Tohono O'odham Nation – Office of Emergency Management | Community Climate Profiles to Support Adaptation Planning - end user |
| Town of Patagonia, AZ | Community-based responses to climate-related water challenges - key partner, end user |
| Town of Superior, AZ | Community-based responses to climate-related water challenges - key partner, end user |
| Tucson Water | Is Adaptation Maladaptation? An assessment of mosquitoes and water harvesting - key partner, end user |
| Non-governmental and Non-profit Organizations | |
| Adaptation International | Community Climate Profiles to Support Adaptation Planning - research partner, funder, end user |
| Agribusiness and Water Council of AZ | Colorado River Shortage Declaration: Planning, Responses, and Consequences - end user |
| AZ Farm Bureau | Colorado River Shortage Declaration: Planning, Responses, and Consequences - end user; Sectoral Impacts of Drought and Climate Change - end user |

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| AZ Food Systems Network | Building Regional Food System Resilience in Southern Arizona - funder, end user |
| AZ Land and Water Trust | Community Climate Profiles to Support Adaptation Planning - end user |
| AZ Parks and Trails | Sectoral Impacts of Drought and Climate Change - end user, funder |
| AZ Vignerons Alliance | Improved Understanding of Climate Variability and Change Relevant to Orchards and Vineyards - key partner, end user |
| Community Food Bank of Southern Arizona | Building Regional Food System Resilience in Southern Arizona - funder, end user |
| National Parks Conservation Association | Sectoral Impacts of Drought and Climate Change - end user |
| National Phenology Network | Visualization & Analysis Tools for the North American Monsoon – Integrating Citizen Science Data and Observations - end user |
| The Nature Conservancy | Evaluating Existing & Developing New Drought Indices Using Modeled Soil Moisture Time Series - key partner, end user |
| NM Trucking Association | Impacts of Climate Extremes to Interstate and Local Trucking Industry – key partner, end user |
| Salt River Project | Influence of Climate on Lower Colorado Streamflow Variability: Present, Past, and Future - key partner, end user; Community-based responses to climate-related water challenges - end user; Planning for a Sustainable Future with an Electric Utility: Emissions Reductions and Cumulative Carbon Budgets - end user |
| Santa Cruz Watershed Collaborative | Community-based responses to climate-related water challenges - key partner, end user |
| Society for Range Management | USDA Livestock Forage Disaster Program and Ranching - end user |
| Trust for Public Land | Evaluating the Use of Urban Heat Island and Heat Increase Modeling in Land Use and Planning Decision-Making - end user |
| Western Energy Institute | Planning for a Sustainable Future with an Electric Utility: Emissions Reductions and Cumulative Carbon Budgets - end user |
| Universities and Research Institutes | |
| Jornada Experimental Range – National Wind Erosion Network | Impacts of Climate Extremes to Interstate and Local Trucking Industry - end user |
| NM State University Cooperative Extension | Improved Understanding of Climate Variability and Change Relevant to Orchards and Vineyards - key partner, end user |
| University of AZ Cooperative Extension | Improved Understanding of Climate Variability and Change Relevant to Orchards and Vineyards - key partner, end user |

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| Urban Land Institute | Evaluating the Use of Urban Heat Island and Heat Increase Modeling in Land Use and Planning Decision-Making - end user |
| Water Resources Research Center | Colorado River Shortage Declaration: Planning, Responses, and Consequences - end user |
| Yavapai College Viticulture and Enology Program | Improved Understanding of Climate Variability and Change Relevant to Orchards and Vineyards - key partner, end user |
| **Community Organizations** | |
| Aravaipa Watershed Conservation Alliance | Community-based responses to climate-related water challenges - key partner, end user |
| Cobre Valley Watershed Partnership | Community-based responses to climate-related water challenges - key partner, end user |
| Green Infrastructure/Low Impact Development Working Group | Evaluating the Use of Urban Heat Island and Heat Increase Modeling in Land Use and Planning Decision-Making - end user |
| The Highlands at Dove Mountain, AZ | Community Climate Profiles to Support Adaptation Planning - key partner, end user |
| Pima County Food Alliance | Building Regional Food System Resilience in Southern Arizona - research partner, end user |
| PROTECT Campaign in Prescott, AZ | Community Climate Profiles to Support Adaptation Planning - key partner, end user |
| Upper Gila Watershed Alliance | Sectoral Impacts of Drought and Climate Change - end user |
| **Private Sector** | |
| AZ Public Service | Planning for a Sustainable Future with an Electric Utility: Emissions Reductions and Cumulative Carbon Budgets - end user |
| Cascadia Consulting Group, Inc. | Community Climate Profiles to Support Adaptation Planning - funder, end user |
| Merkin Vineyards | Improved Understanding of Climate Variability and Change Relevant to Orchards and Vineyards - key partner, end user |
| Mesilla Valley Trucking | Impacts of Climate Extremes to Interstate and Local Trucking Industry – key partner, end user |
| Ron Doba Management Services LLC | Influence of Climate on Lower Colorado Streamflow Variability: Present, Past, and Future - end user |
| Routson Orchards | Improved Understanding of Climate Variability and Change Relevant to Orchards and Vineyards - end user |
| Tucson Electric Power | Planning for a Sustainable Future with an Electric Utility: Emissions Reductions and Cumulative Carbon Budgets - key partner, end user |

# Appendix B: Publications related to the reporting period


Anderson, T.G., C.A. Woodhouse, D.B. Ferguson. 2020. Upper Lake Mary Lake Level Response to Climate Variability: Report to Flagstaff Water Services.

Arizpe, A., D.A. Falk, C.A. Woodhouse, T.W. Swetnam. 2020. Widespread fire years in the US-Mexico sky islands are contingent on both winter and monsoon precipitation. International Journal of Wildland Fire 29: 1072-1087. https://doi.org/10.1071/WF19181

Austhof E., V. Berisha, B. McMahan, G. Owen, L. Keith, M. Roach, H.E. Brown. 2020. Participation and Engagement of Public Health Stakeholders in Climate and Health Adaptation. Atmosphere 11(265): 1-12. https://doi.org/10.3390/atmos11030265

Austhof, E., H.E. Brown. 2021. Flexibility and partnerships perceived as supportive of dual hazard response: COVID-19 and Heat Related Illness, Summer 2020. Journal of Climate Change and Health 4:100068. https://doi.org/10.1016/j.joclim.2021.100068

Austhof, E., H.E. Brown. 2022. Global warming's six MTurks: a secondary analysis of a US-based online crowdsourcing market. International Journal of Environmental Research and Public Health 19(14): 8320. http://doi.org/10.3390/ijerph19148320

Bellante, L., M. Carney, and G. Owen. 2022. Leveraging university resources to build awareness, support regional food policy, and disrupt dominant narratives guiding food-based development: Examples from University of Arizona's Center for Regional Food Studies. Journal of Agriculture, Food Systems, and Community Development 11(3): 9–11. https://doi.org/10.5304/jafscd.2022.113.017

Bhakta, A. 2023. Interim Report – Update on methods, findings from pilot study, and evaluation process. Pima County Food Alliance, University of Arizona.

Bhakta, A., K. Bartels, R. Gildersleeve, G. Owen, R. Leih, S. Thompson, L. Bellante, A. Hilton. 2024. Community Priorities for Food System Action in Pima County, Arizona: Report of Interview and Focus Group Findings. Food Systems Research Lab and Climate Assessment for the Southwest, University of Arizona.

Bickel, A.K., D. Duval, G. Frisvold. 2021. Drought and Insured Crop Losses in Arizona. Report to the National Integrated Drought Information System program. Boulder, CO.

Bickel, A.K., D. Duval, G. Frisvold. 2021. The Effects of Drought on Arizona Forage Production. Report to the National Integrated Drought Information System program. Boulder, CO.

Bickel, A.K., D. Duval, G. Frisvold. 2021. National Economic Development Analysis Greene Wash Watershed, Arizona. Report for Atkins, member of the SNC-Lavalin Group. In support of the Greene Wash Watershed Plan/ Environmental Assessment for the USDA Natural Resources Conservation Service.

Bickel, A.K., D. Duval, G. Frisvold. 2021. Drought and Agriculture in Arizona. Final Report to the Arizona Department of Water Resources. University of Arizona Cooperative Extension.

Bickel, A.K., D. Duval, G. Frisvold. 2020. Agriculture in Graham and Greenlee Counties. https://economics.arizona.edu/agriculture-graham-and-greenlee-counties

Bickel A.K., D. Duval, G. Frisvold. 2019. Simple approaches to examine economic impacts of water reallocations from agriculture. Journal of Contemporary Water Research & Education 168: 29-48. https://doi.org/10.1111/j.1936-704X.2019.03319.x

Bickel, A.K., D. Duval, G. Frisvold. 2018. Contribution of on-farm agriculture and agribusiness to the Pinal County economy. Tucson: University of Arizona Cooperative Extension.

Brice, B., G.H. Guiterman, C. Woodhouse, C. McClellan, P. Sheppard. 2021. Comparing tree-ring based reconstructions of snowpack variability at different scales for the Navajo Nation. Climate Services 22. https://doi.org/10.1016/j.cliser.2021.100213

Brischke, A.S., M.A. Crimmins, J. Grace, A.L. Hall, M.P. McClaran. 2020. Financial Options for Livestock Producers During Natural Disasters. University of Arizona Cooperative Extension Bulletin.

Brischke, A.S., M.A. Crimmins, J. Grace, A.L. Hall, M.P. McClaran. 2020. Monitoring drought in Arizona. University of Arizona Cooperative Extension Bulletin.

Brischke, A.S., M.A. Crimmins, J. Grace, A.L. Hall, M.P. McClaran. 2020. The U.S. Drought Monitor. University of Arizona Cooperative Extension Bulletin.

Brown, H., L. Keith, V. Madera-Garcia, A. Taylor, N. Ramirez, and I. Ogata. 2022. Greening up for mosquitoes: A comparison of green stormwater infrastructure in a semi-arid region. Journal of the American Mosquito Control Association 38(2): 109–112. https://doi.org/10.2987/21-7055

Brown, H.E., J. Jernberg, J. Wishnie. 2024. Cooling Center Evaluation Pilot: A Summary Report. Arizona CDC Building Resilience Against Climate Effects (BRACE).

Brown, H.E., L. Sedda, C. Sumner, E. Stefanakos, I. Rubino, M. Roach. 2021. Understanding Mosquito Surveillance Data for Analytic Efforts: a case study. Journal of Medical Entomology. https://doi.org/10.1093/jme/tjab018

Carroll, S.R., R. Akee, D. Cormack, T. Kukutai, R. Lovett, M. Suina, R.K. Rowe. 2021. Indigenous Data During COVID-19: From Outside to Within. Frontiers in Sociology 6:617895. https://doi.org/10.3389/fsoc.2021.617895

Carroll, S.R., I. Garba, O.L. Figueroa-Rodríguez, J. Holbrook, R. Lovett, S. Materrechera, M. Parsons, K. Raseroka, D. Rodriguez-Lonebear, R.K. Rowe, R. Sara, J.D. Walker, J. Anderson, M. Hudson. 2020. The CARE Principles for Indigenous Data Governance. Data Science Journal 19: 43. https://doi.org/10.5334/dsj-2020-043

Carroll, S.R., E. Herczog, M. Hudson, K. Russell, S. Stall. 2021. Operationalizing the CARE and FAIR Principles for Indigenous Data Futures. Nature: Scientific Data 8: 108. https://doi.org/10.1038/s41597-021-00892-0

Carroll S.R., M. Hudson. 2019. CARE Principles for Indigenous Data Governance. Research Data Alliance International Indigenous Data Sovereignty Interest Group, September 2019. The Global Indigenous Data Alliance.

Carroll, S.R., M. Hudson, J. Holbrook, S. Materrechera, Ja. Anderson. 2020. Working with the CARE principles: operationalizing Indigenous Data Governance. Ada Lovelace Institute. https://www.adalovelaceinstitute.org/operationalising-indigenous-data-governance/

Carroll S.R., A. Martinez. 2020. Policy Brief: Indigenous Data Sovereignty in Arizona. Tucson: Native Nations Institute, University of Arizona and the Inter Tribal Council of Arizona.

Carroll, S.R., D. Rodriguez-Lonebear, R. Akee, A. Lucchesi, J.R. Richards. 2020. Indigenous Data in the COVID-10 Pandemic: Straddling Erasure, Terrorism, and Sovereignty. Social Science Research Council, Items: Insights from the Social Sciences.

Carroll S.R., D. Rodriguez-Lonebear, A. Martinez. 2019. Indigenous Data Governance: Strategies from United States Native Nations. Data Science Journal 18(1):31. https://doi.org/10.5334/dsj-2019-031

Chambers, S., G. Boyce, D. Martinez, C. Bongers, L. Keith. 2023. The contribution of physical exertion to heat-related illness and death in the Arizona borderlands. Spatial and Spatio-temporal Epidemiology 100590. https://doi.org/10.1016/j.sste.2023.100590

Chambers, S., H. Brown, L. Keith, E. Austhof. 2022. Summary of Body Heat Storage Layer Development. A Report for the Arizona CDC Building Resilience Against Climate Effects (BRACE) project. University of Arizona.

Colby, B. 2023. Teaching Water Resource Economics for Policy Analysis. Applied Economic Teaching Resources 5(3):1-18. https://doi.org/10.22004/ag.econ.338382

Colby, B. 2020. Acquiring environmental flows: ecological economics of policy development in western U.S. Ecological Economics 173: 106655. https://doi.org/10.1016/j.ecolecon.2020.106655

Colby, B., H. Hansen. 2022. Colorado Basin Incentive-Based Urban Water Policies: Review and Evaluation. Journal of the American Water Resources Association 55: 1098–1115. https://doi.org/10.1111/1752-1688.13041

Colby, B., R. Isaaks. 2019. Water Trading: Innovations, Modeling Prices, Data Concerns. Journal of Contemporary Water Research and Education 165(1):76—88. https://doi.org/10.1111/j.1936-704X.2018.03295.x

Colby, B., R. Young. 2018. Tribal Innovations in Western Water Management. Western Economics Forum 16(1):38-46.

Colorado River Research Group. 2018. When is Drought Not a Drought? Drought, Aridification, and the "New Normal." Colorado River Research Group.

Colorado River Research Group. 2017. Innovations in Agricultural Water Conservation and Use: Fertile Ground for Lasting Solutions. Colorado River Research Group.

Crimmins, M.A. 2021. Climate change made Arizona's heat wave worse. And it won't be the last one. The Washington Post. June 21, 2021. https://www.washingtonpost.com/outlook/2021/06/21/arizona-heat-climate-change/

Crimmins, M.A. 2021. NOAA releases 1991-2020 Climate Normals Update. Arizona Rangelands - Quarterly Newsletter, 1.

Crimmins, M.A. 2018. Monitoring Precipitation on Rangelands: Tools, Strategies, and Best Practices. Proceedings from the 40th Annual Arizona/Utah Range Livestock Workshop and Tour. Orderville, UT. April 3, 2018.

Crimmins, T. and M. Crimmins. 2022. Large-scale citizen science programs can support ecological and climate change assessments. Environmental Research Letters 17: 065011. https://doi.org/10.1088/1748-9326/ac72b7

Crimmins T.M., M.A. Crimmins. 2019. Biologically-relevant trends in springtime temperatures across the United States. Geophysical Research Letters 46: 12377– 12387. https://doi.org/10.1029/2019GL085251

Crimmins M.A., T.M. Crimmins. 2019. Does an early spring indicate an early summer? Relationships between intraseasonal growing degree day thresholds. Journal of Geophysical Research: Biogeosciences 124: 2628– 2641. https://doi.org/10.1029/2019JG005297

Crimmins, M.A., and T.M. Crimmins. 2021. The Ebb and Flow of Desert Rains and Blooms. Vermillion Flycatcher, 66(1), 6–9.

Crimmins M., Z. Guido, B. McMahan. 2022. Guide to Southwest U.S. Station Climate Summaries. University of Arizona Cooperative Extension Bulletin.

Crimmins, M.A., C. Maxwell, D.B. Ferguson, G.B. Frisvold. 2024: Burn Period: A use-inspired metric to track wildfire risk across Arizona and New Mexico in the southwest U.S. Journal of Applied Meteorology and Climatology. https://doi.org/10.1175/JAMC-D-24-0067.1. In press.

Crimmins, M.A., B. McMahan, W.F. Holmgren, and G. Woodard. 2021. Tracking precipitation patterns across a western US metropolitan area using volunteer observers: RainLog.org. International Journal of Climatology 41: 4201–4214. https://doi.org/10.1002/joc.7067

Crisman, J., L. Keith, I. Sami, G. Garfin. 2023. Designing Chill City: An interactive game supporting public learning about urban planning for extreme heat. The Journal of Environmental Education 54(3): 225–239. https://doi.org/10.1080/00958964.2023.2183173

Cvitanovic C., M. Howden, R. Colvin, A. Norström, A.M. Meadow, P. Addison. 2019. Maximising the benefits of participatory climate adaptation research by understanding and managing the associated challenges and risks. Environmental Science & Policy 94:20—31. https://doi.org/10.1016/j.envsci.2018.12.028

Darapuneni, M.K., O.J. Idowu, B. Sarihan, D.W. DuBois, K. Grover, S. Sanogo, K. Djaman, L.M. Lauriault. 2021. Growth characteristics of summer cover crop grasses and their relation to soil aggregate stability and wind erosion control in arid Southwest. ASABE Applied Engineering in Agriculture 37(1): 11-23. https://doi.org/10.13031/aea.13972

Deol, S., B.G. Colby. 2018. Economies of Tribal Nations: Water Rights, Agriculture and Gaming, Journal of Contemporary Water Research and Education 163(1):45-63. https://doi.org/10.1111/j.1936-704X.2018.03269.x

Dew, T.J. 2021. It is a Dry Heat: Econometric Model of Historic Fires. M.S. Thesis, Department of Agricultural & Resource Economics, University of Arizona. https://repository.arizona.edu/handle/10150/663407

Dinan, M., P.B. Adler, J. Bradford, M. Brunson, E. Elias, A. Felton, C. Greene, J. James, K. Suding, and E. Thacker. 2021. Making research relevant: Sharing climate change research with rangeland advisors to transform results into drought resilience. Rangelands 43(5):1850193. https://doi.org/10.1016/j.rala.2021.08.004

Dinan M., E. Elias, N.P. Webb, G. Zwicke, T.S. Dye, S. Aney, M. Brady, J.R. Brown, R.R. Dobos, D. DuBois, B.L. Edwards. 2021. Addressing air quality, agriculture, and climate change

across the Southwest and Southern Plains: A roadmap for research, extension, and policy. Bulletin of the American Meteorological Society 102(7):E1394-401. https://doi.org/10.1175/BAMS-D-21-0088.1

Dormody T.J., P. Skelton, G. Rodriguez, D.W. Dubois, D. VanLeeuwen. 2021. Assessing the Impact of a Weather and Climate Curriculum on Youth Science Comprehension, Journal of Agricultural Education 62(3):153-166. https://doi.org/10.5032/jae.2021.03153

Dormody, T.J., P.D. Skelton, G. Rodriguez, D.W. DuBois, D. VanLeeuwen. 2020. Lesson Worksheets: A Tool for Developing Youth Weather and Climate Science Comprehension. Journal of Extension, 58(2). https://tigerprints.clemson.edu/joe/vol58/iss2/16/

Dormody, T.J., P.D. Skelton, G. Rodriguez, D.W. DuBois. 2020. Science Comprehension Retention Among Youth Agriscience Students Instructed in Weather and Climate. Journal of Youth Development 15(6): 116-135. https://doi.org/10.5195/jyd.2020.902

DuBois, D. 2022. Dust Mitigation Monitoring Project, Final Report. Prepared for NMDOT Research Bureau. Prepared by New Mexico State University, Department of Plant and Environmental Sciences.

DuBois, D. 2020. Drought - Be a Citizen Scientist. NMDA Natural Hazard Mitigation. Las Cruces, NM: New Mexico Department of Agriculture.

Dunbar N., D. Gutzler, K. Pearthree, F. Phillips, P. Bauer, C. Allen, D. DuBois, M. Harvey, J. Phillip King, L. McFadden, B. Thomson, A. Tillery. 2022. In: Climate Change in New Mexico Over the Next 50 Years: Impacts on Water Resources, N. Dunbar, D. Gutzler, K. Pearthree, and F. Phillips (eds.) Socorro, NM: New Mexico Bureau of Geology and Mineral Resources.

Duval, D., A.K. Bickel, G. Frisvold. 2024. Differential effects of drought on Arizona state park Visits: Implications for visitor spending and local economies. *Journal of Regional Analysis & Policy* 54(2) (in press).

Duval, D., A.K. Bickel, G Frisvold. 2022. Effects of reservoir levels on Arizona national recreation area visitation, visitor spending, and local economies. Journal of the American Water Resources Association 58: 622–638. https://doi.org/10.1111/1752-1688.12962

Duval, D., A.K. Bickel, G. Frisvold. 2021. Drought Effects on Arizona State Park Visits, Visitor Spending, and Local Economies. Final Report to the National Integrated Drought Information System. Boulder, CO.

Duval, D., A.K. Bickel, G. Frisvold. 2021. Drought Effects on National Park Visits, Visitor Spending, and Local Economies. Final Report to the National Integrated Drought Information System. Boulder, CO.

Duval, D., A. Bickel, and G. Frisvold. 2021. The Effects of Reservoir Levels on Arizona National Recreation Area Visitation, Visitor Spending, and Local Economies. Final Report to the National Integrated Drought Information System. Boulder, CO.

Duval, D., A.K. Bickel, and G. Frisvold. 2021. The Costs of Wildfire in Arizona: A Survey of Methods, Data, and Estimates. Final Report to the Arizona Department of Water Resources. University of Arizona Cooperative Extension. December 2021.

Duval, D., A.K. Bickel, G.Frisvold, W. Zheng. 2021. The Nature-Based Restorative Economy (NBRE) in Santa Cruz County, Arizona. Department of Agricultural and Resource Economics, University of Arizona, Cooperative Extension. Tucson, AZ.

https://economics.arizona.edu/nature-based-restorative-economy-santa-cruz-county-arizona

Duval, D., A.K. Bickel, G. Frisvold. 2020. Arizona County Agricultural Economy Profiles. Tucson: University of Arizona Cooperative Extension.

Duval, D., A.K. Bickel, G. Frisvold. 2020. County Agricultural Economy Profiles for Southern Arizona. Making Action Possible in Southern Arizona (MAP Dashboard) White Paper #14. Economic and Business Research Center. Eller College of Management. University of Arizona. https://mapazdashboard.arizona.edu/sites/default/files/images/county_agricultural_economy_profiles_final.pdf

Duval, D., G. Frisvold, A. Bickel. 2020. The economic value of trails: A travel cost method study. Final Technical Report to the Arizona Parks Board. Tucson: University of Arizona Cooperative Extension.

Duval, D., A.K. Bickel, G. Frisvold, X Wu, C Hu. 2018. Contribution of Agriculture to the Maricopa County and Gila River Indian Community Economies. Department of Agricultural & Resource Economics, Cooperative Extension Report. University of Arizona.

Ferguson, D.B., G.B. Frisvold, C. Maxwell, M.A. Crimmins. 2024. How Are Weather and Climate Products and Decision Support Systems Used in Wildland Fire Decision Making in the US Southwest? *Weather, Climate, and Society.* https://doi.org/10.1175/WCAS-D-24-0069.1. In press.

Ferguson, D.B., A.M. Meadow, H.P. Huntington. 2022. Making a Difference: Planning for Engaged Participation in Environmental Research. Environmental Management 69:227–243. https://doi.org/10.1007/s00267-021-01585-5

Flores-Margez, J.P., J.A. Jimenez-Cervantes, J.A. Hernández-Escamilla, E. Olivas-Enríquez, M.K. Shukla, A. González-Delgado, D.W. DuBois. 2020. Fungal genus detected in soils of Chihuahuan Desert during dust storms along United States-Mexico border. Terra Latinoamericana 38(4): 725-734. https://doi.org/10.28940/terra.v38i4.754

Ford, M. 2022. Connections Between Cropping Trends, Water Availability, And Groundwater Regulations. Master's Thesis, Hydrology & Atmospheric Sciences, University of Arizona. https://repository.arizona.edu/bitstream/handle/10150/665019/azu_etd_19702_sip1_m.pdf

Frederick, S.E., C.A. Woodhouse. 2020. A multi-century perspective on the relative influence of seasonal precipitation on streamflow in the Missouri River headwaters. Water Resources Research. https://doi.org/10.1029/2019WR025756

Frisvold, G. 2024. Arizona policy responses to water shortage: Can they have an impact? *Choices* 39: 1-7.

Frisvold, G. 2020. Improving Water Footprint Calculations Using Local Agronomic and Environmental Data. Final Report to Barilla Corporation.

Frisvold G. 2018. Improving Water Footprint Calculations Using Local Agronomic and Environmental Data. Technical Report prepared for Barilla Company.

Frisvold, G., J. Atla. 2024. Agricultural economic water productivity differences across counties in the Colorado River Basin. *Hydrology 11*:125. https://doi.org/10.3390/hydrology11080125

Frisvold, G., H. Chen. 2021. The Conservation Reserve Enhancement Program (CREP) as a vehicle for water conservation: An annotated bibliography.

Frisvold, G., D. Duval. 2024. Agricultural water footprints and productivity in the Colorado River Basin. *Hydrology* 11:5. https://doi.org/10.3390/hydrology11010005

Frisvold, G., D. Duval. C. Montanía. 2024 Economic Impacts of Groundwater Restrictions in the Gila Bend and Willcox Basins. Briefing Report to the Arizona Farm Bureau.

Frisvold, G., A. Marcheva. 2021. Reverse water auctions in theory and practice. Report.

Frisvold, G., C. Sanchez, N. Gollehon, S.B. Megdal, P. Brown. 2018. Evaluating Gravity-Flow Irrigation with Lessons from Yuma, Arizona, USA. Sustainability 10(5):1548. https://doi.org/10.3390/su10051548

Frisvold, G.B., N. Zhang, M.A. Crimmins, D. Ferguson, C. Maxwell, C. 2024. Demand for Information for Wildland Fire Management. *Atmosphere* 15(11): 1364. https://doi.org/10.3390/atmos15111364.

Fuentes J. 2019. Using time-lapse footage to estimate mineral dust concentrations at heights correlating to passenger and commercial vehicles. MS Thesis, New Mexico State University.

Gangopadhyay, S., C. Woodhouse, G. McCabe, C. Routson, D. Meko. 2022. Tree rings reveal unmatched 2nd century drought in the Colorado River Basin. Geophysical Research Letters 49: e2022GL098781. https://doi.org/10.1029/2022GL098781

Gardner-Vandy K., D. Scalice, et al. 2020. Relationships First and Always: A Guide to Collaborations with Indigenous Communities. An EDI Community Paper to the 2020 Planetary Science and Astrobiology Decadal Survey 2013-2032. Submitted as part of a collaborative effort organized by the Equity, Diversity, and Inclusion Working Group (EDIWG). https://doi.org/10.3847/25c2cfeb.0de1af1a

Gerlak, A., Z. Guido, G. Owen, S. Rodriguez McGoffin, E. Louder, J. Davies, K. Smith, A. Zimmer, A. Murveit, A. Meadow, P. Shrestha, N. Joshi. 2023. Stakeholder Engagement in the Co-Production of Knowledge for Environmental Decision-making. World Development 170: 106336. https://doi.org/10.1016/j.worlddev.2023.106336

Gerlak, A., S. Karambelkar, D.B. Ferguson. 2021. Knowledge Governance and Learning: Examining Challenges and Opportunities in the Colorado River Basin. Environmental Science & Policy 125:219-230. https://doi.org/10.1016/j.envsci.2021.08.026

Gerlak, A., B. McMahan. 2017. Climate risks and impacts for the regional utility sector: results of a collaborative research process with Tucson Electric Power. CLIMAS: University of Arizona.

Gerlak, A., H. Vafai, D.B. Ferguson, and L. Salame. 2021. Science Diplomacy in Education. In Sustainable Development for the Americas: Science, Health, and Engineering Policy and Diplomacy, eds. E.W. Colglazier, H.A. Vafai, K.E. Lansey and M.D. Bryson: CRC Press.

Gerlak, A., J. Weston, B. McMahan, R.L. Murray, M. Mills-Novoa. 2017. Climate risk management and the electricity sector. Climate Risk Management 19:12-22. https://doi.org/10.1016/j.crm.2017.12.003

Ghodsi Zadeh Z. 2018. Modeling of dust emission for a crusted surface. MS Thesis, New Mexico State University.

Gildersleeve, R., R. Leih. 2023. Pima County Food Alliance (PCFA) Actor Mapping Summary Report. Community Research, Evaluation, and Development (CRED), University of Arizona.

Gildersleeve, R., R. Leih, G. Owen, S. Thompson, A. Bhakta, K. Bartels, L. Bellante, A. Hilton. 2024. Considerations for a More Sustainable and Equitable Organizational Structure for the Pima County Food Alliance: Report of Interview and Focus Group Findings. Food Systems Research Lab and Climate Assessment for the Southwest (CLIMAS), University of Arizona.

Gonzalez, P., G.M. Garfin, D.D. Breshears, K.M. Brooks, H.E. Brown, E.H. Elias, A. Gunasekara, N. Huntly, J.K. Maldonado, N.J. Mantua, H.G. Margolis, S. McAfee, B.R. Middleton, B.H. Udall. 2018. Southwest. In: Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II. D.R. Reidmiller, et al., eds. U.S. Global Change Research Program, Washington, DC. https://nca2018.globalchange.gov/chapter/25/

Greene, C. 2024. *Drought Monitoring Insights from the New Mexico Drought Monitoring Working Group*. Tucson, AZ: Climate Assessment for the Southwest.

Greene, C. 2021. "Drought isn't just water, it is living": Narratives of drought vulnerability in California's San Joaquin Valley. Geoforum 121: 33-43. https://doi.org/10.1016/j.geoforum.2021.02.007

Greene, C., M. Crimmins 2024. Perceptions and Experiences with Drought and the Livestock Forage Disaster Program in Arizona. Climate Assessment for the Southwest – University of Arizona, Tucson, AZ.

Greene, C., D.B. Ferguson. 2024. Equity, Justice, and Drought: Lessons for Climate Services from the U.S. Southwest. Bulletin of the American Meteorological Society 105:E45-E58. https://doi.org/10.1175/BAMS-D-22-0185.1

Greene, C., H. Wilmer, D. Ferguson, M. Crimmins, M. McClaran. 2022. Using scale and human agency to frame ranchers' discussions about socio-ecological change and resilience. Journal of Rural Studies 96: 217–226. https://doi.org/10.1016/j.jrurstud.2022.11.001

Guido, Z., B. McMahan, D. Hoy, C. Larsen, B. Delgado, R. Granillo, M. Crimmins. 2022. Public Engagement on Weather and Climate with a Monsoon Fantasy Forecasting Game. Bulletin of the American Meteorological Society 104(1): E249–E256. https://doi.org/10.1175/BAMS-D-22-0003.1

Gutierrez J. 2019. Automated detection of dust storms from ground-based weather station imagery using neural network classification. MS Thesis, New Mexico State University.

Hansen, H. 2022. Climate, Prices, and Federal Programs: Choices for Irrigated Agriculture. Master's Thesis. Department of Agricultural and Resource Economics, University of Arizona. https://economics.arizona.edu/climate-prices-and-federal-programs-choices-irrigated-agriculture

Hiraldo D., S.R. Carroll. 2020. Policy Brief: Native Nation Rebuilding Lessons for Tribal Research and Data Governance. Tucson: Native Nations Institute, University of Arizona.

Hiraldo, D., S.R. Carroll, D.M. David-Chavez, M.B. Jäger, M. Jorgensen. 2020. Native Nation Rebuilding for Tribal Research and Data Governance. NNI Policy Brief Series. Tucson: Native Nations Institute, University of Arizona.

Hiraldo, D., K. James, S.R. Carroll. 2021. Indigenous Sovereignty in a Pandemic: Tribal Codes in the United State as Preparedness. Frontiers in Sociology 6:617995. https://doi.org/10.3389/fsoc.2021.617995

Hoy, D., R.L. Granillo, L. Boeman, B. McMahan, M.A. Crimmins. 2023. Data aggregation, ML ready datasets, and an API: leveraging diverse data to create enhanced characterizations of monsoon flood risk. Frontiers in Climate 5:1107363. https://doi.org/10.3389/fclim.2023.1107363

Hu, C. 2019. Econometric Analysis of the Arizona Alfalfa Market. MS Thesis. Department of Agricultural & Resource Economics. University of Arizona. https://repository.arizona.edu/handle/10150/634264

Hughes, H., D. Breshears, K. Cook, L. Keith, J. Burger. 2023. Household energy use response to extreme heat evaluated with a biophysical model of temperature regulation: An Arizona case study. PLOS Climate 2(4): e0000110. https://doi.org/10.1371/journal.pclm.0000110

Isaaks R., B. Colby. 2020. Empirical application of rubinstein bargaining model in western U.S. water transactions. Water Economics and Policy 6(1): 1950010. https://doi.org/10.1142/S2382624X19500103

Isoe, J., L.E. Koch, Y.E. Isoe, A.A. Rascon, H.E. Brown, B.B. Massani, R.L. Miesfeld. 2019. Identification and characterization of the mosquito-specific eggshell organizing factor in Aedes aegypti mosquitoes. PLoS Biology 17(1):e3000068. https://doi.org/10.1371/journal.pbio.3000068

Jagannathan, K., G. Emmanuel, J. Arnott, K. Mach, A. Bamzai-Dodson, K. Goodrich, R. Myer, M. Neff, K. Dana Sjostrom, K. Timm, E. Turnhout, G. Wong-Parodi, A. Bednarek, A. Meadow, A. Dewulf, C. Kirchhoff, R. Moss, L. Nichols, E. Oldach, M. Carmen Lemos, and N. Klenk. 2023. A Science of Actionable Knowledge research agenda: Drawing from a review of the most misguided to the most enlightened claims in the science-policy interface literature. Environmental Science & Policy 144:174–186. https://doi.org/10.1016/j.envsci.2023.03.004

Jäger M.B., C. Behe, D.B. Ferguson, et al. 2019. Building an Indigenous Foods Knowledges Network Through Relational Accountability. Journal of Agriculture, Food Systems and Community Development 9(B): 45-51. https://doi.org/10.5304/jafscd.2019.09B.005

Johnson, N., K.S. Erickson, D.B. Ferguson, M.B. Jäger, L.L. Jennings, A.R. Juan, S. Larson, W.K.S. Smythe, C. Strawhacker, A. Walker, S.R. Carroll. 2021. The Impact of COVID-19 on Food Sovereignty for Alaska Natives. In 2021 Arctic Report Card, eds. T.A. Moon, M.L. Druckenmiller and R.L. Thoman. NOAA.

Johnson, N., M.B. Jäger, L. Jennings, A. Juan, S.R. Carroll, D.B. Ferguson. 2020. Indigenous Foods Knowledges Network: Facilitating Exchange between Arctic and Southwest Indigenous Communities on Food and Knowledge Sovereignty. Witness the Arctic. www.arcus.org/witness-the-arctic/2020/3/highlight/2

Karambelkar, S., A.K. Gerlak. 2020. Collaborative Governance and Stakeholder Participation in the Colorado River Basin: An Examination of Patterns of Inclusion and Exclusion. Natural Resources Journal 60. https://digitalrepository.unm.edu/nrj/vol60/iss1/3

Keith, L. 2022. Adaptation to Urban Heat in Tucson. In Planning for Climate Mitigation and Adaptation, M. Bucchin and A. Tuley (eds.) Planning Advisory Services (PAS) Report 601. American Planning Association, pp. 113-115. https://www.planning.org/publications/report/9250330/

Keith L. 2019. Assessing Policy Innovation: Climate Action Planning in the U.S. Southwest. PhD Dissertation. University of Arizona, Tucson.

Keith,L., C.J. Gabbe, E. Schmidt. 2023. Urban heat governance: examining the role of urban planning. *Journal of Environmental Policy & Planning* 25(5):642-662. https://doi.org/10.1080/1523908X.2023.2244446

Keith, L., A.K. Gerlak. 2021. There's no place in the US safe from the heat. August 20, 2021. https://thehill.com/opinion/energy-environment/568718-theres-no-place-in-the-us-safe-from-the-heat/

Keith, L., N. Iroz-Elardo, I. Sami, E. Austhof. 2021. Extreme Heat at Outdoor Vaccination Sites: Banner South (Kino) Report. The University of Arizona.

Keith, L., N. Iroz-Elardo, I. Sami, E. Austhof. 2021. Extreme Heat at Outdoor Vaccination Sites: Tucson Medical Center Report. The University of Arizona.

Keith, L., N. Iroz-Elardo, I. Sami, E. Austhof. 2021. Extreme Heat at Outdoor Vaccination Sites: UArizona POD Report. The University of Arizona.

Keith L., B. McMahan, T. Wagner. 2019. Urban heat island maps and decision-making. University of Arizona, Climate Assessment for the Southwest (CLIMAS).

Keith, L., S. Meerow. 2022. Planning for Urban Heat Resilience. Planning Advisory Services (PAS) Report 600. American Planning Association. http://www.planning.org/publications/report/9245695/

Keith, L., S. Meerow. 2021. Beat Extreme Heat with these 8 Tactics. Planning Magazine. Winter 2021:12-14. https://www.planning.org/planning/2021/fall/beat-extreme-heat-with-these-8-tactics/

Keith, L., S. Meerow. 2021. Cities must plan for heat resilience now. Thomson Reuters Foundation. July 5, 2021. https://news.trust.org/item/20210705161002-pz8g0

Keith, L., S. Meerow, P. Berke, J. DeAngelis, L. Jensen, S. Trego, E. Schmidt, S. Smith. 2022. Plan Integration for Resilience Scorecard (PIRS) for Heat: Spatially evaluating networks of plans to mitigate heat (Version 1.0). https://www.planning.org/publications/document/9257652/

Keith, L., S. Meerow, D.M. Hondula, V.K. Turner, J.C. Arnott. 2021. Deploy heat officers, policies, and metrics. Nature 598(7879):29-31. https://doi.org/10.1038/d41586-021-02677-2

Keith, L., S. Meerow, S. Trego, E. Schmidt. 2022. City of Tempe, AZ: Plan Integration for Resilience Scorecard (PIRS) For Heat. https://repository.arizona.edu/handle/10150/666700

Keith, L., S. Meerow, S. Trego, E. Schmidt, L. Jensen, P. Berke, J. DeAngelis. 2022. City of Kent, WA: Plan Integration for Resilience Scorecard (PIRS) for Heat. https://www.planning.org/media/document/9260042/

Keith, L., S. Meerow, T. Wagner. 2020. Planning for extreme heat: a review. Journal of Extreme Events 6(03n04): 2050003. https://doi.org/10.1142/S2345737620500037

Khatri-Chhetri P., S.M. Hendryx, K.A. Hartfield, M.A. Crimmins, W.J.D. van Leeuwen, V.R. Kane. 2021. Assessing Vegetation Response to Multi-Scalar Drought across the Mojave, Sonoran, Chihuahuan Deserts and Apache Highlands in the Southwest United States. Remote Sensing 13(6): 1103. https://doi.org/10.3390/rs13061103

Kinkaid, E., G. Owen, L. Bellante. 2021. Tucson Opinion: COVID-19 impacts demonstrate why Southern Arizona needs more farmers. Arizona Daily Star, July 17, 2021. https://tucson.com/opinion/local/tucson-opinion-covid-19-impacts-demonstrate-why-southern-arizona-needs-more-farmers/article_daeda632-e5ae-11eb-bf80-3fab70963ab9.html

Konyar, K., G. Frisvold. 2019. Climate Policies as Water Policies. In: Applied Methods for Agriculture and Natural Resource Management. S. Msangi, D. MacEwan, eds. Natural Resource Management and Policy 50:189—211. https://doi.org/10.1007/978-3-030-13487-7_11

Leih, R., R. Gildersleeve. 2023. Cultivating Equitable Food Policy in Pima County. Fall 2023 Research Brief. https://www.pimafoodalliance.org/written-products/fall-2023-research-brief.

Lemos, M.C., J.C. Arnott, N.M. Ardoin, K. Baja, A.T. Bednarek, A. Dewulf, C. Fieseler, K.A. Goodrich, K. Jagannathan, N. Klenk, K.J. Mach, A.M. Meadow, R. Meyer, R.H. Moss, L. Nichols, K.D. Sjostrom, M. Stults, E. Turnhout, C. Vaughan, G. Wong-Parodi, C.A. Wyborn. 2018. To co-produce or not to co-produce. Nature Sustainability 1(12): 722. https://doi.org/10.1038/s41893-018-0191-0

LeRoy, A., A.M. Meadow, J. Weiss. 2018. Climate-Related Hazards in the Town of Oro Valley, Arizona. CLIMAS Community Climate Profiles. Tucson, University of Arizona.

Martin J., G.T. Pederson, C.A. Woodhouse, E.R. Cook, M. McGuire, D. Broman, J. Lanini, et al. 2019. 1200 years of Upper Missouri River streamflow reconstructed from tree rings. Quaternary Science Reviews 224: 105971. https://doi.org/10.1016/j.quascirev.2019.105971

Martin, J.T., G.T. Pederson, C.A. Woodhouse, and 16 co-authors. 2020. Increased drought severity tracks warming in the United States' largest river basin. Proceedings of the National Academies of Science (PNAS). https://doi.org/10.1073/pnas.1916208117

McCabe, G., D. Wolock, C.A. Woodhouse, G. Pederson, S. McAfee, S. Gray, A. Csank. 2020. Basin wide hydroclimatic drought in the Colorado River basin. Earth Interactions 24: 1–20. https://doi.org/10.1175/EI-D-20-0001.1

McGowan G. 2019. Geospatial analysis and quality control of monsoon season precipitation data from citizen reporters near Tucson, Arizona. MS Thesis, Geographic Information Systems Technology. University of Arizona.

McGreal, B., B. Colby. 2023. Effects of Economic and Climatic Factors on Arid Agricultural Water Use. Journal of Soil and Water Conservation September 2023, 78 (5) 397-411. https://doi.org/10.2489/jswc.2023.001300

McKellar, T. 2022. Drought Monitoring in the Southwestern U.S.: Analysis of Seasonal Precipitation, Multiscalar Indices, and Soil Water. Ph.D. Dissertation, Department of Soil, Water, and Environmental Science, University of Arizona. https://repository.arizona.edu/handle/10150/665665

McKellar, T., M.A. Crimmins, M. Schaap, C. Rasmussen. 2023. Defining the Multiscalar Index Timescale – Soil Water Depth Continuum for the Southwestern United States. Journal of Geophysical Research – Atmospheres. http://doi.org/10.1029/2023JD039348

McMahan, B., A. Gerlak. 2020. Climate risk assessment and cascading impacts: Risks and opportunities for an electrical utility in the US Southwest. Climate Risk Management 29: 100240. DOI: 10.1016/j. crm.2020.100240. https://doi.org/10.1016/j.crm.2020.100240

McMahan, B., R.L. Granillo, B. Delgado, M. Herrera, M.A. Crimmins. 2021. Curating and Visualizing Dense Networks of Monsoon Precipitation Data: Integrating Computer Science into Forward Looking Climate Services Development. Frontiers in Climate 3. https://doi.org/10.3389/fclim.2021.602573

McMahan, B., W. Holmgren, A. Gerlak. 2020. Climate and TEP Resource Portfolios – Emissions Reduction and Cumulative Carbon Budgets. An appendix to the Tucson Electric Power 2020 Integrated Resource Plan. https://www.tep.com/wp-content/uploads/TEP-2020-Integrated-Resource-Plan-Lo-Res.pdf

Meadow A.M., S. Leroy, J. Weiss, L. Keith. 2020. Climate Profile for The Verde Valley. CLIMAS Climate Profiles. University of Arizona.

Meadow A.M., S. Leroy, J. Weiss, L. Keith. 2019. Climate Profile for The Highlands at Dove Mountain. CLIMAS Community Climate Profiles. University of Arizona.

Meadow, A.M., S. Leroy, J. Weiss, L. Keith. 2018. Climate Profile for the City of Flagstaff, Arizona. CLIMAS: Tucson, AZ.

Meadow, A.M., G. Owen. 2021. Planning and Evaluating the Societal Impacts of Climate Change Research Projects: A guidebook for natural and physical scientists looking to make a difference. Advancing Research Impacts in Society, University of Michigan.

Meadow, A.M., G. Owen, N. Joshi. 2022. Societal Impacts Assessment Report: How AIRES Contributes to our Region and the World. Arizona Institute for Resilient Environments and Societies, University of Arizona.

Meadow, A.M., J. Weiss, M. Crimmins, and the Quad Cities Profile Working Group. 2023. Climate Profile for the Quad Cities Region of Arizona. Climate Assessment for the Southwest – University of Arizona.

Meadow, A.M, J. Weiss, S. Leroy. 2021. Climate Profile for the Upper Santa Cruz Watershed.

Meadow A.M., J. Weiss, S. Leroy, L. Keith, S. Hausam, E. Nasser, S. Petersen, A. Basaraba, N. Russell. 2019. Climate Profile for the Pueblo of Laguna. CLIMAS Climate Profiles. University of Arizona.

Meerow, S., L. Keith. 2021. Planning for extreme heat: A national survey of U.S. planners. Journal of the American Planning Association. https://doi.org/10.1080/01944363.2021.1977682

Meko, D.M, C.A. Woodhouse, A.G. Winitsky. 2022. TreeRing Perspectives on the Colorado River: Looking Back and Moving Forward. Journal of the American Water Resources Association, 1-18. https://doi.org/10.1111/1752-1688.12989

Mokari E., D. DuBois, Z. Samani, H. Mohebzadeh, K. Djaman. 2021. Estimation of daily reference evapotranspiration with limited climatic data using machine learning approaches across different climate zones in New Mexico. Theoretical and Applied Climatology, https://doi.org/10.1007/s00704-021-03855-y

Mokari E., H. Mohebzadeh, Z. Samani, D. DuBois, P. Daggupati. 2021. Spatiotemporal imputation of MODIS land surface temperature using machine learning techniques (Case study: New Mexico's Lower Rio Grande Valley), Remote Sensing Applications: Society and Environment 24: 100651. https://doi.org/10.1016/j.rsase.2021.100651

Mokari, E., Z. Samani, R. Heerema, E. Dehghan-Niri, D. DuBois, F. Ward, C. Pierce. 2022. Development of a new UAV-thermal imaging-based model for estimating pecan evapotranspiration. Computers and Electronics in Agriculture 194: 106752. https://doi.org/10.1016/j.compag.2022.106752

Murveit, A., S. Delphin, C. Domingues, S. Bourque, S. Faulstich, G. Garfin, N. Huntly, A. Meadow, V. Preston. 2023. Stories as Data: Indigenous Research Sovereignty and the "Intentional Fire" Podcast. Environment and Planning F. https://doi.org/10.1177/26349825221142293

Ottman M., P. Brierly, G. Frisvold. 2020. Tools for Nitrogen Management of Wheat. Final Report to Barilla Corporation.

Owen, G. 2023. Conceptualizing effectiveness in climate change adaptation action: applications for the Global Stocktake. In Perspectives: Adequacy and Effectiveness of Adaptation in the Global Stocktake, J. Gao and L. Christiansen (eds.) UN Environment Program Copenhagen Climate Centre, Copenhagen. https://unepccc.org/project/the-adaptation-working-group-awg-of-the-independent-global-stocktake-igst/Owen, G. 2021. Equity and justice as central components of climate change adaptation. Preview article. One Earth 4(10):1373-1374. https://doi.org/10.1016/j.oneear.2021.09.008

Owen, G. 2020. Evaluating socially engaged climate research: Scientists' visions of a climate resilient U.S. Southwest. Research Evaluation, rvaa028. https://doi.org/10.1093/reseval/rvaa028

Owen, G. 2020. What makes climate change adaptation effective? A systematic review of the literature. Global Environmental Change 62: 102071. https://doi.org/10.1016/j.gloenvcha.2020.102071

Owen, G. 2019. Evaluating Effectiveness in Climate Change Adaptation and Socially-Engaged Climate Research. PhD Dissertation, School of Geography and Development, University of Arizona.

Owen, G., D.B. Ferguson, B. McMahan. 2019. Contextualizing climate science: applying social learning systems theory to knowledge production, climate services, and use-inspired research. Climatic Change 157: 151-170. https://doi.org/10.1007/s10584-019-02466-x

Owen, G., E. Kinkaid, L. Bellante, S. Maccabe. 2021. Executive Summary: State of the Tucson Food System Report, Assessing the impacts of the COVID-19 pandemic in

southern Arizona, 2020-2021. Center for Regional Food Studies, University of Arizona. https://crfs.arizona.edu/sites/crfs.arizona.edu/files/Executive%20Summary_2020-21%20State%20of%20the%20Tucson%20Food%20System%20Report.pdf

Owen, G., E. Kinkaid, L. Bellante, S. Maccabe. 2021. State of the Tucson Food System Report: Assessing the impacts of the COVID-19 pandemic in southern Arizona 2020-2021. Center for Regional Food Studies, University of Arizona. https://crfs.arizona.edu/sites/crfs.arizona.edu/files/2020-21%20State%20of%20the%20Tucson%20Food%20System%20Report_3.pdf

Pendergrass, A.G., G.A. Meehl, R. Pulwarty, M. Hobbins, A. Hoell, A. AghaKouchak, C. J.W. Bonfils, A.J.E. Gallant, M. Hoerling, D. Hoffmann, L. Kaatz, F. Lehner, D. Llewellyn, P. Mote, R. Neale, J.T. Overpeck, A. Sheffield, K. Stahl, M. Svoboda, M.C. Wheeler, A.W. Wood, C.A. Woodhouse. 2020. Flash droughts: High impact events that present a new challenge for subseasonal to seasonal prediction. Nature Climate Change 10: 191–199. https://doi.org/10.1038/s41558-020-0709-0

Pereira, M. 2022. Relationships Between Groundwater, Climatic, and Economic Factors in Southeastern Arizona. M.S. Thesis, Hydrology & Atmospheric Sciences, University of Arizona. https://repository.arizona.edu/bitstream/handle/10150/664383/azu_etd_19651_sip1_m.pdf

Qiao, X. 2018. Water Use and Climate Effects on Farm Profitability in the Colorado Basin. MS Thesis, Department of Agricultural and Resource Economics, University of Arizona.

Roach, M., E. Austhof, V. Berisha, H.E. Brown, D. Carr, L. Harlow-Smith, D. Hondula, K. Snyder. 2018. Addendum to the Arizona Climate and Health Adaptation Plan. A report prepared for the United States Centers for Disease Control and Prevention Climate-Ready States and Cities Initiative.

Roach, M., E. Barrett, H.E. Brown, B. Dufour, D.M. Hondula, H. Putnam, B. Sosa. 2017. Arizona's Climate and Health Adaptation Plan. A report prepared for the United States Centers for Disease Control and Prevention Climate-Ready States and Cities Initiative.

Rodriguez-Lonebear, D., N.E. Barceló, R. Akee, S.R. Carroll. 2020. American Indian Reservations and COVID-19: Correlates of Early Infection Rates in the Pandemic. Journal of Public Health Management and Policy 26(4): 371-377. https://doi.org/10.1097/PHH.0000000000001206

Sami, I., L. Keith. 2023. How do streetcar transit users and streetcar decision-makers perceive heat risk? Journal of Public Transportation 25: 100045. https://doi.org/10.1016/j.jpubtr.2023.100045

Singh, S., G. Johnson, D. DuBois, I. Kavouras. 2022. Assessment of the Contribution of Local and Regional Biomass Burning on PM2.5 in New York/New Jersey Metropolitan Area. Aerosol and Air Quality Research 22(9): 220121. https://doi.org/10.4209/aaqr.220121

Smarik S.G., S. Aney, A. Boes, D. Brown, D. DuBois, B. Edwards, E. Elias, M. Eve, R. Steele, N. Webb, M. Wilson, G. Zwicke. 2019. Dust Mitigation Handbook. Washington, DC: U.S. Department of Agriculture. https://dust.swclimatehub.info/

Stahle, D.W., E.R. Cook, D. J. Burnette, M.C.A. Torbenson, I.M. Howard, D. Griffin, J. Villanueva, B.I. Cook, P.A. Williams, E. Watson, D. Sauchyn, N. Pederson, C.A. Woodhouse, G.T. Pederson, D. Meko, B. Coulthard, C.J. Crawford. 2020. Dynamics, variability, and change in seasonal precipitation reconstructions for North America. Journal of Climate. https://doi.org/10.1175/JCLI-D-19-0270.1

Tintor, W.L., C.A. Woodhouse. 2021. The variable climate response of Rocky Mountain bristlecone pine (Pinus aristata Engelm). Dendrochronologia 68: 125846. https://doi.org/10.1016/j.dendro.2021.125846

Uhlman, K., C. Eastoe, Z. Guido, M.A. Crimmins, A. PurkeyDeller, S. Eden. 2020. Assessing the Vulnerability of an Aquifer to Climate Variability through Community Participation in Arivaca, Arizona. Journal of Contemporary Water Research & Education 170. https://doi.org/10.1111/j.1936-704X.2020.03337.x

Vano, J.A., D. Behar, P. Mote, D.B. Ferguson, R. Pandya. 2017. Partnerships Drive Science to Action Across the AGU Community. Eos 98. https://doi.org/10.1029/2017EO088041

Von Ohlen, K., H. Brown, L. Keith, E. Austhof, L. Watkins, S. Chambers. 2022. Summary of Pima County Cooling Center Spatial Optimization. A Report for the Arizona CDC Building Resilience Against Climate Effects (BRACE) project. University of Arizona.

Walsh, K., C. Greene, M. Crimmins, D. Ferguson, M. McClaran, H. Wilmer. 2022. What does resilience mean to ranchers. USDA, ArcGIS Story Map. https://storymaps.arcgis.com/collections/b08b39a1ca134e658d98915afe91b13f

Watkins, L., H. Brown, L. Keith, E. Austhof, H. Lin Cox, S. Chambers, J. Tabor, A. Gettel, M. Guardaro. 2024. A co-produced workflow for addressing inequities in cooling center access. *Community Science,* In press.

Weiss, J. 2020. Exploratory Analysis of Spinach and Temperature Data for Duncan Family Farms. University of Arizona Cooperative Extension.

Weiss, J. 2020. Initial Modeling of Sulfur Application Timing for Powdery Mildew at Buhl Memorial Vineyard, 2017-2020. University of Arizona Cooperative Extension.

Weiss, J. 2020. Timing of Leaf Removal and Cluster Thinning in the Context of Seasonal Heat – An Analysis for Merkin Vineyards. University of Arizona Cooperative Extension.

Weiss, J., M.A. Crimmins. 2017. DroughtView: Satellite-based drought monitoring and assessment. The University of Arizona Cooperative Extension Publication AZ1737. https://cals.arizona.edu/research/climategem/resources/Weiss&Crimmins(2017)UACEDroughtView.pdf

Weiss, J., M. Crimmins, D. DuBois, G. Garfin. 2018. El Niño 2018—2019? An Overview of What It Might Mean for New Mexico. CLIMAS Climate Fact Sheet. Tucson, University of Arizona.

Weiss, J., M.A. Crimmins, and G. Garfin. 2020. La Niña 2020-2021: An Overview of What It Might Mean for Arizona. University of Arizona Cooperative Extension Climate Fact Sheet. https://cals.arizona.edu/research/climategem/sites/cals.arizona.edu.research.climategem/files/la-nina-2020-2021-overview.pdf

Weiss, J., M. Crimmins, G. Garfin, P. Brown. 2018. El Niño 2018—2019? An Overview of What It Might Mean for Arizona, University of Arizona Cooperative Extension Climate Fact Sheet. Tucson, University of Arizona.

https://cals.arizona.edu/research/climategem/sites/cals.arizona.edu.research.climategem/files/ENwatch20182019overview.pdf
Weiss, J., S. Leroy, A.M. Meadow, C. Castro. 2018. Climate Change Impacts on the North American Monsoon: Summary for the Tohono O'odham Nation. CLIMAS Community Climate Profiles. Tucson, University of Arizona.
Weiss J., M.B. Roudaut. 2020. Bud Break at Buhl Memorial Vineyard, 2016-2020, Climate Assessment for the Southwest (CLIMAS), University of Arizona.
Weiss, J., M.B. Roudaut. 2018. An Introduction to Improved Understanding of Climate Variability and Change Relevant to Orchards and Vineyards in Arizona and New Mexico for Bonita, Arizona. CLIMAS: Tucson, AZ.
Weiss, J., M.B. Roudaut. 2018. An Introduction to Improved Understanding of Climate Variability and Change Relevant to Orchards and Vineyards in Arizona and New Mexico for the Farmington Agricultural Science Center, New Mexico. CLIMAS: Tucson, AZ.
Weiss, J., M.B. Roudaut. 2018. An Introduction to Improved Understanding of Climate Variability and Change Relevant to Orchards and Vineyards in Arizona and New Mexico for Los Lunas 3 SSW, New Mexico. CLIMAS: Tucson, AZ.
Weiss, J., M.B. Roudaut. 2018. An Introduction to Improved Understanding of Climate Variability and Change Relevant to Orchards and Vineyards in Arizona and New Mexico for New Mexico State University. CLIMAS: Tucson, AZ.
Weiss, J., M.B. Roudaut. 2018. An Introduction to Improved Understanding of Climate Variability and Change Relevant to Orchards and Vineyards in Arizona and New Mexico for Yavapai College Verde Valley Campus, Arizona. CLIMAS: Tucson, AZ.
Weiss, J., M.B. Roudaut. 2018. Initial Assessment of Daily Minimum Temperature from Data Loggers in Routson Orchards. Climate Assessment for the Southwest, University of Arizona.
Weiss J., M.B. Roudaut, A.M. Meadow. 2020. Review of the 2019 Winegrape Growing Season in Arizona, Climate Assessment for the Southwest (CLIMAS), University of Arizona.
White S., S.R. Carroll. 2019. Policy Brief: Supporting Tribal Data Governance for Indigenous Community Climate Resilience. Tucson: Native Nations Institute and Climate Assessment for the Southwest, University of Arizona.
Williams, A.P., K.J. Anchukaitis, C.A. Woodhouse, D.M. Meko, B.I. Cook, K. Bolles, E.R. Cook. 2020. Tree rings and observations suggest no stable cycles in Sierra Nevada cool season precipitation. Water Resources Research. https://doi.org/10.1029/2020WR028599
Wilmer, H., D.B. Ferguson, M. Dinan, E. Thacker, P.B. Adler K. Bills Walsh, J.B. Bradford, M. Brunson, J.D. Derner, E. Elias, A. Felton, C.A. Gray, C. Greene, M.P. McClaran, R.K. Shriver, M. Stephenson, and K. Nash Suding. 2024. Resilience Is Not Enough: Toward a More Meaningful Rangeland Adaptation Science. Rangeland Ecology & Management 95:56-67. https://doi.org/10.1016/j.rama.2024.04.003
Wilmer, H., A.M. Meadow, A.B. Brymer, S.R. Carroll, D.B. Ferguson, I. Garba, C. Greene, G. Owen, D.E. Peck. 2021. Expanded Ethical Principles for Research Partnership and

Transdisciplinary Natural Resource Management Science. Environmental Management 68:453-476. https://doi.org/10.1007/s00267-021-01508-4

Woodhouse C.A., D.M. Meko, E. Bigio. 2020. A long view of southern California water supply: perfect droughts revisited. Journal of the American Water Resources Association 56: 212-229. https://doi.org/10.1111/1752-1688.12822

Woodhouse, C.A., D.M. Meko, E.R. Bigio, S.E. Frederick. 2017. Using Tree-Ring Records for Understanding Droughts in a Long-Term Context: A Guidebook for the California Department of Water Resources. https://www.water.ca.gov/-/media/DWR-Website/WebPages/Water-Basics/Drought/Files/Publications-And-Reports/UofAZ-tree-ring-Guidebook-dec-2017.pdf

Woodhouse C.A., G.T. Pederson. 2018. Investigating runoff efficiency in upper Colorado River streamflow over past centuries. Water Resources Research 54(1):286-300. https://doi.org/10.1002/2017WR021663

Woodhouse, C.A., R.M. Smith, S.A. McAfee, G.T. Pederson, G.J. McCabe, W.P. Miller, A. Csank. 2021. Upper Colorado River Basin 20th century droughts under 21st century warming: Plausible scenarios for the future. Climate Services 21. https://doi.org/10.1016/j.cliser.2020.100206

Woodhouse, C.A., B. Udall. 2022. Arid land rivers in a changing climate. Earth Interactions 26:1-14. https://doi.org/10.1175/EI-D-21-0014.1

Woodhouse, C.A., E.K. Wise. 2020. The changing relationship between the upper and lower Missouri River basins during drought. International Journal of Climatology 1–18. https://doi.org/10.1002/joc.6502

Wu, X. 2019. Recreation Visits to Lake Mead and Glen Canyon National Recreation Areas: A Replication Study. MS Thesis. Department of Agricultural & Resource Economics. University of Arizona. https://repository.arizona.edu/handle/10150/634266