Evaluating Socially-Engaged Climate Research: Scientists' Visions of a Climate Resilient U.S. Southwest

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Abstract

Socially-engaged science and collaborative research practices offer promising ways to address complex environmental and societal problems like climate variability and climate change. However, it is unclear if and how these types of collaborative knowledge production result in tangible impacts. Drawing from a six-year evaluation, this paper investigates the outcomes and contributions of ten collaborative research projects supported by a federally-funded climate research program in the U.S. Southwest. Based on a series of narratives that outline researchers' objectives, anticipated outcomes are compared to those that emerged over a six-year period. Results indicate several contributions that the program has made toward raising awareness about climate issues in the U.S. Southwest, increasing capacity to adapt to climate change and climate variability, and building lasting individual and institutional collaborative relationships. However, researchers sometimes envision direct applications of their work, such as informing policy, planning, and decision-making, to be different than what occurred within the six-year timeframe. Further exploration of these results reveals implicit assumptions in understanding how scientific information translates into use. This paper offers insight into how researchers envision their impact, the management and development of a mission-oriented research program, and the use of evaluation to understand how collaborative research contributes to societal and environmental change.

1. Introduction

The Southwest region of the United States is climatically variable, subject to extreme drought and heat, and vulnerable to climate change impacts. Given current and predicted climatic conditions, the region faces several sustainability crises. Approximately 40 million people in the western U.S. and northwestern Mexico, for example, rely on Colorado River water for domestic, industrial, and agricultural uses (U.S. Bureau of Reclamation 2012). However, increased temperatures have already reduced streamflow in the upper portion of the Colorado River basin by seven percent (McCabe et al. 2017). Model-based temperature projections indicate Colorado River streamflow reductions of 20 percent by 2050 and 35 percent by 2100 (Udall and Overpeck 2017). Human health and safety are at risk due to increased severity of heat extremes (Garfin Leroy, and Jones 2017) and respiratory problems caused by intense dust and windstorms (Rodopoulou et al. 2014). Combined, these climate impacts could bring a cascade of social, economic, and environmental problems (Leroy, Garfin, and Black 2016).

While these studies paint a gloomy picture for the future Southwest, people are also preparing for climate-related challenges in numerous ways. The City of Flagstaff, AZ implemented an adaptation plan informed by customized reports that address city-specific climate impacts (Meadow et al. 2018). Farmers in Yuma, AZ adopted more efficient irrigation technologies, agricultural infrastructure, and production practices to conserve water (Frisvold et al. 2018). Riparian environments along the Colorado River are springing back to life due to increased streamflow allotments for ecological restoration (Kerna, Colby, and Zamora 2017).

Activities like these inspire hope for a Southwest region that is resilient and adaptable to climate change and climate variability.

These examples are associated with studies conducted by social, natural, and physical scientists in the Climate Assessment for the Southwest (CLIMAS) program. The CLIMAS research agenda centers climate information needs of individuals, communities, organizations, and institutions in Arizona and New Mexico, and aims to improve people's understanding about climate and inform their climate-related planning or policy decisions. CLIMAS researchers collaborate directly with representatives from regional groups to coproduce knowledge and information that is useful for planning, policy, and decision-making processes.

The theoretical underpinnings of CLIMAS are grounded in socially-engaged approaches to research, which combine scientific and practical forms of knowledge to address global challenges. Engaged research incorporates "advice and perspectives of key stakeholders…to understand a complex social problem" (Van de Ven 2007, ix). Ideally, stakeholders and scientists collaborate to define research problems and questions, design and conduct studies, and interpret results.

Many scholars agree that engaged and participatory research approaches are necessary to address societal and environmental issues (e.g. Kates et al. 2001; Nowotny et al. 2001; Lemos and Morehouse 2005; Pahl-Wostl et al. 2007). However, it is still unclear if and how collaborative knowledge production results in societal improvement (Zscheischler, Rogga, and Lange 2018). In addition, scientists' expectations of the outcomes of collaborative research (e.g. societal and environmental change) are often more optimistic than what occurs (Lang et al. 2012), indicating a need to assess these outcomes. To address this need, this paper presents results from a six-year assessment of the CLIMAS program. This assessment provides insight into a) how CLIMAS projects, information, and services contribute—and fail to contribute—to societal and environmental change; and b) how outcomes of socially-engaged research compare to researchers' visions of their impact.

First, this paper briefly reviews socially-engaged frameworks for knowledge production, research evaluation techniques, and challenges to research evaluation in the U.S. Then it details the process of developing the CLIMAS program evaluation, which involved coproducing narratives with CLIMAS researchers to define anticipated outcomes and their visions for achieving those outcomes. Analysis focused on the comparison between anticipated project outcomes and the outcomes that emerged over a six-year period. Results indicate several contributions toward increasing regional climate resilience and adaptive capacity. An in-depth review of one project shows how the evaluation process encourages researchers to reflect upon project outcomes, especially when outcomes do not manifest as anticipated.

This evaluation helped program management categorize the ways that CLIMAS research contributes to a climate-resilient Southwest region, established an evaluation framework to build upon in subsequent funding cycles, informed the program's approach to future research, and revealed researchers' implicit assumptions about how socially-engaged research results in societal change. In addition to research findings, this paper offers methodological insight for similar research programs interested in implementing evaluation.

2. Socially-engaged research practices and evaluation

Among the goals of scientific research is the improvement of society. Current U.S. science policy and most university-supported research is based on a model of scientific "freedom of inquiry" (Bush 1945). This vision of science policy, originally developed to maintain scholarly independence from government or corporate influence (Dennis 2015), assumes that discoveries made by academic experts will be delivered to societal members who will use results to inform policy, practice, and technology (Cash, Borck, and Patt 2006; Van Drooge and Spaapen 2017). However, the model does not explain how scientific results will be delivered, consumed, or used. This conceptualization of science for society is of limited use when addressing highly complex, systemic problems such as environmental change, climatic shifts, and other global sustainability issues (Nowotny, Scott, and Gibbons 2001; Cash et al. 2003; Wiek et al. 2012).

In response, a rich literature has emerged to describe a different model for scientific production that can be broadly categorized as socially-engaged research. Various ideas within this vein include action research (Lewin 1946; Greenwood and Levin 2007); post-normal science (Funtowicz and Ravetz 1993); Mode 2 knowledge production (Gibbons et al. 1994; Nowotny, Scott, and Gibbons 2001); boundary work (Guston 2001; Cash et al. 2003); knowledge coproduction (Jasanoff 2004; Lemos and Morehouse 2005); transdisciplinarity (Pohl and Hirsch-Hadorn 2008; Jahn, Bergmann, and Keil 2012); transformational sustainability science (Kates et al. 2001; Wiek et al. 2012); social learning (Wenger 2000; Pahl-Wostl et al. 2007); and useful science or usable knowledge production (Dilling and Lemos 2011; Beier et al. 2017). These frameworks converge and diverge in terms of agenda and approach. However, they all make one thing clear: scientists must collaborate with people outside of the academic realm if they want their research to inform policy or create societal and environmental change.

Socially-engaged research approaches outline ideal scenarios for how scientists collaborate with others to address societal problems. However, the outcomes of socially-engaged research often remain more aspirational and theoretical than fully realized in practice

(Jagannathan et al. 2020; Lang et al. 2012). The nature of working across disciplinary and social boundaries is messy and unpredictable. External factors like inconsistent political, public, and financial support and sudden shifts in institutional operations or personnel impede progress (Meadow, Crimmins, and Ferguson 2013; Wall, Meadow, and Horangic 2017). Internal social dynamics like poor communication, lack of leadership, personality conflicts, and inequitable processes for decision-making also challenge momentum (Jakobsen, Hels, McLaughlin 2004; Pohl 2005).

Regarding transdisciplinary research in particular, Felt et al. (2016) argue for "careful investigation of the concrete intertwinements of imaginations, expectations, structures…, people, and values" (737). Although transdisciplinarity upholds the importance of incorporating multiple forms of expertise, it still relies on established systems of governance, policy, and administration. These systems, according to Meehan, Klenk, and Mendez (2018), "reflect implicit logics of accountability and imaginaries of social impact that shape program design, collaboration, and the very conditions for knowledge mobilization" (760). For example, research funding for transdisciplinary programs is typically channeled through universities or other science-based institutions, in which scientists manage research agendas. As Felt et al. (2016) illustrate, it is typical for these programs to center the legitimacy of scientific logic and expertise and only be informed by other types of knowledge, rather than fully engage them in research design and activities. This imbalance exemplifies one inconsistency between the theories and common practices of socially-engaged research.

Underlying assumptions within socially-engaged research processes influence how knowledge is used, by whom, and for what objectives. Both Felt et al. (2016) and Meehan, Klenk, and Mendez (2018) employ the concept of imaginaries as drivers of socially-engaged knowledge production; specifically, they reference Jasanoff and Kim's concept of the socio-technical imaginary (2009). Jasanoff (2015) defines socio-technical imaginaries as "collectively held, institutionally stabilized, and publicly performed visions of desirable futures, animated by shared understandings of forms of social life and social order attainable through and supportive of advances in technology" (4). This constructivist viewpoint argues that scientific solutions to complex social problems are directly intertwined with individual and shared visions of modernity, progress, and a better future world.

What has not been sufficiently examined in this literature are the roles that individual scientists play in maintaining, performing, and contesting sociotechnical imaginaries and visions of societal progress. The notion of imaginary draws attention to the epistemological framings that comprise how researchers envision societal progress, how their research supports that vision, and how collaborative knowledge production frameworks guide that vision. Despite the profound influence of these individual and collective imaginaries, researchers' visions of their own socially-engaged research processes usually remain implicit and unquestioned.

Evaluation methods offer ways to identify scientists' implicit visions and assumptions and measure outcomes and societal impacts. Scholars have used evaluation to measure contributions of transdisciplinary knowledge (e.g. Roux et al. 2010; Belcher et al. 2016), use-inspired knowledge (e.g. McNie 2008; Ferguson et al. 2016a), and coproduced knowledge (e.g Fazey et al. 2014; Wall, Meadow, and Horangic 2017). Program theory-based evaluation offers methods to demonstrate tangible contributions of research in addressing societal issues (Funnell and Rogers 2011). This approach supports developing an underlying program theory—an explicit declaration of expected changes that will occur and how they will occur. Some evaluators elaborate these underlying program theories using theories of change, described by

Belcher et al. (2017) as “a comprehensive description and illustration of how and why a desired change is expected to happen in a particular context” (3). Logic models are related evaluation tools that facilitate the articulation of a logic, or causal narrative, that links activities to outputs, outcomes, and impacts. Theories of change and logic models invite researchers to explain their visions for what they want their research to accomplish and how, including research design, potential challenges, deliverable products, and end results. In doing so, researchers’ assumptions about how their research will achieve these visions become explicit.

The theory of change approach also provides ways to examine research effectiveness and outcomes. By articulating logic model narratives, researchers develop criteria to determine if and how their scientific work contributes to improving societal issues. As projects conclude, researchers recall their initial visions and objectives and compare anticipated goals to those accomplished. This examination reveals research challenges and opportunities and encourages researchers to investigate their own roles and positionality within research processes. Self-reflection helps researchers improve their future socially-engaged research endeavors; collectively, this type of reflection can help research programs prioritize certain efforts, strategically design their portfolios, and make necessary adjustments to operations.

A major limitation to this approach is establishing causality between actions, outputs, outcomes, and impacts (Stufflebeam 2001; Lang et al. 2012). Systematic evaluation increases clarity in understanding connections between activities, outputs, and outcomes but does not always indicate direct causation. Several contextual factors influence if and how research is used (Boaz, Fitzpatrick, and Shaw 2009; Mach et al. 2020), such as cultural, institutional, economic, and political barriers (Dilling and Lemos 2011), or time delays between the generation of outputs and evidence that demonstrates implementation of these outputs into new practices, policies, or decisions (Spaapen and van Drooge 2011). Instead of attribution, contribution frameworks show how researchers help influence societal change through various pathways of engagement (Morton 2015). Contribution analysis examines if anticipated results occurred and if particular activities or processes helped produce those results, identifies additional factors that influenced results, and may reveal other explanations for why results occurred (Belcher et al. 2017). Using multiple outcome categories within a contribution framework can help researchers identify specific ways that a project has instigated changes in behaviors, thinking, and actions.

There are numerous ways to categorize research outcomes and broader societal impacts (e.g., Edwards and Meagher 2019; Reed 2018; NSF 2014). Defining outcome categories for a set of projects allows for comparison between projects and monitoring over time. Flexibility within these outcome typologies is also important because research often produces outcomes that are unexpected or unintended (Fazey et al. 2014; Wiek et al. 2014). Outcome categories should be well-defined, but a set of categories may be expanded or adjusted to accommodate new types of research results.

In the past decade, research institutions in Europe and Australia have developed and implemented rigorous reporting frameworks to document research outcomes and impacts (e.g., Research Excellence Framework; Australian Engagement and Impact Assessment). Some institutions in the U.S. are now following a similar path (Abel and Williams 2019), however, there are no comparable sets of guidelines, criteria, or requirements for U.S. researchers. Current academic evaluation in the U.S. prioritizes metrics such as the number of peer-reviewed journal articles, citations scores, and acquired grant funding to assess performance, scientific rigor, promotion, and tenure. Incorporating the societal impacts of research would mean a considerable change for most U.S. institutions and academic researchers. Encouraging researchers to identify, document, and monitor their impacts is a multi-step and long-term process. This paper outlines the progression of embedding evaluation within the CLIMAS program and presents the results of that process.

3. The CLIMAS Program

3.1 Background

In the 1980s, scientists and staff in the U.S. National Oceanic Atmospheric Administration (NOAA) outlined ways to connect climate observations to national-scale policy and decision-making. Ultimately, they decided, a functional climate information system should be inspired by real-world and regional applications of that information (Meadow 2017). In the late 1990s, these framings informed the NOAA Regional Integrated Sciences and Assessments program (NOAA-RISA). This federal program has evolved into 11 currently funded research programs distributed throughout the country that practice use-inspired and socially-engaged methods of knowledge production. A recent ethnography of NOAA-RISA "revealed a deeply held belief in the power of knowledge about climate patterns and changes—when developed in optimal ways—to make tangible positive impacts on the lives of people around the world" (Meadow 2017: 13). While individual NOAA-RISA programs vary in form, function, and focus, they each operate within this ideology.

Founded in 1998, the Climate Assessment for the Southwest (CLIMAS) is the oldest currently-funded NOAA-RISA program. CLIMAS projects are based in two southwestern states, Arizona and New Mexico, but activities and outcomes often extend to the U.S. Southwest region. The underlying vision and mission have not significantly changed since early program days: CLIMAS aims to improve the Southwest's ability to respond sufficiently and appropriately to climatic events and changes by creating usable knowledge with and for non-academic partners. While the program fluctuates in size and composition, it is generally comprised of 10 to 15 physical, natural, and social scientists at the University of Arizona and New Mexico State University. Research topics shift based on the needs of project partners and stakeholders. A core office, consisting of a program director and two to three additional research staff, manages routine program operations and interactions with the NOAA-RISA program.[1] As the program has evolved, CLIMAS has moved toward transdisciplinary research and social learning systems that support regional climate resilience (Owen, Ferguson, and McMahan 2019).

3.2 CLIMAS Program Evaluation Process and Methods

Objectives for the 2012-18 CLIMAS program evaluation were to 1) demonstrate if and how the program contributed to a more resilient and adaptive Southwest society; 2) establish an on-going evaluation strategy for CLIMAS; 3) feed results into program operations; and 4) understand how socially-engaged research leads to impacts beyond academic ones. In 2011, CLIMAS core office members drew from theory-based evaluation (Funnell and Rogers 2011) to guide the evaluation process; the design and methods fit these objectives and the financial and human resources available at the time. Following this approach, CLIMAS core office members generated an underlying mission statement of how the program operated: *Engaging with existing and potential climate stakeholders in the Southwest results in usable knowledge. These interactions and information products expand people's capacities to adapt to climatic shifts and changes.* This statement represents an initial attempt toward developing a programmatic theory of change; however, it did not explicitly outline how impacts would be generated—a necessary

[1] During this program evaluation, the author was a member of the CLIMAS core office research staff.

component (Van Drooge and Spaapen 2017). To better understand how stakeholder interactions and information products led to expanded adaptive capacity, core office members held two focus groups with 10 CLIMAS researchers in 2012 and 2013. These focus groups revealed several distinct ways that researchers designed projects, interacted with stakeholders, and developed information products, but still did not explicitly connect how their research and interactions led to change. Focus group findings pointed to further investigation, documentation, and categorization of these different approaches and outcomes.

In 2012, 11 CLIMAS researchers participated in a first round of individual interviews about how they imagined their research having impact in society and increasing the adaptive capacity of the Southwest. An important part of these interviews was to understand what researchers sought to accomplish and why. As Felt et al. (2016) and Meehan, Klenk, and Mendez (2018) argue, project goals reflect researchers' implicit values and desires. Asking researchers why their goals are important and why they want to accomplish them makes these values and desires more explicit (Friedman, Rothman, and Withers 2006). CLIMAS researchers' answers were slight variations of a singular narrative: they wanted to use their knowledge and skills to help people anticipate and prepare for current and future climate risks, thereby reducing the amount of human and environmental damage incurred. Underlying values driving this narrative were the importance of collaboration, a desire to solve real-world problems, and visions for a resilient and flourishing Southwest society. Ultimately, CLIMAS researchers agreed that their objectives were to improve human well-being and influence social and environmental change. CLIMAS researchers envisioned achieving these objectives by producing outreach products to strengthen people's understanding of climate, providing decision support, advancing scientific knowledge related to climate, and providing training in conducting use-inspired science.

Understanding the team's collective values, visions, and objectives encouraged further exploration about how CLIMAS project activities and outputs reflect those values and fulfill those visions and objectives. Ten CLIMAS projects were selected to explore these connections. Throughout 2013 and 2014, researchers participated in a second round of interviews, which provided the basis for understanding how researchers imagined their work contributing to desired societal changes. To link research to impact, interview questions were structured around the components of a logic model, including: *assumptions* and *context* in which the project occurred; *inputs*—the human, financial, and institutional resources needed; *activities*—the methods of engagement with research partners and research activities; *outputs*—the products from research activities and analysis; *outcomes*—specific changes in behavior, attitudes, knowledge, relationships, skills, policies, or practices; and *impacts*—broader changes that occur within communities, regions, or systems resulting from program activities (Figure 1). A third round of interviews with CLIMAS researchers occurred in 2016 and 2017, to document progress toward outputs and outcomes. Additionally, researchers submitted annual progress reports between 2012 to 2018, which outlined project outputs and findings, activities and events, new partnerships, and other updates (https://www.climas.arizona.edu/annual_reports/).

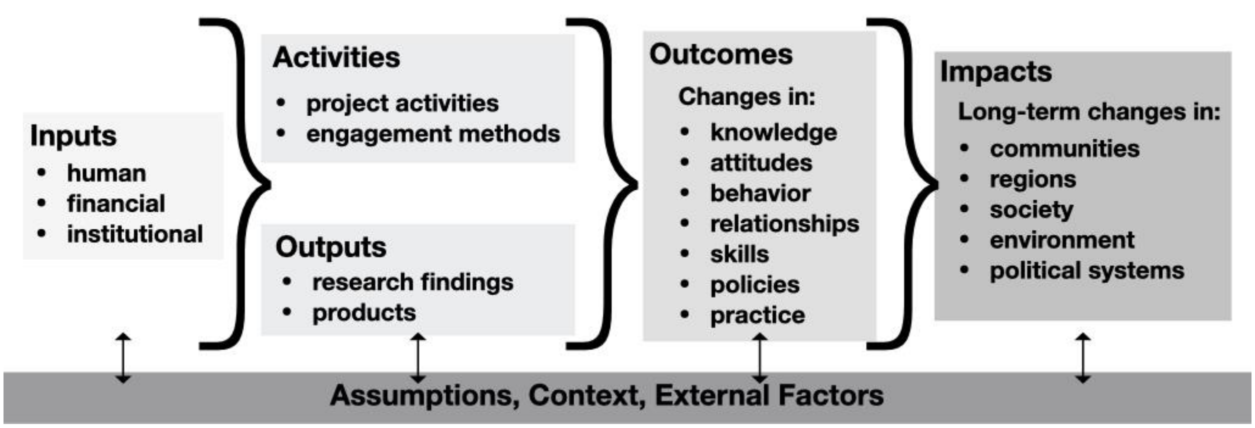

Figure 1: Logic model components used to structure interviews with CLIMAS researchers

Data from interviews and reports were entered into a FileMaker Pro database for content analysis and included: activities, such as research methods and communication strategies; outputs, such as reports for partners, models or data analyses, workshops, presentations, or information tools; and anticipated, unanticipated, and reported project outcomes, or changes resulting from the research process. Researchers' descriptions of project results and outcomes formed the basis of documentation; however, reported outcomes were only counted if additional evidence substantiated their descriptions. Sources of secondary data included citations of CLIMAS research findings, reports, or papers in stakeholder-produced policies, plans, presentations, funding proposals, newsletters, graphics, emails, or other documents. Data sources were provided by CLIMAS researchers or found via news media or internet searches.[2] The comparison of output and outcome data about anticipated project goals (from 2013-12014 interviews) and documented project results (from 2016-2017 interviews and 2012-2018 annual reports) comprised the basis for analysis in this paper.

Outcome categories were established after data collection. After preliminary analysis, a typology from Meagher and Martin (2017) and Meagher and Lyall (2013) demonstrated the best fit and enough flexibility to apply across all projects. CLIMAS researchers span multiple disciplines and CLIMAS projects tend to be interdisciplinary and incorporate multiple methods. This typology—developed and tested across multiple academic disciplines and types of research—is based on the following five outcome categories:

[2] Plans to collect feedback from external project partners were part of the initial evaluation design, however, information was not collected for all 10 projects due to logistical constraints. This point is addressed further in the discussion section.

- *capacity building*: developing collaborations or providing the information and training necessary to engage in a particular activity;
- *instrumental applications*: direct influence or use in policy, practice, or decision-making;
- *conceptual change*: changes in thinking, raising awareness, or improving understanding;
- *enduring connectivity*: relationships lasting beyond a particular project or activity;
- *attitudinal or cultural shifts*: changes in institutional, group, or individual attitudes regarding issues or toward engaging in collaborative activities or knowledge exchange.

Project outcomes were aggregated across these categories to analyze trends at the program-level. The following section further explores applying this typology to the CLIMAS program.

5. Results and Analysis

Project outputs encompass multiple ways that CLIMAS researchers share research results with scientists, partners, and broader publics. Most outputs were written (e.g. technical reports, data analyses, and peer-reviewed publications) or orally delivered (e.g. presentations to project partners, public, and academic audiences). Researchers generally completed the outputs they proposed and produced more items than originally anticipated (Figure 2). Four anticipated outputs did not materialize by 2018, including two academic papers, a collection of outreach materials, and an information tool.

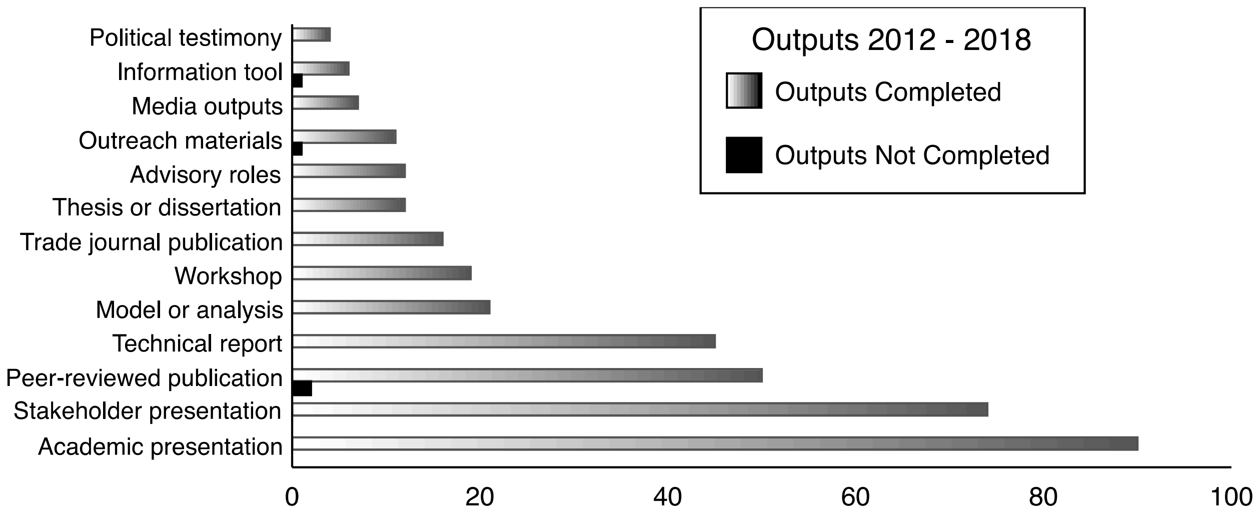

Figure 2. CLIMAS project outputs completed and not completed between 2012 and 2018.

In total, CLIMAS researchers reported 61 outcomes spread across the five outcome categories (Table 1). Capacity building outcomes were most frequent (26.2%), followed by instrumental applications (21.3%), conceptual shifts (19.7%), and enduring connectivity outcomes (19.7%). The smallest number of outcomes comprised the attitudinal or cultural type (13.1%).

Outcome Type	*Description*	*Percent of Frequency*	*Example from a CLIMAS Project*
Capacity Building:	Developing collaborations or providing the information and training necessary to engage in a particular activity	26.2% (n=16)	Through an iterative research process, FEMA-R9 representatives identified potential uses for 30-day climate forecasts in their agency's operations. This collaboration led to the development of a climate information tool for disaster preparedness.
Instrumental Applications:	Direct influence or use of research in policy, practice, or decision-making	21.3% (n=13)	The New Mexico Department of Transportation used CLIMAS research about the sources and patterns of dust storms to apply for federal funds for improved highway signs, warnings, and road markings. The approved funding was used to build new infrastructure

			along a stretch of the Interstate-10 Freeway.
Conceptual Shifts:	Changes in thinking, raising awareness, or improving understanding of an issue	19.7% (n=12)	Results from a paleoclimate project with the U.S. Geological Survey and water resource managers increased awareness and understanding of how temperatures impact streamflow and drought in the Colorado River basin.
Enduring Connectivity:	Relationships lasting beyond the course of a particular project or activity	19.7% (n=12)	An electric utility company in Tucson, AZ initiated a new project on carbon reduction with CLIMAS researchers a year after the initial project ended.
Attitudinal or Cultural Shifts:	Changes in attitudes toward engaging in climate research or knowledge exchange activities	13.1% (n=8)	Municipal government representatives in Ciudad Juárez, Mexico shifted from participants to leaders in a collaborative heat and health initiative in the New Mexico/Texas/Chihuahua region.

Table 1. Percent of frequency and examples of five outcome types

CLIMAS researchers reported 16 capacity building outcomes. A commonality across all projects was the prevalence of iterative interactions with partners to maintain collaboration, build trust, and exchange information and skills. For example, representatives of the Federal Emergency Management Agency Region 9 (FEMA-R9) contacted CLIMAS researchers for help developing a climate information tool for disaster preparedness. Through multiple interactions, including in-person and virtual meetings, phone calls, interviews, and participant observation with FEMA-R9 personnel, connections strengthened between project collaborators. CLIMAS researchers better understood how FEMA-R9 functioned and how decisions were made. This iterative process helped FEMA-R9 representatives identify potential uses for 30-day climate forecasts, which they had not used before, and led to the co-creation of an information dashboard that could be incorporated into FEMA-R9's operations.

Instrumental outcomes were reported 13 times and included instances of direct influence or application of CLIMAS research in developing policy, informing practice, or guiding decision-making. CLIMAS researchers gave testimony in state hearings on water supply and agricultural economics; partners cited CLIMAS research to support difficult resource management decisions; and research analyses validated new governmental or institutional policies. The New Mexico Department of Transportation, for example, used CLIMAS research regarding the sources and patterns of dust storms—which caused numerous human casualties on the Interstate-10 Freeway near Lordsburg—to apply for federal funds to improve highway signs, warnings, and road markings. Funding was approved and new infrastructure was installed in 2017 and 2018.

CLIMAS researchers reported 12 conceptual outcomes through information products that raised awareness, expanded knowledge about regional climate dynamics and impacts, and increased people's understanding of managing climate risk. These products manifested as tailored models or analyses, outreach materials, peer-reviewed publications, or technical reports. Results from a paleoclimate project with the U.S. Geological Survey and water resource managers, for example, increased awareness and understanding of how temperatures impact streamflow and drought in the Colorado River basin. Researchers found that cool season precipitation is the primary driver of variability in streamflow. However, in drier years, temperature has a greater influence on streamflow variability than during wet years (Woodhouse et al. 2016). These findings directly apply to regional water management as temperatures are projected to increase. Research results were shared with water managers and other stakeholders through workshops, presentations, technical reports, fact sheets, and a website.

Evidence of enduring connectivity between CLIMAS researchers and project partners was reported 12 times. Indications that relations lasted beyond the course of a project included continued collaboration, designing and seeking funding for new projects, and recurring requests from partners for climate information. In 2015, CLIMAS researchers collaborated with an electric utility company in Tucson, AZ. Utility employees identified several regionally-specific climate and environmental risks that could impact operations; researchers provided tailored data and analyses to address their concerns. This project ended in 2017; a year later, utility employees sought further CLIMAS assistance to explore scenarios for carbon reduction.

Attitudinal changes toward engaging in climate research or collaboration were reported eight times, based on evidence of detectable shifts in project participation. Some project partners expressed greater acceptance about the realities of climate change; others assumed new roles in the research process or sought additional collaborations to address climate challenges. For example, an initiative in the border cities of El Paso, Texas, Ciudad Juárez, Chihuahua, and Las Cruces, New Mexico, aimed to improve an early warning system for extreme heat and associated health risks. Officials from the Oficina de Resiliencia in Ciudad Juárez initially participated in meetings and events. Over time, they assumed leadership roles, sought funding, and developed new plans with El Paso to reduce urban heat island effects using green infrastructure.

Of the 61 outcomes reported, 16 were unanticipated by researchers, meaning they were not described during interviews in 2013 or 2014 (Figure 3). Unanticipated outcomes mostly fell under enduring connectivity and instrumental applications. Regarding connectivity, eight unanticipated long-term relationships were established through new research avenues after initial projects concluded. While long-term relationships were frequent outcomes of CLIMAS projects, few researchers explicitly identified building long-term relationships as a type of project outcome during initial interviews.

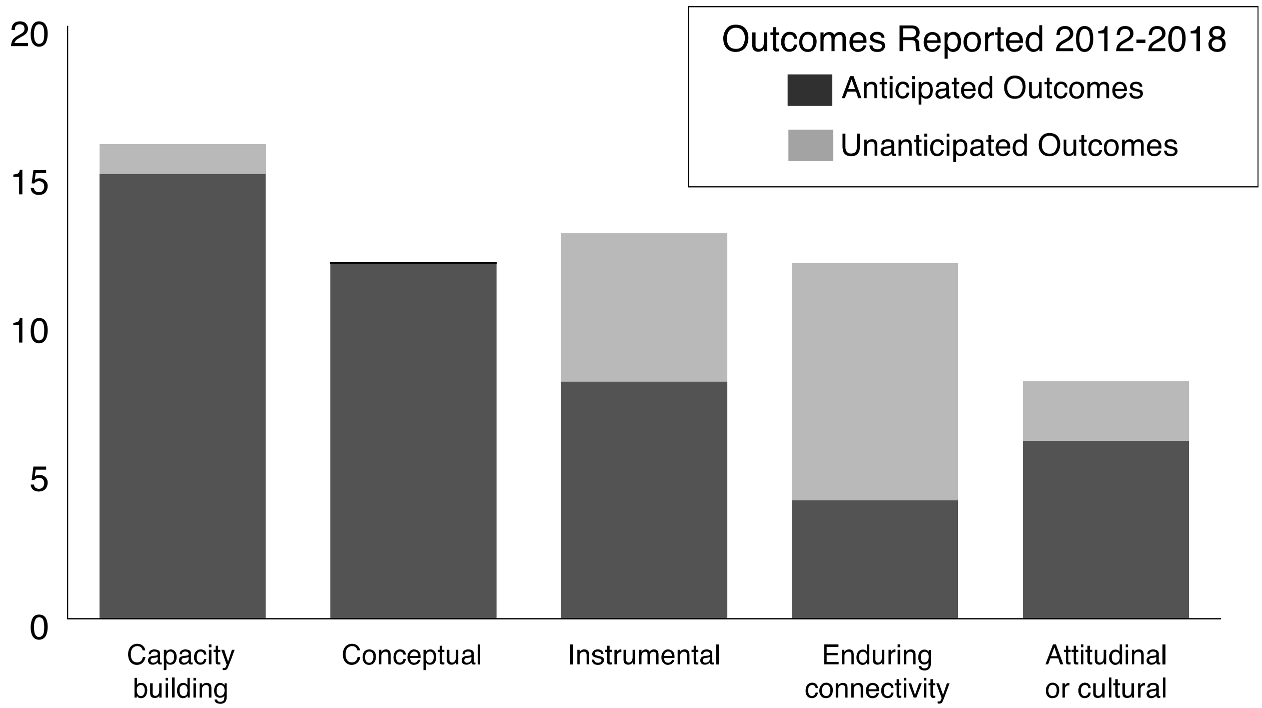

Figure 3. Total CLIMAS project outcomes reported between 2012 and 2018, divided by outcomes that were anticipated at the beginning of a project and outcomes that were unanticipated.

In the category of instrumental applications, five unanticipated outcomes were reported. During initial interviews, researchers often anticipated instrumental types of outcomes; however, in these five cases, researchers did not anticipate these particular outcomes to occur. Two stemmed from a CLIMAS project that developed resource management tools to increase water supply reliability. This project focused on groundwater banking and voluntary water trading agreements. Groundwater banking uses underground reserves to store surface water during times of surplus water availability to be used during shortages (O'Donnell and Colby 2010). A CLIMAS researcher collaborated with the U.S. Bureau of Reclamation to assess the feasibility of water banking and trading programs for the Lower Colorado River basin. In 2017, the Central

Arizona Water Conservation District approved over $5 million (USD) for infrastructure to increase underground water storage capacity for the City of Tucson, and Towns of Marana and Oro Valley. Explicit project objectives included raising awareness and increasing interest in water supply reliability tools but did not include implementing new infrastructure or policy. Although open to instrumental applications of their research, researchers were sometimes uncomfortable defining how others might apply findings to policies, practices, or decisions.

Several anticipated outcomes (n=23) were not reported within the evaluation timeframe (Figure 4). When envisioning impact, CLIMAS researchers articulated realistic conceptual outcomes such as improving people’s awareness and understanding. All anticipated conceptual outcomes were reported as accomplished, and none were unanticipated. Researchers were less precise in defining instrumental applications of their work in comparison to the other four outcome types. Out of 22 instrumental outcomes initially identified as project goals, only eight were reported by the projects’ completion, suggesting that CLIMAS researchers had more difficulty fulfilling the instrumental outcomes they hoped to achieve within a six-year timeframe.

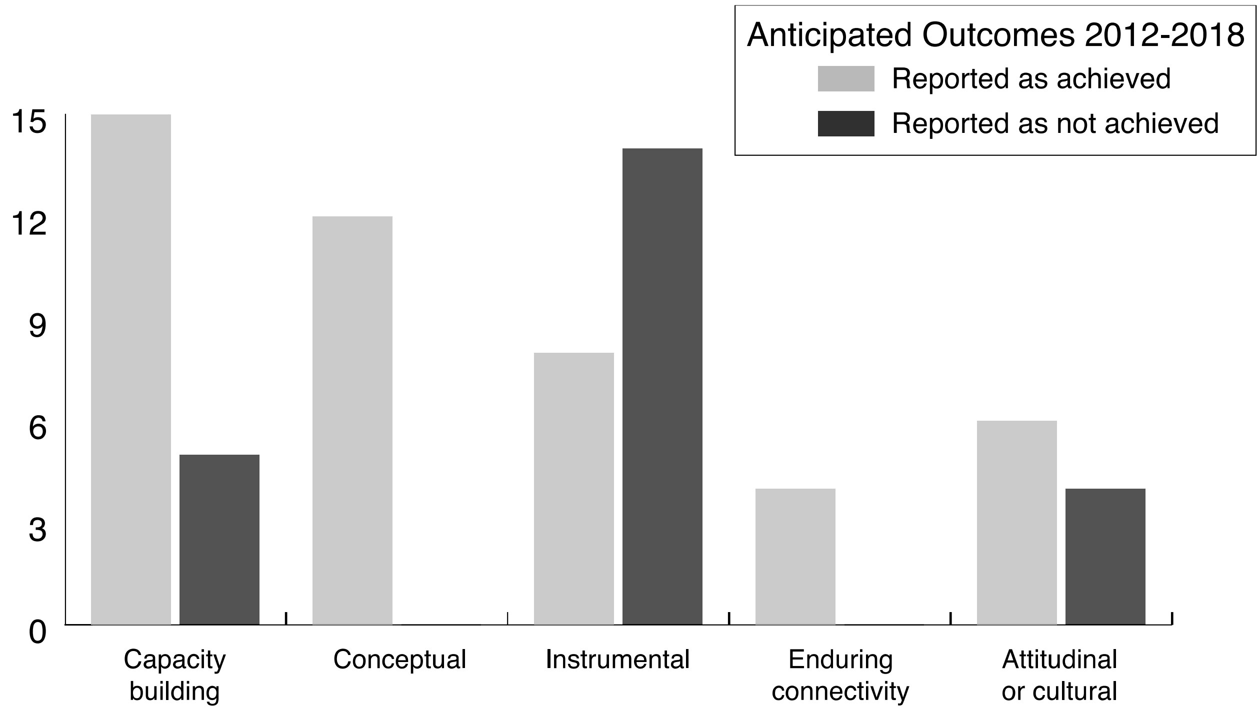

Figure 4. Explicitly anticipated CLIMAS project outcomes reported as achieved and reported as not achieved

Researchers' visions for how information would be used by project partners did not always manifest as intended. Sometimes, unexpected factors such as changes in political, economic, and environmental conditions or shifts in research needs impeded pathways to achieving instrumental outcomes. To improve the practice of socially-engaged research, it is important to understand these challenges. The following section uses one project evaluation to illustrate barriers that CLIMAS researchers faced in achieving their anticipated objectives, particularly those involving instrumental applications. This review demonstrates how evaluation processes encourage researchers to reflect upon their approaches to socially-engaged research and improve future research practices.

5. Case Study: Planning for Drought in the Warming and Drying Southwest: Supporting Tribal Decision Making in the Four Corners[3]

The Four Corners region, where Arizona, New Mexico, Colorado, and Utah meet, is currently home to several Native Nations, one of which is the Hopi Tribe. Hopi people descended from populations who practiced dryland maize farming in this region since at least 700 AD (Ferguson et al. 2016b). Ranching practices began in the 1500s when Spanish colonialists introduced livestock to the region. Dryland ranching and rainfed farming practices remain prevalent on Hopi lands and rely on underground aquifers for water resources (Ferguson et al. 2016b), making these practices particularly sensitive to drought.

In 2009, the Hopi Department of Natural Resources (HDNR) contacted two CLIMAS researchers for technical insight on monitoring regional drought conditions. Over time, CLIMAS researchers and HDNR staff designed a project to monitor drought conditions on Hopi lands that could inform decisions made by HDNR and tribal leaders. One project component was designed to better understand how drought information was used by HDNR and the Hopi Tribe's government. The project also included interviews with a small group of ranchers, farmers, and other community members to better understand local concerns about drought (Ferguson et al. 2016b). The research team used these findings, alongside climate and drought analyses, to inform a drought monitoring approach that would match the HDNR's needs and resources.

One underlying issue, they found, stemmed from inadequate monitoring systems and inaccurate depictions of drought conditions across the Four Corners. The U.S. Drought Monitor

[3] This section draws on data from annual progress reports, research articles, and interviews with two CLIMAS researchers in 2012, 2014, 2016, and 2017 and one interview in 2017 with a Hopi research associate who contributed to this project.

developed by the U.S. Department of Agriculture, NOAA, and the National Drought Mitigation Center, combines weather and hydrological data from multiple sources and monitoring sites to show nationwide drought conditions at weekly timescales. Drought indices range in intensity between abnormally dry (D0), to moderate (D1), severe (D2), extreme (D3), and exceptional (D4) drought. In 2008 and 2009, the Drought Monitor showed a range of D0 to D1 in the northeast corner of Arizona where Hopi lands are located, but HDNR staff and others in the region reported that local conditions were worse. This geographically diverse landscape is similar in size to South Carolina but with far fewer weather stations, making it difficult for the Drought Monitor to accurately characterize drought conditions (Ferguson and Crimmins 2009).

With insufficient drought monitoring data available, HDNR personnel did not have adequate information to guide government management decisions or evidence to apply for federal drought-relief funds. The HDNR and CLIMAS collaboration was driven by the desire to develop a monitoring program that would inform how tribal leaders would deal with extreme drought conditions. CLIMAS researchers envisioned that the project's outcomes would equip HDNR personnel to manage Hopi lands differently for drought.

5.1 Project Evaluation

In a 2013 interview, two CLIMAS researchers outlined their project goals, assumptions, contextual factors, activities, outputs, and outcomes (Figure 5). In 2016 and 2017, after the project concluded, CLIMAS researchers and a research associate from the Hopi Tribe (referred to as researchers A, B, and C below) reflected on the research process and project outcomes.

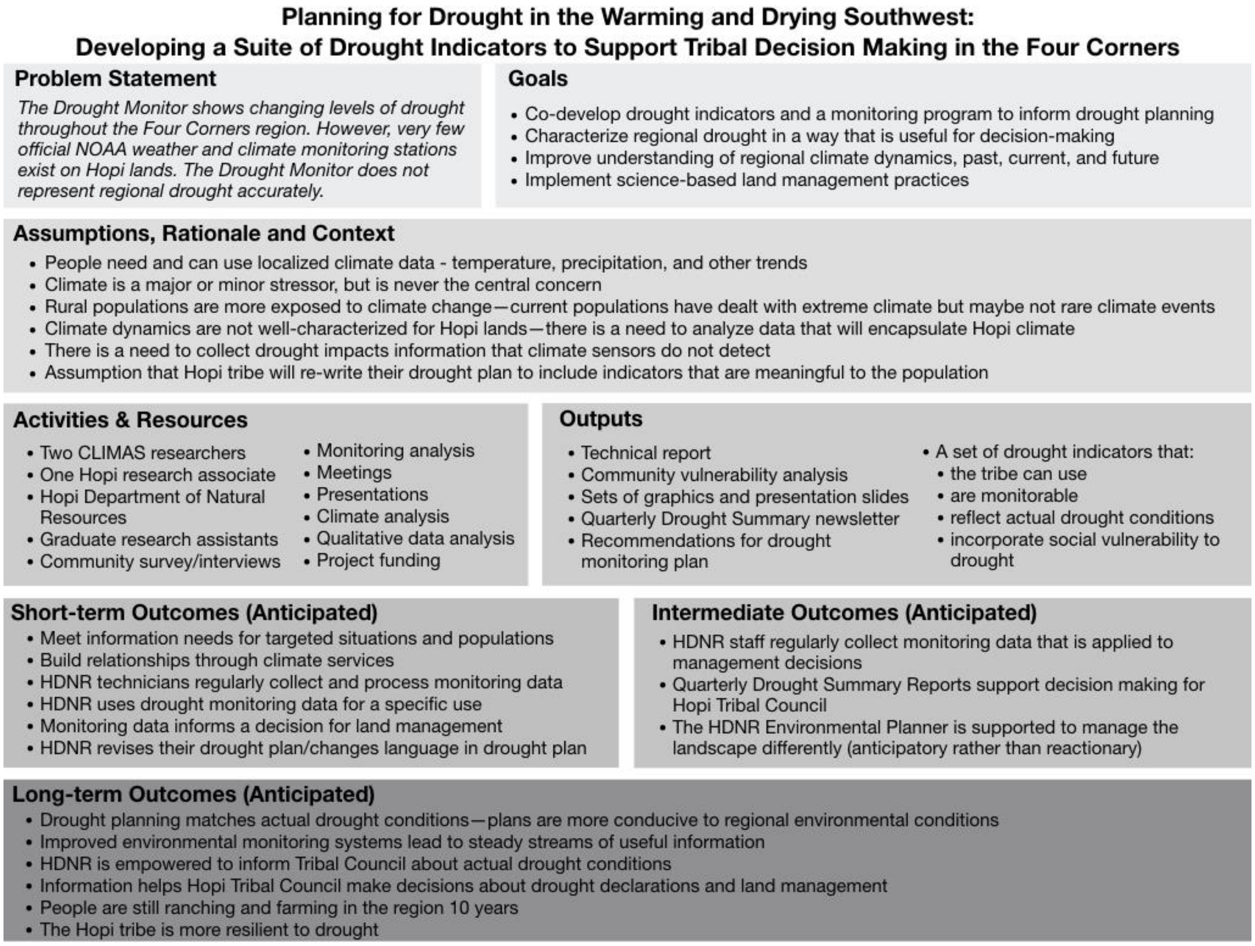

Figure 5. Project evaluation plan developed from interviews with CLIMAS researchers in 2013

By the end of the project, all anticipated outputs were produced. However, researchers found that only three short- and medium-term anticipated outcomes came to fruition. These outcomes included meeting informational needs for targeted situations and populations (building capacity), providing data to inform land management decisions (instrumental applications), and building relationships through climate services (enduring connectivity). Informational needs were met by providing a comprehensive report with climate information specific to the Four Corners and four editions of a Quarterly Drought Summary newsletter containing local climate and range conditions. This summary was used to inform land management decisions. For example, in October 2014, the Hopi government cited Quarterly Drought Summary data to support their decision to impound horses, sheep, and cattle grazing on land in poor condition (Ferguson et al. 2016b). Lasting relationships between Hopi community members and CLIMAS researchers were built during fieldwork and maintained through short visits, long stays, phone calls, and other personal interactions. Since the project ended, interactions between members of CLIMAS, HDNR, and the Hopi government have continued.

Other short- and medium-term anticipated outcomes did not happen as originally envisioned. A drought information system and monitoring program was put into practice, however, over time monitoring data were no longer collected regularly. Without these data, the Quarterly Drought Summary was not published after the project ended. Because the original project outcomes were not achieved, CLIMAS researchers described feeling a sense of defeat when reflecting upon this project.

5.2 Reflecting on Project Outcomes

The evaluation process revealed insights about the project’s implications that may have otherwise remained unacknowledged. The first point of reflection involved the shifting nature of drought conditions and the fact that Hopi communities have survived several extreme droughts without official drought monitoring programs. When drought discussions between CLIMAS and HDNR began in 2009, conditions were relatively severe. By mid-2015, annual precipitation increased and “things got progressively better drought-wise, so perhaps we had trouble articulating why HDNR should do all this work,” said researcher A in a 2016 interview. “It no longer fit into an immediate need or specific decision that the Hopi Tribal Council needed to wrangle with at that moment.”

Another point of reflection involved CLIMAS researchers' initial visions for how the project would function. They assumed the process would be relatively straightforward: scientific information in the form of monitoring data would help establish more sustainable land management practices. Researchers believed that co-developing a monitoring program with HDNR using available resources could lead to its permanent implementation. They assumed that rain and temperature data collected via monitoring would inform the Quarterly Drought Summary and that HDNR and the Hopi government would consult it for drought management decisions. However, as researcher C said "No one in the [HDNR] office was assigned to do this work. And the value of the summaries wasn't communicated back up to tribal leadership in a way that adequately promoted the idea" (personal communication 2017).

A compounding factor involved changes in executive tribal leadership. During the project, elections for a new chairman and vice-chairman were held twice; the leaders who initially approved and influenced project development were no longer in charge when the project ended. It is unclear how familiar new officials were with the project's goals or outcomes. Without a directive from the chairman, vice-chairman, or the Hopi government to continue monitoring and producing the summary and without someone inside HDNR to promote these activities, they simply ended. As Researcher B pointed out, "Externalities like an enthusiastic partner, a champion for the project, are crucial. It can be a single point of failure [without one]," (personal communication 2017).

These qualitative reflections invited researchers to learn from their successes and failures and bring those lessons into new projects. Researcher A explained, "We learned about what actually happens in a drought impacted landscape as opposed to what you see from a dataset. Also, I have a better sense of what data sovereignty means. For future work I'm going to be much more thoughtful about who owns that data and information" (personal communication 2017). Researcher B added, "When you do physical science, you're there to proffer stuff for people. You think you should be able to do what you want and have access to the data you want, because you assume it will be helpful" (personal communication 2017). These reflections helped researchers refine how they might envision future research outcomes and uncover their implicit assumptions, which are explored in further detail in the following section.

6. Discussion

The CLIMAS program evaluation aimed to: 1) demonstrate if and how the program contributed to a more resilient and adaptive Southwest society; 2) establish an on-going evaluation strategy for CLIMAS; 3) feed results into program operations; and 4) understand how socially-engaged research leads to impacts beyond academic ones. The following discussion further examines these four objectives.

6.1 CLIMAS program contributions

This evaluation helped researchers explicitly link how their activities and outputs lead to outcomes that contribute to their visions for a resilient Southwest society. This process provided rich feedback for researchers about their individual contributions. The typology of outcomes—building capacity, instrumental applications, enduring connectivity, and conceptual and attitudinal shifts—provided a way to aggregate project contributions to a program scale.

As the CLIMAS program continues to document future outcomes over time using this typology, longer-term trends regarding societal and environmental impacts may emerge. In the current five-year funding cycle, CLIMAS researchers are exploring how to integrate research projects, findings, and outcomes rather than simply aggregate. To move toward this goal, researchers are synthesizing research findings across three areas of focus: 1) demonstrating the program's shift from disciplinary research toward interdisciplinary and transdisciplinary approaches; 2) reviewing how systemic buffers will help the Southwest be resilient to climate risk, especially in water resources, human health, and planning; and 3) framing the complexities of Southwest drought to develop better monitoring and adaptation strategies.

The program evaluation also uncovered gaps in the underlying theory of how the program operates within a larger network of individuals, communities, and organizations that aspire to build climate resilience in the Southwest region. Multiple types of knowledge, practice, expertise, and skills exist within this network, of which academic knowledge and skills comprise one type. Roles that CLIMAS plays within the larger network—communicating, convening, consulting, collaborating, and training— were revealed through this evaluation process and are explained in further detail in Owen, Ferguson, and McMahan 2019.

6.2 Develop methods to evaluate the CLIMAS program

Initial efforts toward evaluation helped CLIMAS develop a structured framework to assess future program outcomes, in terms of scientific achievement and societal impact. Early focus groups with CLIMAS researchers helped developed the team's collective values, visions, and objectives. Interviews based on logic model components encouraged CLIMAS researchers to articulate how they imagined their research actions and outputs creating change and for whom. Researchers reflected on their anticipated outcomes in follow-up interviews. Outcomes were categorized in a typology that will be used as a framework for future program outcomes. Using this typology will help CLIMAS program management observe trends in outcome types over time.

Most CLIMAS researchers had not previously evaluated the impact of their research. Although all agreed that they wanted to bring about societal and environmental change through their projects—and understood the value of research evaluation—it took several iterative steps to develop a rigorous evaluation process that would not be overly burdensome. Like most researchers in the U.S., CLIMAS researchers are not incentivized by their academic departments to document or monitor impact of their research. The process of periodic interviews and annual reporting worked well as ways to collect information from CLIMAS researchers about project results and outcomes. During interviews, several researchers commented that it was a welcome change to think through if and how their research contributed to societal impacts.

However, CLIMAS researchers engaged in the evaluation process at different levels. During interviews in 2013 and 2014, some outlined project objectives in great detail while others loosely defined objectives and provided simplistic links between actions and outcomes. For instance, one CLIMAS researcher described two anticipated outcomes, both very broad in scope, regarding research with agricultural communities. Project activities, outputs, and outcomes were loosely connected. At the end of the project, the researcher reported tangible evidence of fulfilling both anticipated outcomes. Conversely, researchers in the Four Corners drought project identified nine relatively specific outcomes, many of which did not occur. The two CLIMAS drought researchers made specific connections between project activities, outputs, and outcomes during initial interviews, while the CLIMAS agricultural researcher provided more specific connections after outcomes occurred. A logic model developed in detail ahead of time may result in more anticipated outcomes that do not manifest over the course of a project. However, these instances also provide important learning opportunities to improve socially-engaged research practices.

This lesson demonstrates the need for better facilitation during the logic model development process. In future interviews, researchers will be encouraged to provide more detail about anticipated outcomes and connection to project activities and outputs. In addition, logic models will be used as flexible tools, to be reviewed annually with researchers and revised as necessary, to accommodate adjustments and allow for unexpected challenges.

Another major revision for the next evaluation cycle is to incorporate input from CLIMAS researchers' external project partners. Plans for collecting external feedback were included in the 2012-2017 evaluation design, however, information was not collected for all 10 projects due to logistical constraints. A comprehensive evaluation of a socially-engaged program must include structured feedback from external partners about the usefulness and usability of research findings and outputs, the changes they experienced, and their reflections on process.

6.3 Feeding evaluation results into program operations

Embedding evaluation as standard practice provides data for evidence-based decisions for program operations and future project design. A profound operational change occurred in early 2016, as the team developed their proposal for another CLIMAS funding cycle. Preliminary evaluation findings informed the team's approach to proposal design and project selection. In prior proposals, CLIMAS researchers provided thoughtful, but general project ideas and objectives. For the 2017-2022 proposal, researchers were encouraged to submit ideas that explicitly defined project goals, partners, and anticipated outputs and outcomes; ideas that did not were not included.

6.4 Develop better understandings of socially-engaged research

This evaluation has important implications for refining the practice of socially-engaged research. One implication emerges from the difference between anticipated instrumental outcomes and those that were reported as achieved. Fourteen of the 22 instrumental outcomes initially identified as project goals did not materialize within the six-year timeframe. CLIMAS researchers generally described instrumental applications in terms of providing scientific evidence to inform resource management decisions and planning efforts to reduce risks associated with climate variability and climate change. As a whole, CLIMAS researchers envisioned more applications of their science-based analyses, information products, and decision support tools than was evidenced in reality. While acknowledging the non-linearity of socially-engaged research processes, CLIMAS researchers still imagine a relatively linear pathway between the provision of science and its application in real-world scenarios. This finding reveals a persistent assumption about the role of science in solving societal and environmental issues. Although several CLIMAS projects are collaboratively designed with and led by non-academic research partners, all CLIMAS researchers assume that academic science and knowledge will, at least partially, solve people's climate-related problems.

A related assumption is that the main barrier to a climate-adapted society is lack of knowledge or an information deficit. Researchers believe that partners know the types of information they need or that this need can be ascertained. It is assumed that research partners, or other climate information users, are empowered to implement science-based decisions. Sometimes, science does fill identifiable knowledge gaps, and linear links can be traced between science and its applications. However, in many cases, researchers find that external and internal factors impede straightforward applications of research. As a federally-funded research program housed in an academic setting and led by social and physical scientists, the CLIMAS program has tended to center scientific knowledge production. But CLIMAS project evaluation findings show how politics, turnover in partner organizations, environmental changes, and shifts in partner interest present considerable barriers to linear applications of science. As Dilling and Lemos (2011) indicated, even when scientific knowledge is coproduced with societal partners, it will not always be usable in practice due to these contextual barriers. How, then, might a socially-engaged research program center other ways of knowing and understanding and what might such a program accomplish?

McNie (2012) draws attention to the need "to build relationships and tend to social systems" (25), a need mirrored in this paper. The number of capacity building and enduring connectivity outcomes that CLIMAS researchers reported reflect this call for relationship building. Delivering salient, robust, and relevant science builds trust among research partners. Iterative interaction and routine communication help solidify these relationships. While the intensity of relationships will fluctuate over time—sometimes interactions are frequent and other times sporadic and informal—the connections built through repeated interactions are crucial: partners learn from CLIMAS researchers and CLIMAS researchers learn from their partners. Through these interactions, researchers come to understand the unique blends of social, political, and environmental contexts in which projects are embedded. Over time, this knowledge helps researchers' develop more realistic expectations and assumptions about their impact. Through iterative interactions, research partners often gain a greater understanding about regional climate, the types of available climate information, and how to incorporate this information into operations.

Although CLIMAS researchers acknowledge the importance of collaborative relationships, only one third of reported connectivity outcomes were explicitly stated as anticipated outcomes. Researchers (and research funders) should place higher value on the establishment and maintenance of lasting connections. Mature partnerships promote mutual understandings of one another's needs, increase levels of rapport and trust, and strengthen participants' commitments to projects (Kothari et al. 2011). Researchers may not identify lasting connections as research outcomes; for some, it may be assumed. Asking researchers explicitly about partnership objectives in future evaluation interviews may address this issue. As one CLIMAS researcher noted about his role, "Sometimes we plant the seeds, maybe we even harvest the crop; but sometimes we just till the ground" (personal communication 2017). Perhaps less tangible than instrumental outcomes like economic policies or operational decisions, connectivity outcomes lay the groundwork for societal and environmental change.

7. Conclusion

Scientific advancements have improved the understanding, attribution, monitoring, and prediction of climate variability and change. Socially-engaged science is based on the idea that collaborations between scientists and other societal members will produce beneficial outcomes. The CLIMAS mission reflects this notion: *Engaging with existing and potential climate stakeholders in the Southwest results in usable knowledge. These interactions and information products expand people's capacities to adapt to climatic shifts and changes.* This paper suggests that this statement is sometimes, but not always, true. CLIMAS research leads to demonstrable outcomes such as expanded skills and capacity to adapt to climate risk, increased awareness about climate, direct application to policies or decisions, long-lasting individual and institutional relationships, and increased willingness to engage on climate-related issues. However, CLIMAS research does not always lead to intended outcomes. The ways that program partners actually use scientific information often differs from how researchers envision their partners using this information. Exploring these results reveals implicit assumptions about how scientific information is used. One assumption maintains that the lack of scientific knowledge and information presents fundamental barriers to a climate-resilient society; therefore, provision of this knowledge and information will directly inform policy, planning, or operational decision-making. However, political, social, and economic challenges often present stronger barriers than the lack of knowledge and information.

Theories of change and logic models help make researchers' assumptions and objectives explicit. In this context, concepts like imaginaries and envisioned futures aim to reveal what and how researchers think about the world and what the world should be. Socially-engaged research aims to bring these visions into reality. This type of research demands purposeful examination into the process of effecting societal change. While scientists are often asked to connect their work to broader societal impacts, researchers are not typically expected, nor given the time or financial resources by their institutions, to actually measure or reflect upon the societal impact of their research and their accountability to research partners. An extensive body of literature discusses the theoretical components of socially-engaged research and research evaluation, but there is still much to explore about the outcomes and impacts of socially-engaged research practices.

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