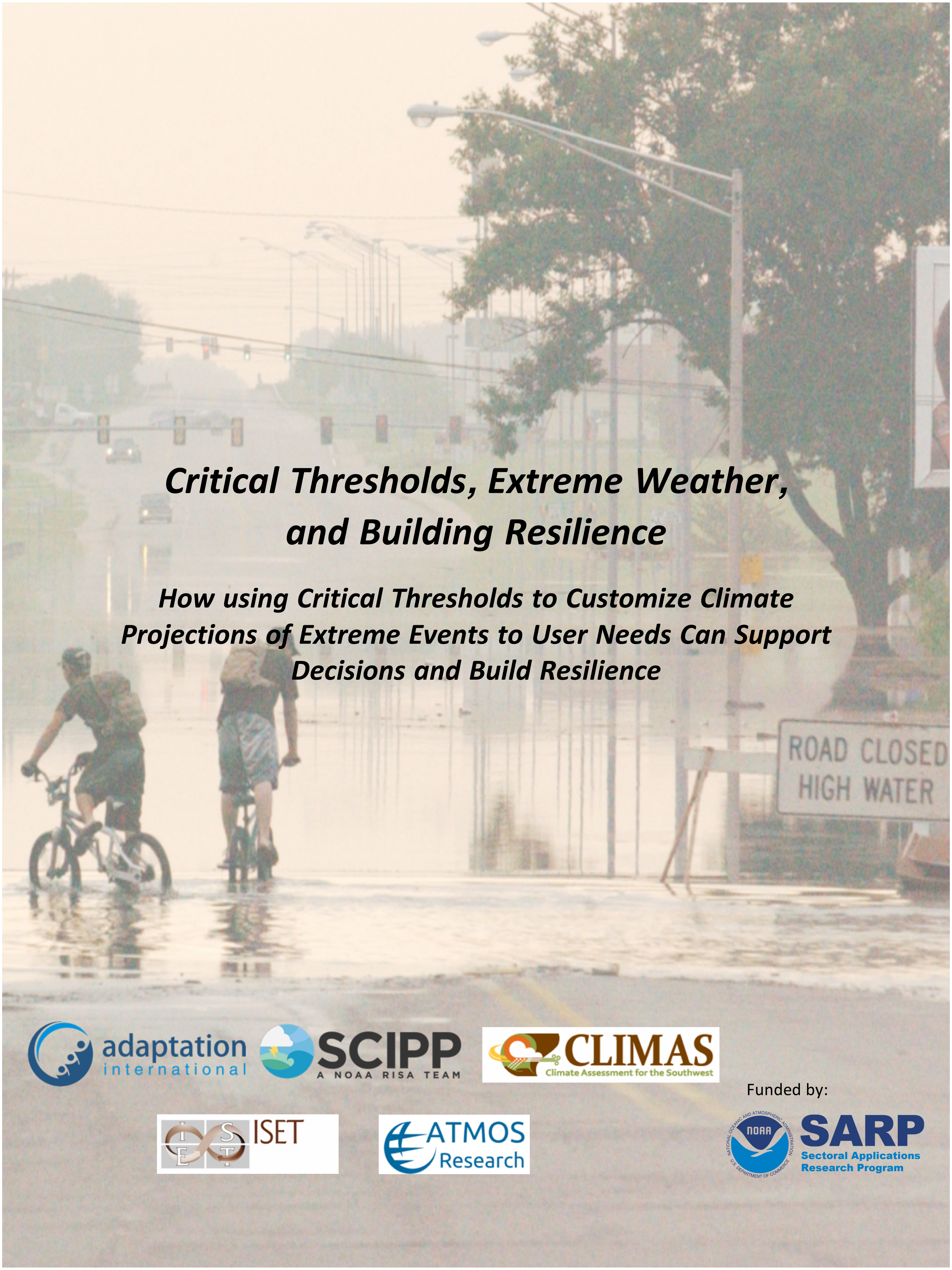

Critical Thresholds, Extreme Weather, and Building Resilience

How using Critical Thresholds to Customize Climate Projections of Extreme Events to User Needs Can Support Decisions and Build Resilience

Funded by:

A Final Project Report submitted to:
National Oceanic and Atmospheric Administration (NOAA), Department of Commerce
Climate Program Office, Climate and Societal Interactions-Extreme Events Award Number:
NA14OAR4310248

Using Critical Thresholds to Customize Climate Projections of Extreme Events to User Needs and Support Decisions

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Thank You!

The project team would like to thank each of our community project leads: Brett KenCairn, Russ Sands, and Greg Guibert (Boulder); Glenda Longan (Miami); AJ Fawver and Sandra Villarreal (San Angelo); and Lisa LaRocque (Las Cruces) for all their insights, guidance, and support throughout this project. We would also like to thank Danny Mattox from the K20 Center, Monica Deming from the Oklahoma Climatological Survey, Laura James from Atmos Research, and Atalie Pestalozzi for her graphic design work. This project would not have been successful without all your contributions.

Cover Photo: Gary Crow – from 29.25 Flood 2007, Miami and Ottawa County Oklahoma.

Recommended Citation: Petersen, S., MacClune, K., Garfin, G., Allen, C., Shafer, M., Hayhoe, K., Kos, L., LeRoy, S., Nasser, E., Riley, R., Stults, M., 2017. *Critical Thresholds, Extreme Weather, and Building Resilience: How Using Critical Thresholds to Customize Climate Projections of Extreme Events to User Needs Can Support Decisions and Build Resilience.* A Sectoral Applications Research Program Project supported by the National Oceanic and Atmospheric Administration’s Climate Program Office. Award Number: NA14OAR4310248.

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I. Executive Summary

When does weather go from being a nuisance to a problem? Communities already know that extreme weather events can affect the people who live in their communities, challenge City departmental operations, and negatively impact important assets and resources. Many of these extreme weather vulnerabilities will increase as the climate changes. ***This project developed and tested a community-specific participatory process to identify and customize projections of impact-relevant extreme event thresholds to guide climate change adaptation and resilience efforts.***

During 2015 and 2016, four small- to medium-sized communities from the South Central United States (Boulder, CO; Las Cruces, NM; Miami, OK; and San Angelo, TX) joined a multi-disciplinary project team to: 1) collaborate on identifying critical thresholds for extreme weather events in their communities; 2) create downscaled climate projections specific to each community's thresholds; 3) review the customized climate projections; and 4) identify and implement a resilience action project. A great deal of information was learned through these limited engagements with these four pilot communities, both about the potential value of using community defined thresholds, and about the nature of adaptation and building resilience in small and medium-sized communities.

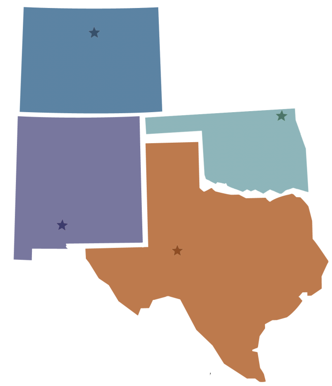


Figure 1: Pilot cities involved in this project. Clockwise from top left, stars indicate approximate location of Boulder, CO; Miami, OK; San Angelo, TX; and Las Cruces, NM.

Project Process - The process worked similarly with each of the communities. The project team collaborated with a leader in each city to develop a committee for the project. Each city's committee participated in two Shared Learning Dialogues (SLDs). These workshops set the foundation for action and culminated in the funding and completion of a pilot project to build resilience. The first workshop provided an overview of the project, explored climate and extreme weather concerns, and introduced the concept of climate/weather thresholds. The second workshop focused on presenting localized climate projections customized around each of the community-generated thresholds of concern. The participants also worked to generate pilot project ideas and select a specific resilience action project. Figure 3 depicts a generalized framework for the overall project process.

Figure 2: City of Boulder Municipal Climate Change Workshop. Photo Credit: Russ Sands

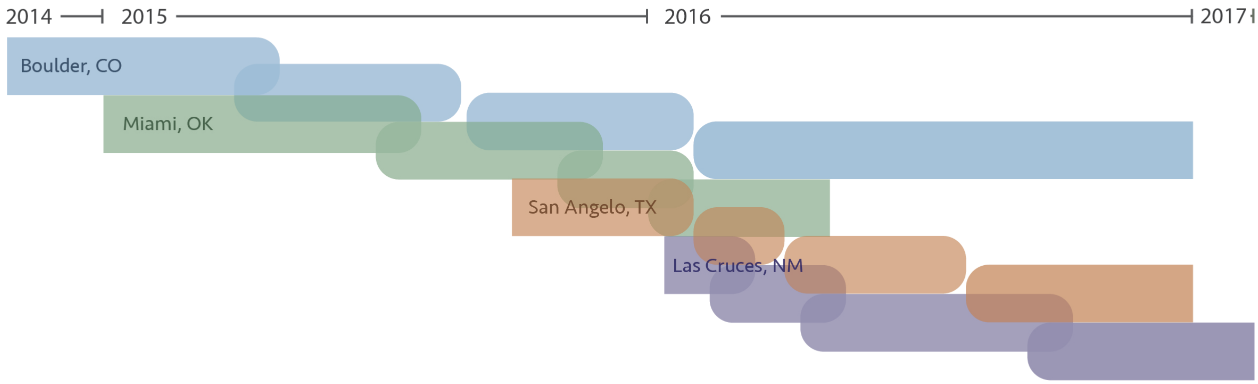


Figure 3: Project timeline for each of the communities. First ovals are the identification of community specific critical thresholds, second ovals are the custom analysis of climate projections around those thresholds. Third oval is the discussion of those results and identification of a resilience action project. Fourth oval is the implementation of the resilience action project. Boulder is shown in blue; Miami is shown in green; San Angelo is shown in brown; and Las Cruces is shown in purple.

Stakeholder Engagement - *Both broad stakeholder engagement and expected attrition in participation can be used to strengthen efforts to build community climate resilience.* Our experience highlights that initial community engagement should draw from a large, highly varied pool, even if organizers doubt participants will remain engaged beyond an initial workshop. Community resilience to extreme weather ultimately requires awareness and engagement from the full range of community sectors. Focusing just on emergency management, water operations, etc. can leave out critical perspectives and issues. Indeed, Boulder, based in part on their experience with this project, determined that to effectively act on climate change they need a much broader base of knowledge across all City government departments, including departments such as information technology, finance, public health, and human resources. It can also be difficult to identify the stakeholders who are most and least engaged before conducting the workshops. However, engagement that draws a highly diverse group will almost certainly include stakeholders who see little immediate connection between their daily responsibilities and climate change. These stakeholders are unlikely to engage beyond an initial workshop. As attrition almost inevitably occurs, this self-selection and narrowing of the stakeholder base presents an opportunity to tailor later workshops to the expertise and needs of the participants that remain.

Climate Science Thresholds - *Communities are interested in threshold levels tied to specific local events and more extreme than those typically selected in scientific analyses.* Unlike traditional science-derived indicators typically expressed in terms of percentile of the distribution, stakeholders from the four pilot communities emphasized impact-related values attached to specific temperature or precipitation thresholds. They selected thresholds related to recent extreme weather and climate episodes, including heat waves, floods, cold snaps, and droughts. In many cases, the selected threshold values were significantly higher (or more extreme) than those typically used by the World Meteorological Organization and that form the basis for the climate extreme indices often used in analyses of historical trends and future projections (Table 1). This qualitative difference between science-derived and community-derived indicators and threshold values is important; it emphasizes that what is challenging for communities is not a 90th percentile event, but events, episodes, and impacts that are less frequent and to which the community has not successfully adapted. This highlights the value of location-specific stakeholder engagement — impact-based thresholds help stakeholders make the connection between abstract climate statistics and the far more memorable and relevant impacts experienced by the community.

Table 1: Comparison of single-day temperature and precipitation thresholds identified by the WMO (World Meteorological Organization; Klein Tank et al. 2009) and the four pilot communities. Temperatures expressed in degrees Fahrenheit (F). Precipitation (Precip) expressed in inches per day.

WMO	BOULDER	LAS CRUCES	MIAMI	SAN ANGELO
Tmax > 77°F	80°, 90°, 95°	90°, 100°, 105°	95°, 100°, 105°	90°, 100°, 105°
Tmax > 90th percentile	74^{th}, 92^{nd}, 98^{th} percentiles	75^{th}, 97^{th}, 99.9^{th}	93^{rd}, 98^{th}, 99.7^{th}	72^{nd}, 95^{th}, 99.5^{th}
Tmin > 68°F	75°	80°, 85°	80°	80°
Precip > 0.4", 0.8" per day	2", 4"	2.5"	2.7" in 2 days	2", 4"

Resilience Actions - ***Communities are opportunistic when acting to build community resilience.*** In most cases, the four pilot communities chose resilience projects that fit with on-going efforts. In San Angelo, for example, that choice was based on a combination of pragmatism and political feasibility. The City had a nascent residential rainwater harvesting program that was already supported by the city council. Also, they had already investigated the potential installation of a larger rainwater harvesting system in a central city park and knew that it could be done within the budget and time constraints for the project. This does not mean that the selected projects did not address climate concerns or build climate resilience, but rather highlights that there are many factors that influence action and whether those actions are initiated and successful.

Each community selected a resilience action project that has co-benefits and helps build more than one aspect of resilience *(Figure 4).* For example, in Las Cruces, the community chose to implement a rainwater harvesting project and develop a green infrastructure plan that not only reduced physical drought vulnerability in the area near the project, but also helped the city develop a more integrated planning process for infrastructure that addresses an underserved portion of the community. They leveraged the plan developed as part of this project to encourage the Public Works department to provide $200,000 in matching funds for a community block grant and make a $400,000 investment in enhancing green infrastructure in the traditionally underserved neighborhood.

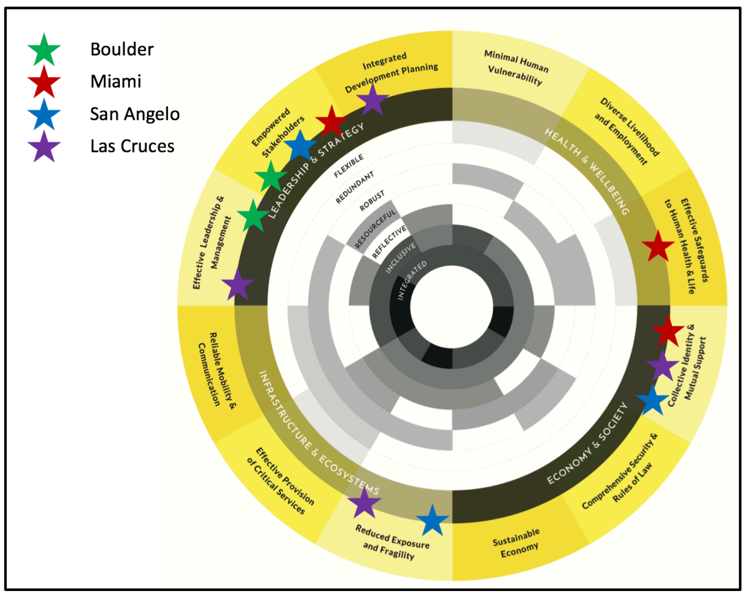


Figure 4: Community resilience action projects overlaid on factors contributing to community resilience as defined by the City Resilience Framework developed by the Rockefeller Foundation and Arup (used with permission). Aspects of resilience enhanced by each of the community resilience actions project are shown by the colored stars. Green stars = City of Boulder, CO; Red Stars = Miami, OK; Blue Stars = San Angelo, TX; and Purple Stars = Las Cruces, NM.

Insights - ***The thresholds concept is useful as an entry point for discussions about climate change.*** The concept helped ground conversations in issues of concern to local decision makers, helped put projected climate changes in the context of the past extreme events (which are the most noticeable ways in which climate and weather affect stakeholders), and provided a foundation for presentations and discussions that demystified the perceived black box of complex global climate models.

Nevertheless, ***most participants were neither prepared nor motivated to think beyond the daily to weekly time scales.*** This is perhaps because most participants' job responsibilities are associated with short-term time scales, or because professional standards of planning practice (e.g., civil engineering design standards) do not yet accommodate climate projections. Further research on these perceptions and constraints would be useful to inform future climate change adaptation planning.

Successful co-production of actionable science, based on the extreme weather events thresholds concept, shows potential to bridge the gap between climate science and on-the-ground action to build resilience.

II. Process Summary

A. Project Motivation

Communities are already vulnerable to extreme events, and many of these vulnerabilities will increase as the climate changes. Yet, previous approaches for sharing climate projection information do not generally tie to the needs and concerns of the communities (Tryhorn and DeGaetano, 2001). How can projects make climate change impacts tangible and locally relevant? Our hypothesis was that identifying and better understanding critical thresholds for extreme events, many of which are highly localized in nature, is central to developing effective community responses to climate change.

***This project developed and tested a community-specific participatory process to identify and develop projections of impact-relevant extreme event thresholds to guide climate change adaptation and resilience efforts*.**

In this pilot project, our team of climate scientists, social scientists, and capacity-building organizations worked collaboratively with staff from local governments, community organizations, and state and county agencies to identify climate- and weather-related thresholds relevant to each community. Project outputs included a set of user-defined climate thresholds and resilience action projects that begin addressing concerns related to exceeding these thresholds. Outcomes included increased capacity to understand and use information from climate change projections and stronger interdepartmental connections important for implementing actions to build resilience.

B. Process Framework

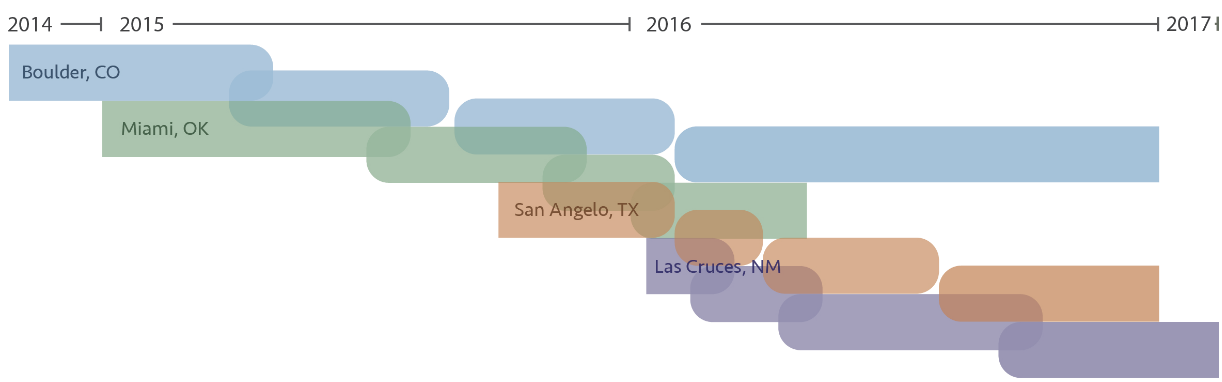


Figure 5: Project timeline for each of the communities. First ovals are the identification of community specific critical thresholds, second ovals are the custom analysis of climate projections around those thresholds. Third oval represents the discussion of those results and identification of a resilience action project. Fourth oval is the implementation of the resilience action project. Boulder is shown in blue; Miami is shown in green; San Angelo is shown in brown; and Las Cruces is shown in purple.

1. Selecting pilot communities and identifying stakeholders

The project team identified four small- to medium-sized cities across the South Central United States (CO, OK, NM, TX) to help pilot this approach. The communities face a variety of climate and extreme weather challenges, from floods to droughts and extreme heat to ice storms. The collaboration with each community lasted approximately 18 months and the communities were grouped into two cohorts, with two cities each. Boulder, CO and Miami, OK started in the first year of the project and San Angelo, TX, and Las Cruces, NM started in the second year of the project. This staggered approach allowed the project team and second cohort to benefit from the experiences of the first cohort.

The project team began by enlisting key people in each city to act as champions and project coordinators. This step was important for creating a solid foundation for the rest of the project; achieving buy-in for the project; and establishing trust relationships with partners. The champions invited participants from a variety of professional backgrounds, including local government staff from several departments, emergency personnel, school district staff, hospital staff, and others who plan for or respond to extreme events in their region. Project staff oriented participants to the goals of the project, the process, and potential climate-related concerns as the first step in interactive learning between the project team and local practitioners. Through this process, researchers and city staff learned from each other about what information is needed and what climate science can provide. This initial engagement was done through webinars, in-person meetings, and telephone conversations. The project team also conducted a pre-engagement survey to identify participants' key climate- and weather-related concerns, sources of information, attitudes, and constraints or opportunities for action.

2. Engagement phase

The direct engagement phase of the project was separated into three key components: an initial shared learning dialogue, analysis of customized climate projections, and a second shared learning dialogue.

First Shared Learning Dialogue

A Shared Learning Dialogue is a workshop designed to convene a highly diverse set of stakeholders in a way that supports all stakeholders and active learning between participants. The key to this approach is an attitude of mutual problem solving: researchers learn about local practitioners' concerns and what they need to better address their challenges, and practitioners learn both how science can be useful and how to deal with scientific uncertainties and limitations (Tyler & Moench, 2012; Reed et al., 2013).

For this project, the initial shared learning dialogue in each city focused on identifying when weather goes from being a nuisance to a serious problem that stresses participants' ability to do their jobs and manage their systems. City water staff discussed drought and heavy rainfall events; hospital staff mentioned increases in emergency room visits during heat waves and extreme winter weather events; participants charged with managing parks and other green spaces discussed rainfall, drought, temperature variability, and wildfire; and emergency managers discussed extreme events ranging from floods to ice storms. The project team introduced the basics of climate change science, including local historic climate variations, as well as the concepts of climate projections, uncertainty, and confidence. Participants learned about national and regional climate projections. After this exchange, participants identified key critical local extreme weather event thresholds. Each community identified at least 10 potential thresholds for the project team to investigate; one community (Las Cruces) identified more than 30 potential thresholds. At this stage in the engagement, the emphasis was on making the subject matter as concrete as possible, informing the science with user concerns and needs, and encouraging climate time-scale thinking.

To help make the potential impacts of climate change tangible and locally relevant, we asked the community to answer the following questions:

- *How does climate and weather affect your job, the people you serve, and your family/community?*
- *When does weather go from being a nuisance to a problem?*
- *What are the multi-sector or multi-department impacts of extreme weather, climate variability, and climate change?*

Customized Climate Projections

Many thresholds initially identified by the communities required further discussion between participants and the project team to clarify the nature of the events in question, the degree to which climate parameters could be used to evaluate the potential frequency or magnitude of future events, or to further refine the definition of these events.

Once the thresholds were refined and/or finalized, the project team evaluated the historical frequency of events that passed these thresholds. The project team then statistically downscaled CMIP5 global climate model simulations for each region for a lower and higher future climate scenario (RCP 4.5 and RCP 8.5) to determine the projected frequency of future events under both scenarios. Some of the threshold projections, such as maximum daily or nightly temperature and 24-hour precipitation, were well suited for evaluation using these techniques. Other thresholds were more difficult. For example, correlating historical flooding to precipitation events in Miami, OK was complicated by the need to account for rainfall both in the community and upstream in the watershed, as well as the pre-rainfall height of water in a nearby lake. In a third set of cases, the thresholds identified were not well suited for evaluation using site-specific climate projections. One example was the desire to investigate changes to wildfire risk in and around Boulder, CO. Wildfire risk is affected by many complex, non-climatic factors, such as the amount and type of vegetation available to burn. Finally, there were several instances in which the thresholds participants were most concerned with were either (a) not possible to model (e.g., tornadoes) or (b) not feasible to model given the time and budget constraints of the project (e.g., changes to vegetation when considering wildfire risk, or ice storms).

Second Shared Learning Dialogue

The second shared learning dialogue started by reminding participants of the process used up to that point and presented detailed information on the results of the customized threshold analysis (including confidence levels). Participants discussed the results and the implications for their work. In most cases, participants acknowledged that the future will not be the same as the past, and expressed greater understanding that their planning and budgeting would need to adjust to this new reality of generally more frequent extreme events. In two cases, the large projected increase in the frequency of extreme heat events caught participants by surprise. The dialogue process built confidence in climate change science, including understanding of the limitations of the science, and, in some cases, further developed the participants' climate-timescale (seasonal to decadal) thinking. *Formatting the climate projections based on user needs and choices rather than presenting pre-packaged climate information made the climate science more relevant to participants.*

During the second half of the dialogue, participants identified, prioritized, and developed pilot projects to address the climate-related issues they identified. This activity helped participants apply earlier discussions to practical action in their cities, and allowed the project team to see how the provided climate information could lead to local applications. The questions that the project team used to motivate the knowledge-to-action discussions included:

- *Does the proposed project address community concerns?*
- *Are the right people available to implement the project?*
- *What will motivate local decision-makers to participate?*

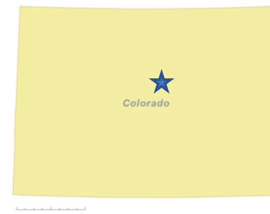
Following the second shared learning dialogue, city champions worked with the project team to refine the project proposals. Grant funding provided $10,000 to $15,000 to complete the projects. In most situations, the amount provided was sufficient to complete a small but tangible project.

3. Implementation phase

The project team supported resilience action project implementation as necessary. Project champions and dialogue participants generated local approval for projects, implemented those projects, and have started assessing their success. Examples of resilience action projects include the installation of a rainwater harvesting system in a city park (San Angelo) or at a low-income neighborhood community center (Las Cruces) and a public-school curriculum on extreme weather thresholds and emergency preparedness (Miami). The rainwater harvesting systems demonstrate the principle of integrating climate change-related strategies into existing public policy, because these systems address multiple climate-related issues, e.g., extreme precipitation (by diverting and absorbing stormwater) and drought (by providing an irrigation water source during dry seasons). These systems also address multiple policy goals, such as stormwater management, making city amenities more attractive, bringing improvements to underserved or at-risk neighborhoods, and raising awareness about weather and climate.

In two cases, the small resilience action projects led to successful grant applications or the securing of additional funds to continue to build resilience. San Angelo secured almost $25,000 for the planning and implementation of a second rainwater harvesting system in another city park. Las Cruces leveraged the green stormwater and infrastructure plan created through this project to encourage the Public Works department to provide $200,000 in matching funds for a community block grant and is making a $400,000 investment in enhancing green infrastructure in a traditionally underserved neighborhood.

III. City Summaries



A. Boulder, Colorado (1st cohort)

Size: *Medium* – Population 107,349[1]
Location: At the junction of the Rockies and the Great Plains

Primary Climate- and Weather-Related Concerns: Flooding, drought, wildfire, and extreme cold
Potential Future Concerns: Extreme heat; increased frequency or intensity of flooding, drought, and wildfire; and increased variability in weather, particularly in spring and fall

Description: Boulder is a progressive, medium-sized city in the greater Denver metropolitan area. Home values are high, promoting growth of surrounding communities, often with less planning than the City government would like. The City of Boulder frequently experiments with novel means of city planning, zoning, and municipal codes, largely with the support of the citizens, although in the last few years, public support for this kind of experimentation seems to be eroding. Capacity of City staff to understand climate information is high, and relationships are good with Boulder County staff who address similar information in similar ways. Due to recent events, flooding and wildfire are high-profile issues for both the city and county, and both issues have received significant attention and proactive, innovative investment to reduce vulnerability. There is political commitment to addressing climate concerns, though until recently the emphasis has been more on mitigating the city's carbon footprint than on adapting to climate change and building resilience.

Unique Considerations: The City of Boulder pursues progressive policies in a state that has mixed views on the need to address climate issues. The state supports vigorous climate assessments, but action is constrained by more conservative elements in the legislature. Given Boulder's location at the transition from the Rocky Mountains to the Great Plains, there are fairly high uncertainties in climate projections for this area. The city is home to the flagship campus of the University of Colorado. The student population of 30,800 (many of whom live within the city limits during the academic year) comprise a significant portion of the total city population. This portion of the population has high turnover, and understanding of and preparedness for local risks is likely low.

Timeline:

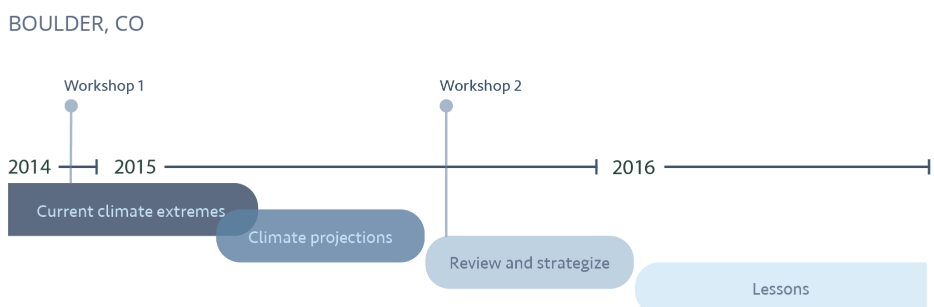


Figure 6: City of Boulder timeline. Shared Learning Dialogues (Workshops) shown with markers.

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[1] https://www.census.gov/quickfacts/table (2015)

Lessons:

- ***What went well?***

Throughout the project, there was good participation by decision-makers concerned with environmental issues. Discussion of important weather events and critical thresholds were vigorous and detailed.

- ***What could have been improved?***

Shared Learning Dialogues one and two were nine months apart, which led to a drop-off in enthusiasm and participation. Because Boulder was the first pilot city in this project, the process for moving from proposed thresholds to finalized thresholds took longer than initially anticipated. In replicating this work, the implementation team should plan for two to three weeks of focused engagement with participants following the first dialogue This would allow for secondary data acquisition, threshold refinement, and a follow-up meeting or meetings to finalize thresholds within a month after the first dialogue. High-resolution climate projections should be generated immediately.

- ***Surprises or unexpected outcomes?***

City staff reported that they couldn't use some of the threshold information developed throughout the project because they currently have no way to directly build the projections into their work, and for other thresholds they have no framework for even thinking about them. For example, because the city currently does not experience heat waves, there is no mechanism for engaging within departments (or with the community) around extreme heat. They noted that more climate-aware city procedures are needed to make it easier to integrate these ideas into their planning and management.

Final Thoughts:

Boulder's recognition that the climate issues raised in the thresholds work are issues for which they have no city process is critically important in working with cities around climate change adaptation. The challenge of climate change isn't always that we're going to get more of the same or more intense versions of the same – more flooding, more droughts, more windstorms. In some cases, the challenge is the new and unexpected – things that haven't been seen. The greatest challenge with these new events is convincing policy-makers they are real threats, likely to occur on a reasonable timeframe and, thus, need to be prioritized and funded alongside preparation for events that are already occurring. This challenge is one that Boulder identified and is taking head-on. This is an example of how the thresholds approach to climate data can be extremely helpful. Illustrating how events that aren't occurring regularly enough to be a concern now may become regular events in the future provides an opening for these important discussions.

Figure 7: Photos from the City of Boulder climate change workshop series, which grew from and extended beyond this project. Photo Credits: Russ Sands.

B. Miami, Oklahoma (1st cohort)

Size: *Small* – Population 13,611[2]
Location: Southern Plains in Northeast Oklahoma

Primary Climate- and Weather-Related Concerns: Riverine flooding, tornadoes, and ice storms **Potential Future Concerns:** Extreme heat

Description: Miami (pronounced "My-am-uh") is in northeastern Oklahoma, in Ottawa County. The region is primarily agricultural and has large tribal populations in and around the city; 17% of the county's population is Native American and eight tribes have jurisdictional areas within the county. Miami is in a relatively low-lying area at the foot of the Ozark Mountains and is prone to flooding from both local and upstream heavy rainfall events. The area is also frequently affected by drought, winter storms, and severe thunderstorms. The City has been devoting attention to extreme weather events since major flooding occurred in 2007. Little to no discussion of climate change had occurred among city officials prior to the start of this project.

Unique Considerations: In addition to the City of Miami, eight tribal nations, each with its own tribal government, are located with in Ottawa County. Discussions among project participants during the two shared learning dialogues suggested that the tribes might, in some cases, have more funding to support preparedness initiatives than the City. For example, when discussing how to prepare for and respond to extreme heat, city officials referred to the fact that several tribal nations open a cooling center for people seeking relief from hot temperatures whereas the City of Miami does not.

Timeline:

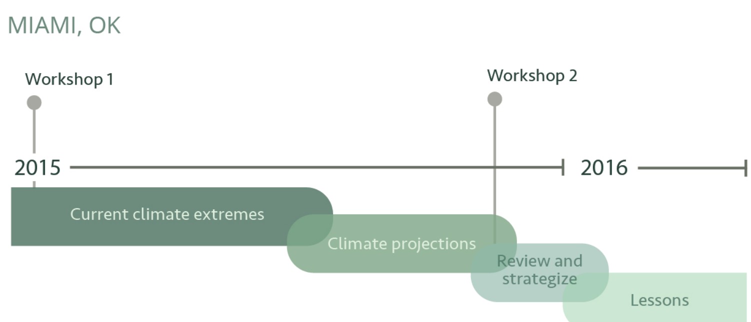

Figure 8: City of Miami timeline. Shared learning dialogues (Workshops) shown with markers.

Lessons:

- ***What went well?***

The project was fortunate enough to have a strong local champion (the emergency management coordinator for the City) who had worked for the city for more than 11 years and had existing relationships with key officials and community members. The extreme weather and climate lesson completed at the end of the project went extremely well. Outreach to the community through the lesson to the eighth-grade students exceeded the expectations of both the project team and the local champion. Anecdotally, the project champion received many comments from community members about the lesson and what they had heard from their children about extreme weather preparedness.

[2] https://www.census.gov/quickfacts/table (2015)

- ***What could have been improved?***

There was an extremely sharp drop in attendance and participation between the first and second shared learning dialogues. It would have been better to have the two shared learning dialogues no more than three months apart, not only to retain stakeholder interest but also to provide more time to implement the action-oriented project at the end of the engagement. Ensuring that the analysis of climate projections was completed further in advance of the second workshop would have given the workshop team more time to prepare and provide a better foundation for the discussion during the dialogue.

- ***Surprises or unexpected outcomes?***

The final selected action focused on designing and teaching a lesson to eighth-grade students was a surprise. During the key action brainstorming session at the second dialogue, the participants kept steering the conversation toward actions they could take to promote public awareness of severe weather and improve preparedness and response. The project champion decided that community outreach through the eighth-graders would ultimately be much more effective at building overall extreme weather preparedness than having an event hosted by the City.

Final Thoughts:

The thresholds concept was somewhat beneficial, but for the most part the climate science capabilities did not match the needs or focus of the stakeholders. Project participants were most concerned with one to two days prior to an extreme weather event and did not embrace the longer-term thinking (years and decades) needed to prepare for climate change. This was partially because, within the limited scope of this project, it was not possible to generate original, directly relevant, and useful projections that addressed their main concerns (flooding and ice storms). The project team was also unable to help participants think internally about city operations. Instead, participants focused solely on public or community education. At the end of the project, the local champion's focus had not changed from emergency management. Her future goals for the community included finding funding to provide more weather radios to the city residents, beginning to fund safe rooms, and doing more outreach about severe weather events. The project team is not sure the project moved the needle and helped the City think about climate change.

Figure 9: Photos from the City of Miami extreme weather lessons and first shared learning dialogue. Left: Eighth-graders in Miami, OK working through a lesson designed specifically for this project on extreme weather thresholds, changing climate conditions, and emergency preparedness. Right: Participants discussing extreme weather thresholds in the City of Miami, OK during the first shared learning dialogue. Photo Credits: Danny Maddox (left) and Sascha Petersen (right).

C. Las Cruces, New Mexico (2nd cohort)

Size: *Medium* – Population 101,643[3] within city limits
Location: Chihuahuan Desert of south-central New Mexico

Primary Climate- and Weather-Related Concerns: Monsoon thunderstorms and flooding, extreme temperatures (hot and cold), drought, and dust storms
Potential Future Concerns: Extreme heat and drought

Description: Las Cruces is located 46 miles north of the Mexican border. The Rio Grande river flows through the city, and much of the city lies within the geologic floodplain of the river. Las Cruces is the economic and geographic center of the Mesilla Valley, the agriculture region on the Rio Grande extending from Hatch, NM to El Paso, TX. The climate of Las Cruces is characteristic of an arid desert, with large diurnal and moderate annual temperature ranges, variable precipitation, low relative humidity, and abundant sunshine. Sunny days comprise more than 80% of all days in an average year. More than half of the annual precipitation falls from July through September in intense monsoon thunderstorms, which can dump inches of rain in a single storm, resulting in flash flooding—a large concern for the community. Both monsoon storms and spring weather systems are often accompanied by strong wind and blowing dust; that can have serious impacts on transportation and public health.

Unique Considerations: Given how close Las Cruces is to the U.S.-Mexico border, more than half of the population is Hispanic or Latino, and there are many undocumented residents. More people in Las Cruces live below the poverty line (24%) than the U.S. average (15%)[4].

Timeline:

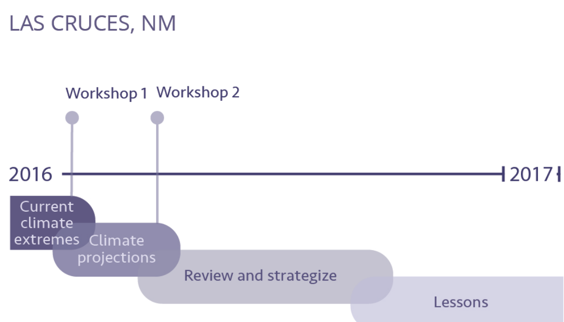

Figure 10: City of Las Cruces timeline. Shared learning dialogues (workshops) indicated with markers.

Lessons:

- **What went well?**

The project started with strong participation by many local stakeholders at the first shared learning dialogue. The refinement of the thresholds and the climate analysis was completed quickly, which promoted continued stakeholder engagement at the second shared learning dialogue. Participation at both dialogues built relationships that hadn't previously existed (e.g., between the City and the local National Weather Service office, and the City and New Mexico State University) and spawned further collaboration. There was also a public event hosted by the City the evening after the second dialogue, which attracted more than 100 attendees, including several city council members.

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[3] https://www.census.gov/quickfacts/table (2015)
[4] 2010 estimate; https://www.cia.gov/library/publications/the-world-factbook/fields/2046.html

- **What could have been improved?**

The project was not considered a high priority for many of the city stakeholders, who tended to focus on shorter-time-scale weather decisions and annual budgets. Our engagement was successful as an introduction and initial foray into the topic; however, long-term success will require further capacity building if local stakeholders are to develop the expertise to successfully respond to climate change. To discern which factors contributed to participation and enthusiasm for the topic and process, the project could have been improved by an enhanced, and adequately funded, social science component. The project lacked the capacity and expertise to adequately assess and evaluate people's motivation for participation and follow-up activities.

- **Surprises or unexpected outcomes?**

Our key contact, the City's Sustainability Officer, was surprised by the extent and richness of the interaction among participants that resulted from this project. She now works more closely with the local National Weather Service office and climatologists at New Mexico State University (NMSU), and she did not anticipate this result when the project started. In fact, the collaboration with NMSU was strengthened through their provision of weather data that was used to incorporate humidity and heat index in the climate analysis and make it more relevant to the interests of the stakeholders.

Final Thoughts:

The thresholds concept was beneficial for communicating about climate changes in the region. However, the broad acceptance, associated institutional capacity (both personnel and funding), and experience planning and prioritizing on long-term time-scales was not in place prior to the project and limited the ability to coproduce actionable science based on the thresholds concept. Participants had a difficult time thinking beyond the daily to weekly time scales associated with their job responsibilities and professional standards of practice.

The local project champion was critical to the project's success and continues to be engaged on these issues. She recently worked with the Public Works department to secure the $200,000 in matching funds needed to receive a community block grant and invest $400,000 in green infrastructure improvements in a historically underserved neighborhood in the city. The investment was catalyzed by the completion of a green infrastructure assessment for the neighborhood funded as part of this project.

Figure 11: Photos from the first shared learning dialogue in Las Cruces and of the rainwater harvesting system selected as part of the community's resilience action project. Left: Participants at the first shared learning dialogue. Right: Rainwater harvesting system installed at the Safe Haven Community Center Complex as part of the selected resilience action project. Photo Credits: Gregg Garfin (left) and Lisa LaRocque (right).

D. San Angelo, Texas (2nd Cohort)

Size: *Medium* –population 100,450[5]
Location: Concho Valley of West Texas

Primary Climate- and Weather-Related Concerns: Riverine flooding, extreme heat, ice storms, and wildfires
Potential Future Concerns: Flooding, extreme heat, ice storms, wildfires

Description: Home to Angelo State University and the Goodfellow Air Force Base, San Angelo has seen rapid population growth, nearly doubling its population since the 1960s. With this growth, the city government has been challenged by urban sprawl and, in the late 2000s, began efforts to revitalize the downtown area and increase density in the urban core. The city lies at the junction of the North and South Concho Rivers, with the rivers running through the heart of downtown, an amenity to the city's efforts to create denser development and enhance economic activity in the area. This region of West Texas experiences a wide variety of extreme weather events and hot and dry conditions in the summer commonly lead to heat waves, drought, and a higher risk for wildfires.

Unique Considerations: Situated in the politically conservative state of Texas, the City of San Angelo mirrors the state's hesitancy to accept and discuss climate change. This hesitancy was highlighted by the unwillingness of the City's emergency management department to associate with the project. However, it became clear during the project that there is an eagerness amongst some stakeholders in San Angelo to learn about and discuss climate change.

Timeline:

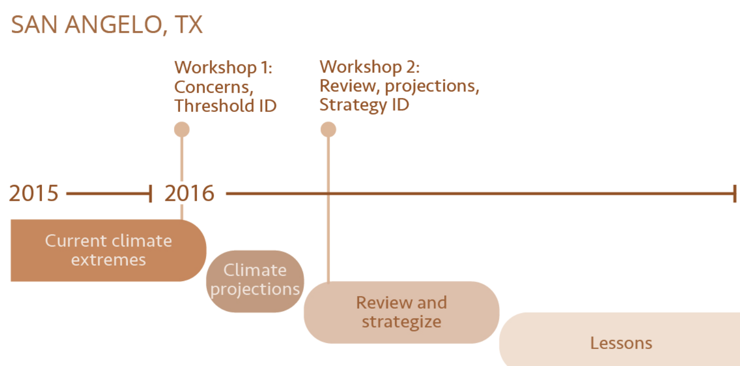

Figure 12: City of San Angelo timeline. Shared Learning Dialogues (workshops) indicated with markers.

Lessons:

- ***What went well?***

The first shared learning dialogue engaged participants with personal accounts of the impacts of extreme weather and climate. This personal connection to extreme events allowed for a smooth transition to discussing thresholds as well as a willingness to engage in dialogue activities. The project had an exceptional champion (the planning department director) who was committed to and excited about the project. Additionally, the project brought together people who do not normally interact and perhaps also helped them think about the bigger picture effects climate and extreme weather can have on the community.

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[5] http://www.census.gov/quickfacts/table (2015)

The resilience action projects—installation of a rainwater harvesting system and an evapotranspiration (ET) weather station—have been embraced by the water department and others in the City. The City has also separately applied for and received a $25,000 grant to design and install another rainwater harvesting system in a different city park. While they continue to work to secure the remaining $19,000 necessary to complete the project, this successful application to expand the program highlights their commitment to addressing the water resource needs of their community.

- ***What could have been improved?***

More targeted initial outreach and more time spent by the project team reviewing the goals of the project with the participants might have helped many of the stakeholders more clearly connect to how extreme weather and/or climate is, and will increasingly be, an integral part of their work. This understanding could have been further strengthened by shortening presentations on the climate science and strengthening the links to on-the-ground issues affecting the city.

- ***Surprises or unexpected outcomes?***

The city project coordinator was surprised by the enthusiastic engagement of specific people in the group whom she thought would not be engaged. It was exciting to see a progressive and productive consideration of climate change in West Texas. When the City Council reviewed the resilience action project proposal, there was enthusiastic discussion about how this project could set precedence, highlighting City leadership on an important issue, and strengthening the partnerships formed with outside organizations necessary to make the installation of the rainwater harvesting system a success.

Final Thoughts:

The selected resilience action project lays the foundation for the City to be engaged in similar projects in the future. The project coordinator left San Angelo for a job in another city after the resilience action project was approved but before it was implemented. This meant a loss of knowledge and of an internal champion to continue to carry forward and promote climate preparedness; but the fact that other project participants applied for and secured additional funding highlights the possibility that a broad range of stakeholders will continue to be engaged in the City's climate resilience efforts.

Figure 13: Photos from the second shared learning dialogue and the rainwater harvesting system installed as part of San Angelo's resilience action project. Left: Participants discussing solutions to weather-related problems during the second shared learning dialogue in San Angelo. Right: Rainwater harvesting system installed in the Bosque Park in the center of San Angelo, TX. Photo Credits: Sascha Petersen (left) and Sandra Villarreal (right).

IV. Stakeholder Engagement

Both broad stakeholder engagement and expected attrition can be used to strengthen efforts to build community climate resilience.

One main premise of this project is that engaging with local stakeholders is essential to conducting effective climate adaptation work with communities. Climate projections need to be customized to local conditions based on stakeholder input and perceptions (Tryhorn and DeGaetano, 2001). This customization makes the information more meaningful, relevant, applicable, and hence better able to support climate change action.

For this reason, stakeholders were asked to identify when weather goes from being a nuisance to a problem, and the project team customized climate projections around these thresholds. Stakeholders in the four pilot cities identified very different thresholds, which clearly supports the thesis that one-size-fits-all climate information is of limited use in determining how climate events will translate to impacts on the ground, and may not lead to identifying or developing effective adaptation strategies. However, there are challenges to projects and processes that rely heavily on stakeholder engagement. In this section, we briefly analyze our experience, and provide suggestions as to how to frame and/or address potential challenges in engaging stakeholders in climate change work.

In general, it can be challenging to keep stakeholders engaged on projects related to climate adaptation. Climate adaptation work tends to be unfamiliar and it is difficult for participants to see how it relates to or supports their day-to-day responsibilities. Stakeholders frequently battle limited funding, challenges in allocating staff time, difficulty in gaining the commitment of supervisors, political unwillingness to engage in the issue, and difficulty generating interest among political officials (Carmin et al. 2012, Bierbaum et al. 2013, Riley et al. 2013). These general findings are consistent with the challenges encountered in all four of our pilot communities across a broad cross-section of previous climate knowledge and engagement, from prior avoidance (San Angelo) to deep interest (Boulder). In the mix of these competing priorities, reallocating their limited time to something new needs to have clear value to the stakeholders. Consequently, we were not surprised when stakeholder engagement declined between the first and second dialogues. Many stakeholders from different City/County departments and other local organizations (e.g., local National Weather Service (NWS) Forecast Offices, local universities, local health services, etc.) actively participated in the first shared learning dialogue and most were receptive to the information presented. Lower participation at the second shared learning dialogue could be due to several factors including but not limited to: too much time between the dialogues, the perception that this project didn’t directly apply to their work, or the determination that participation in the project was not the most effective use of their time. In all cases, multi-departmental engagement beyond the second dialogue was minimal, with only a few key stakeholders remaining actively engaged on the implementation of the resilience action project.

The decline in engagement did not negatively impact the execution of the project. Each city received both summaries of historic climate conditions and customized climate projections. Stakeholders from all four cities noted elements of these projections that were new to them and consistently expressed the opinion that presenting the information in this way made it more compelling. Ultimately, all four cities developed and implemented resilience action projects designed to address their climate and extreme weather concerns and make them more resilient.

Is continued engagement from multiple stakeholders across the lifetime of a project necessary? Based on our experience in this work, we would suggest, “no, it is not necessary”. What *is* necessary is:

- **One (or more) champions** in the community who will own the work, move it forward, and pull in additional players as needed (Beirbaum et al. 2013; Snover et al. 2007);
- **A second group of stakeholders who participate in both workshops**, are interested in knowing about climate change, understand potential adaptation options, and support action at the local level;
- **A third group within the community that is open to exploring whether climate change is relevant to their current roles and responsibilities** and willing to take the time to periodically expand their knowledge base and engage across sectors around climate and extreme weather issues.

The first and second groups were expected to be key participants in the project from the beginning. But, this third group, potentially represented by the stakeholders that attended the first shared learning dialogue but not the second, is particularly interesting. Though these stakeholders apparently determined that the information and discussions at the shared learning dialogues were not immediately relevant to their day-to-day roles and responsibilities, their participation and input at the first dialogue significantly influenced the issues discussed. In some cases, the disconnect between their daily activities and climate projection was driven by the fact that their climate concerns couldn’t be effectively modeled given the constraints of this project (e.g. ice storms in Miami); or that the direct climate link to their concerns has yet to be quantitatively established (e.g. mental health concerns in Boulder). Nonetheless, their participation at the first shared learning dialogue was highly valuable in broadening the thinking of the other participants and champions that remained engaged throughout the project. Additionally, in many cases, the issues brought up by those who didn’t continue to participate in the process highlighted areas where further climate information is needed if those sectors are to be engaged. The key contributions of these people who “dropped out” were:

- **They provided unique input to the project.** For example, in Boulder, participation by representatives of the mental health and community hospital staff at the first dialogue introduced a significant human-impacts element into what otherwise might have been a primarily technical, engineering, and utilities-focused discussion.

- **They began building relationships and connections, especially between departments and entities that wouldn’t normally work together.** For example, the sustainability officer in Las Cruces now works more closely with the local university and National Weather Service office because of this project.

- **They helped identify where lack of information about climate issues is constraining action.** For example, in Miami, OK, both emergency responders and electric utility system managers wanted additional information on ice storms that can significantly affect their operations. Due to the complex atmospheric dynamics that influence the creation of ice storms, this was beyond the scope of this project. But, this type of information on user needs should be communicated back to information providers to help direct future research efforts.

Our experience with these four pilot communities highlights how important it is that participants for the first shared learning dialogue be drawn from a large, highly varied pool. Even if organizers doubt participants will remain engaged beyond an initial meeting, they should still be included. Indeed, Boulder, based in part on this experience, has determined that to effectively act on climate change they need a much broader base of understanding across all City government departments, including departments such at IT, finance, and human resources that aren't normally included in the process.

A potential positive outcome of stakeholder attrition is that the work naturally becomes more focused on the needs and interests of the people still present. This type of self-selection and narrowing of the stakeholder base presents an opportunity to tailor the second shared learning dialogue to the expertise and needs of the participants that attend. For this project, both the first and second dialogues were structured broadly and designed to provide examples and scenarios from a range of disciplines and sectors. However, based on experiences with the four pilot communities, we recommend leaving the first dialogue as a broad presentation for stakeholders in varied expertise, but then working to identify who will attend the second dialogue early, and narrowing the focus based on the climate and adaptation strategies most relevant to the expertise of those who will be in the room. In Miami, most of the participants who attended the second dialogue were engaged in emergency management and preparedness. Thus, the second dialogue could have focused more specifically on those issues. This approach would allow the project team to provide more specific and concrete examples of adaptation strategies relevant to the community stakeholders in the room, with detailed information on how these projects were implemented.

Overall, we recommend that any organization or agency planning a climate change engagement activity should plan for and leverage both broad stakeholder engagement and attrition. Broad multi-department and multi-disciplinary engagement can generate new ideas and create new connections, which are keys for strengthening networks and continuing adaptation work in the community. Understanding who drops out of the process and why can help highlight where more specific climate information is needed. In future project work, it would be great more rigorously explore this issue and have a greater focus on collecting and/or analyzing stakeholder data. And, knowing who will stay involved will allow those communities to tailor further engagement to directly address their needs and interests.

V. Climate Projection Thresholds

***Communities are interested in threshold levels more extreme than those typically selected in scientific analyses, and in a wider range of extremes*.**

A. Threshold Methods

Another key goal of the project was to examine the relationship between the science-derived, statistics-based thresholds (e.g., 90th percentile exceedance values) used to define climate extremes and the community-identified thresholds. Given the additional effort required to conduct a stakeholder engagement process, we wanted to determine whether value is added through the investment in this process and using community-identified thresholds as compared to using pre-existing indices in common use at the national and/or global scale. In this section, we compare the community-derived thresholds with thresholds from the World Meteorological Organization (WMO; Klein Tank et al. 2009), the third National Climate Assessment (NCA3; chapters within Melillo et al. 2014), and the IPCC's Special Report on climate extremes (SREX; IPCC, 2012; Seneviratne et al. 2012).

There are multiple definitions and characterizations of climate and weather extremes. Definitions vary based on spatial and temporal scales of interest, period of record for available high-quality data, baseline reference period, persistence of the extreme episode (e.g., single day for heavy precipitation versus multiple years for drought), the magnitude of the extreme, onset and/or continuity of the episode or event, and the connection between the extreme indicator and societal impact.

Table 2 provides a range of sample indicators and thresholds from the climate and weather extremes literature, related to both primary (e.g., temperature) and secondary (e.g., floods, wildfires) impacts. These are varied, but tend to cluster in two broad categories: the probability of occurrence (e.g., expressed in terms of percentiles), and specific numerical thresholds determined based on historical observations (Seneviratne et al. 2012).

Table 2: Example definitions of temperature and precipitation extremes.

Extreme	Timeframe	Threshold Description	Source
Heat or Cold	Multiple	Typical scientific indices include the number, percentage, or fraction of days with maximum temperature (T_{max}) above the 90th, 95th, or 99th percentile or minimum temperature (T_{min}) below the 1st, 5th, or 10th percentiles, generally defined for given time frames (days, month, season, annual) with respect to the 1961-1990 reference period.	IPCC, 2012
Heat	Days/Year	98% exceedance threshold for daily temperature (hottest 2% of days/year).	Shafer et al. 2014
Heat	Days	Once-in-20-year extreme heat days.	Walsh et al. 2014
Heat	Season	Summertime (June-August) temperatures that ranked in the hottest 10% of the 118-year period of record.	Georgakakos et al. 2014
Heat	Season	Summertime temperatures among the hottest 5% (1950-1979 time period).	Walsh et al. 2014
Precipitation	Daily	Percent change in the annual amount of precipitation falling in the heaviest 1% of all daily events from 1901 to 2012 for each region.	Walsh et al. 2014
Precipitation	Daily	Average amount of precipitation falling on the wettest day of the year as compared to 1971-2000.	Walsh et al. 2014
Precipitation	Multi-day	2-day precipitation total that is exceeded on average only once in a five-year period, also known as a once-in-five-year event.	Walsh et al. 2014
Precipitation	Daily	Daily precipitation totals with 2-, 5-, and 10-year average recurrence periods.	Georgakakos et al. 2014
Precipitation	Daily	Heavy precipitation events that historically occurred once in 20 years.	Georgakakos et al. 2014
Dry Spell	Days	Annual maximum number of consecutive dry days (receiving less than 0.04 inches (1 mm) of precipitation).	Walsh et al. 2014

B. Comparing Thresholds

The community-derived temperature and precipitation thresholds identified by the project participants were primarily related to *(a)* well-known impacts from the historic record (e.g., August 2006 floods in Las Cruces, NM), *(b)* professional practice (e.g., drastic temperature shifts affecting urban tree planting, in Boulder, CO), and *(c)* round numbers associated with high temperatures and/or NWS heat advisories (e.g., T_{max} > 100°F). Examples of the community-derived thresholds are shown in Tables 3 and 4. Table 3 shows temperature-related thresholds; Table 4 shows precipitation-related thresholds. A few of these thresholds were combination or accumulative thresholds, such as the combination of high temperatures and relative humidity that renders evaporative coolers ineffective during the summer season, or the accumulated cooling-degree days—which is related to electric power demand for cooling (Table 3). Communities also identified a third set of thresholds, impact-related thresholds such as risk for wildfires, dust storms, high wind events, or ice storms. In some cases, the communities asked specific questions such as: How will temperatures affect hatch green chilies or pecan harvests? (Las Cruces); or What is the likelihood of 0.5-inch accumulation of ice and wind speeds greater than 15 miles per hour? (Miami). We were unable to follow up on these thresholds because they require impact-specific process models. Consequently, these types of thresholds do not appear in this summary.

Table 3: Sample of community-derived temperature-related thresholds. Comments are italicized.

	Boulder, CO	Miami, OK	San Angelo, TX	Las Cruces, NM
Heat	Days per year with maximum daytime temperature $T_{max} \geq$ 85°F, 90°F, and 95°F.	Days per year with $T_{max} \geq$ 95°F, 100°F, 105°F.	Days per year with $T_{max} \geq$ 90°F (occupational exposures), 100°F and 105°F for 1-2 consecutive days.	Days per year with T_{max} > 95°F, 100°F and 105°F. *Human health issues emerge at 95°F. At 100°F, the El Paso International Airport short runway closes.*
Heat	Nights per year with minimum nighttime temperature T_{min} > 75°F.	Nighttime T_{min} > 80°F for two days or longer. *NWS Tulsa WFO Heat Advisory temperature criterion.*	T_{min} > 80°F for two or more nights.	T_{min} > 80°F for 2 or more nights, or > than 85°F for one night.
Heat	Multi-day (3+) heat waves defined by T_{max} > 90°F, 95°F or T_{min} > 75°F.			T_{max} > 100°F for 3+ and 5+ days. Changes to the maximum & average length of heat waves.
Cool	Nights per year with T_{min} < 32°F.			Number of nights of freeze (32°F), hard freeze (28°F).
Cool				Maximum and average length of cold snaps. *Feb. 2011 freeze event, T_{max} < 32°F for two or more days.*
Cool				Timing of first/last freeze (32°F) and hard freeze (28°F) in the fall/spring.
Temp Swings	Temperature swings > 50°F, 60°F, 70°F in 3 days and T_{min} < 20°F. *Important for urban tree mortality.*			
Heat & Moisture				Temperatures $\geq$ 90°F ***and*** relative humidity $\geq$ 35%. *The threshold at which evaporative cooling is no longer effective.*

Table 4: Sample of community-derived precipitation-related (Precip) thresholds. Comments are italicized.

	Boulder, CO	Miami, OK	San Angelo, TX	Las Cruces, NM
Precip	Likelihood of daily precipitation exceeding the 99th percentile of Historic record.		Daily precipitation $\geq$ 2".	Daily precipitation $\geq$ 2.5" *10-year event threshold similar to Aug. 1, 2006.*
Precip	Rain total on the wettest day, 3 days & 5 days of the year.	Precipitation $\geq$ 2.7" in 2 days Precipitation $\geq$ 3.5" in 3 days Precipitation $\geq$ 3.8" in 7 days *City officials didn't define exact values, but noted the association between rain events and floods. Project team used flood records to identify thresholds.*	Daily precipitation $\geq$ 4".	Three or more consecutive days of $\geq$ 0.1" of precipitation per day.
Snow/ice				Potential recurrence of events of record: April 5-7, 1983; December 13-14, 1987; Dec 26-27, 2015. *Historic snow events.*
Dryness	Dry years matching rainfall in 2002 and 2012 or 2000-2006.			Summers that have less precipitation than the driest summer on record.
Water resources			24-month water supply, 18-month water supply, 12-month water supply. *City of San Angelo water management thresholds.*	The occurrence of 3+ days of 100°F or higher temperatures combined with no precipitation. *Related to water demand.*

In general, there is some overlap between IPCC SREX indicators, NCA indicators, and community-derived temperature and precipitation indicators, such as numbers of days, or consecutive days, with temperatures or precipitation above or below thresholds of interest. We found that the participants in our project are interested in threshold levels more extreme than those typically selected in SREX or NCA analyses, and in a wider range of extremes (e.g., a sequence of extreme temperatures from the 75^{th} through 99.5^{th} percentiles).

The WMO thresholds were the most comprehensive, consistent, and well detailed of the thresholds we evaluated. In the tables, below, we compare WMO temperature and precipitation indicators with community-derived thresholds (Tables 3 & 4). In general, only a few of the stakeholders' concerns matched or were close to the WMO indicators and thresholds. For example, none of our pilot communities identified monthly values or percentages of days above or below a certain threshold as concerns. So, while such values may be important climate diagnostics, they lack connection with impacts, which are a primary motivator for stakeholders.

Table 5: Examples of WMO (World Meteorological Organization; Klein Tank et al. 2009) temperature-based thresholds. T_{max} is daily maximum temperature; T_{min} is daily minimum temperature. ***Bold item*** *indicates direct correspondence between community-derived and WMO thresholds. Italics indicate correspondence between community-derived and WMO indicators, but substantial differences between threshold values. Grey boxes indicate no correspondence between community-derived indicators or thresholds of interest and WMO indicators or thresholds.*

World Meteorological Organization Temperature Thresholds
Number of frost days: Days when T_{min} < 32°F
Number of summer days: Days when T_{max} > 77°F
Number of icing days: Days when T_{max} < 32°F
Number of tropical nights: Days when T_{min} > 68°F
Growing season length
Monthly maximum value of daily T_{max}
Monthly maximum value of daily T_{min}
Monthly minimum value of daily T_{max}
Monthly minimum value of daily T_{min}
Percentage of days when T_{min} < 10^{th} percentile
Percentage of days when T_{max} < 10^{th} percentile
Percentage of days when T_{min} > 90^{th} percentile
Percentage of days when T_{max} > 90^{th} percentile
Warm spell duration index: T_{max} > 90^{th} percentile for at least 6 consecutive days
Cold spell duration index: T_{min} < 10^{th} percentile for at least 6 consecutive days
Daily temperature range: Monthly mean difference between T_{max} and T_{min}

Table 6: Examples of WMO (World Meteorological Organization; Klein Tank et al. 2009) precipitation-based thresholds. ***Bold item*** *indicates direct correspondence between community-derived and WMO thresholds. Italics indicate correspondence between community-derived and WMO indicators, but substantial differences between threshold values. Grey boxes indicate no correspondence between community-derived indicators or thresholds of interest and WMO indicators or thresholds.*

World Meteorological Organization Precipitation Thresholds
Monthly maximum consecutive 5-day precipitation
Simple precipitation intensity index
Annual count of days when precipitation is ≥ 10mm (0.4")
Annual count of days when precipitation is ≥ 20mm (0.8")
Annual count of days when precipitation is ≥ user defined threshold
Maximum length of dry spell
Maximum length of wet spell
Total annual precipitation on wet days (daily precipitation in the top 5% of daily totals)
Total annual precipitation on wet days (daily precipitation in the top 1% of daily totals)
Annual total precipitation in wet days

Table 7: Comparison of single-day temperature and precipitation thresholds identified by the WMO (World Meteorological Organization; Klein Tank et al. 2009) and the four pilot community identified thresholds. Temperatures expressed in degrees Fahrenheit. Unless otherwise noted, precipitation (precip) is expressed in inches per day.

WMO	BOULDER	LAS CRUCES	MIAMI	SAN ANGELO
T_{max} > 77°F	80°, 90°, 95°	90°, 100°, 105°	95°, 100°, 105°	90°, 100°, 105°
T_{max} > 90th percentile	74^{th}, 92^{nd}, 98^{th} percentiles	75^{th}, 97^{th}, 99.9^{th}	93^{rd}, 98^{th}, 99.7^{th}	72^{nd}, 95^{th}, 99.5^{th}
T_{min} > 68°F	75°	80°, 85°	80°	80°
Precip > 0.4", 0.8" per day	2", 4"	2.5"	2.7" in 2 days	2", 4"

C. Threshold Discussion

In the four pilot cities that we investigated, the most important qualitative difference between science-derived and community-derived indicators and threshold values was the emphasis stakeholders placed on impact-related values. Stakeholders selected many thresholds related to recent extreme weather and climate episodes, including heat waves, floods, cold snaps, and droughts. Moreover, in many cases they selected threshold values significantly higher than those used by the WMO, or used in standard analyses in SREX and NCA3. This qualitative difference is important, because it points to events, episodes, and impacts that are infrequent and to which society has not yet successfully adapted. This highlights the value added by investing in place-based stakeholder engagement. ***Our study design cannot definitively state that stakeholders are more invested in, or can make better sense of, climate projections based around the indicators and thresholds they selected; however, we can be certain that impact-based thresholds help stakeholders make the connection between the abstraction of statistics and the visceral memory of impacts experienced by the community.***

For example, pilot community stakeholders were concerned with daily maximum temperature indicators both lower (75% range) and higher (95%+) than the WMO's 90% threshold (Note: all communities had a temperature threshold close to the NCA3 98% exceedance value); shorter time-period extreme heat events (2-3 days) not the 6-day events identified by the WMO; higher nighttime temperatures (75-80°F) than the WMO identified threshold for tropical nights (68°F); cold temperatures related to freezing and hard freeze conditions that were above (in the mid 20% range) the WMO's lower 10% category for cold events; and precipitation events far in excess of the 0.4" or 0.8" daily values used by the WMO.

Another key factor is that stakeholders expressed concern with *(a)* complex combinations of parameters, such as heat and humidity, and *(b)* factors related to indirect impacts, such as fire, road conditions, and so on. These result points to the need for additional climate services, such as place-specific process-based modeling, to address climate-related secondary impacts such as wildfires, floods, and public health risks such as vector-borne diseases. It also highlights the continued need for applied research to make connections between critical climate thresholds and risks.

VI. Resilience Actions

Communities are opportunistic when acting to build community resilience.

In the United States, urban areas are at the forefront of preparing for and adapting to the impacts of climate change (Bierbaum et al. 2013, Vogel et al. 2016). Thus, the resilience action projects selected and completed by our pilot cities are not unique. Cities have been on the front lines of climate change for decades and the issues they face are likely to become more pressing in the years to come.

A variety of organizations and researchers are assessing how best to define a resilient city or community (Vogel et. al., 2016b; CARE, 2013; Arup, 2014), how to identify and measure progress (Arnott, Moser, Goodrich, 2016), and how to define successful adaptation (Moser and Boykoff, 2013). The frameworks for both determining resilience and for identifying progress vary based on who developed them and their intended purpose. The third goal in this project was to support next steps for operationalizing and mainstreaming inclusion of the community specific climate information generated in the project into planning and preparedness.

A. Frameworks and Summary of Selected Actions

There are many frameworks for evaluating actions and determining whether they help a community become more resilient. For this analysis, we chose to focus on the City Resilience Framework (Arup & Rockefeller 2014) because of its inclusion of both social and physical determinants of resilience and how it has been used by the 100 Resilient Cities program and other cities. Three of our pilot cities were funded directly through our collaboration to implement a project specifically designed to address a current and future extreme weather related vulnerability. In Boulder, our collaboration spurred the development of a broader municipal government initiative that was not directly funded by this project. The pilot cities selected the following resilience actions for implementation and, in every case, the city successfully implemented the project.

- ***Boulder, CO –*** Developed and implemented a three-part training program for city employees to foster inter-departmental connections, increase awareness and understanding of climate-related threats and vulnerabilities, and ultimately lead to enhanced buy-in for scenario-based planning efforts. Presentations in the first and second trainings included team members from this project.

- ***Miami, OK –*** Collaboratively developed a lesson on climate thresholds and emergency management and preparedness for eighth-graders at the local middle-school. The lesson was developed by the K20 educational center at the University of Oklahoma, taught over two days, and included the distribution of emergency preparedness bags that included emergency supplies and weather radios.

- ***San Angelo, TX –*** Purchased and installed two new weather-related systems. First, through a collaboration with Texas A&M University's *Water Your Yard* program and with additional funding from the City of San Angelo's Water District, they installed an evapotranspiration weather station to collect, monitor, and distribute weather data and communicate this information to city residents. Second, they installed a rainwater harvesting system in a central park to demonstrate City leadership in preparing for drought, serve as a point of education for the community about water conservation, and further build interdepartmental collaboration.

- ***Las Cruces, NM –*** Installed a rainwater harvesting system at a local community center in a traditionally underserved portion of the community, and worked with the Watershed Management Group in Tucson, AZ to develop a green infrastructure and stormwater management plan for the same underserved community. The strategic plan will not only guide future green infrastructure investment within the community but has already helped secure a $400,000 investment in green infrastructure for that historically underserved portion of the community.

Each of the community actions are plotted below on the City Resilience Framework diagram (Figure 13). The framework identifies four broad categories (Leadership & Strategy, Healthy & Wellbeing, Economy & Society, Infrastructure & Ecosystems), each with three sub-categories, detailing aspects of a community that influence its climate resilience. As shown in Figure 13, each city project addressed more than one resilience area.

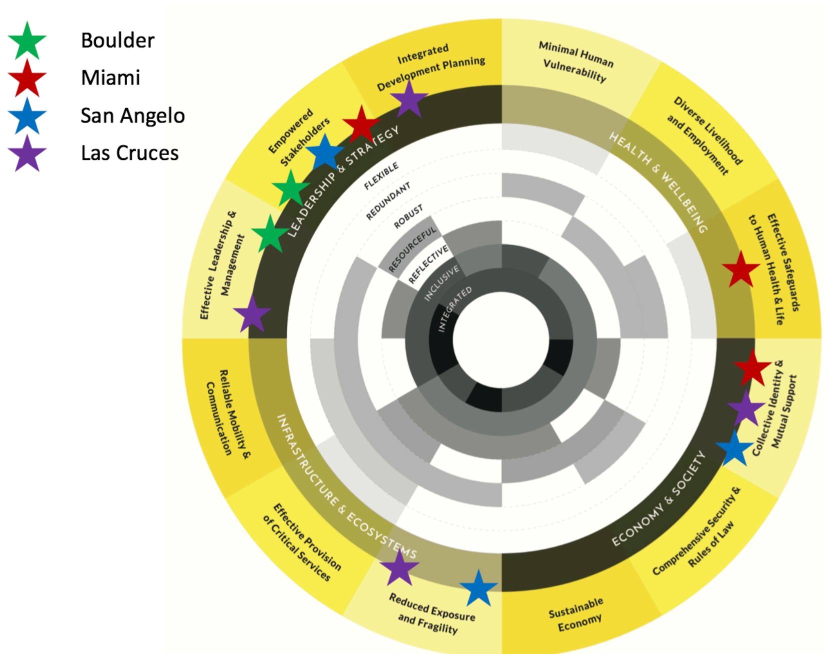

Figure 14: Community resilience action projects overlaid on the City Resilience Framework set of factors contributing to community resilience as defined by the Rockefeller Foundation and Arup (used with permission). Aspects of resilience enhanced by each of the community resilience actions project are show by the colored stars. Green stars are connected to the City of Boulder, CO. Red Stars = Miami, OK; Blue Stars = San Angelo, TX; and Purple Stars = Las Cruces, NM.

B. Findings and Constraints

- ***Resilience action projects choices were limited by project timeframe and available budget.*** The suite of actions selected by the communities for these initial resilience actions is by no means representative of their overriding climate and extreme weather-related challenges or the community's ideal project. As noted in the stakeholder engagement section, lack of funding is a common barrier to implementing adaptation actions, and our pilot communities were no exception. In almost all cases (Boulder is the exception) these mid-sized communities did not have extra budget or staff to devote to the projects beyond what could be directly funded by the project. They were therefore constrained by the $10,000 to $15,000 of funding the project could provide. They were also time-limited; projects needed to be completed before the end of the cities' engagement with the project team (generally 6-10 months from the second shared learning dialogue). These constraints limited the scope and extent of the projects selected. Yet, in two of the four cases, these initial resilience actions opened the door for additional projects and funding.

- ***Project selection was determined by a small group of stakeholders.*** The stakeholders who started and remained engaged throughout the project ultimately helped determine the resilience action project. While this was true in all cases, it was very apparent in Miami and Las Cruces. In Miami, the community champion was the City's emergency manager and she drove the selection of a project to develop and teach a lesson on extreme weather and preparedness to eighth-graders. The lessons included the distribution of emergency preparedness kits ("Go-Bags") and weather radios. In Las Cruces, the sustainability officer chose to focus on installing a rainwater harvesting system at a community center and invest in the development of a green infrastructure plan for a historically underserved neighborhood. These choices were both a reflection of the personal interests of the project champions and of the narrower stakeholder group that participated in the second dialogue where these projects were selected.
- ***Communities were opportunistic in selecting their projects.*** In most cases, the communities chose projects that fit with on-going efforts. In San Angelo, for example, the project choice was based on a combination of pragmatism and political feasibility. The City had a nascent residential rainwater harvesting program already supported by city council that the City was trying to grow. They had also already investigated the potential installation of a larger rainwater harvesting system in a central city park and knew that it could be done within the budget and time constraints for the project. This does not mean that the selected projects did not address climate concerns or build climate resilience, but rather highlights that there are many factors that influence action and whether those actions are initiated and successful.
- ***Each community selected a project that has co-benefits and helps build more than one aspect of resilience.*** Each community selected a project that addressed more than one aspect of resilience (Figure 13). For example, in Las Cruces, the rainwater harvesting project and green infrastructure plan not only reduced physical drought vulnerability in the area near the project, but also helped the City develop a more integrated planning process for infrastructure that addresses an underserved portion of the community. This small project was the catalyst for a $400,000 investment in greener stormwater infrastructure in the community. In San Angelo, the resilience action project initiated a collaboration between the City and Texas A&M University through the *Water Your Yard* program as well as the in-kind maintenance of the station.

VII. Conclusion

A great deal of valuable information was learned through these limited engagements with our four pilot communities, both about the potential value of using community defined thresholds and the nature of adaptation and building resilience in small- and medium-sized communities. Most the lessons can be summarized by the following three findings.

A locally focused approach to identifying extreme weather thresholds was useful as an entry point for discussions about climate change. It helped ground conversations in issues of concern to local decision makers, and put projected climate changes in the context of the historical baseline of extreme events, which are the most noticeable ways in which climate and weather affects stakeholders. The thresholds approach also provided a foundation for presentations and discussions that demystify the perceived black box of complex global climate models and future projections.

Nevertheless, ***most participants were neither prepared nor motivated to think beyond daily to weekly time scales.*** This is perhaps because most participants' job responsibilities are associated with short-term time scales, or because professional standards of planning practice (e.g., civil engineering design standards) do not yet accommodate guidance from climate projections. Further research on these perceptions, or constraints, would be useful to inform future climate change adaptation planning. In addition, we surmise that additional staff time, funding, and development of decision-maker capacity to plan and prioritize on multi-decadal climate time scales would increase the chances for successful co-production of actionable science based on the thresholds concept.

Adaptation in these communities, and likely many others, is opportunistic but still has value and can help build resilience. The resilience action projects selected by the communities were constrained by both time and funding and guided by the sub-set of community champions and stakeholders who remained engaged throughout the project. The selected actions built upon existing community concerns, previous actions, and addressed multiple aspects of resilience. The fact that many participants dropped out between the two shared learning dialogues could be leveraged in future projects to tailor project content and focus the resilience action project discussion. In most cases, the multiple levels of participant engagement and implementation of the resilience action project helped build capacity to address not only current climate and extreme weather-related concerns, but also to begin preparing for the challenges associated with climate change.

VIII. References

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