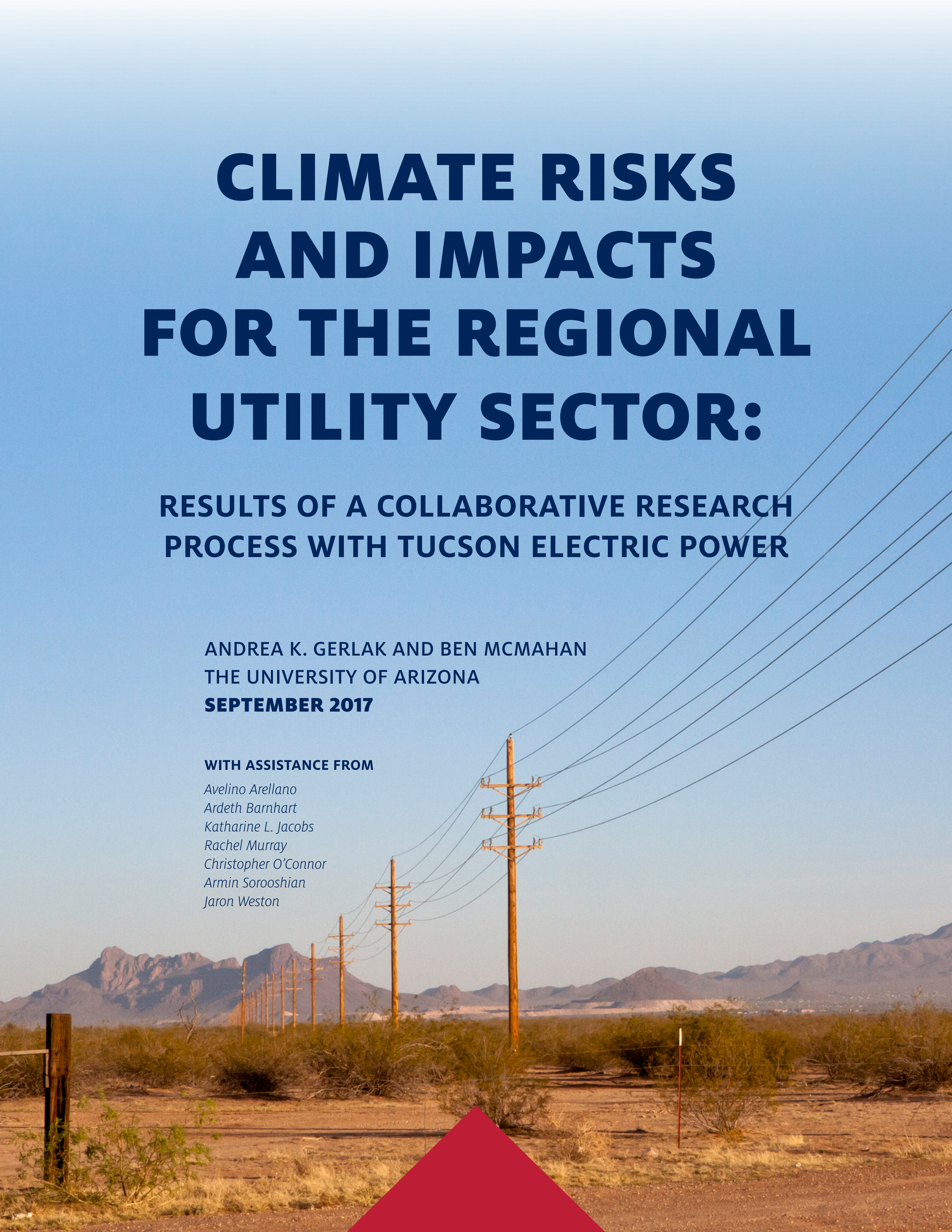

CLIMATE RISKS AND IMPACTS FOR THE REGIONAL UTILITY SECTOR:

RESULTS OF A COLLABORATIVE RESEARCH PROCESS WITH TUCSON ELECTRIC POWER

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Center for **Climate Adaptation Science** and **Solutions**

CLIMAS
Climate Assessment for the Southwest
A NOAA RISA TEAM

LIST OF ACRONYMS

ABRI	Arizona Business Resilience Initiative
ADEQ	Arizona Department of Environmental Quality
ADWR	Arizona Department of Water Resources
AF	Acre Feet
AMA	Active Management Area
CAP	Central Arizona Project
CPP	Clean Power Plan
ENSO	El Niño-Southern Oscillation
EPA	U.S. Environmental Protection Agency
GIS	Geographic Information Systems
INA	Irrigation Non-Expansion Area
IRP	Integrated Resources Plan
LST	Land Surface Temperature
NCA	National Climate Assessment
NERC	North American Electric Reliability Corporation
NOx	Nitrogen Oxides
O_3	Ozone
PNM	Public Service Company of New Mexico
RVS	Rangeland Vegetation Simulator
SRP	Salt River Project
SWCA	Southwest Climate Change Assessment
TEP	Tucson Electric Power
UA	University of Arizona
UHI	Urban Heat Island
VOCs	Volatile Organic Compounds

EXECUTIVE SUMMARY

The Arizona Business Resilience Initiative (ABRI) was launched at the University of Arizona (UA) in 2015 with the aim to develop a methodology to collaborate with business entities to learn from and contribute to ongoing efforts targeted at assessing opportunities and managing risks to their operations, especially those associated with climate change and variability. As an initiative of the Vice President of Research, Kimberly Andrews Espy, ABRI applies university resources and expertise to develop a replicable framework and robust process. It aims to enhance businesses' ability to react and adapt to specific climate risks and also improve the private sector's resilience to anticipated environmental and social changes more generally.

Over an 18-month period, from spring 2015 to winter 2016, researchers at the UA worked in collaboration with partners at Tucson Electric Power (TEP), Tucson's local electrical utility, to develop and pilot an innovative qualitative risk assessment process. Throughout the course of the initiative, more than a dozen researchers at the UA worked to gather, interpret, and synthesize information regarding the current state of the climate in relation to TEP decision-making, and to develop and inform plausible future scenarios for TEP's planning purposes, especially their Integrated Resources Plan (IRP) process.

The ABRI process was focused on climate and environmental risk areas that TEP identified as key concerns for electrical utilities operating in the arid Southwest, where extreme temperatures, drought, and climate variability all affect planning and decision-making. These four risk areas include: Heat, Wildfire, Water, and Air. UA and TEP followed an iterative process characterized by a series of exchanges of knowledge and information regarding risk areas, scope of data, and gaps and needs. The initiative was built upon the collaborative process of co-discovery ignited by an exploration of existing scientific knowledge and TEP experience.

Within the four risk areas, the UA teams worked with TEP to identify their key concerns, data and information that would further aid in decision making and planning, and recommendations for future actions that would help TEP plan for present and future climate and environmental risks. The Heat team focused on the role of a changing climate on peak load and seasonal market demand, as well as wear and longevity of infrastructure. The Wildfire team emphasized the high impact but low probability risks of extreme wildfire (to specific infrastructure), as well as the larger and more general threat that increased fire risk and changing fire seasonality might pose. The Water team focused on the role of drought and water availability, as well as how future energy utility portfolio decisions might (or might not) be subject to competition over water resources. The Air team emphasized regulatory and policy questions about location and concentration of pollutants, and the role that changes to federal regulatory frameworks might play in decision making regarding air quality and the location of generating stations.

Researchers then explored a network of interrelated effects to understand the widest range of possible connections and outcomes that overlap within this system, and have the potential to amplify the cluster specific impacts, especially given current climatic trends. This process of synthesizing risks that span the topical clusters helped identify possible trade-offs between managing and adapting to the four distinct risks, and can be used to plan, understand past events, and anticipate future events. The overlapping management concerns related to interactions between the key risk areas and the management implications for these overlapping concerns for TEP.

The analysis of cascades and network effects reveals the interconnected nature of the four risk areas, and the difficulty of managing these complex relationships. Interventions that target critical pathways in the chain of events, are ideal candidates for intervention, particularly those with increased likelihood of producing negative impacts (e.g. fuel load reduction along major transmission lines, planning for changes to summertime seasonal peak load and regional market demand, or moving away from water intensive coal fired generation that is likely to see additional regulatory limits in the future to renewables and natural gas). By identifying high impact risks within our assessment, and by establishing frameworks wherein additional monitoring and analysis can assess which impacts are most likely – as standalone events, or as part of a chain of events – these analyses of cascades and network effects demonstrate a process by which a holistic assessment framework could be further developed and employed by TEP, or by other Arizona businesses.

Within each of the four risks, we identify recommendations, including recommendations for further research as well as recommended risk mitigation and adaptation actions.

INTRODUCTION

Arizona has experienced significant environmental, economic, and demographic changes over the last fifty years, including major changes to its water supply and demand, forest loss due to insect outbreaks and wildfires of record size, and a drier, warmer climate. The 2013 climate change assessment for the Southwest United States predicts that warming will continue and precipitation will decline in the mid- to late-twenty-first century, with longer and hotter heat waves and reduction in mountain snowpack leading to reductions in runoff, streamflow and soil moisture for vast swaths of the Southwest (Theobold et al., 2013) (See Figure 1). The increase in evaporation from soil and organic material and decrease in precipitation results in massive amounts of dry fuels, particularly in the sky islands bioregions, aiding the spread of wildfire. In addition, increased lightning strikes from warmer air cause many of the most devastating fire events.

It is also expected that drought, as defined by Colorado River flow will become more frequent, more intense, and more prolonged, resulting in water deficits in excess of those during the last 110 years (Theobold et al., 2013). This prolonged drought, along with reductions in groundwater recharge, will affect electricity generation in the region. Most electricity generating plants in the western United States, need a constant flow of cooling water to regulate their internal temperatures and prevent overheating. Utility plans for capacity expansion could, under some scenarios, require so much cooling water that they will worsen summer water shortages in the region (Sovacool and Sovacool, 2009).

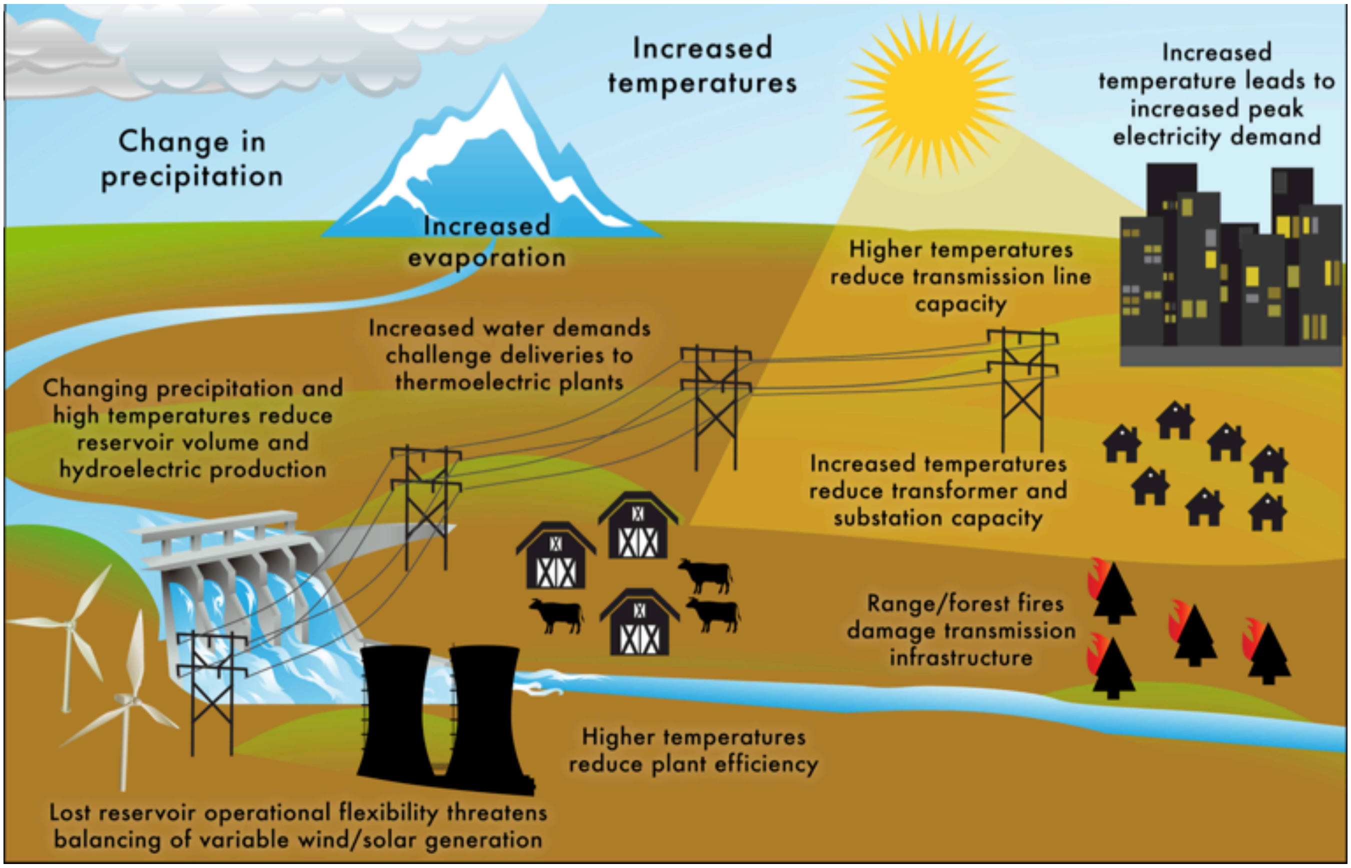


Figure 1. Cascading impacts of drought and climate in the West

Trends in climate, along with seasonal, interannual, and decadal variability (e.g., drought, flooding, etc.), impose cascading and interrelated impacts across multiple sectors (e.g. business, transportation, energy, infrastructure, etc.). In their technical report to the U.S. Department of Energy, Pacific Northwest National Laboratories emphasized the implications of the interdependency of energy systems, water systems, and land resources—and the compounding effect of climate change impacts across these sectors on energy reliability in the Southwest (Skaggs, 2012) (See Figure 2). Utilities are experienced with managing risk, but they face new challenges in anticipating the individual components of risk posed by climate change. Cascading effects further complicate planning efforts, as they are linked to future climate-related impacts, and associated changes in water availability, more severe and sustained heat waves, and higher drought and flood risks. In response to these trends, the Arizona Business Resilience Initiative (ABRI) was launched at the University of Arizona (UA) in 2015 with the aim to develop a methodology to collaborate with business entities to learn from and contribute to ongoing efforts targeted at assessing opportunities and managing risks to their operations, especially those associated with climate change and climate variability. In applying university resources and expertise to develop a replicable framework and robust process, ABRI promises to significantly enhance businesses' ability to react and respond to specific climate risks and also improve the private sector's resilience to anticipated environmental and social changes more generally.

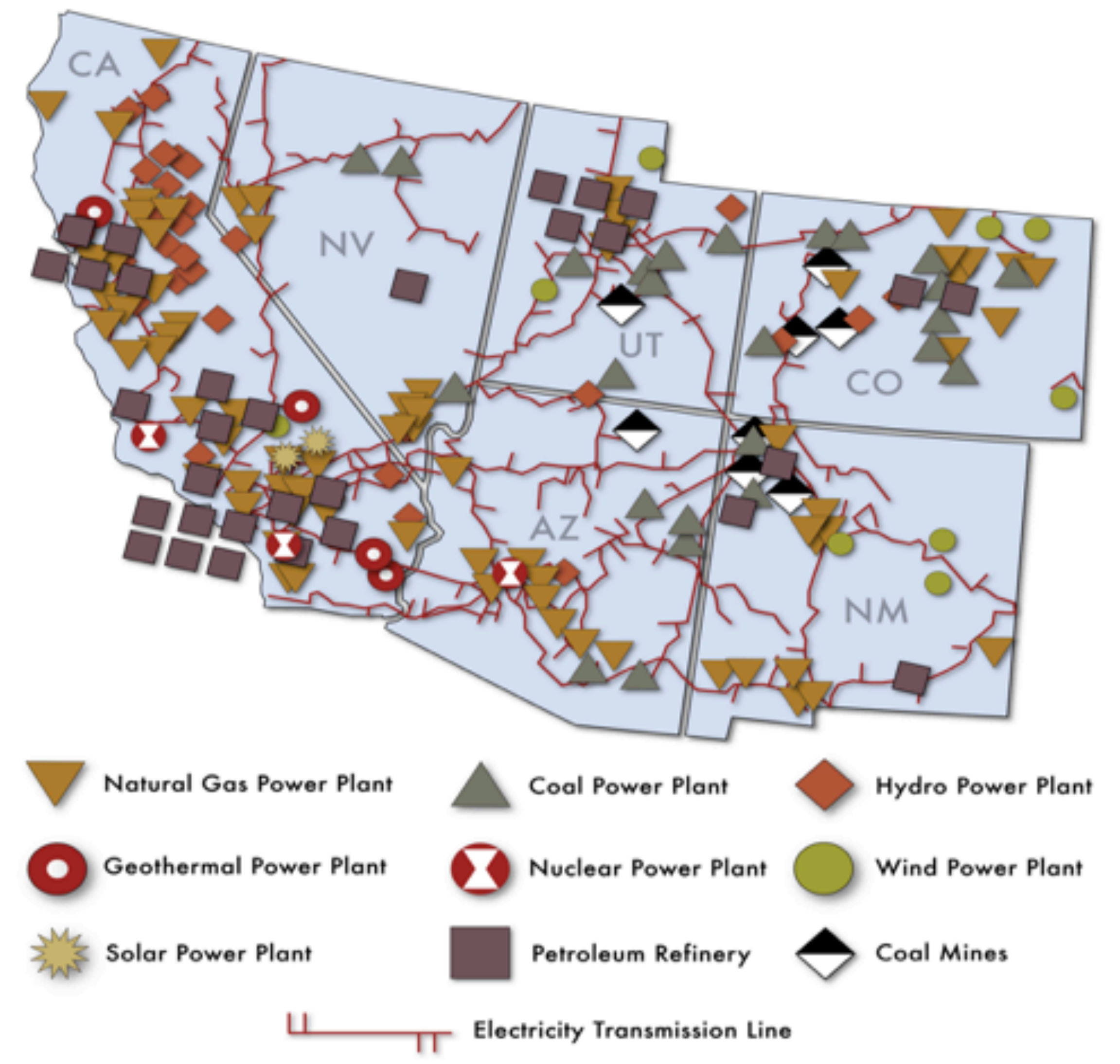


Figure 2. Energy distribution networks in the Southwest

Adaptation planning for climate change often applies tools and methods from risk management (Willows and Connell, 2003). Climate risk management can be seen as a process that incorporates "knowledge and information about climate-related events, trends, forecasts and projections into decision-making to increase or maintain benefits and reduce potential harm or losses" (Travis and Bates, 2014: 1). It can serve as an effective framework for assessing adaptation by underscoring the likelihood and implications of potential climate change impacts that adaptation actions are seeking to address (Jones and Preston, 2011). Focusing on risk requires organizations to identify specific climate change-related threats, hazards, and potential impacts as a starting point for developing adaptation measures. Adaptation planning addresses questions such as: Can we ascertain how future climatic and non-climatic conditions will differ from those of the past? Are the expected changes pertinent to current decisions? How will future conditions alter our current planning horizons? Adaptation planning is about making recommendations about who should do less, more, or differently, and with which resources (Fussell, 2007). Iterative assessments that combine scientific and stakeholder knowledge and insight to explore the 'what-ifs' enable decision-makers to test ideas and understand the complex issues entangled in climate risk management and adaptation (Harrison, 2013). These assessments allow stakeholders to develop strategies and actions in the face of deep uncertainty and and/or incomplete climate risk information.

A UNIVERSITY-BUSINESS PARTNERSHIP

ENGAGEMENT WITH TUCSON ELECTRIC POWER

For ABRI's inaugural project, UA partnered with Tucson Electric Power (TEP), Tucson's local electrical utility (See Figures 3 and 4). This partnership between the university and utility built on earlier positive engagements between the UA and TEP, and responds to the changing environmental and policy conditions for TEP. This was the first partnership for TEP focusing on climate risk management. Prior to this, TEP's primary focus had been on managing environmental risks (including heat extremes, weather events, and other sources of risk), without specific planning targeted at climate change. TEP was broadly aware of the general implications for a changing Southwestern climate, including increased temperatures, extreme heat events, and increased variability of precipitation, owing to relatively high visibility efforts such as the National Climate Assessment (NCA). These efforts present information at regional to global scales, and the information produced and circulated within the context of the NCA was detailed or locally focused enough for TEP to contextualize local climate trends. TEP was aware of the potential risks associated with climate variability and climate change, and they were interested in expanding their risk management activities to encompass these concerns. They did, however, lack access to specific operational information and data that could inform practices or implement changes to climate risk management policies.

Figure 3. Tucson Electric Power (TEP) generation/transmission network

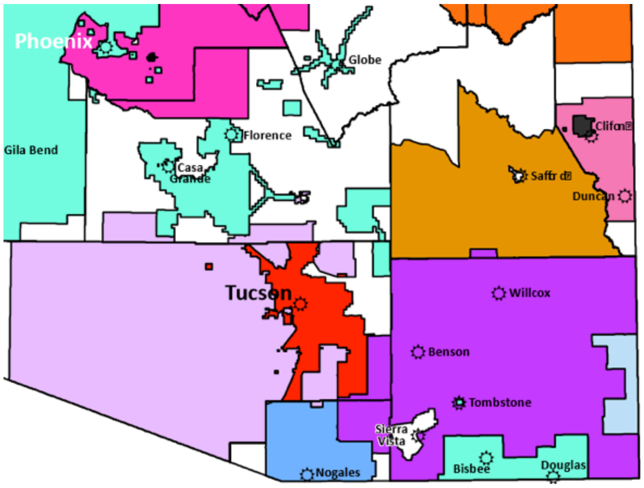


Figure 4. Southwest Arizona service areas, 2017 (TEP service area in red)

CONTEXT AND BACKGROUND

TEP is increasingly finding it necessary to plan for and respond to environmental, legislative, and economic factors related to climate change. Severe drought conditions and extreme heat waves in the Southwest are major factors guiding the behavior of the electrical utility industry. High ambient temperatures decrease efficiency and capacity, and limit the cooling ability of air-cooled systems. High temperatures also reduce the efficiency and outputs of photovoltaic units, lower the thermal limits of transmission lines and circuit breakers, increase transmission loss and operational cost, and lower throughputs of transformers (US DOE, 2012). Long-term increased temperatures and decreased water availability drive simultaneous increases in energy and water demands, while reducing efficiency and capacity in the energy system. The increasing intensity and frequency of heatwaves and droughts, as well as shifts in water supply reduce the ability of electric utilities, like TEP, to respond during peak periods of energy demand. Additionally, climate-related extremes result in increased service interruptions and increased risk of costly cascading electricity failures (Skaggs et al., 2012).

On the policy front, TEP is affected by broader national efforts to reduce air pollution and greenhouse gas emissions. In 2012, President Obama acted administratively to link energy and the environment, with the Clean Power Plan (CPP). Through shared federal-state regulatory responsibilities, the CPP requires state-based plans that will significantly reduce greenhouse gas emissions, particularly carbon dioxide, from existing fossil-fuel electric generating units (Tomain, 2016). Consistent with the overall design of the Clean Air Act, the legal source of the U.S. Environmental Protection Agency's (EPA) authority to regulate in this arena, the EPA was establishing carbon dioxide reduction goals for states. States have leeway to craft compliance plans but must meet EPA's 2030 target for emission reductions and continue to do so from that point forward (Tomain, 2016). The CPP presents potential opportunities as traditionally structured utilities reorient their business practices, specifically, these new regulations can encourage: (1) technological innovation; (2) investments in renewable resources and energy efficiency; and (3) grid improvement and modernization (Tomain, 2016).

In response to this policy/regulatory development, TEP, along with many other utilities across the United States, have begun to explore how they could adjust their energy portfolio strategy to respond to regulatory elements embedded within the EPA's CPP. At the same time, many energy portfolio decisions are informed by market conditions as much as regulatory contexts, and the relatively inexpensive price of natural gas has further pushed regional utilities away from coal powered electricity generation in some contexts.

On the national front, in March 2017, the Trump Administration issued an executive order terminating the CPP with the goal of eliminating the regulation of greenhouse gases. This action creates significant uncertainty for the electrical utility industry (Timmer, 2017) but many western states are continuing to make plans to reduce greenhouse gas emissions despite the present lack of a federal mandate. Each state has its own patchwork of regulations. Some states appear to thoroughly embrace the need to develop clean energy resources, in some cases expressly in response to climate change imperatives. Other states have protected utilities' reliance on traditional energy sources and structures (Murphy, 2017). The result of this regulatory upheaval, as well as such factors as regional variations in energy source availability, is that no uniform transition strategy is appropriate for all utilities (Murphy, 2017). California will continue to drive action to mitigate climate change in the region. The state uses 40% of the West's electricity, and has the most ambitious renewable energy mandate—50% by 2030. Additionally, California's electricity sector is part of a cap-and-trade program that aims to reduce greenhouse gas emissions to 1990 levels by 2020 with a further 40% reduction by 2030 (Shogren, 2017). Other Western states also have renewable energy mandates such as Colorado's requirement that investor-owned utilities get 30% of their electricity from renewables by 2020. New Mexico has mandated that 20% of electricity be renewable by 2020, and Washington now has the requirement that 15% be renewable by 2020 (Shogren, 2017). Of the western states, Arizona has the least stringent renewable energy mandate at 15% by 2025.

In Arizona, the 2019 closure of the Navajo Generation plant exemplifies the transition of electricity utilities away from coal generation due to market forces (A.P., 2017). The plant was built in the early 1970s as part of a federal project to pump Colorado River water more than 300 miles along a canal south to Phoenix and Tucson; today the 2,250-megawatt plant, owned jointly between the federal government and four utilities (including TEP), is no longer cost-effective compared with other power resources, primarily natural gas. The plant will continue to operate for the next two years to provide an opportunity for economic and infrastructural transition in an area where there are no ready substitutes for power plant jobs, over 90% of which belong to Native Americans (Beeler, 2017). The U.S. Bureau of Reclamation however, part owner of the plant, has been facilitating the negotiations to keep the plant open for the next two years in the hopes of buying time to find new owners to keep the more expensive coal power facility running until at least 2030, an effort being co-led by Peabody Energy, owner of the nearby Kayenta mine that is the sole supplier of the generating station's coal (Beeler, 2017). If the tribal government, federal government, and Peabody Energy cannot find a new owner, the Navajo Nation legislation will identify several pieces of the power plant infrastructure that the Nation will keep operating when the plant closes in 2019, including access to power lines that would allow for solar or wind projects on the reservation to get their power to the market (Randazzo, 2017).

In April 2017, TEP filed its own Integrated Resources Plan (IRP) with the Arizona Corporation Commission (ACC), setting a goal of sourcing 30% of its electricity from renewable resources by 2030 (See Figures 5 and 6). While retiring and replacing some coal-generating facilities, TEP also plans to invest more heavily in energy storage, energy efficiency measures and advanced natural gas technologies (Daily Energy Insider Reports, 2017) and considering the economic benefits of participating in the California Independent System Operator energy imbalance market, which can "create market opportunity for balancing loads and resources given the intermittent characteristics of wind and solar resources" (Walton, 2017). Recently, TEP completed three energy storage projects with a total capacity of 22MW. The successful implementation of TEP's 2017 energy plan will allow the utility to retire up to 508MW of coal-fired energy generation by 2022 (Metering and Smart Energy International, 2017).

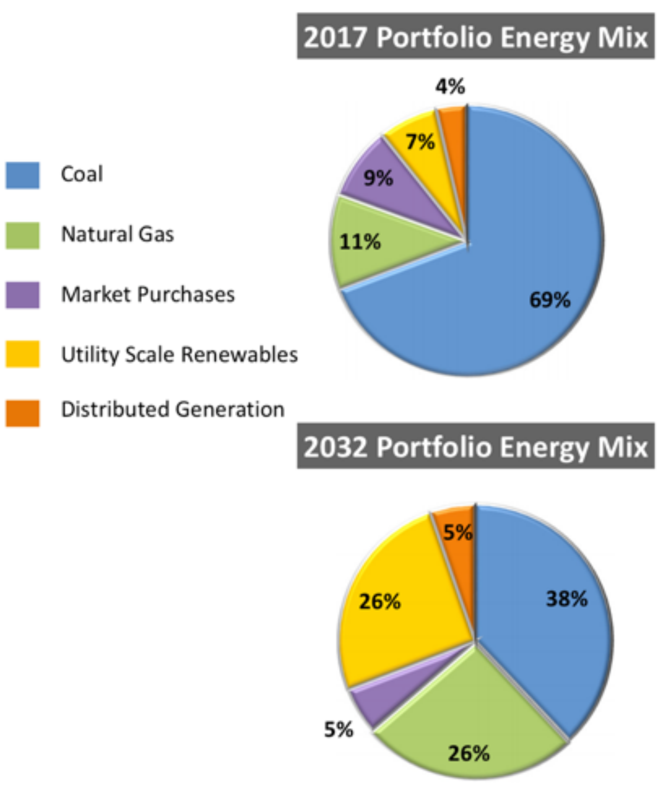


Figure 5. TEP Resource Portfolio (2017 TEP IRP)

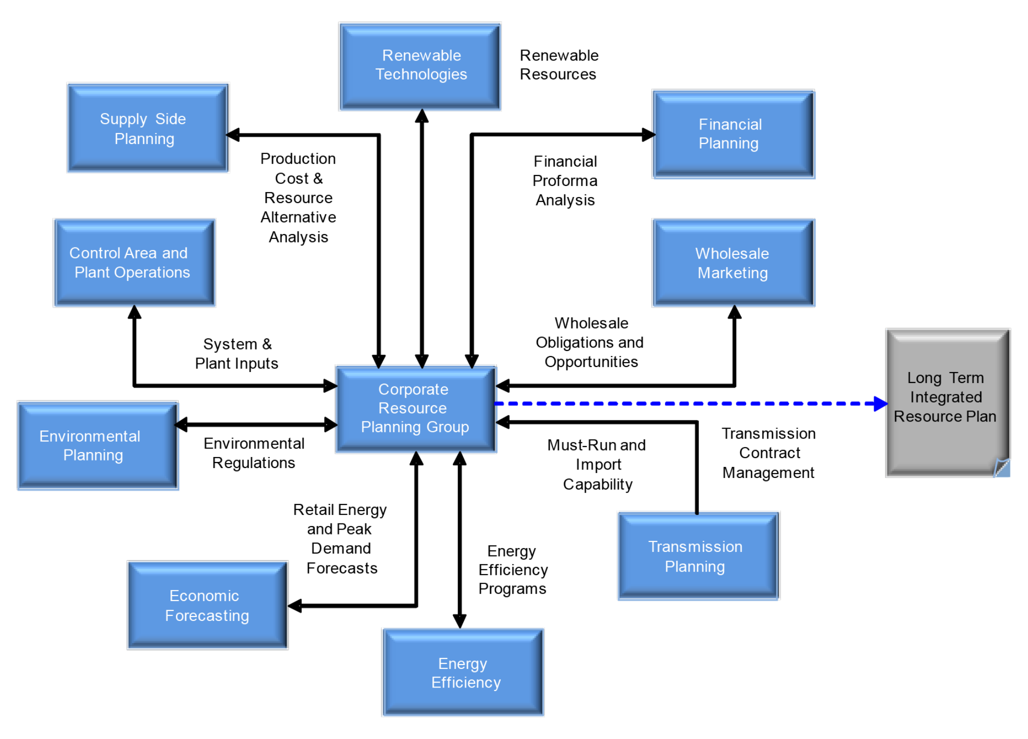


Figure 6. TEP Corporate Resource Planning Group

PROJECT GOALS AND OBJECTIVES

The ABRI effort is a collaborative approach to climate services. Climate services involve the generation, provision, and contextualization of information and knowledge derived from climate research for decision-making at all levels of society (Vaughan and Dessai, 2014). Climate services are designed to offer tools and products to help users anticipate and address the immediate, intensifying and potentially dangerous impacts of climate variability and change, and have the potential to contribute to human security by enhancing societal benefits and reducing losses, related to climate (Adams et al., 2015). ABRI embraces a collaborative mode of climate services by involving stakeholder (TEP) input to identify the climatic and environmental risk areas of key concern for electrical utilities in the Southwest, as well as the values and constraints that influence their decision-making (Meadow et al., 2015).

From spring 2015 through winter 2016, researchers at the UA worked in collaboration with partners at TEP to develop and pilot an innovative qualitative risk assessment process. The core UA project team was composed of Andrea K. Gerlak, Ardeth Barnhart, Ben McMahan, Jaron Weston, and Sam Chambers. The team worked to connect expertise at UA with TEP to gather and summarize information regarding the current state of the climate in relation to TEP decision- making and to develop and inform plausible future scenarios for planning purposes. Technical support was provided by the Climate Assessment for the Southwest and the Center for Climate Adaptation Science and Solutions.

The ABRI process was focused on climate and environmental risk areas that TEP identified as key concerns for electrical utilities operating in the arid Southwest, where extreme temperatures, drought, and climate variability all affect planning and decision-making. The process was designed to identify and prioritize areas where additional climate information and environmental data would be most useful, and to develop targeted information, cutting edge applications and decision support tools that could assist TEP in making critical management decisions, and contribute to their IRP.

THE ABRI PROCESS

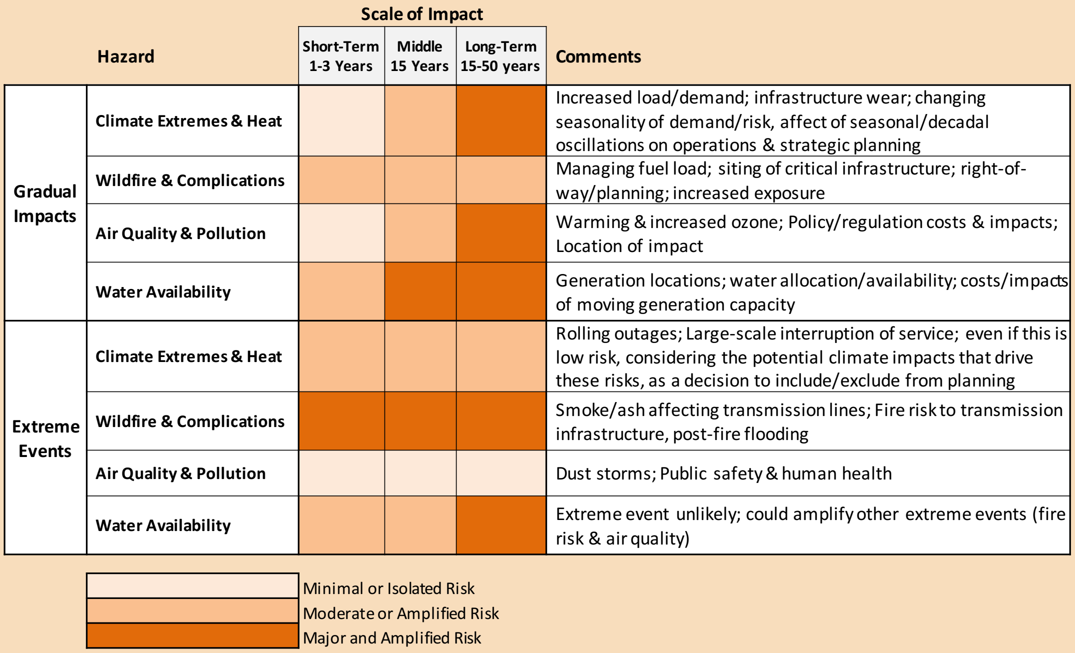
The UA core project team conducted an initial scoping analysis and preliminary assessment to summarize key concerns that might be relevant to TEP regarding specific features of the climate of the Southwest, as well as the general relevance of climate risk management to TEP operations. Following initial presentations and summaries by the UA core project team around a few key subject areas, including climate risk management for business and the state of the climate in the Southwest, the project proceeded in four phases.

1st Phase: Identifying Climate Risks

April 2015 – July 2015

The UA core project team engaged in a sustained dialogue with TEP personnel to better understand how TEP thinks about climate risks, including vulnerabilities and opportunities. This process included a set of meetings where ABRI project team members presented initial results from preliminary assessments and scoping, and solicited feedback from TEP regarding their key concerns about the state of the present and future climate of the Southwest, as well as the values that shape and influence TEP's decision-making priorities. This included an examination of the types of data and information TEP currently relies upon, other data sources they felt would contribute to their decision-making process, and priority areas where they felt they would benefit from additional or more detailed information. This discussion also included TEP providing additional information to the ABRI core team regarding planning processes at the utility, and the temporal scales that dictated how they develop their decision-making process. Through a process of co-discovery, building from existing scientific knowledge and TEP experience, four climate risk areas were identified. These include: (1) Heat; (2) Wildfire; (3) Water; and (4) Air.

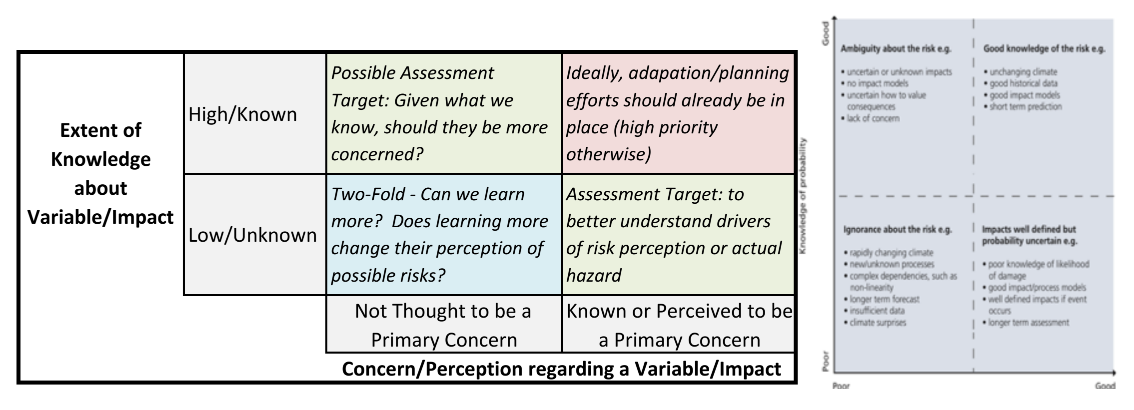
The risks areas were initially assessed and summarized on the basis of a matrix that was designed to facilitate ongoing discussions between the UA core project team, the UA science teams, and TEP to conceptualize the intensity and timing of the various risks, and to further assess the ways that these risks might affect planning and policy on a number of timescales (See Figure 7. Table 1 represents the final version co-produced with TEP). This matrix was a modification of a standard risk assessment process that categorizes potential risks on the basis of their probability and their severity (cf. knowledge of probability vs. consequence, See Figure 8). The UA team used a modified version of this matrix to identify risk areas based on how much information was known about the risk, and the perceived intensity of the risk.



	Hazard	Scale of Impact			Comments
		Short-Term 1-3 Years	Middle 15 Years	Long-Term 15-50 years	
Gradual Impacts	Climate Extremes & Heat	░	▒	▓	Increased load/demand; infrastructure wear; changing seasonality of demand/risk, affect of seasonal/decadal oscillations on operations & strategic planning
	Wildfire & Complications	▒	▒	▒	Managing fuel load; siting of critical infrastructure; right-of-way/planning; increased exposure
	Air Quality & Pollution	░	▒	▓	Warming & increased ozone; Policy/regulation costs & impacts; Location of impact
	Water Availability	▒	▓	▓	Generation locations; water allocation/availability; costs/impacts of moving generation capacity
Extreme Events	Climate Extremes & Heat	▒	▒	▒	Rolling outages; Large-scale interruption of service; even if this is low risk, considering the potential climate impacts that drive these risks, as a decision to include/exclude from planning
	Wildfire & Complications	▓	▓	▓	Smoke/ash affecting transmission lines; Fire risk to transmission infrastructure, post-fire flooding
	Air Quality & Pollution	░	░	░	Dust storms; Public safety & human health
	Water Availability	▒	▒	▓	Extreme event unlikely; could amplify other extreme events (fire risk & air quality)

░	Minimal or Isolated Risk
▒	Moderate or Amplified Risk
▓	Major and Amplified Risk

Figure 7. Risk and scale of impact matrix



Extent of Knowledge about Variable/Impact	High/Known	*Possible Assessment Target: Given what we know, should they be more concerned?*	*Ideally, adapation/planning efforts should already be in place (high priority otherwise)*
	Low/Unknown	*Two-Fold - Can we learn more? Does learning more change their perception of possible risks?*	*Assessment Target: to better understand drivers of risk perception or actual hazard*
		Not Thought to be a Primary Concern	Known or Perceived to be a Primary Concern
		Concern/Perception regarding a Variable/Impact	

Figure 8. ABRI project – Risk vs. impact assessment framework

2nd Phase: Assembling Science Teams

July 2015 – September 2015

After identifying the four climate risk areas, the UA core project team reached out to colleagues within the UA research network to identify potential collaborators who possessed expertise in one of the prioritized risk areas. In an initial planning meeting, the UA core project team introduced the project background and motivation, discussed the project framework and reviewing scoping work conducted up to that point. The outcome of this meeting was to identify key collaborators who were interested in making a contribution to this project.

The UA core project team then assembled four science teams that corresponded with the identified risk areas (See Box 1). The UA core project team facilitated and worked with each team to develop team-specific processes for assembling data and information that would be relevant to TEP by providing baseline assessments of risks, data, and information that could inform these risks, and to further refine these assessments based on input from TEP. The ABRI core team initially revised their assessment information to incorporate TEP priorities expressed during scoping meetings, and also worked in collaboration with the UA science teams to identify unknown or emergent risks based on 1) the current state of knowledge for each risk area; 2) the values and priorities as expressed by TEP; and 3) any unknown or emergent information and data that would alter how TEP assessed or perceived a given risk. As the project evolved, a new area of work around Geospatial Tools began, headed by Sam Chambers at UA.

BOX 1. UA SCIENCE TEAM MEMBERS BY RISK AREA

Heat: *Mike Crimmins, Ben McMahan, Kerrie Geil*

Wildfire: *Kit O'Connor, Cori Dolan, Jaron Weston*

Water: *Andrea Gerlak, Kathy Jacobs, Kiyomi Morino*

Air: *Avelino Arellano, Ardeth Barnhart, Armin Sorooshian*

3rd Phase: Assessing and Prioritizing Climate Risks

September 2015 – February 2016

At first, the four UA science teams worked independently to assess and prioritize key climate risks for TEP, specific to each of their subject areas, as well as those risk areas that might exhibit some topical overlap with other risk areas (e.g. wildfire and air, heat and water). The teams identified primary areas of concern where current data and information was available to inform the initial concerns expressed by TEP. The teams also identified primary areas of impact where these climate/environmental features were likely to affect TEP planning and decision-making. This phase of the project led to an iterative process wherein each science team engaged in a series of knowledge and information exchanges with TEP collaborators, regarding risk areas, scope of data, and gaps and needs. The initiative was built upon the collaborative process of co-discovery ignited by an exploration of existing scientific knowledge and TEP experience. The UA core project team then worked to document these overarching concerns and the links between the UA science teams, both to inform a discussion of cascading impacts – the 'network of overlapping effects', as well as to develop a procedural framework that could be replicated with other utilities in the Southwest, or other businesses in Arizona (See Figure 9).

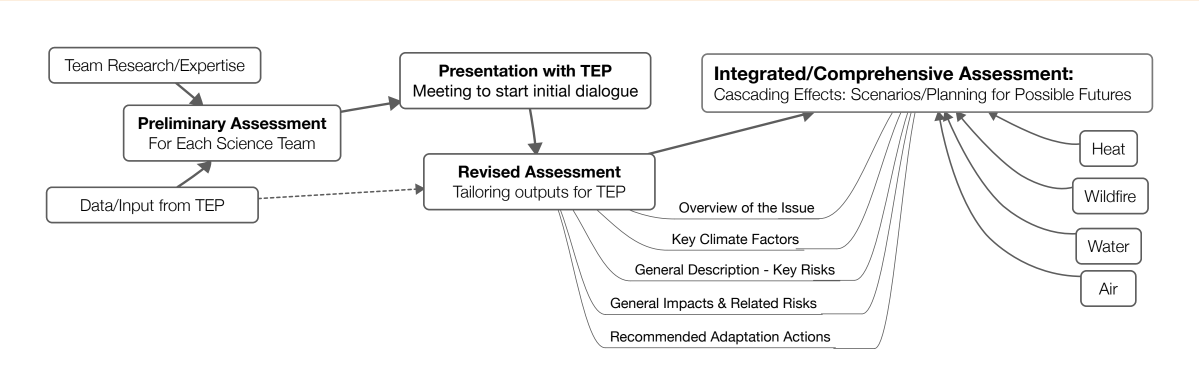


Figure 9. ABRI project framework and iterative process

4th Phase: Synthesizing Interactions across the Network of Interrelated Climate Risks and Effects

March 2016 – December 2016

Following the development of team-specific interactions, the UA core project team facilitated interaction and engagement between the four science teams, kicked off by a cascading effects workshop, and culminating in summary interim reports from each science team detailing the team specific context, identified concerns, and emergent priorities. The UA core project team worked with the four UA science teams to synthesize the key risks and to identify important connections that spanned across the risk areas. This network of connected impacts represents a wide range of possible connections that overlap within this system, and has the potential to amplify the cluster specific impacts, especially given current climatic trends. The process of synthesizing risks that span the topical clusters helped identify possible trade-offs between managing and adapting to the four distinct risks, and can be used to understand past events and plan for future events.

In the final phase of the project, the UA core project team worked to identify the cluster specific risks that are being managed by TEP and new climate information or models that could further contribute to these decision-making processes. Additionally, the overlapping management concerns related to interactions between the key risk areas and the management implications for these overlapping concerns, based on the contributions of TEP, the UA science teams, and the UA core project team, were examined.

HEAT

BACKGROUND RISK PROFILE

In the Southwest, the warm season is characterized by sustained high temperatures starting in the spring, continuing through the summer, and extending well into fall. Seasonal heat is punctuated by extreme heat wave events that most commonly occur in the early summer before monsoon precipitation and increased moisture cools off the otherwise arid Southwest. Sustained high temperatures are a well-known feature of Southwestern climatology. Therefore, electrical utilities are managed and energy production systems and distribution networks are designed and engineered with the expected extremes of the regional climate in mind. Utilities plan for increased demand associated with summertime heat and increased utility load and extended utility demand (tied to increased use of interior climate control). They assess daily peak load and seasonal load/demand in order to incorporate plausible scenarios for daily and seasonal patterns into long-term projections and seasonal forecasting. Extreme heat poses an additional challenge, as heat waves can cause spikes in demand that increase pressure on regional energy supply/markets, and can affect the efficiency and stability of regional distribution systems. These events can also cause additional complications if the electrical distribution network fails causing either a local outage or regional blackout.

Energy production and distribution systems are generally designed with current and near future climate conditions in mind, but the role of long term climate forecasts and outlooks in design is less well defined. This is partly due to the lack of precise climate change models and information that match the scale and timeframe required for planning by regional utilities. There is widespread scientific consensus that Arizona will see gradual warming in the coming decades, but most of the information and data products are produced at regional or national scales. For example, the National Climate Assessment (Melilo et al., 2014) and the Southwest Climate Change Assessment (SWCA) (Garfin et al., 2014) identified a number of likely outcomes, including: 1) gradual warming of baseline (daily and monthly average) temperatures for the entire calendar year; 2) increased frequency and intensity of heat waves during the warm season; and 3) increased duration of the warm season, including longer summers and shorter winters, as the higher temperatures of summer extend into late spring and early fall (See Figure 10 for projected changes in average temperature as compared to 1971-1999 and Figure 11 for the summertime Heat Wave Index).

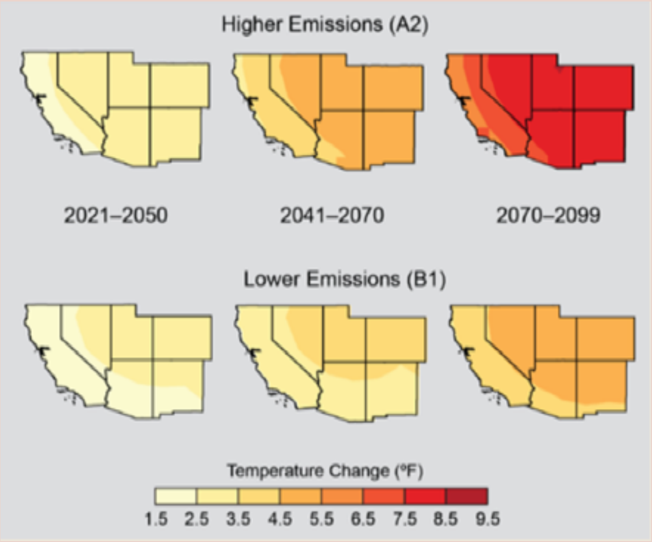


Figure 10. Projected changes in average temperature

Note: The top row shows projections assuming heat-trapping gas emissions continue to rise (A2). The bottom row shows projections assuming substantial reductions in emissions (B1).

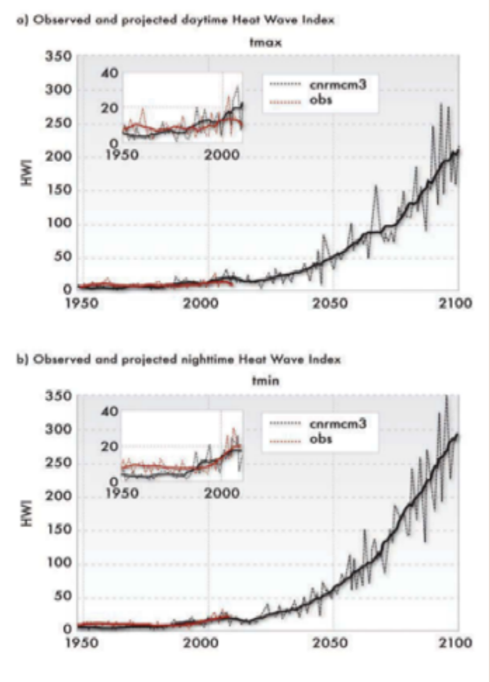
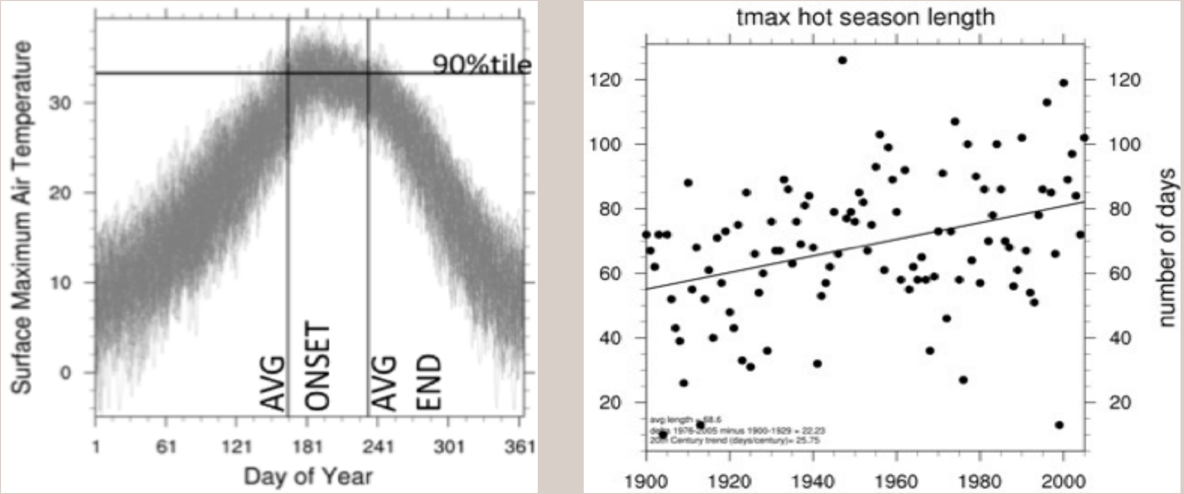


Figure 11. The summertime (May-September) Heat Wave Index (HWI) for maximum temperatures (Tmax) (a) and minimum temperatures (Tmin) (b) for the Southwest region

In addition to warming trends highlighted by the NCA and SWCA, observational data in the Southwest demonstrates that there is an increased duration of summertime temperatures, a trend that is all but certain to continue in the 21st century. This will bring longer periods of elevated temperatures that start sooner in the spring and last later into fall. Over the 20th century, the warm season grew by 18 to 26 days in length, with 15 to 17 more "hot" days. This suggests that while future temperature extremes are a key part of long-term planning for regional utilities, the changing seasonality of the Southwest, and in particularly the elongation of the summer/warm season, is another key issue for regional utilities to address in their planning. Put simply, under climate change, the extremes are expected to become more extreme. It is likely that there will be more extreme/heat wave events, and the period of "normal" summer heat will also expand (See Figure 12 for the daytime versus nighttime Heat Wave Index).



	ONSET (days/century)	END (days/century)	LENGTH (days/century)	NUM HOT DAYS (days/century)
TMAX	-12.79	+12.95	+25.75	+14.09
TMIN	-8.57	+9.65	+18.21	+16.75

Figure 12. Change in hot season onset/end

Climatologically, June is the warmest month of the year in southern Arizona. Looking at the last two years for Arizona, the state set temperature records in June of 2016 and 2017, with extreme heat wave events that started on June 19 in both years. The 2017 event lasted longer, but these events illustrate the way that expected conditions (i.e. the normal summer temperatures in June) have been amplified by extreme/record warm conditions. Climate projections indicate that these kind of heat waves are likely to occur in the future, and are more likely to be increasingly extreme in nature (See Figure 13 for this data from 2016 and 2017).

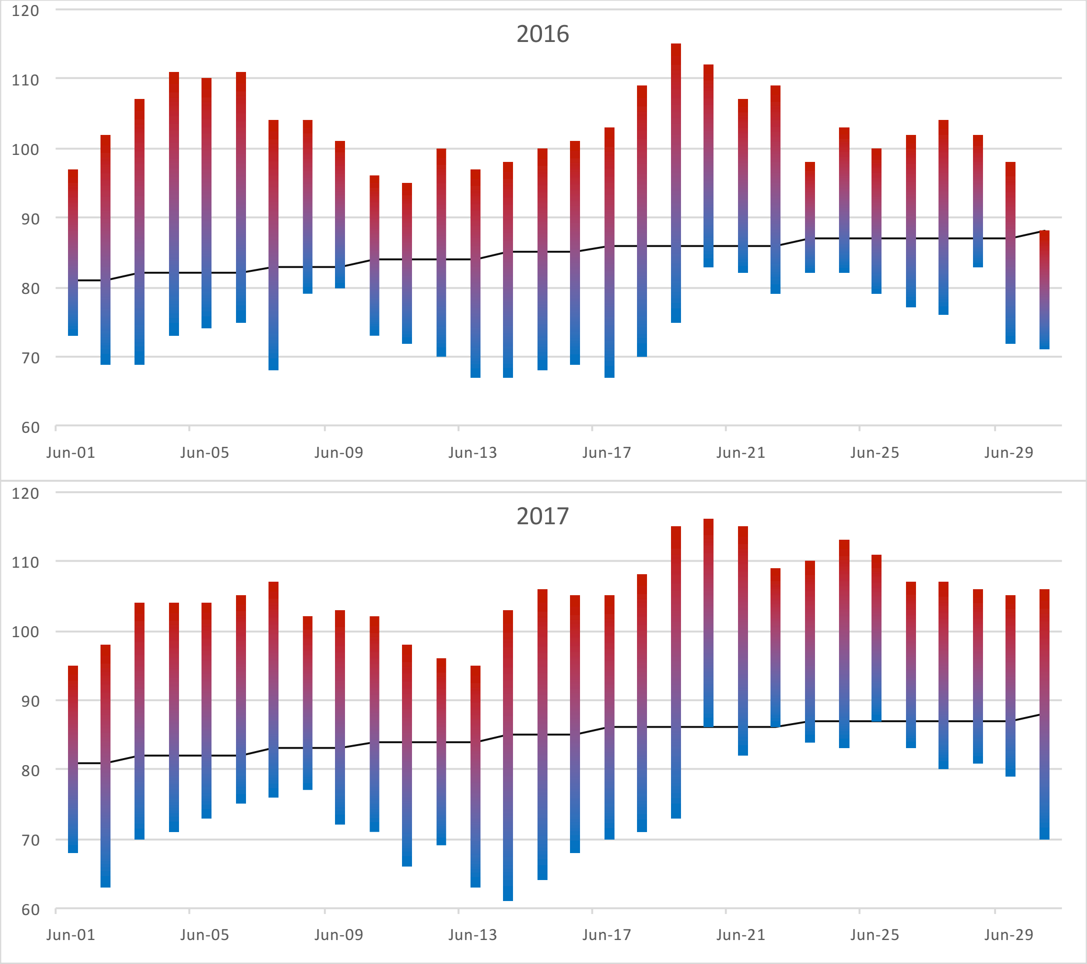


Figure 13. June daily temperature range vs. average temperatures in Arizona for 2016 and 2017

The changing energy demand in Arizona is also shaping how climate change risks are manifesting. The "old" model of summer load curve (See the left panel of Figure 14) is changing. The prevalence of solar electricity generation is actually creating a new shape to the summer load curve (sometimes called a "duck curve" (Denholm, 2013)– where the demand or "load" actually drops off as the sun comes up, when under the old system load is a steady increase until use peaks (See Figure 15). However, now the peak is later and lower (unless something interferes with solar production) so the risks and opportunities have changed. Another issue related to heat and gradual warming, is the role that urban heat islands will play going forward (See Figure 16).

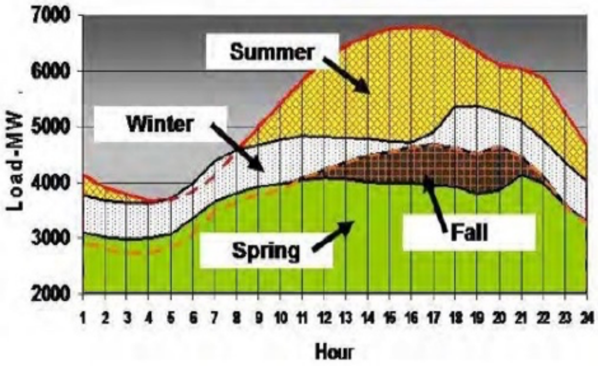


Figure 14. Seasonal Load Curves

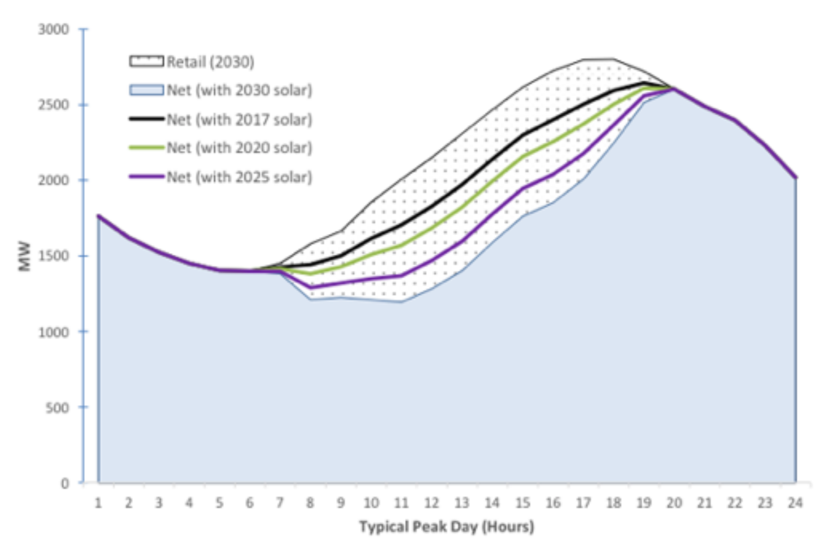


Figure 15. Forecast summer day load profile – influence of solar generation

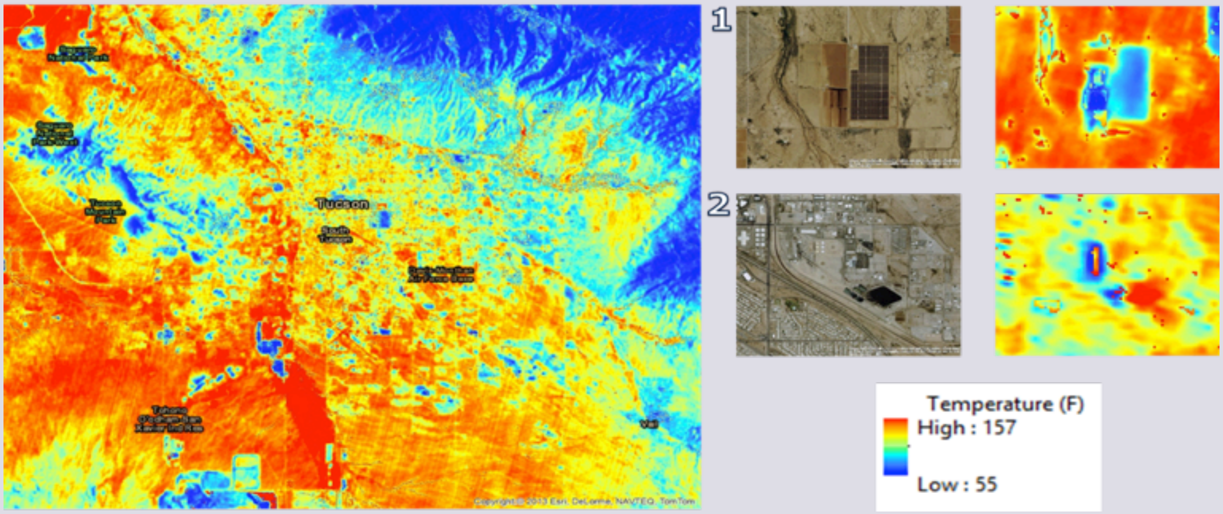


Figure 16. Sample output of Heat Tool showing temperatures ranging from 55 to 157 F in Tucson, AZ and 1) a series of solar panels and 2) a power facility

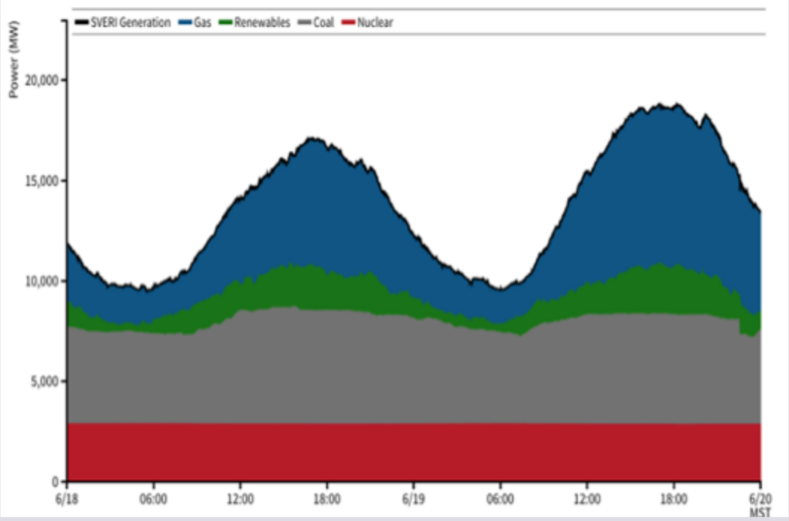


Figure 17. Generation by fuel type

PRIMARY AREAS OF CONCERN

(1) Heat Waves – Extreme Heat

Heat wave events and sustained extreme temperatures affect demand on regional energy production and distribution systems, including the market availability and price of energy during times of high regional demand. These events can also exacerbate disruptions ranging in scale and intensity from minor neighborhood blackouts of limited duration (cf. heat wave in Tucson AZ, June 19, 2016), to widespread events that can cause much more dangerous or catastrophic outcomes (California Legislature, 2011). An electrical outage can be problematic or even dangerous any time of the year, but these outages are particularly dangerous during extreme heat events.

> ***Action:*** Diagnoses of chains of past events that led up to a particular outcome (increased load, above average temperatures, heat waves, distribution bottlenecks), will help better characterize the factors that contributed to that particular event. Looking forward, analyses and forecasting can anticipate conditions based on observed clusters of phenomena that are flags or markers for increased vigilance, given past events.

(2) Gradual Warming

The role that a warming climate will play on a regional energy portfolio and local decision-making and planning is less well understood. Despite these uncertainties, it is generally accepted that power generation/transmission facilities, and utilities that interface with the public will need to incorporate climate related risks into long term planning. For example, there will likely be a decreased capacity for both thermoelectric generation and photovoltaic systems with increased ambient temperature, and gradually increasing temperatures may approach limits of optimal operating temperature ranges. In addition, there will be increased energy demand as seasonal shifts in temperature occur and higher sustained temperatures become the norm. Finally, increased monsoon activity in summer months increases the intermittency of variable energy sources (e.g. solar), and extreme winds associated with monsoon activity can have a damaging effect on production, transmission, and distribution infrastructure. These impacts, however, are notoriously difficult to forecast. Transmission capacity expansion and increased cooling water for plants in areas experiencing increased heat may be necessary.

> ***Action:*** Ongoing assessment of how baseline temperature affects energy market demand. Intermittent assessment of vulnerability/resilience of infrastructural components given present climate and future climate projections.

Conservative estimates of weather impacts are generated with meteorological data (wind speed and direction, temperature), in conjunction with project parameters such as resistance and current in a particular power line. These inputs are used as case studies that can be applied to other lines. Assessments of temperature focus on current conditions, including extremes and gradual changes to low/high temperatures.

> ***Action:*** Develop models that better identify/predict peak demand to help mitigate load issues, most of which are driven by a particular hour of maximum demand/load. Assess the implications of maxed load if the infrastructure were to underperform to anticipate necessary changes.

(3) Changing Seasonality

Warming conditions may actually increase revenue during transitional seasonal periods (i.e. spring and fall) when electrical demand has historically been lower. Warming conditions may also introduce periods of increased demand on a regional scale when other electrical utilities will be looking to meet their own regional demand.

> ***Action:*** Assess how changing climate and seasonality may alter utility scale demand within the customer network. Investigate how changing seasonality may alter regional energy markets to anticipate periods of future demand or surplus.

(4) Equipment Wear and Infrastructure Lifespan

Performance degradation of the infrastructure may increase under heat conditions, leading to increased operation and maintenance costs to reduce recoverable losses in plant operations. Increased nighttime temperatures will prevent equipment from cooling off and high daytime temperatures may overload equipment (e.g. transformers) causing them to overheat and shortening equipment lifespans. Transmission line loss efficiency may vary from 1% to 2.5% and substation capacity loss may increase at 1% - 3%. There will likely be reduced wind pocket and shadow events to cool equipment, reducing efficiency. Increased heat is mostly a load forecast concern, and few plans are asking how these systems work in a warming climate. Resource planning addresses these questions by ensuring that equipment specifications meet current temperatures vs. projected temperatures, but small shifts in temperature don't dramatically affect operation. Other equipment is engineered to operate at extreme temperatures, therefore, there is less concern about gradual temperature changes. More temperature-sensitive technologies such as solar and solar storage may present a case where gradual temperature changes play a more significant role in planning

> ***Action:*** Most equipment appears to be over engineered such that gradual increases in baseline temperature do not outpace typical equipment replacement schedules. It remains important to monitor gradual changes in temperature to determine if temperature increases (including changing seasonality – i.e. longer summers and more persistent extreme temperatures) play a role in equipment performance and longevity. Most of the planning and decision-making are based on the current climatological conditions; the role of gradual change needs to be monitored.

(5) Urban Heat Island (UHI) Effect

Climate projections of increasing baseline temperatures and changing seasonality highlight trends that influence the resource planning of an electrical utility, but offer little specific information that would support policy decisions given their coarse spatial and temporal resolutions. Spatially explicit heat map models using remotely sensed data allow for more precise analyses of areas with elevated temperatures, as well as the correspondence between observed weather station data, modeled surface temperature data, and ambient air temperature calculations. The final output of the heat tool (Fig. 16, above) consists of three parts: Land Surface Temperature (LST), heat islands, and future heat islands. The LST values reflect potential areas of stress to TEP infrastructure. The product shows the surface temperature of the date when the image was captured, which can be used to infer where hotspots are found, and where areas of higher temperature will likely be in the future. Relatively simple functions can then be used to integrate the likely effects of climate change. The LST-derived output will be of primary interest for energy infrastructure relating to transmission and distribution.

> ***Action:*** Integrate existing Geographic Information Systems (GIS) based surface temperature tool to calculate LST, and help improve UHI based spatial assessment to determine relevance of small scale heat maps in utility planning, integrating these data and information where appropriate. Data collection of sample temperature measurements coinciding with satellite imagery collection could be used in the future to better verify or improve the method and tool.

(6) Gradual Warming & Climate Change

More precise climate projections and models – on multiple timescales, would help TEP in its ongoing long-term planning efforts. For new infrastructure assets, TEP evaluates temperature specifications based on what they know about asset specifications and projected temperatures. From a longevity perspective – TEP's large transformers have a maximum operating temperature of 118F without any anticipated negative impact on the operating life of the transformer, small exceedances do not drastically alter performance, and distribution equipment is engineered to operate at even higher temperatures. Current planning does not incorporate the effect that changing seasonality might have on wear of the transformer equipment, but TEP sees this as a specific example of how this information could eventually contribute to their planning.

In terms of economic demand, TEP currently calculates the peak hour based on the load profile. If model projections for the next 15-50 years could dial in the effect of temperature profiles under climate change to better model gradual changes, these changes would need to include updates on hourly temperature, since factoring in the hottest hour that is key to calculating peak hour. This means changing seasonality might not matter as much as absolute temperature maximums for load forecasting, although changing seasonality would matter for equipment and for the duration of high demand load seasons. There is widespread consensus among utilities and decision-makers in the Southwest that the gradual warming of the Southwest is a necessary consideration for future planning. However, for the relevant data and information to be useful, they need information at finer spatial and temporal scales and/or more targeted timeframes that map onto the planning horizons of utility decision-making.

Current seasonal forecasts use the same demand curve every year, and while they factor in population growth and energy efficiency, forecasts do not reflect the warming climate. There is strong desire among the partners in this project to bring the resource planners a better seasonal and long-term forecast that considers a warming Southwestern climate. At a customer level, TEP is also interested in looking at customer profiles, and assessing the urban heat island effect on an hourly basis to learn more about customer experience and utility demand.

Action: Integrate research and collaborate with UA HAS researchers identify the influence of the best performing models for the Southwest to update and improve the characterization of future Southwestern climate and climate extremes (including: average and extreme temperatures, extreme heat duration and intensity, and changes to the onset and duration of warm season).

RECOMMENDATIONS

FURTHER RESEARCH

- More precise temporal and spatial models of temperature trends as well as the distribution of climate extremes (e.g. GIS maps of temperature hotspots) to identify high risk areas for infrastructure stress
- Incorporation of historical climatological data and climate projections to better model wind to determine if assumptions about convective cooling potential for passive cooling of infrastructure are accurate or will change over time
- Better characterizations of the downstream impacts that warming temperatures could have on other components of this system – specifically in terms of wildfire risk and effect on air quality such as nitrogen oxides (NOx), but also general precipitation patterns that might affect water storage, dust concerns, wildfire risk, etc.
- Updated and improved heat extreme characterizations for the Southwest, including further research to better characterize southwestern heat waves, including the projected average and extreme temperatures, and how changing seasonality might extend summertime temperature profiles

RISK MITIGATION AND ADAPTATION ACTIONS

- Increased demand response and energy efficiency to reduce demand at peak hours
- Deploy newer technologies that have higher temperature thresholds and software upgrades for load shedding at feeder circuits to protect equipment during heat waves

WILDFIRE

BACKGROUND RISK PROFILE

In the western United States, fire is a natural component of ecosystems, and its occurrence is strongly correlated with climate variability (Garfin et al., 2013). Rising temperatures result in earlier snowmelt, decreasing summer flows and increased fire risk owing to drier seasonal conditions. Long-term drought can further stress forests and vegetation, increasing wildfire risk. Warmer and drier climate also alters the distribution of vegetation types within a region, creating conditions that can lead to more frequent and severe wildfires. In Arizona, evolving climate conditions have led to drying conditions in higher elevations south of the Mogollon Rim and longer monsoon seasons in the summer. These changes are anticipated to create conditions favorable for fine fuel growth and larger, more severe fires in the future, posing a risk for utilities.

Over the past three decades, the fire season in the Southwest has been lengthening, and inter-annual and decadal variability in weather patterns is difficult to predict. In these conditions, the total area burned is strongly influenced by the El Niño-Southern Oscillation (ENSO). Although historically, big fires have occurred under La Niña conditions in the Southwest (See Figure 18), between 1990 and 2004 widespread fires occurred during El Niño when persistent drought and high fuel loads overcame the limitations posed by wet El Niño winter conditions (Yocom, 2010; O'Connor et al., 2014).

Climate projections for the 21st century indicate that conditions we would consider "extreme" in the 20th century (i.e. the hottest and driest years on record) will become more common, even normal, in the late-21st century (See Figure 19). Changing fire dynamics are derived from increased growth in fine fuels, frequency and severity of recent forest fires, and increased particulate matter. The short-term spatial fire risk, or wildfire hazard potential is likely to remain high in the near future (<3 years) (See Figure 20), despite recent large fires (See Figure 21). The abundance of accumulated fuels and warming drying conditions suggest fire hazard will remain high into the foreseeable future without a significant increase in fuel reduction treatments through a combination of managed wildfire, prescribed fire, and mechanical treatments (North et al., 2012).

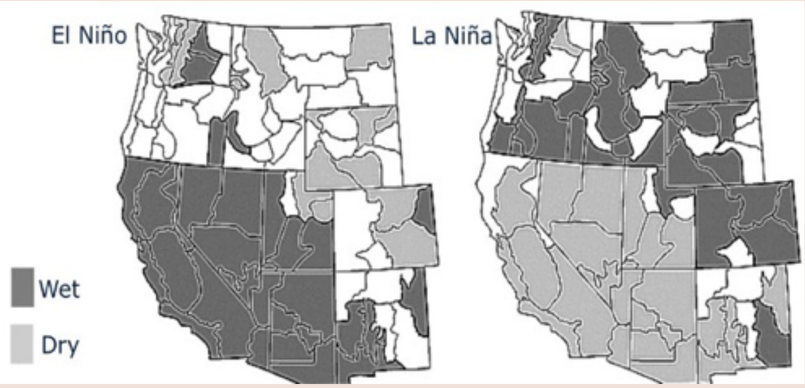


Figure 18. Decadal-scale variability: fire risk and La Nina relationship

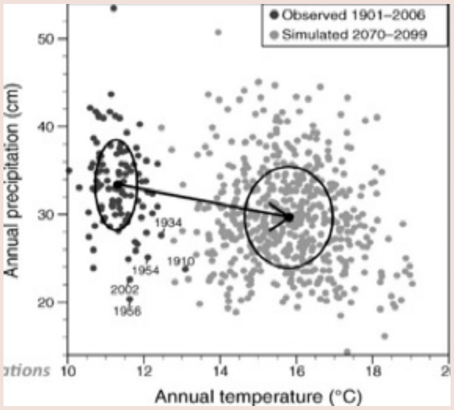


Figure 19. Observed/simulated temp and precip ratios in the Southwest

In recent years, insect outbreaks across the western United States have led to widespread tree mortality in the West. These tree die-offs, in the short term (1-3 years), increase the wildfire risk potential in the short term (1-3 years), when the presence of dead canopy fuels facilitates fire spread. After needle drop, fire risk may be reduced for a decade or more (Simard et. al., 2011; Hart et al., 2015). Drought and warming climates are both implicated in stressing otherwise healthy trees, putting these trees at increased risk of beetle infestation (Williams et al., 2012; O'Connor et al., 2015).

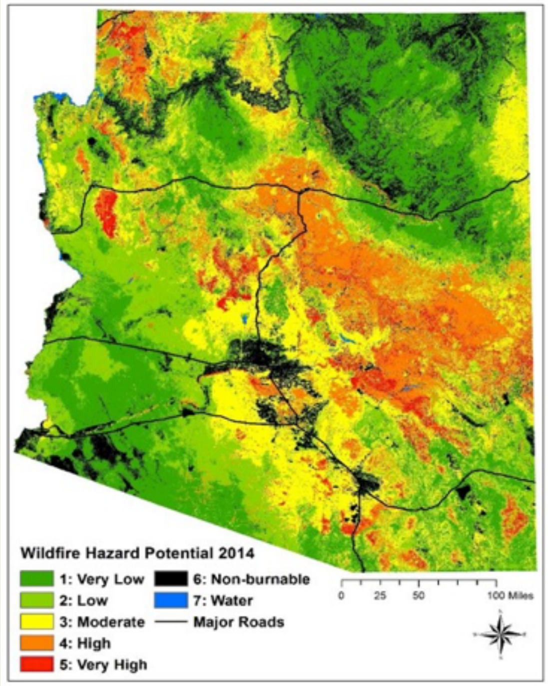


Figure 20. Arizona wildfire hazard potential, 2014

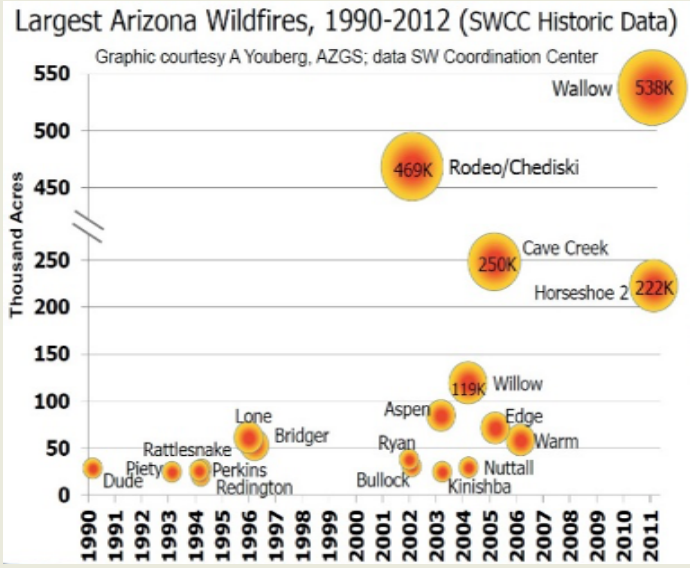


Figure 21. Largest Arizona wildfires, 1990-2012

As is commonly observed across the West, disturbed areas are often more susceptible to invasive species (Lake and Leishman, 2004). In the case of buffelgrass, a history of grazing activity in exurban regions, as well as construction and new development due to population growth in the West, has resulted in areas of disturbance in and around populated areas. These disturbed areas are more susceptible to buffelgrass invasion, and there is increased wildfire risk associated with these infestations.

Recent literature on precipitation trends in the Southwest has identified that monsoon precipitation is projected to be both more intense and more frequent in many locations in the Southwest (Garfin et al., 2014). While these increasingly intense events pose flash flood risks, these events can also amplify the post-fire runoff effects resulting in destructive flooding (post-fire debris flow flooding) that can damage or destroy infrastructure, or disrupt the operation of electric utilities by cutting off access.

PRIMARY AREAS OF CONCERN

(1) Fire Risk in Major Transmission Corridors

Transmission lines connecting remote generation systems to regional utility grid networks are especially vulnerable to increased wildfire activity. Wildfires can cause physical damage to structures, conductors, and other related equipment, and may also cause outages if the ambient temperature of the air around the conductors exceeds operating parameters or if smoke causes the line to arc. Models estimating the probability of wildfire impacts on transmission lines for the Southwest do not exist outside of California. Combined with seasonal climate models, this information is useful in determining priority areas for line siting, maintenance and vegetation management strategies.

> ***Action:*** To manage for wildfires, TEP's current plan addresses only fuel load. First, TEP considers wildfire hazard when siting infrastructure. But inevitably, infrastructure must be sited in areas at risk of wildfire exposure. In recent years, TEP has transitioned to a proactive vegetation management strategy in heavily-forested areas, clearing the full width of rights-of-way, rather than the previous practice of "feathering" vegetation. This helps maintain North American Electric Reliability Corporation (NERC) clearance requirements and reduces wildfire hazards.

(2) Particulate Matter Concentration

Heat, dense smoke, and other particulate matter can impact the capacity of transmission lines; soot accumulates on the insulators causing leakage currents and ionized air in the smoke can act as a conductor causing phase-to-phase (line to line), or phase-to-ground (line to ground) arcing. Arcing events can damage switchgear equipment and can be lethal to people and wildlife on the ground during a phase to ground discharge. Dense smoke from wildfires can “trip” a circuit, causing it to go out of service. Outages can also result from emergency line de-rating or shut-downs during a nearby fire in order to prevent thermal damage to the line, to prevent a smoke-caused trip, or to meet the safety needs of firefighters (California Public Utility Commission, 2008). In addition, a spike in particulate matter around an urbanized area can take time to rectify and may exacerbate other air quality issues.

> ***Action:*** Further study and potential improved technology development is needed for both performance thresholds for transformers and switchgear under different forest fire conditions and types of aerosols in an area (Brown et al., 2009).

BOX 2. FIRE-BASED RISK AND TEP

TEP transmission lines originating from the Springerville Generating Station in Western Arizona and San Juan Generating Station and Four Corners Power Plant in Northwestern New Mexico cross densely-forested areas that have experienced several major fires in the past decade. These fires burned significant areas of the forest adjacent to the transmission corridor. Notably, in June 2000 Tucson experienced an emergency blackout when a forest fire in New Mexico disrupted service via TEP’s 345kV lines into Vail (Emerson and Smith, 2001) and the Wallow Fire in 2012 generated significant concern over the risk it posed to regional transmission infrastructure based on the potential loss of the lines to wildfire, and the potential shutdowns associated with particulate matter arcing/tripping the transmission lines (McMahan, 2017).

(3) Buffelgrass and Fire Risk

Buffelgrass (Pennisetum ciliare) is a rapidly spreading invasive species that increases fire risk. Buffelgrass has a tendency to migrate into disturbed areas and transmission lines are often located in disturbed areas due to the removal of fuel loads.

> ***Action:*** Despite being a major concern to a wide range of land managers, there is not yet a reliable, up-to-date map of buffelgrass distribution, nor is there a reliable, up-to-date model that predicts buffelgrass spread. Improved modeling and analysis would identify critical areas where buffelgrass posed additional or emergent threats to utility resources. As such, TEP is currently making a great effort to address buffelgrass by partnering with organizations with a notable focus on removal and/or management of buffelgrass and other invasive species.

(4) Fire Behavior and Changing Seasonality

The fire season is lengthening in the Southwest under current climate conditions (Abatzoglou and Williams, 2016). The seasonality of vegetation growth responds to inter and intra-annual variability, with seasonal and annual fluctuations in precipitation and temperatures that encourage vegetation growth. For example, increased monsoon activity in the summer can increase fine fuel growth at lower elevations while drought in the winter months can increase vulnerability of both low-elevation shrub/grasslands and forests at higher elevations.

> ***Action:*** Understanding and modeling the growth rate of different types of vegetation (herbaceous, shrubby, woody types) by geographic area can also be used to refine vegetation management strategies. TEP’s vegetation management plan is updated annually, taking into account safety, regulatory requirements and vegetation conditions, most notably for the company’s extra high voltage (EHV) system. The Rangeland Vegetation Simulator (RVS) model developed by Dr. Matthew Reeves at the US Forest Service Rocky Mountain Research Station models shrub and grass growth in response to seasonal climate at annual time steps.

(5) Post-fire Flooding Risk: Following fire, de-vegetated landscapes are more unstable and susceptible to landslides, and the resulting debris flow poses a critical threat to infrastructure. Post-fire flooding is of heightened concern in mountainous areas of the Southwest that experience monsoon rain events immediately following the late-spring fire season. Long-term climate projections (next 40 years) predict increased variability in seasonal rainfall, while the risk of extreme events is also expected to increase. This could further exacerbate post-fire flooding risks if extreme rains fall in years following extended drought and wildfire events. There is also a trend toward decreasing winter precipitation and streamflow/runoff that coincides with an increase in runoff variability. This suggests more frequent winter drought and loss of vegetative cover, with the potential to exacerbate erosion potential during monsoons over the next several decades (Garfin et al., 2016).

Action: Most transmission and distribution infrastructure is located in regions unlikely to be affected by post-fire flooding and debris flows. Given the high impact of such an event, however unlikely, continued monitoring of wildfire locations and a yearly assessment of post fire flooding and debris flow potential is a low-cost, high reward strategy for reducing risk. Secondarily, in the event of a large wildfire event or wildfire event in a high traffic transportation corridor, it would be helpful to monitor and assess whether any fire activity might potentially cut off access to a given facility due to a damaged or destroyed road or bridge.

RECOMMENDATIONS

FURTHER RESEARCH

- Expand research and mapping of buffelgrass and other invasive, fire-adapted species

RISK MITIGATION AND ADAPTATION ACTIONS

- Utilize LANDFIRE fuels data in fire models such as FlamMap to predict rate of spread or crownfire potential under a user specified weather scenario
- Monitor current fires and their progression through https://fsapps.nwcg.gov/googleearth.php
- Monitor wildfire hazard potential through https://www.firelab.org/project/wildfire-hazard-potential
- Assess emission projections by fuel type
- Determine effects of fuel modification on emissions
- Identify thresholds of particulate matter concern
- Utilize BlueSky or VSmoke to identify smoke emissions projections for specific ignition points

WATER

BACKGROUND RISK PROFILE

The interdependencies between the energy and water sectors, and climate vary greatly by geographic region and are a result of complex interactions between natural processes and human activities. Densely populated urban centers in the southern part of Arizona are partially dependent on power generation systems located in more remote areas of the state. Socio-economic sustainability and power generation are both dependent on surface water flow and groundwater resources, and are directly affected by climate variability. Generally, the Southwest is expected to experience reduced snowpack, earlier peak surface flows, and overall reductions in precipitation.

In terms of water supply, most of the region’s major river systems are expected to experience reductions in streamflow. With increasing temperatures, total streamflow is likely to be reduced due to higher evapotranspiration, reduction in groundwater recharge and lowering groundwater tables. Meanwhile, there is also potential for increased flooding due to increased intensity of rainfall and post-fire events. (Figure 22 displays expected declines in annual runoff in several western states).

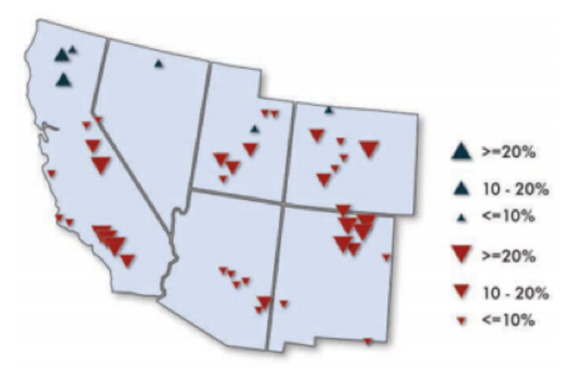


Figure 22. Ensemble median percentage change in annual runoff (2050s vs. 1990s)

The drought impacts on Central Arizona Project (CAP) availability in Arizona are widely recognized but probably not directly connected to TEP management issues in the near term. However, increased intensity of rainfall and post-fire events (such as ashflows) could increase flood damage to facilities and decrease reservoir capacity in the Salt River Project (SRP) and other water delivery systems. The type of power plant and its cooling system technology, and the geographic location of the plant, will determine the relative water use intensity of the facility and also its relative vulnerability to changes in climate. Different sources of water will be affected differently by changes in temperature and precipitation, so the impacts on the water availability differs even for plants within close proximity to each other.

There is a relationship between temperature and both the efficiency of the cooling process and the availability of water for cooling. A 2015 energy report indicated that "Ongoing drought has revealed the vulnerability of thermoelectric power plants to the risks of low water levels and high water temperatures.... In general, a rise in ambient cooling water temperature of 1°C could cause a reduction in power output of 0.15–0.5%." (Cook et al., 2015: 193).

Today, power to support growing urban population centers in the Southwest is typically generated from a combination of hydroelectric and thermoelectric power plants within the regional watershed. Both of these power generation types depend on water for cooling, either sources from surface flows or groundwater resources. (See Figure 23 for the utility service areas in Arizona and parts of New Mexico and California).

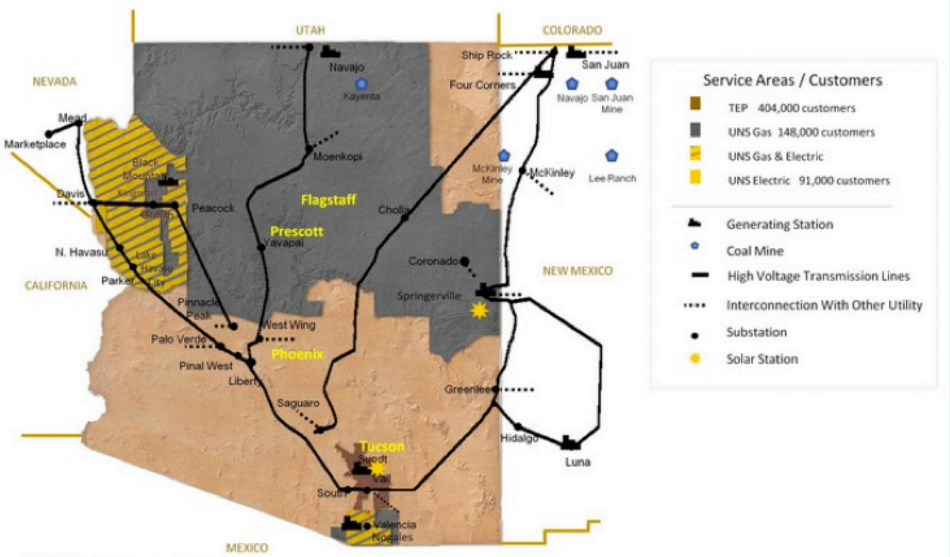


Figure 23. Arizona utility service areas and customers

Power plants in the Southwest that are not co-located with surface water sources withdraw from ground water aquifers, some of which may already suffer from overdraft. TEP's Springerville plant is not currently in an overdraft situation, however, it is located in an area with a projected increase in competition for groundwater resources (DOE, 2010).

Despite the broader concerns about impacts of climate change on water supplies, TEP's groundwater rights within the Tucson Active Management Area (AMA) are secure because of the 1980 Groundwater Management Act, which "grandfathered" in historical groundwater use. TEP's rights are 10,079 acre feet/year, which far exceeds the current usage of about 2,600 acre feet (af) and projected use for the Tucson AMA of 5,000 af/year for all power plants in 2025 (TAMA, 2016). There is currently no known issue with the legal availability of groundwater for use by TEP and physical availability is a low-risk issue in the near-future. TEP has Type 2 Electrical Generation rights, a right to pump groundwater from a well for non-irrigation purposes. These rights are moveable within the AMA for power generation only.

On a statewide level, Arizona is undergoing changes in power generation that involve switching from surface-water dependent coal-fired power plants in the mountain plateau to increased natural gas production near urban centers of Phoenix and to a lesser extent Tucson. Competing water demands in arid environments mean less water availability for thermoelectric power generation that could result in reductions in power output in the future. Less water for urban centers may result in higher water costs and increased pumping of local ground water supplies. Most of the projected increase in generation near Phoenix relies on groundwater resources for cooling and while most of the generating capacity is within the AMAs, the outcomes of competing needs for water supplies for the region under projected climate conditions are not well understood. (Figure 24 compares present power generation water use with projected use).

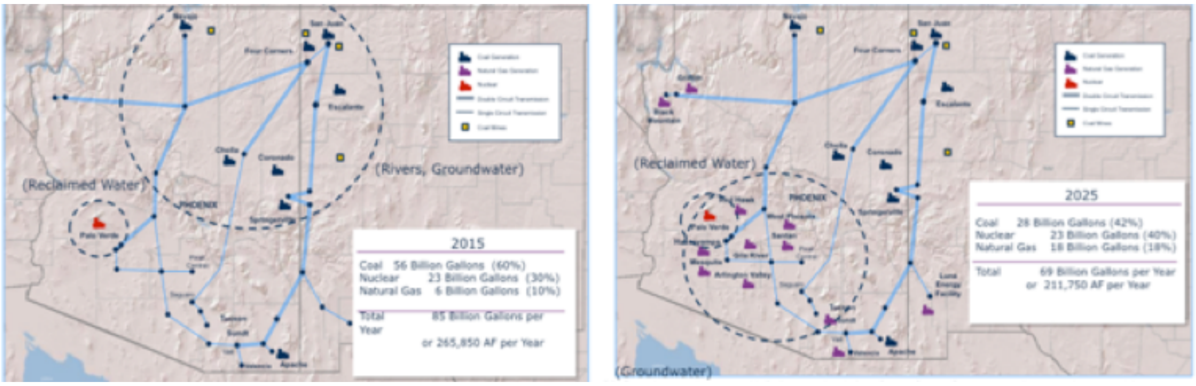


Figure 24. Power generation water use 2015 and 2025

In addition to water quantity concerns, water quality impacts are expected due to more frequent high-intensity precipitation events, and increased sediment in surface water as a result of increasing forest fires. Water quality generally decreases with depth to water in the aquifer. Depth to groundwater in production wells and trends in water levels in groundwater are important for long-term cost considerations and water quality. Changes in water quality can affect cooling tower efficiency and blowdown quality, and potentially create discharge issues. Since large cooling towers are regulated under the Arizona Department of Water Resources (ADWR) management plans in the AMAs and the basis of the regulation is cycles of concentration, the quality of the intake water matters a great deal. Seven cycles of concentration results in highly concentrated blowdown water, so the way that water is managed for discharge, evaporation or reuse may be of great concern from a cost or environmental standpoint.

Water temperatures are expected to increase and riparian areas in Arizona are especially vulnerable to the combined effects of higher temperatures and lower precipitation and/or groundwater recharge. These issues are likely to increase pressures on endangered species, which could lead to additional regulation of water supplies.

PRIMARY AREAS OF CONCERN

(1) Shift in Generating Location and Subsequent Shift in Demand on Water Resources

Under conditions where generating capacity is moving from coal powered generating capacity in the four corners region, to natural gas powered generating capacity in the Phoenix region (See Figure 25), water consumption for power generation shifts from the Arizona Mountain Plateau to the Desert Basin region to support natural gas capacity increases in the Phoenix area. Increased capacity in natural gas combined cycle plants will mean higher consumption of water, and increasing consumption in the summer could increase water demand. Reduced groundwater recharge and downward trends in groundwater levels may impact water availability in the future. TEP may also be affected by the increased consumption of water by other natural gas systems in the region that TEP is planning on increasing the capacity of in the future. This impact may have an adverse effect on operations or provide a competitive advantage from losses of water availability for competitors. See Appendix for data from multiple sources linking production capacity to location, production efficiency and water source generated.

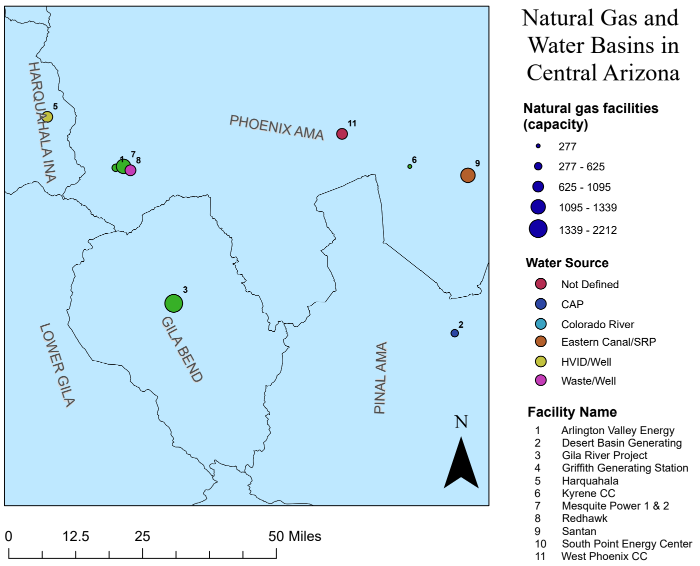


Figure 25. Central Arizona basins

Action: Verification is needed to determine if sufficient water resources will be available to support increased generation capacity and changes in location of generation facilities.

Action: There may be competitive advantages to monitoring water availability issues for competing utilities. These issues should be considered when constructing, refurbishing, or investing in production capacity for plants in central Arizona, which are expected to be needed if there is a transition to a more natural-gas dependent production process in the future. In general, renewables have very low water requirements (except for solar thermal).

(2) Regulatory Impacts of Water Resource Management

There are different regulatory and physical risks in each natural gas plant location in central Arizona. We have plotted the locations of these facilities (Appendix A), and have found that they are located in the Phoenix AMA, the Pinal AMA, the Harquahala Irrigation Non-Expansion Area (INA), and the Gila groundwater basin. See Figure 25 for the location of natural gas plants relative to groundwater basin. TEP also has an ownership stake in the Gila River Project natural gas system in Gila Bend, Arizona. This facility consumes groundwater but may be located outside the Phoenix AMA. There may be regulatory risks depending upon the water source. Groundwater Code regulations are protecting the availability of groundwater in the AMAs for municipal and industrial use, particularly in the Phoenix and Tucson AMAs (Pinal AMA and Harquahala INA have less restrictive management goals), so the most advantageous place to be located from a groundwater perspective is in the highly-regulated basins.

> ***Action:*** Changes in the Arizona Groundwater Management Act, surface water laws, the federal Endangered Species Act and the Clean Water Act could all have implications for the water supply inputs associated with electric power generation. In general, groundwater management requirements protect existing users. To date regulation of water use has not had a known negative effect on electric power generation within the AMAs. However, future changes in regulations may limit management options so it is necessary to stay abreast of and understand the impacts of new or existing national and federal regulations.

(3) Drought Conditions in the Mountain Plateau

Seasonal fluctuations or changes in availability of surface water in the Mountain Plateau that supplies water for the San Juan Generating Station and 4 Corners power plants could affect generating capacity. Decreased availability of water could increase both operational costs and the cost of power produced. Changes in snowpack dynamics that impact surface water and groundwater recharge could have significant impacts on future water availability. The Public Service Company of New Mexico's (PNM) 2014 – 2033 Integrated Resource Plan concludes from their drought sensitivity modeling that drought conditions can increase system costs and decrease system reliability in drought years, but water curtailment at the San Juan Generating Station has a low probability given PNM's water rights (PNM, 2014).

> ***Action:*** Assess the following key question: How could the closure of the coal plants in Northern Arizona impact water availability and water rights for power production in the region?

(4) Potential Impacts of Climate Change on Water Supplies for the Springerville Plant

Water is supplied to the Springerville plant from well fields drawing water from the aquifer (SRP, ND). Pumping volumes close to 20,000 af/year do not currently appear to have a significant impact on groundwater levels. This introduces the possibility that surface water may play a larger role in water supply at this plant (through aquifer recharge) than is currently assumed. The evaporation ponds at the Springerville plant are lined and TEP assumes that 0% of the groundwater withdrawn infiltrates back to the aquifer.

> ***Action:*** Determine role of surface vs. groundwater in supplying Springerville plant (particularly focusing on the sources of groundwater recharge in the region), and the consequent implications given projected changes in temperature and snowpack.

(5) CAP and Reservoir Capacity

Due to the multi-state and highly complex legal management scheme of the Colorado River, electricity production that depends directly on hydroelectric plants or water supplies from mainstream reservoirs may have different impacts from the CAP itself. However, if main stem reservoir levels continue to decline, ongoing negotiations across the basin states could affect power production capacity as well as demand for power in multiple ways that may be hard to anticipate.

> ***Action:*** Keep abreast of ongoing changes to CAP allocation/policy, shortage sharing agreements, drought response mechanisms and reservoir operations.
>
> ***Action:*** Factor water availability by source and geographic location, including issues of seasonal demand for water and power and forecasting of weather conditions, into future resource decisions.
>
> ***Action:*** Consider supply chain impacts to infrastructure construction and maintenance and fuel costs in light of future water availability, changes in policy, and the expected increase in high-impact climate events.
>
> ***Action:*** Stay abreast of industry trends in emergency preparedness and hazard mitigation, given increased intensity of storms and concerns about cascading impacts. TEP can work with water utilities on an integrative portfolio of options to ensure energy/water reliability.

(6) Future Demand in the Tucson Basin

TEP projects 1% annual population growth in its service territory over the next 15 years. TEP currently has access to enough groundwater resources to meet projected load growth and demand. There is a higher probability that the physical availability of groundwater will decline in the longer term, though the fact that Tucson Water has essentially eliminated its overdraft in the central Tucson basin has significantly benefitted water levels in the basin. Physical groundwater availability at TEP's current plant is a low-risk issue in the immediate future, but if access to CAP water is curtailed in the future, Tucson will have to increase its groundwater pumping. Long-term drought will impact the rate of recharge in the Tucson basin itself, and may affect the ability to either attain or maintain the safe-yield management goal. TEP will be affected by the management decisions of other water users in the basin, particularly Tucson Water, though TEP's own water withdrawals within the Tucson AMA are expected to decrease significantly.

> ***Action:*** Identifying areas in the Tucson AMA where population increases will occur will be key in identifying potential risks to water availability and rights for TEP in the future. Monitor City of Tucson water service policies and water sources for large new developments in the region.
>
> ***Action:*** TEP also needs to consider competing water rights for new businesses and development in Tucson in the future due to possible competition and potential decreasing water availability. Seasonal energy demand and associated water requirements are also a consideration for TEP's economic forecasters. Factors that need to be considered in evaluating the impacts of increased water consumption in the Tucson Basin are: 1) trade-offs with other groundwater users such as municipal and agricultural users; 2) water and power load implications of land development plans; and 3) assured water supply requirements in the Tucson AMA and the impact of the CAP reliability on TEP customers in the future. There are fewer state administrative resources available in southern Tucson today in terms of the implementation, monitoring, and enforcement of water management programs since the ADWR Resources closed its Tucson AMA office. This means TEP staff will have a larger burden to understand current trends in water supply and demand.

(7) Climate Extremes

With increased peak energy and water demand under sustained higher temperatures and potential reduced surface water availability, TEP plants that rely on surface water may face future generating challenges. Higher energy demand due to increased groundwater pumping could add to the energy requirements of providing increased air conditioning. Exacerbating these impacts, higher ambient temperature lowers the ability of power plants to shed heat. This combination of factors could lead to system failure in an extreme situation. In addition, "cooling water that is warmer and scarcer can reduce the power plant's efficiency and limit net power generation" (Cook et al., 2015: 202).

> ***Action:*** Explore options of hybrid cooling and dry cooling, which currently present higher capital costs for infrastructure. Use of treated wastewater may add additional capital costs but may be less expensive than new water source development.
>
> ***Action:*** Monitor forecasts and potential for extreme climatic events (floods, storms, etc.) that can damage installed infrastructure for both energy and water systems, affecting their operations and resulting in delays and capital expenditures for repairs and restoration of service. Continue to consider the consequences of extreme events and be prepared for "worst case" scenarios.

RECOMMENDATIONS

FURTHER RESEARCH

- Expand research on water availability and use in Arizona

RISK MITIGATION AND ADAPTATION ACTIONS

- Develop a monitoring plan to evaluate groundwater levels in the vicinity of all power plants in the state – both those that TEP has an interest in, and others, because this may lead to a competitive advantage for some plants over others
- Communicate on a regular basis with ADWR and Arizona Department of Environmental Quality (ADEQ) to indicate interest in managing the water supplies and monitor changes in water quality and water quantity over time. Monitor potential changes in groundwater laws that could lead to relaxation of the current protections for TEP's groundwater rights
- Work with water utilities in the Tucson region to develop a better understanding of the energy-water nexus and implications for hazard mitigation that come from the connections between these systems
- Further explore hybrid cooling and other water conservation technologies
- Monitor drought conditions on the Colorado River and changes in water allocations within Arizona

AIR

BACKGROUND RISK PROFILE

Air quality is a persistent concern in the Southwest, which is linked to a number of environmental factors that affect both the removal of pollutants and the emissions of gases and particulate matter. Particulate matter consists of thousands of different constituents including dust, biological particles, and anthropogenic emissions produced by gases such as nitrogen oxides (NOx), ozone, (O3), and volatile organic compounds (VOCs) associated with oil and gas production activities, combustion engine transportation, and biogenic sources.

Drought conditions and land cover change are two primary drivers of dusty conditions in the Southwest, while particulate matter (PM2.5 and PM10, in particular) is associated with a wide array of factors including wildfire, drought and dusty conditions, emissions, and land cover disruptions. The climate signal commonly associated with dust forecasts is linked to both intra- and inter- annual precipitation variability (Sorooshian et al., 2011). Within a given year, certain regions of the Southwest are projected to be subject to increasingly extreme precipitation and drought regimes, especially during the North American Monsoon, where increasingly extreme precipitation events are punctuated by longer and most sustained dry/drought spells. Across multiple years, periods of extended drought can lead to increasingly dry and dusty conditions, especially during multiple successive years of drought.

In terms of NOx and O3, within the context of a warming climate, it is expected that regions already affected by increased surface level O3 will see the seasonal conditions that favor the formation of O3 expanding, resulting in longer seasons of increased surface level O3 exposure. Additionally, urban population growth in the Southwest will also increase the sources of NOx and VOCs, primarily through increased automobile traffic and combustion engine pollution (See Figure 26).[1] This increased population size will also increase the number of people potentially exposed to surface level O3. The EPA currently projects that all Arizona counties (except for Yuma, Coconino and Cochise) are projected to be in compliance with national limits by 2025.

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[1] *This assumes the increased population will mirror the current patterns of automobile use, and that no other options (such as improved public transportation, increased use of electric vehicles) will offset the increase in combustion vehicle use.*

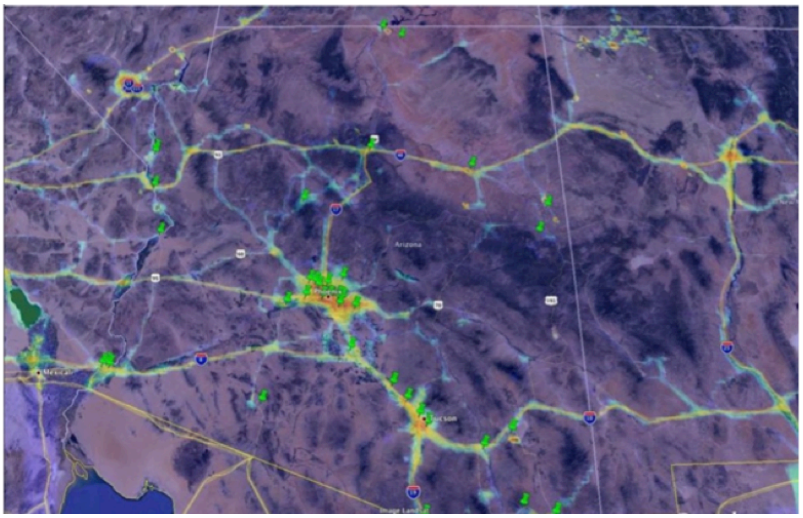


Figure 26. Emissions view of Arizona's air quality (NOx), 2015

Methane is receiving increasing attention as an air pollutant, especially as oil and gas extraction activities have led to a large methane plume in the four corners region (See Figure 27). While not directly tied to utility level management, these highly visible emissions could be the subject of regulatory policy in the future. Many utility and regional power generation decisions have been made within the context of the development and implementation of the CPP. Although President Trump rescinded the CPP, it raised questions about long term viability of carbon producing fuel sources, and drove utilities to reconsider their strategies for anticipating present and future regulatory frameworks.

These factors are part of the ongoing development of anticipatory planning for present and future environmental and regulatory circumstances within the context of air quality concerns in the Southwest. At present, there are limited drivers of immediate change that require specific action by utilities. Looking forward, however, it is important to monitor how gradual increases in baseline temperatures, population growth in the Southwest (and associated emissions), the role of emissions and temperature in shaping air quality, and the implications associated with present and future regulatory frameworks, could interact to affect intermediate and long term planning horizons.

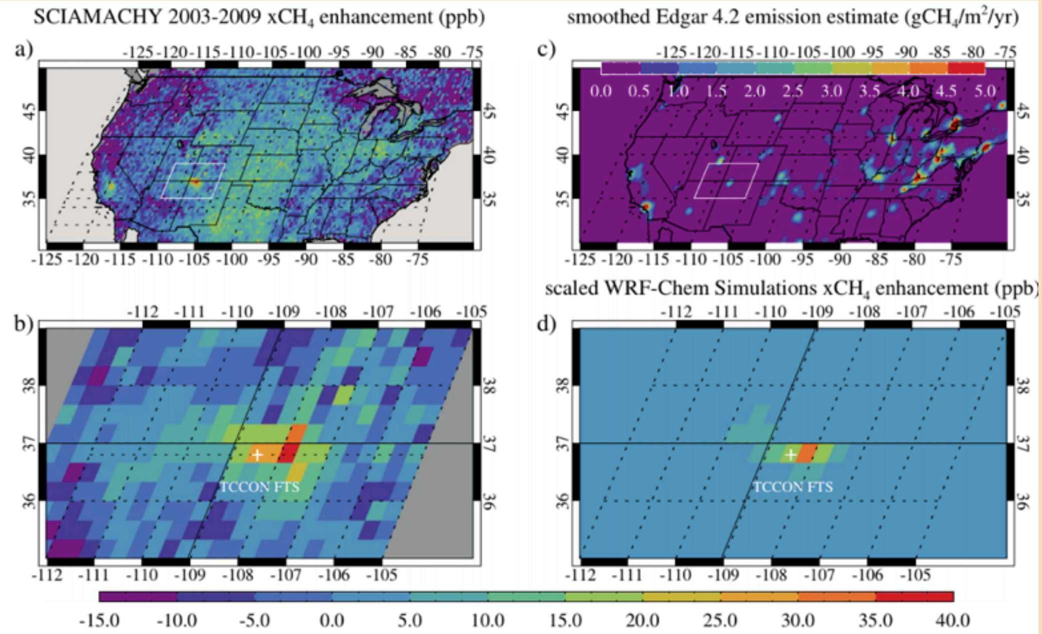


Figure 27. Four Corners: the largest U.S. methane anomaly viewed from space

PRIMARY AREAS OF CONCERN

(1) U.S. EPA Ozone Non-Attainment Status

One of the primary concerns related to the shift from coal fired generating capacity (in the four corners region) to natural gas generating units (in the Phoenix and possibly Tucson areas), is U.S. EPA O3 non-attainment status, and the role that new generating units might play in increased NOx emissions and surface level O3 formation. From a utility perspective, NOx/O3 is primarily a point source concern related to power generating stations they either own or have included in their regional power resource portfolio.

Electricity generation contributes 12% of NOx emissions, but only 0.02% of the VOCs. Electricity generation is responsible for 34% of SOx (Sulphur oxides) emissions, but these are mostly from coal powered plants not located in attainment target areas. The electricity generating facilities are responsible for 1.2% of PM2.5 emissions, with a majority (7/8) from coal, and the remainder (1/8) from natural gas.

These numbers suggest there would be an increase in emissions in the Phoenix region as a result of increased generating capacity, but the increases would be relatively small, especially compared to the amount of NOx and VOCs produced by automotive transportation and freight (e.g. personal vehicles and semi freight hauling). In terms of risks and vulnerabilities, the power generating facilities are stationary as compared to automobiles so if U.S. EPA non-attainment status is reached in the region, power generating locations might see increased regulation, as automobile emissions are more difficult to monitor and regulate. Additionally, recent studies have indicated that California is actually one of the key sources of NOx emissions in Arizona, based on wind patterns that have been identified (Li et al., 2015; Huang, et al., 2013) (See Figure 28 for the 24-hours NOx Emissions Trajectories).

> ***Action:*** Continue to monitor the U.S. EPA attainment status of Phoenix and Tucson to ensure that any changes to attainment status are anticipated, and continue to monitor developments regarding current science tracking utility/power-generation contribution to NOx emissions.

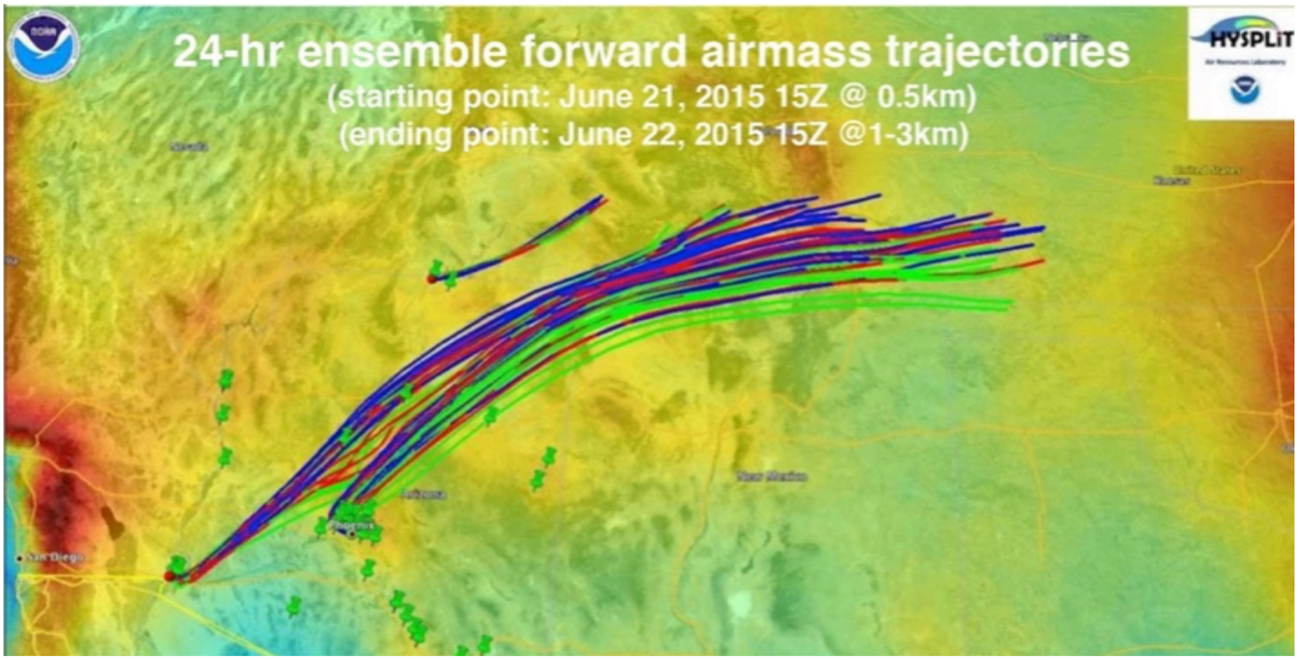


Figure 28. 24-hour NOx Emissions Trajectories

(2) Dust and Particulate Matter

Dust and particulate matter is linked to drought conditions, recent wildfire events, and land cover change activities.

> ***Action:*** Utilities could engage in monitoring the current drought status, the location and intensity of recent fires, and patterns of land use/land cover changes in order to anticipate areas where increased dust and particulate matter may be present, but it remains unclear if any of these environmental risks have any material bearing on the planning and operations of day to day utility management.

(3) Clean Power Plan

The CPP introduced some degree of uncertainty into utility management and planning, by including carbon emissions in the regulatory framework under which utilities and power generating companies operate. There have been recent shifts away from coal fired generating capacity, partly as a result of increased emissions regulation associated with coal fired generating capacity (when the CPP was still in place), but more so because of recent market conditions. Aside from any regulatory or environmental framework, the price of natural gas has caused many utilities to reconsider their resource portfolio and leasing strategies, where natural gas (and renewables) provide competitive options for generating capacity (compared to coal, and without the possible implications of a reinstated EPA CPP).

> ***Action:*** Continue to monitor federal actions for clean energy, but perhaps more importantly, take the opportunity to expand the use of inexpensive natural gas and the declining price of solar to move away from coal generated power, in anticipation of an eventual return to carbon emissions regulations.

RECOMMENDATIONS

FURTHER RESEARCH

- Assess the role of changing seasonality (longer summers) in formation and persistence of NOx, even though utility contribution is proportionally small
- Monitor how fuel mix could affect NOx/VOC contribution to emissions, and intermittently assess the current state of knowledge regarding natural gas contributions to NOx/VOC emissions
- Monitor political dynamics regarding regulatory frameworks to assess risk and vulnerabilities associated with coal vs. natural gas vs. renewable energy, and assess the willingness of customers to pay more for “clean” energy to encourage investment in renewable energy

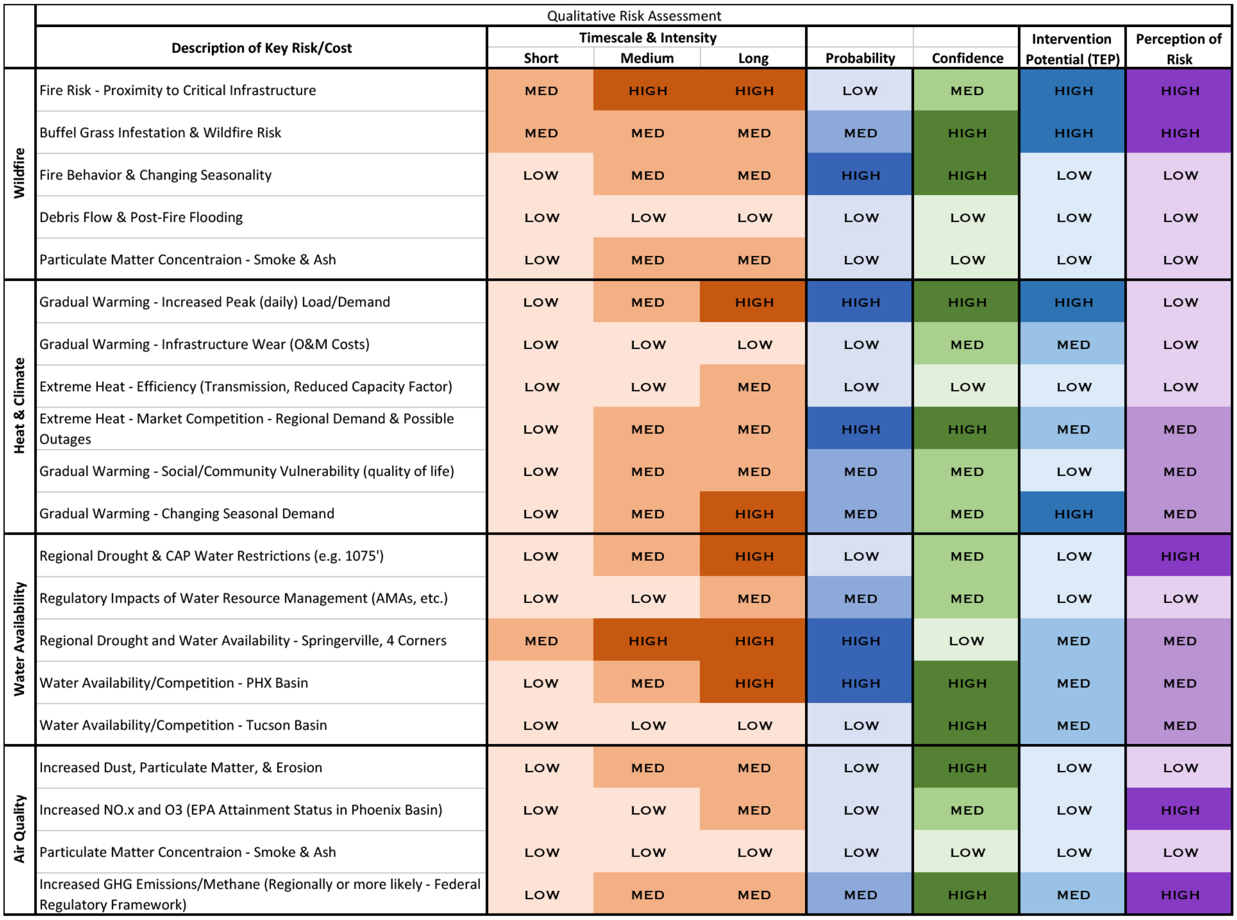
RISK MITIGATION AND ADAPTATION ACTIONS

- Recognize that increasing urban populations may increase non-stationary point sources of NOx (e.g. cars, AC units, etc.)
- Monitor future NOx emissions to observe potential increase as a result of fuel mix

THE NETWORK OF INTERRELATED CLIMATE RISKS AND EFFECTS

Many of the risks identified in the qualitative assessment have connected effects, impacts, and implications that extend beyond the bounds of these specific topical areas. These risks connect within and across the four risk areas in a network of related effects. This network is defined by multiple pathways of risk and opportunity within the context of utility management in the Southwest. These risks also connect via critical paths within the network, in the form of cascading effects, or chains of events that can amplify existing conditions, or serve as triggers for specific crises or decision points. The ABRI project team, TEP, and the UA science teams worked throughout the assessment process to aggregate information and develop additional assessments of these risks regarding known pathways of risk within these networks, as well as to explore unknown connections that might provide crucial information for climate risk management strategies. The assessments focused on providing a depth of knowledge about each risk area, while the assessment of potential cascades and connections focused on improved understanding of the breadth of possible interactions within and across these areas. A detailed assessment of the four risk areas is summarized in the table below (See Table 1).

Table 1. Heat, wildfire, water, and air risk assessments



	Qualitative Risk Assessment							
	Description of Key Risk/Cost	Timescale & Intensity					Intervention Potential (TEP)	Perception of Risk
		Short	Medium	Long	Probability	Confidence		
Wildfire	Fire Risk - Proximity to Critical Infrastructure	MED	HIGH	HIGH	LOW	MED	HIGH	HIGH
	Buffel Grass Infestation & Wildfire Risk	MED	MED	MED	MED	HIGH	HIGH	HIGH
	Fire Behavior & Changing Seasonality	LOW	MED	MED	HIGH	HIGH	LOW	LOW
	Debris Flow & Post-Fire Flooding	LOW	LOW	LOW	LOW	LOW	LOW	LOW
	Particulate Matter Concentraion - Smoke & Ash	LOW	MED	MED	LOW	LOW	LOW	LOW
Heat & Climate	Gradual Warming - Increased Peak (daily) Load/Demand	LOW	MED	HIGH	HIGH	HIGH	HIGH	LOW
	Gradual Warming - Infrastructure Wear (O&M Costs)	LOW	LOW	LOW	LOW	MED	MED	LOW
	Extreme Heat - Efficiency (Transmission, Reduced Capacity Factor)	LOW	LOW	MED	LOW	LOW	LOW	LOW
	Extreme Heat - Market Competition - Regional Demand & Possible Outages	LOW	MED	MED	HIGH	HIGH	MED	MED
	Gradual Warming - Social/Community Vulnerability (quality of life)	LOW	MED	MED	MED	MED	LOW	MED
	Gradual Warming - Changing Seasonal Demand	LOW	MED	HIGH	MED	MED	HIGH	MED
Water Availability	Regional Drought & CAP Water Restrictions (e.g. 1075')	LOW	MED	HIGH	LOW	MED	LOW	HIGH
	Regulatory Impacts of Water Resource Management (AMAs, etc.)	LOW	LOW	MED	MED	MED	LOW	LOW
	Regional Drought and Water Availability - Springerville, 4 Corners	MED	HIGH	HIGH	HIGH	LOW	MED	MED
	Water Availability/Competition - PHX Basin	LOW	MED	HIGH	HIGH	HIGH	MED	MED
	Water Availability/Competition - Tucson Basin	LOW	LOW	LOW	LOW	HIGH	MED	MED
Air Quality	Increased Dust, Particulate Matter, & Erosion	LOW	MED	MED	LOW	HIGH	LOW	LOW
	Increased NO.x and O3 (EPA Attainment Status in Phoenix Basin)	LOW	LOW	MED	LOW	MED	LOW	HIGH
	Particulate Matter Concentraion - Smoke & Ash	LOW	LOW	LOW	LOW	LOW	LOW	LOW
	Increased GHG Emissions/Methane (Regionally or more likely - Federal Regulatory Framework)	LOW	MED	MED	MED	HIGH	MED	HIGH

MAPPING RISKS ONTO THE PROBABILITY VS. IMPACT FRAMEWORK

Early in the project, we identified the key risks identified by each UA science team, as well as a summary of the detailed information found in each sub-section. Image 7 provided a useful heuristic that helped map out risks within the context of how much is known about the probability of these impacts, and how great of an impact each risk area is understood to have on climate risk management.

To visualize the information from this chart, we coded the list of 20 risks found in Table 1 (above), into 2 codes for each of the 4 major risk areas.

- Fire_event (specific wildfires),
- Fire_risk (conditions that favor wildfire),
- Heat_warming (gradual change to the system),
- Heat_extreme (extreme heat events and complications)
- Water_availability (drought and other drivers)
- Water_regulatory (water resource management related risks)
- Air_risk (conditions related to air quality and risk)
- Air_regulatory (factors influenced by policy and regulatory frameworks)

We plotted these risks based on probability vs. impact for the entire each timeframe.

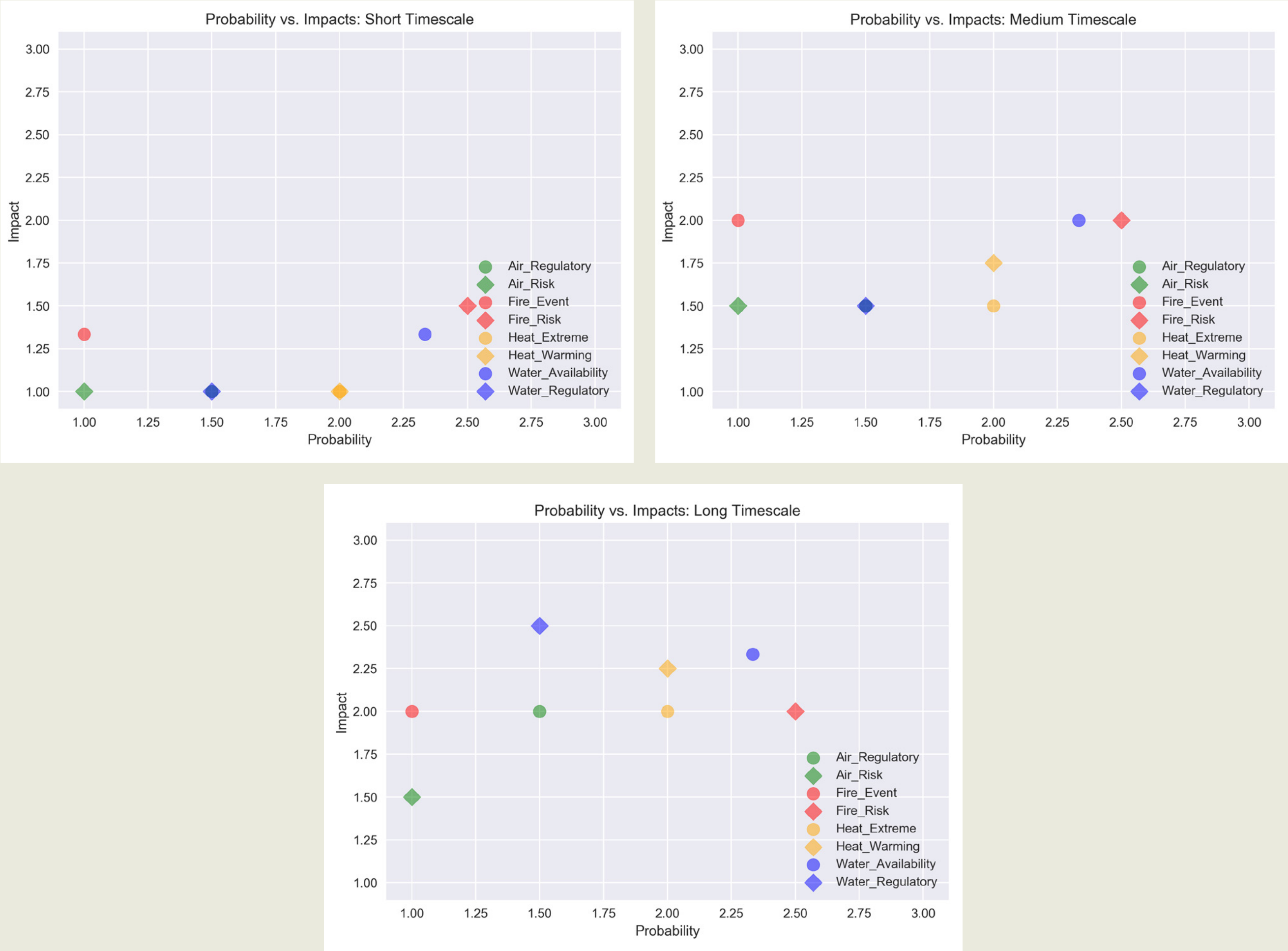


Figure 29. Probability vs. Impact - Short, medium, and long-term timescales

This plotting framework helps identify where the various risk areas fall in terms of their likelihood and the potential scale of their impacts, incorporating both their timeframe and intensity. The risk table (See Table 1) is a helpful first pass as it begins to identify which risks have a higher potential impact and are therefore good targets for intervention. It also helps to position these risks within an assessment of their probability. Additionally, information about the confidence we have in the assessment information can further help prioritize decision-making – i.e. high impact, high probability, high confidence scenarios are an obvious first step. This presentation of data, however, can be problematic as it encourages comparison between the different topical clusters, when the data were not gathered with that specific task in mind. Cluster specific plots of probability vs. impact (See Figures 30-33) give additional perspective on how climate and environmental risks might affect planning and decision-making. These plots visualize risks from the summary table (see Table 1) for each topical cluster area (heat, wildfire, water, air), using the average impact across the short, medium, and long-term timescales.

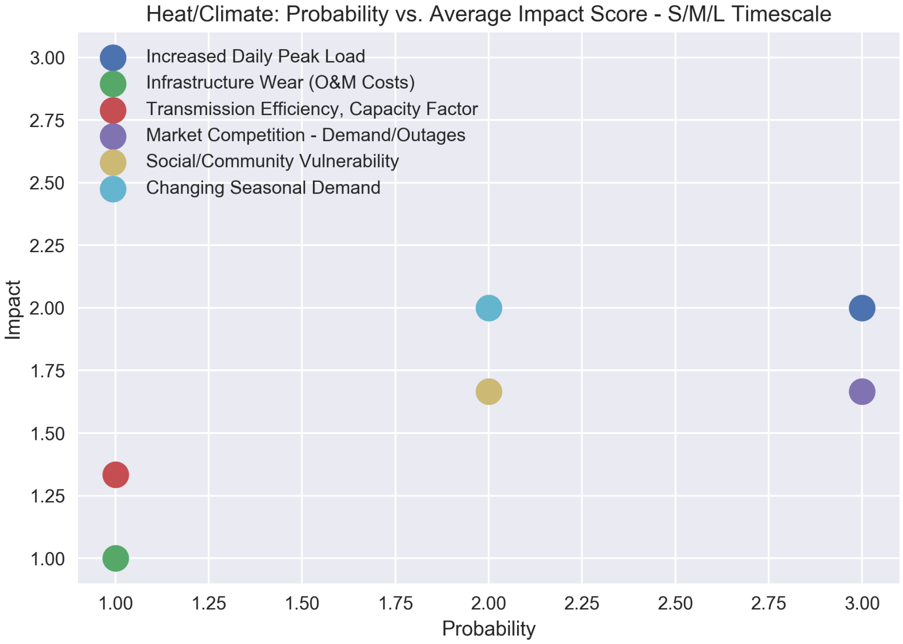


Figure 30. Heat/Climate - Probability vs. Average Impact Score

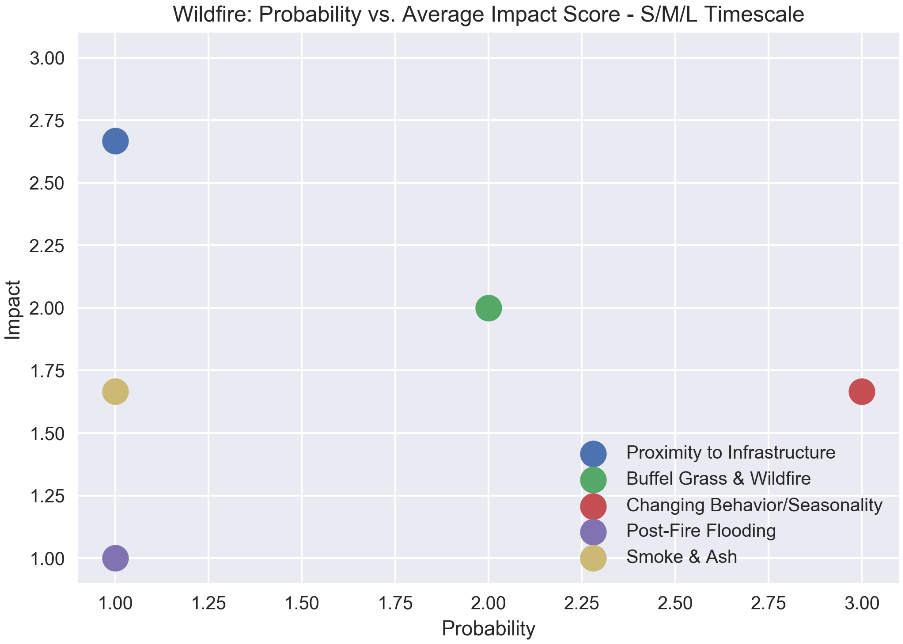


Figure 31. Wildfire - Probability vs. Average Impact Score

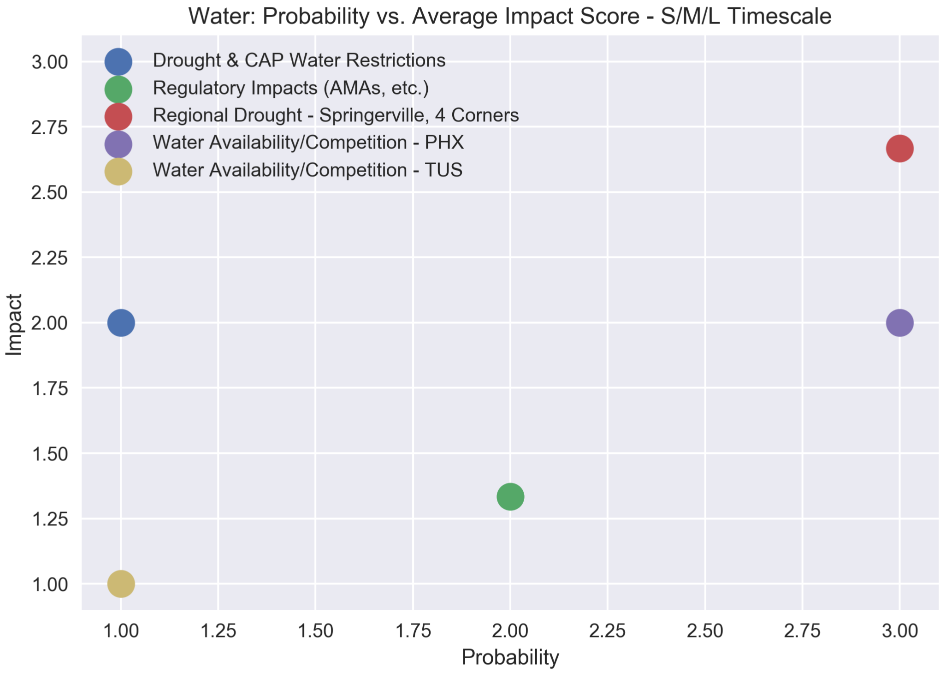


Figure 32. Water - Probability vs. Average Impact Score

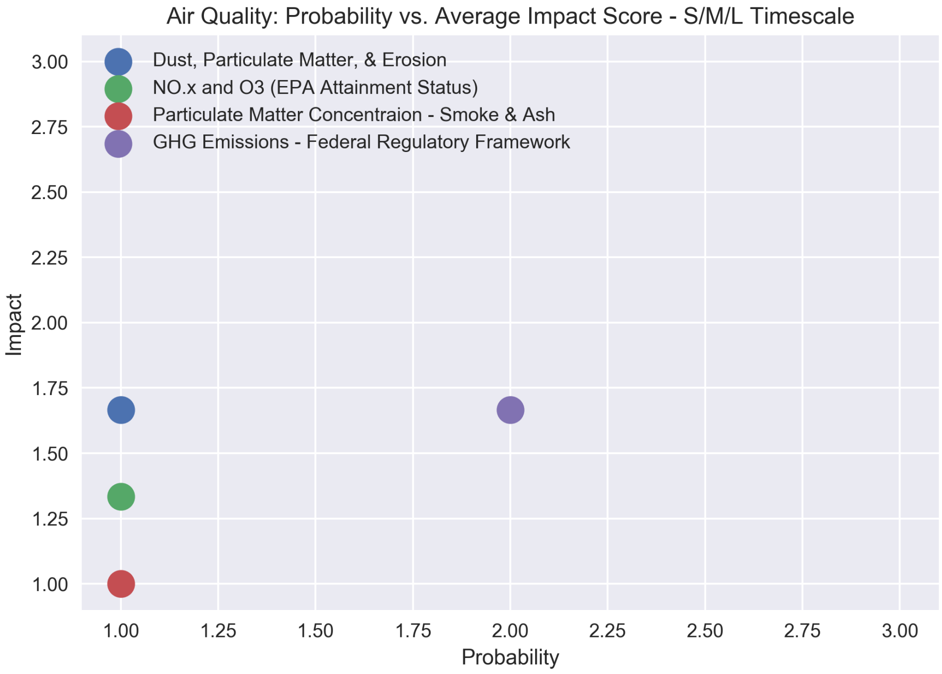


Figure 33. Air - Probability vs. Average Impact Score

SOCIAL AND ENVIRONMENTAL CONTEXT IN CLIMATE RISK MANAGEMENT

The topical assessments were based on information provided by TEP and the expertise of the science teams, and frequently included additional information about underlying conditions and related effects[2] that could alter calculations of risks and management of impacts. We found it useful to explore these interactions within each risk area to identify social and environmental conditions that form the 'input' into a conceptual model (See Figure 34). These antecedent conditions act as a starting point for assessing the impacts of exposure to emergent or ongoing conditions, or in the outcomes of a particular extreme event.

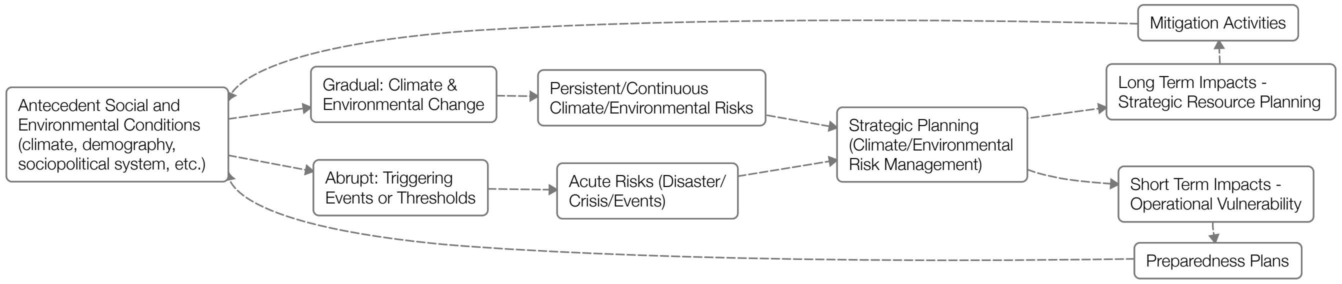


Figure 34. Climate risk management conceptual model

There is an approximate binary that divides these interactions into:

1) ***acute events*** –singular occurrences that are shorter in time frame, have an observable start/stop, and with distinct and bounded outcomes, and
2) ***underlying conditions*** – the persistent social and environmental conditions that form the context for ongoing risk, vulnerability, and opportunity, particularly in the case of gradually changing baseline conditions – as observed regarding climate change observations and projections.

Not all events fit into neatly into this binary,[3] but it provides a useful heuristic for thinking about time scale and mode or manner of intervention. The delineation between an acute event and an ongoing or underlying condition is dependent on the relevant timescale for the risk area under consideration and the analytical question at hand. A broad consideration, however, of the acute or triggering events that might happen in the short term (as defined by the analytical question) and their intersection with underlying conditions (i.e. the baseline conditions the potential for gradual change) are helpful in determining the snapshot of risks now, as well as the potential for future risks and impacts.

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[2] *This includes social phenomena (e.g. demographic change, commercial development, etc.) and environmental conditions (e.g. baseline climate, seasonal and decadal variability, El Niño and La Niña, the SW Monsoon, etc.).*

[3] *Some events are clearly discrete events and "acute" (e.g. a specific wildfire, a flood, or a regional power outage) while others have longer term implications (gradual climate change, multi-year drought, etc.). Many events and circumstances can blur these distinctions – e.g. there can be a short-term water shortage or an interruption in water supply, but most drought in the Southwest is treated as a long-term problem.*

Strategic resource planning and climate risk management must integrate both inputs to adequately anticipate potential future conditions and climate risks associated with gradual change, as well as the implications of specific acute or extreme events. Both are part of a systems-level vulnerability that spans across the Southwest, where electrical generation and utility service are only one (albeit critical) component in the larger regional system that is affected by social factors including demographic change, political trends, and commercial market pressures, as well as environmental factors including baseline climate, climate trends, and drought.

Within each risk area, antecedent conditions are sorted into three key areas:

1) ***Background Climate*** – the relatively stable and persistent climatic and environmental conditions that serve as a baseline for climate risk assessments. Observations (looking back) and projections (looking forward) inform the trend line of changing climate that alters these baseline measures over time. Of particular importance are daily and monthly average temperature, precipitation trends and seasonal climate forecasts (including the role of El Niño and La Niña on drought and water resource management), and changing seasonality associated with climate change (e.g. longer summers with warmer nighttime temperatures)
2) ***Population and Demographic Factors*** – the dynamic social conditions that can quickly alter the context or implications for a given environmental risk. Long term measures of demographic and economic variables identify general trends, but this category is also subject to more rapid change associated with shorter-term ebbs and flows of economic development and demographic change. Of particular importance is how much the regional population is projected to grow, where this growth is forecast to occur, and whether sufficient resources are available to support this growth.
3) ***Short-term Weather Events*** – the random variation around climate trends that generally fall within a range of expected values, but are very difficult to predict more than 7-10 days in advance. Within the context of climate change, the range of expected values is shifting, and in particular the timing and duration of the hot season (changing seasonality of summer), the average daily high and nighttime low temperatures during summer, and the timing and severity of precipitation events during the Southwestern monsoon (summer) and over winter.

The intersection of these 3 inputs were integrated into assessments of the network of related effects of how the social and environmental context informed: 1) the observed events of predicted outcomes, and 2) the predicted or observed impacts – either the persistent effects of these relationships, or in cascading effects that propagated through this system (See Figure 35).

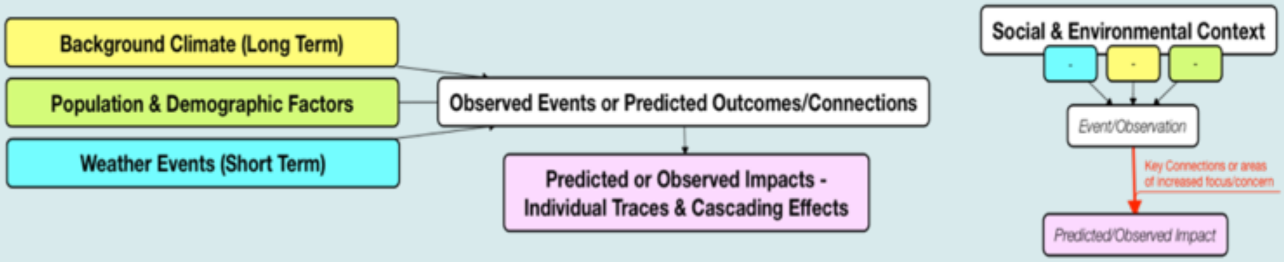

Figure 35. Socio-environmental, meteorological input/impact schema

Heat: The impacts of increased heat and a changing climate are generally associated with gradual increases in baseline temperatures as well as the lengthening of the summer high temperature season (See Figure 36). This presents a unique circumstance where this increase is both a risk and an opportunity for increased revenue. The increases in temperature during the peak of summer are a risk given the increased demand for seasonal load and the increased water resources that might be required, so both the implications of an outage and the resource requirements to meet the increased demand must be included. However, the increased duration of warmer summer temperatures (especially during mid to late spring) present an opportunity for increased revenue as demand for utility service will increase as interior climate control are used earlier across the region. The increase in baseline temperatures are also linked to regional water resource availability - as snowpack is reduced and hydrological patterns are altered based on increased temperatures and decreased winter precipitation; and air quality – where NOx and O3 formation are correlated with seasonal increases in temperatures.

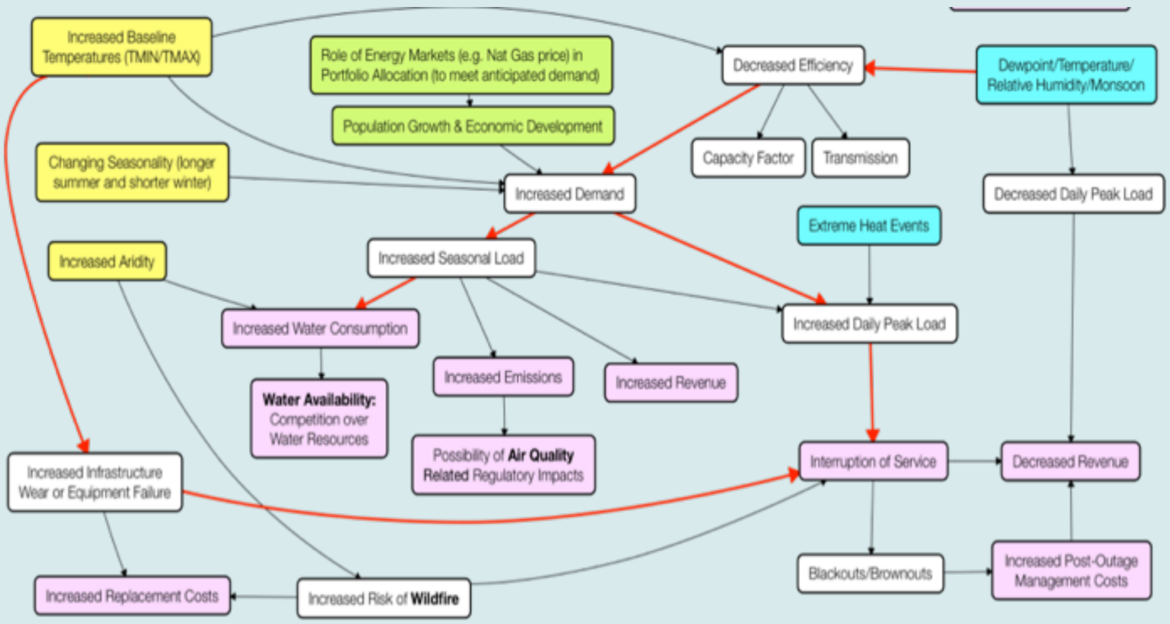

Figure 36. Heat/climate change impact linkages

Wildfire: Wildfire results in one of the most complicated networks of risks and effects given the diverse inputs and impacts associated with wildfire, including increased temperatures, drought, population increases, and a history of fire suppression (see Figure 37). Recent wildfire events in the Southwest serve to highlight the far-reaching connections and implications of wildfire in the Southwest. The critical paths within this network highlight the spread of invasive species, and buffelgrass in particular, as a key driver of increased risk of wildfire frequency and intensity (along with baseline climate and drought inputs). This increased risk of wildfire frequency and intensity intersects with infrastructure risk and facilities management in two ways. The first is the increased risk of damage-to or loss-of regional transmission infrastructure and local distribution infrastructure, and the second is the potential for shorting or arcing lines if heavy smoke or soot/ash plumes affect transmission lines. Both of these events would result in local or regional power outages. If these outages occur in conjunction with regional extreme heat events on top of sustained increases to baseline temperatures, this could result in a number of adverse outcomes, ranging from increased costs of procuring sufficient load to meet regional demand, along with potentially severe external social and economic consequences if the outage persisted over multiple days or weeks during the peak of summer heat.

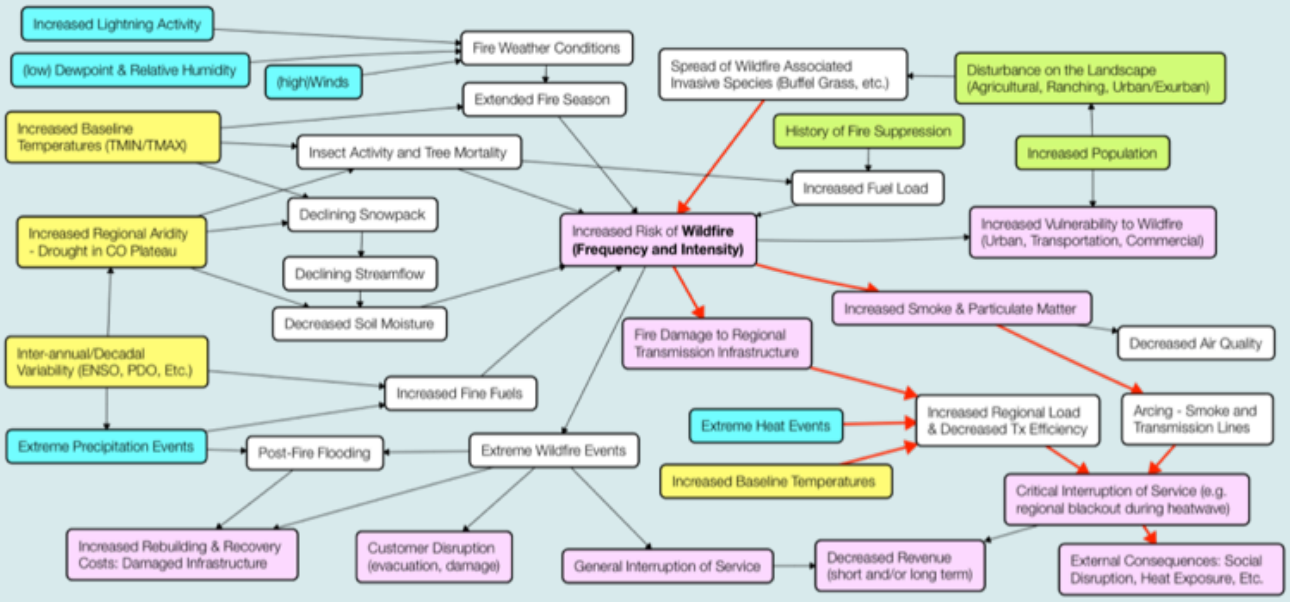

Figure 37. Wildfire inputs and impacts

Water: Water availability concerns are strongly influenced by temperature - where increased temperature affects snowpack, streamflow, and alters the timing of water resource storage. The location and availability of water resources is one of the more critical components determining risk and vulnerability going forward given the number of inputs that affect water storage and availability (climate/temperature, weather, drought, seasonal/decadal variability) and the demands placed on water resources by agricultural, municipal, and commercial interests (See Figure 38).

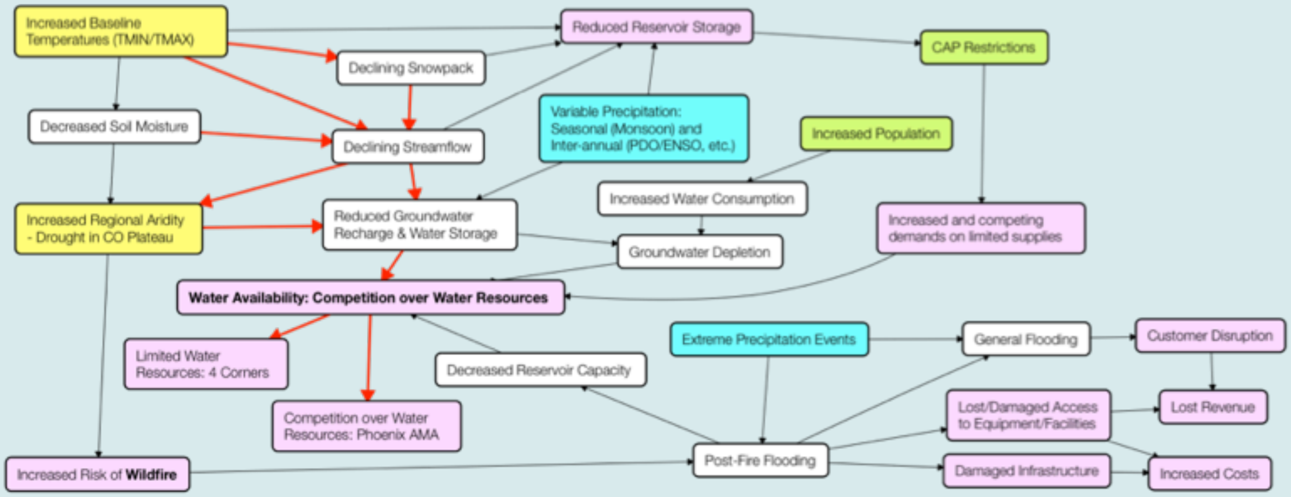

Figure 38. Water inputs and conflicts

Air: While air quality concerns do have specific management implications for regional pollution standards (e.g. NOx and O3 EPA attainment values) utility generation activities are a very small contributor to the overall NOx load in areas subject to these regulations. This does not eliminate these concerns from strategic planning activities, but means that in the absence of other contributing factors (policy change, specific air quality events such as wildfire or dust), there is limited potential for catastrophic cascades in the near term (Figure 39).

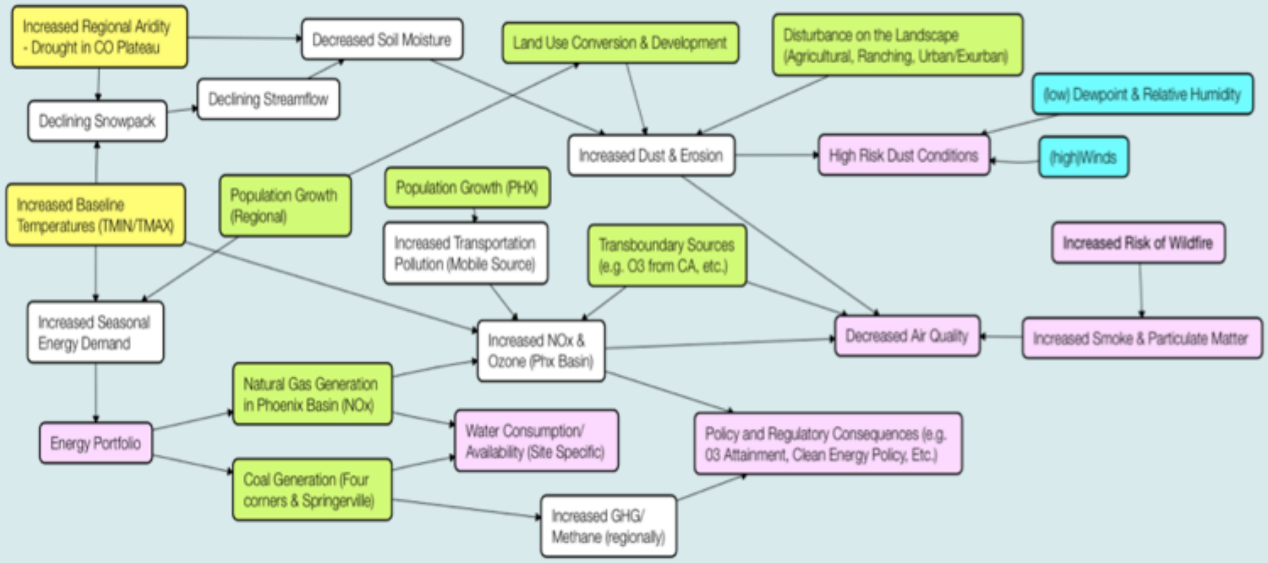

Figure 39. Cascading effects

CASCADES AND SYNTHESIS

Our four risk areas are case studies for how networks of interrelated environmental phenomena overlap and intersect to amplify possible impacts of each risk area. They also illustrate how these impacts must be understood within the social and environmental contexts, of which climate risk management is a key component in addressing both short term (acute) exposure, and the long-term (chronic) risks. The conceptual models for each of the risk areas help reveal some consistent themes that arose from this process.

First, these exploratory assessments serve as information gathering and analysis exercises that produce more information on the **implications for specific courses of action** – these are decision points that are created or informed by new information that might be affected by policy, regulations, management or risks. By planning out various pathways of how environmental risks and impacts might propagate, this allows for better planning that responds to short-term needs as well as long-term planning concerns. For example, the decision to build or invest in a new generating station has short term costs and benefits associated with material investment costs, but this decision also has long-term implications tied patterns of water availability (i.e. is the new or old location more vulnerable to water competition?); regulatory frameworks (i.e. what is the local NOx pollution/regulatory context and how might that affect long term costs and benefits?); and infrastructure needs/risks (i.e. how are environmental risks managed in the new site vs. the old site, what are the implications for change?.

Second, these exploratory assessments also reveal the value of information about the **impact of future environmental conditions** – namely how the current and future climate (hydrology, temperature, precipitation, seasonality, streamflow, air quality, etc.) will affect decision-making on the relevant timescale. For example, the climate of the Southwest is dynamic and changing, but current trends indicate gradual warming and increased uncertainty about precipitation and drought regarding intensity, timing, etc. The risks embedded in this gradual change may affect short and long-term decision-making. Ongoing assessment of how conditions are changing, and what these changes mean over different timescales of decision-making and planning is a crucial part of ongoing climate risk management.

Third, this process has highlighted the possible impact of **often unexpected (yet entirely plausible) extreme events** - these events exist at the confluence of cascading impacts within the aforementioned network of related effects. While extreme events are generally rare, the scale of their impacts can have outsized effects on the regions or industries affected by them. The scale of their impacts can also alter risk perception going forward, despite their relatively infrequent occurrence (i.e. high visibility high impact events last longer in memory than frequent or gradual low impact events or changes). For example, wildfire exacerbated by drought and warming climate, intersecting with population growth and dependency on climate control, can increase vulnerability within the electrical grid. This sets the stage for a possible disaster if a particular chain of events happens all at once. Planning for these potentialities is a key part of preparedness within the emergency management community. Climate risk management within a company or organization will likely not have the capacity to respond to extreme events. Risk management efforts that seek to mitigate links in these chains of events however, could help reduce overall risk/exposure without attempting to address the risks in the entire system.

SCENARIOS: INTERACTIONS ACROSS THE FOUR RISKS

Cascading and interconnected risks are generally not isolated to a specific risk cluster, but instead span across two or more of these clusters, and risks embedded within the system are frequently a result of complex linkages within the larger system of water resource management, electrical service delivery, energy portfolio management, demographic pressure, and baseline and changing climatic conditions in the Southwest. The following examples illustrate the ways that planning and decision-making can be both informed and further complicated by these overlaps.

Example 1: Heat, Climate Change, and Long-Term Planning

Future environmental conditions

While the increased duration of summer temperatures may result in increased revenue, increases in baseline temperature are a fundamental input to a number of short-term concerns and long-term resource planning decisions. In the short to intermediate term, increased temperatures are the fundamental driver for summertime demand for electricity, and these demands are part of larger built environmental system that buffers Southwest residents from climate extremes. An outage within this context would put a large percentage of the regional population at risk, along with social disruption and economic loss attached to the outage. If the outage were sustained, owing to equipment loss or damage as in the case of a wildfire, an extended outage would have much higher potential to disrupt than a short-term outage of a few hours. The overlap of extreme heat with other conditions that might interrupt service provide the most severe immediate consequences. Extreme heat, however, also has implications for longer term management and planning. The effect of increased temperatures on water storage and supply, and demand for these resources, will be another aspect of increased heat that is of critical interest, but requires additional data and information to make more refined conclusions. Similarly, the relationship between heat and air quality is likely to be a persistent concern going forward. The current regulatory framework is unlikely to affect utility operations in municipal areas (like Phoenix), given the majority of ozone is linked to single occupancy vehicle traffic, but were the regulatory framework to shift, this could be a future liability.

Example 2: Water Resource Availability and Competition

Implications of specific courses of action

Competition over limited water resources provides a much more immediate factor to track in both the short term and longer-term planning horizons. A move away from coal fired generation in the four corners region takes place within the larger shifts in environmental regulatory frameworks (e.g. the EPA and CPP), and while current EPA plans are on hold pending further review, these types of regulatory cost and limitations may occur in the future. Therefore, incorporating their role into assessments of risks, costs, and benefits is a key part of climate risk management that not only assesses and responds to possible risks, but takes advantage of emergent market opportunities. The move towards natural gas generation in the Phoenix basin also reveals potential vulnerabilities, the first of which is water resource availability, and competition over limited water resources in this area, especially given demographic growth in the region. The second is the potential future regulation of NOx and O_3 attainment status – and even though natural gas generation is shown to be a small contributor to the overall NOx/O_3 levels in the Phoenix basin (see air quality section above), as a highly visible point source of these compounds. It remains important to monitor changes in regulatory frameworks as well as public and political attention paid to these risks.

Example 3: Wildfire in the Southwest – Wallow fire and utility load

Unexpected but plausible confluence of "rare" events

Wildfire in the Southwest reveals a final example where instead of exposure to ongoing climate and environmental risks (as outlined in Example 1 above), or policy specific concerns about resource availability (as outlined in Example 2 above), specific events can reveal underlying environmental risks and infrastructural/systemic vulnerabilities. The 2011 Wallow fire in the White mountains of Arizona raised specific concerns about systems level vulnerability as it relates to specific infrastructural damage that might degrade or destroy regional transmission capacity, as well as the regional impacts that would result if widespread areas would lose access to power for days or weeks following fire damage. As the Wallow fire burned, there was some concern that it might threaten one of the two major transmission lines that feed into Tucson. Contingency plans were thought to be sufficient to handle alternative transmission plans so that regional communities (e.g. Tucson) would not lose electrical utility service. This event, however, did raise concerns about what might happen if fire events were to impact both of the major transmission lines into Tucson, and highlighted the value of ongoing and additional planning that incorporates these high impact low probability scenarios into ongoing climate risk management activities.

Interconnected effects are often most visible during acute events that verge on (or veer into) disaster, as the event itself is bounded, and the consequences and aftermath are relatively easy to attribute directly. Another example is summer 2011, when a simple human error resulted in multiple hours of power outage across southern California and Southwestern Arizona (AP, 2011). In this case, the error event initiated a cascade of subsequent events through the regional electrical distribution grid, resulting in numerous power outages and interruption of service across the region. This triggered a secondary chain of related effects, all of which were the result of the power outage (e.g. food spoilage, disruption of traffic, wastewater treatment plant dumping raw sewage, etc.), and these events shaped the experience of persons, organizations, and institutions that were responding to the blackout. Interconnected effects can also occur as a result of slower moving or gradual changes.

MANAGING RISK AT TEP: WHAT DOES A NETWORK OF INTERRELATED CLIMATE RISKS AND EFFECTS REVEAL?

To further assess this question, the UA ABRI team held a science team workshop to share major components and connections documented by each UA science team. We focused our interactions with TEP on the three following key points. An assessment of the network of related effects and possible cascades was designed to:

- Inform specific TEP policy decision points tied to strategic planning (internal) and how they assessed role of regulatory frameworks (external);
- Identify the impact of changing environmental conditions (e.g. temperature, precipitation, air quality, etc.) and to further identify prospective analyses that better inform emergent questions; and
- Target interventions and management decisions focused on ongoing or prospective mitigation and adaptation actions where the high-risk areas are, and where are the areas with the most room for mitigating climate risks might exist.

There are challenges of managing risk in a complex system with multiple inputs that can influence ongoing strategic planning. Many of these factors are external to TEP's management and operations, in that they are conditions that are outside the TEP's control, but that directly affect TEP's strategic resource planning. Looking at some of the key risk areas based on intervention potential will help reveal areas where investment might address more pressing issues versus other risk areas where ongoing maintenance and monitoring might be most helpful.

Here, we present the results of a simple coding exercise that attached the risks listed in the table above, to a set of codes that reflect overarching risk areas relevant to utility level management: Infrastructure, Data-Needs, Market Drivers, Regulatory Impacts, and overall Environmental Risks. To visualize these different codes, we plotted Probability times Impact on the x axis, and Intervention Potential on the y axis. The x axis value is a broad approximation of the overall impact of the risks listed, given overall probability and overall impact (See Figures 40-44). The intervention potential is a simple assessment based on information derived from the UA science teams that identified areas where there appeared to be actions that could either generate additional information that would further help with decision-making and planning, or would actually identify possible adaptation actions that would help mitigate the risks associated with these coded areas.

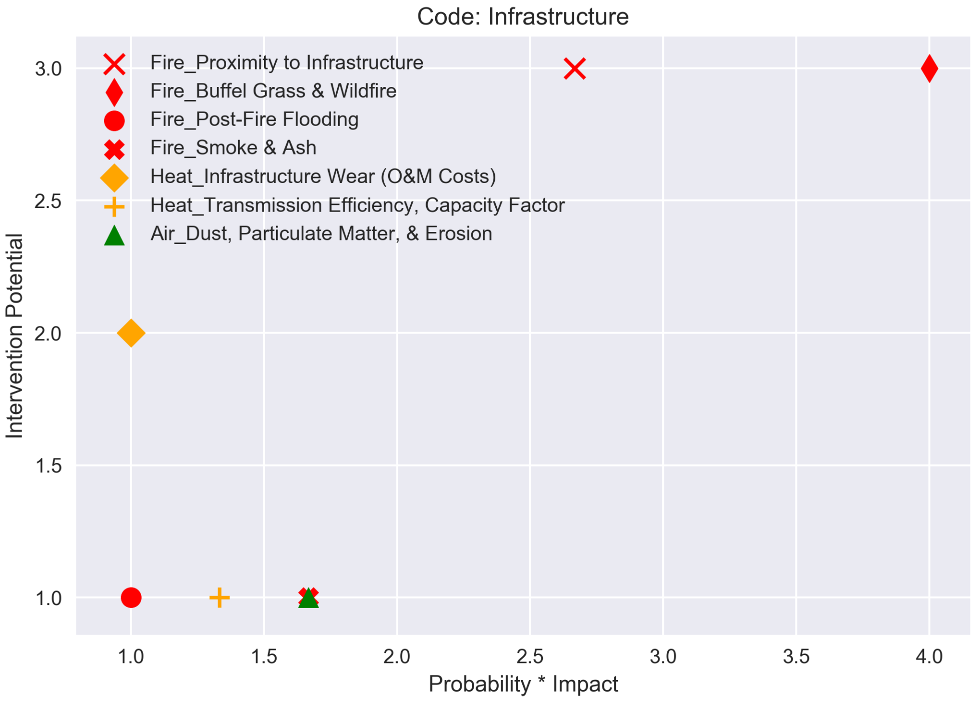

*Figure 40. Code: Infrastructure - Probability * Impact vs. Intervention Potential*

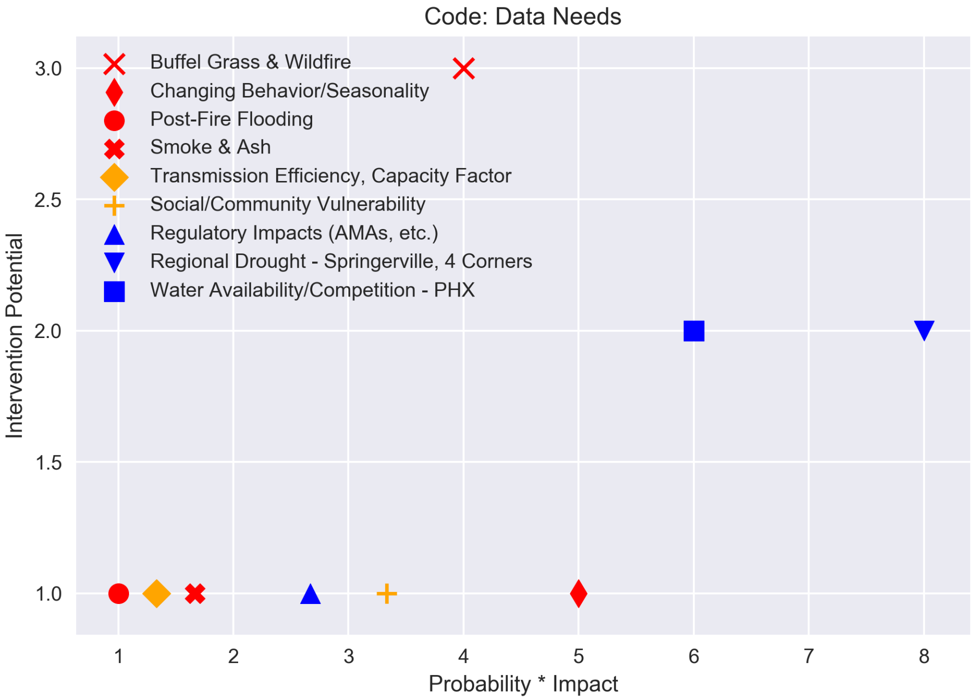

*Figure 41. Code: Data Needs - Probability * Impact vs. Intervention Potential*

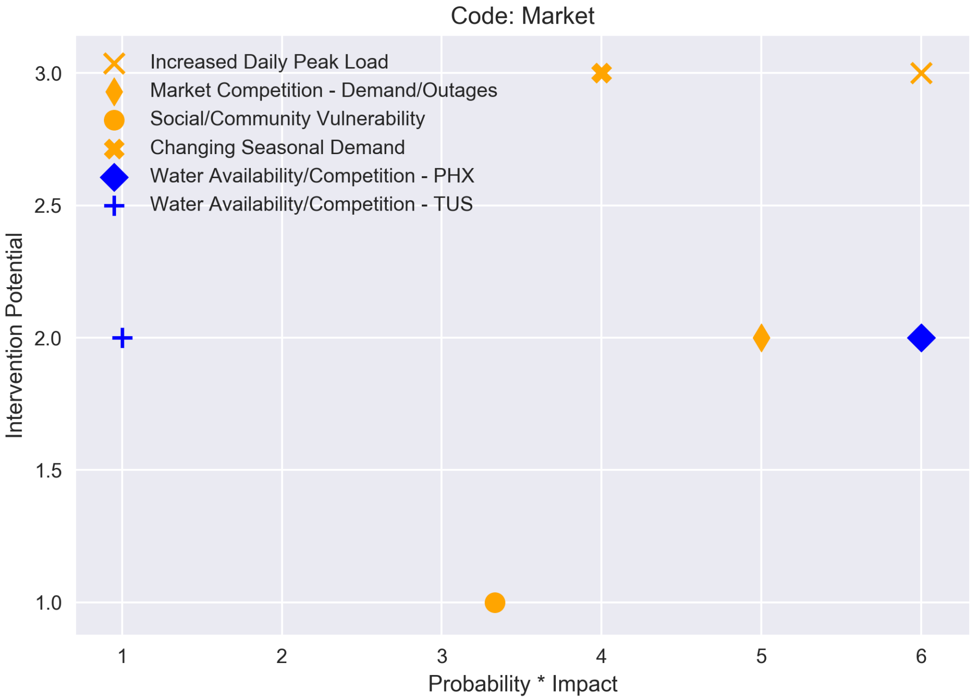

*Figure 42. Code: Market - Probability * Impact vs. Intervention Potential*

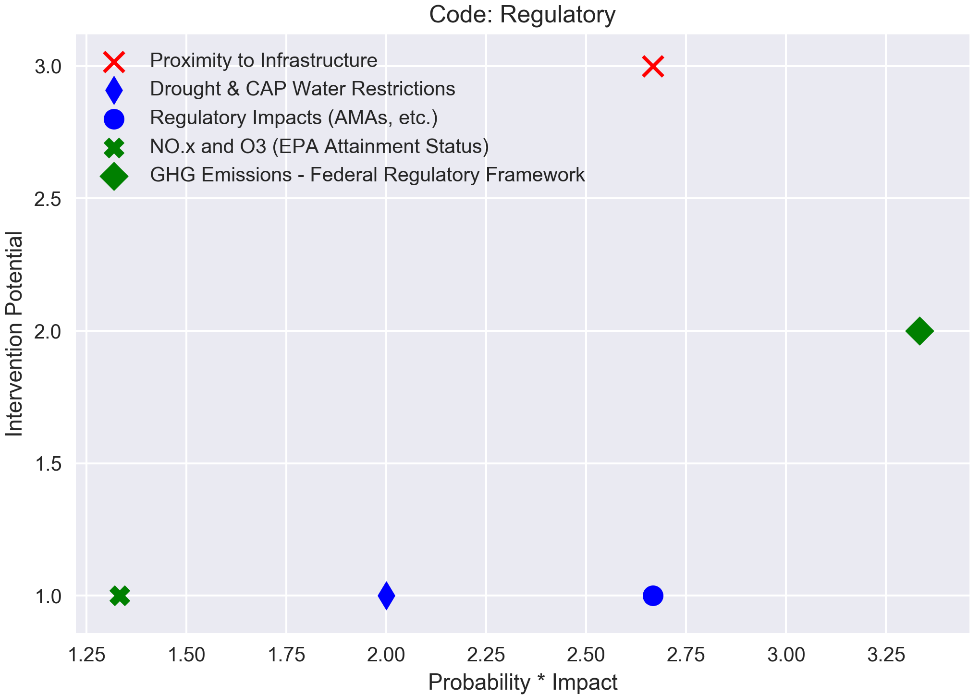

*Figure 43. Code: Regulatory - Probability * Impact vs. Intervention Potential*

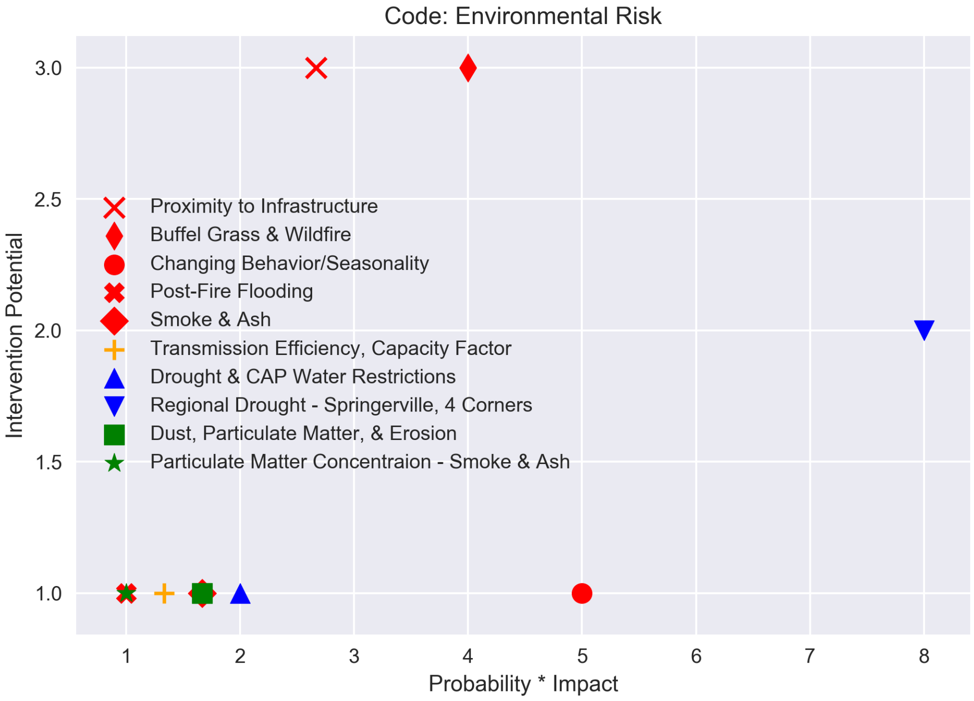

*Figure 44. Code: Environmental Risk - Probability * Impact vs. Intervention Potential*

RECOMMENDATIONS

	Recommendations: Further Research	Recommendations: Adaptation Actions
Heat/Climate	More precise temporal and spatial models of temperature trends (change over time) as well as the distribution of climate extremes (e.g. GIS maps of temperature hotspots) to identify high risk areas for infrastructure stress.	Increased demand response and energy efficiency to reduce demand at peak hours.
	Incorporation of historical climatological data (as well as projections) to calculate wind to determine if assumptions about convective cooling potential (for passive cooling of infrastructure) are accurate or will change over time.	Deploy newer technologies that have higher temperature ratings and software upgrades for load shedding at feeder circuits to protect equipment during heat waves.
	Better characterizations of the downstream impacts that climate/temperature change could have on other components of this system – specifically in terms of wildfire risk and effect on air quality (NOx), but also general precipitation patterns that might affect water storage, dust concerns, wildfire risk, etc.	
	Updated/improved heat extreme characterizations for the southwest, including further research to understand what a Southwest heat wave looks like, including the projected average and extreme temperatures, and how changing seasonality might extend summertime temperature profiles.	
Wildfire	Expand research and mapping of buffelgrass and other invasive, fire-adapted species	Utilize LANDFIRE fuels data in fire models such as FlamMap to predict rate of spread or crownfire potential under a user specified weather scenario
	Identify thresholds of particulate matter concern	Monitoring current fires and their progression through https://fsapps.nwcg.gov/googleearth.php
	Assess emission projections by fuel type & determine effects of fuel modification on emissions	Monitor wildfire hazard potential through https://www.firelab.org/project/wildfire-hazard-potential
		Utilize BlueSky or VSmoke to identify smoke emissions projections for specific ignition points
Air	Assess the role of changing seasonality (longer summers) to formation and persistence of NOx, even though utility contribution is proportionally small	Recognize that increasing urban populations may increase non-stationary point sources of NOx (cars, AC units, etc.)
	Monitor how fuel mix could affect NOx/VOC contribution to emissions, and intermittently assess the current state of knowledge re: natural gas contributions to NOx/VOC emissions	Monitor future NOx emissions to observe potential increase as a result of fuel mix
	Monitor political dynamics regarding regulatory frameworks to assess risk and vulnerabilities associated with coal vs. natural gas vs. renewable energy, and assess the willingness of customers to pay more for "clean" energy to encourage investment in renewable energy	Monitor potential methane leaks
Water	Expand research on water availability and use in Arizona	Develop a monitoring plan to evaluate groundwater levels in the vicinity of all power plants in the state – both those that TEP has an interest in, and others, because this may lead to a competitive advantage for some plants over others
	Work with water utilities in the Tucson region to develop a better understanding of the energy-water nexus and implications for hazard mitigation that come from the connections between these systems	Communicate on a regular basis with ADWR and ADEQ to indicate interest in managing the water supplies and monitor changes in water quality and water quantity over time. Monitor potential changes in groundwater laws that could lead to relaxation of the current protections for TEP's groundwater rights
	Further explore hybrid cooling and other water conservation technologies	Monitor drought conditions on the Colorado River and changes in water allocations within Arizona

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Figure 3: TEP, 2017. IRP at https://www.tep.com/wp-content/uploads/2016/04/TEP-2017-Integrated-Resource-FINAL-Low-Resolution.pdf

Figure 4: APS Statewide Service Territory Map. Retrieved from: https://www.aps.com/en/communityandenvironment/economicdevelopment/Documents/APS%20Statewide%20Service%20Territory.pdf

Figure 5: TEP, 2017. IRP at https://www.tep.com/wp-content/uploads/2016/04/TEP-2017-Integrated-Resource-FINAL-Low-Resolution.pdf

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Figure 13: Made by authors.

Figure 14: WECC, Overview of 2013 Systems Operations Workshop.

Figure 15: TEP, 2017. IRP at https://www.tep.com/wp-content/uploads/2016/04/TEP-2017-Integrated-Resource-FINAL-Low-Resolution.pdf

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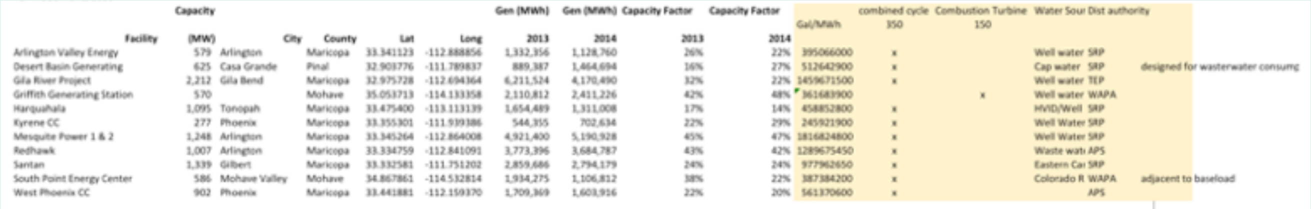
APPENDIX

TEP NGCC Plants 2016



	Capacity					Gen (MWh)	Gen (MWh)	Capacity Factor	Capacity Factor		combined cycle	Combustion Turbine	Water Sour	Dist authority	
										Gal/MWh	350	150			
Facility	(MW)	City	County	Lat	Long	2013	2014	2013	2014						
Arlington Valley Energy	579	Arlington	Maricopa	33.341123	-112.888856	1,332,356	1,128,760	26%	22%	395066000	x		Well water	SRP	
Desert Basin Generating	625	Casa Grande	Pinal	32.903776	-111.789837	889,387	1,464,694	16%	27%	512642900	x		Cap water	SRP	designed for wasterwater consumg
Gila River Project	2,212	Gila Bend	Maricopa	32.975728	-112.694364	6,211,524	4,170,490	32%	22%	1459671500	x		Well water	TEP	
Griffith Generating Station	570		Mohave	35.053713	-114.133358	2,110,812	2,411,226	42%	48%	361683900		x	Well water	WAPA	
Harquahala	1,095	Tonopah	Maricopa	33.475400	-113.113139	1,654,489	1,311,008	17%	14%	458852800	x		HVID/Well	SRP	
Kyrene CC	277	Phoenix	Maricopa	33.355301	-111.939386	544,355	702,634	22%	29%	245921900	x		Well Water	SRP	
Mesquite Power 1 & 2	1,248	Arlington	Maricopa	33.345264	-112.864008	4,921,400	5,190,928	45%	47%	1816824800	x		Well Water	SRP	
Redhawk	1,007	Arlington	Maricopa	33.334759	-112.841091	3,773,396	3,684,787	43%	42%	1289675450	x		Waste wat	APS	
Santan	1,339	Gilbert	Maricopa	33.332581	-111.751202	2,859,686	2,794,179	24%	24%	977962650	x		Eastern Ca	SRP	
South Point Energy Center	586	Mohave Valley	Mohave	34.867861	-114.532814	1,934,275	1,106,812	38%	22%	387384200	x		Colorado R	WAPA	adjacent to baseload
West Phoenix CC	902	Phoenix	Maricopa	33.441881	-112.159370	1,709,369	1,603,916	22%	20%	561370600	x			APS	

Source: TEP, ND.