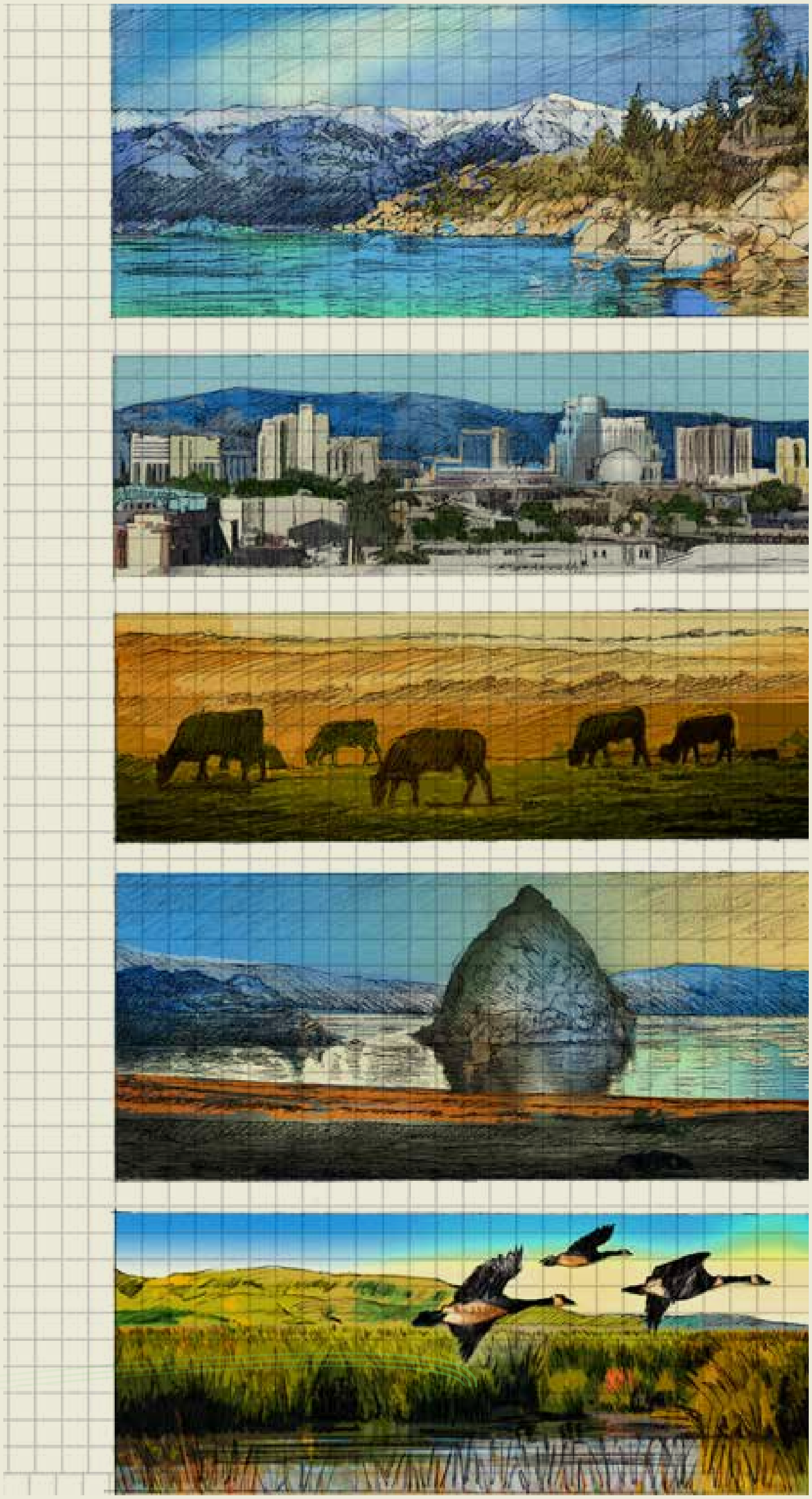
Assessing the Climate Resiliency and Adaptive Capacity of the Truckee-Carson River System



WATER For The SEASONS

"A Program for Sustaining Water Resources in a Changing Climate"

Preliminary Results of a Survey of Local Organizations

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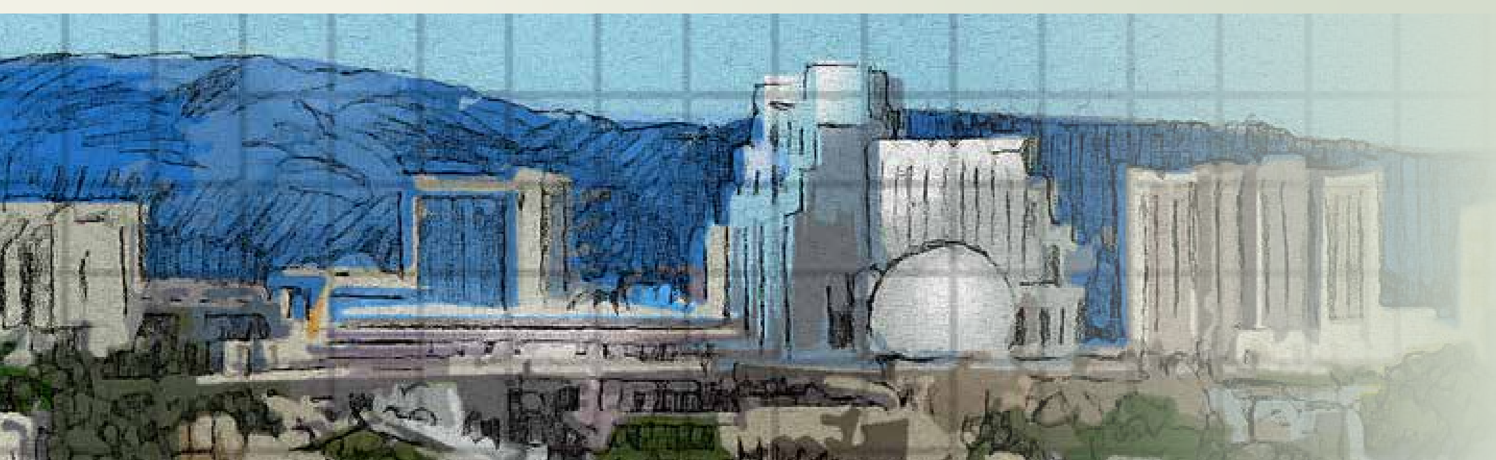

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__Water for the Seasons__ partners scientists with community stakeholders in the Truckee-Carson River System to explore new strategies and solutions for dealing with extreme climate events, such as droughts and floods. Funded by a grant from the National Science Foundation and the U.S. Department of Agriculture, this four-year research and outreach program uses a collaborative modeling research design that strategically links scientific research with community problem-solving. The goal of this program is to assess and enhance community climate resiliency in snow-fed arid-land river systems.

INTRODUCTION

Management of snow-fed arid-land river systems in the western United States has taken on critical importance in response to the impact of variable climate conditions on water supply. In snow-fed arid-land river systems such as the Truckee-Carson River System, the timing and duration of snowpack accumulation and spring runoff are critical factors driving the region's water availability throughout the seasons. Anticipated variability in these hydrologic processes may expose the region and its communities to increased vulnerability to prolonged drought, increasing temperatures and flood events (Kleppe et al. 2011). Assessing and enhancing climate resilience means identifying the ability of the Truckee-Carson River System to absorb the impacts of extreme climate events and to recover, or bounce back, from these impacts.

Collaborative Modeling

Creating effective community responses to improve resilience to extreme climate events, such as prolonged drought, requires acknowledging and understanding the interaction between human and natural systems. Collaborative modeling is one way of inviting public participation into climate science research to facilitate and encourage adaptation strategies for all communities within the river system.

In *Water for the Seasons,* collaborative modeling links scientific research with community problem-solving to produce knowledge useful to both local organizations and scientists striving to improve translation of technical findings related to water resources.
Programmatic goals are to:

- Evaluate Truckee-Carson River System vulnerabilities to climate variability;
- Assess the resilience of the river system's communities, and related decision-making, under climate extremes; and
- Enhance the capacity of these communities to strengthen resiliency and adaptive capacity.

Stakeholder participation in *Water for the Seasons* research occurs through a: 1) survey of local water management/interest organizations to assess the river system's resilience and adaptive capacity and to use these survey data to develop plausible climate scenarios for hydrologic modeling of system vulnerability; 2) survey of water right holders to assess individual decision-making with regards to adaptive capacity and strategies; 3) series of structured workshops that convene scientists with key organizational stakeholders to further assess system resilience and explore ways to enhance adaptive capacity; and 4) series of focus group discussions with key local stakeholders to iteratively identify adaptive strategies in response to the results of stakeholder-informed climate scenarios and hydrologic models. This collaborative modeling research design adopts best practices established to date to support effective participatory research (Butler & Adamowski, 2015; Meadow et al. 2015; Langsdale et al. 2013; Sandoval-Solis et al. 2013; Bourget, 2011).

This Special Publication reports the preliminary results of the first phase of stakeholder participation – a survey of 66 organizations with water management responsibilities or interests in the Truckee-Carson River System. The publication provides a brief background of the river system, describes the development and implementation of the survey of organizations, summarizes key survey findings, and explains how these findings are used to further assess system resilience and adaptive capacity.

Truckee-Carson River System: A Brief Background

The Truckee and Carson Rivers originate in the Sierra Nevada, and rely on winter snowpack and spring runoff as the primary sources of water (see Figure 1). The Truckee-Carson River System is the primary water supply for several urban and rural/agricultural communities of northern Nevada, and is a representative system for understanding the impacts of climate change on snow-fed arid-land river systems.

The Truckee River Basin encompasses an area of approximately 3,060 square miles (1,958,400 acres) in the states of California and Nevada. The Truckee River begins in the Sierra Nevada, flowing approximately 120 miles from Lake Tahoe, California to Pyramid Lake, a desert terminus lake located in northwestern Nevada.

Climate vulnerability *refers to a system's physical predisposition to adverse impacts due to extreme climate events and varies based upon operational rules as well as cultural, socioeconomic, demographic, geographic, institutional and environmental factors. Efforts to evaluate system vulnerability include all of these dimensions (IPCC, 2012). An example of a vulnerable system might include a coastal city inundated with water due to rising sea levels (IPCC, 2007).*

Climate resiliency *is the ability to adapt or respond effectively in the face of extreme climate events. In a climate-resilient community, stakeholders understand, acknowledge, anticipate and absorb extreme climate events, and possess the capacity to reorganize as necessary to maintain essential community functions and identity (Moench, 2014).*

Adaptive capacity *refers to a system's capacity to cope with extreme events or shocks as well as the ability to adaptively manage responses to climate extremes over time. Cultural, political, socioeconomic and environmental factors all interact to influence adaptive capacity (Smit and Wandel, 2006).*

Nearly 25 percent

of the basin is within the State of California, while the remaining 75 percent is within the State of Nevada. Within the Truckee River Basin, the Lake Tahoe Basin is a major sub-basin approximately 506 square miles (323,840 acres), comprising roughly 17 percent of the Truckee River Basin's total area (Horton, 1997). The Truckee River historically terminated in Pyramid Lake, but since completion of Derby Dam in 1905, more than half of the flows of the Truckee River have been diverted to the Lahontan Reservoir in Churchill County, where it has been used, along with Carson River water, for irrigated agriculture (Wilds, 2014).

The Carson River flows approximately 184 miles in length from its headwaters located south of the Lake Tahoe and Truckee River basins in Alpine County, California. Its east fork originates on the slopes of Sonora Peak (11,000 feet); the west fork originates near Carson Pass. The two forks of the Carson River flow north to cross the Nevada border and merge in the Carson Valley, where the water is used to irrigate farmlands in Churchill and Douglas Counties (Wilds, 2014). The Carson River Basin includes a 3,966 square mile or 2,538,230-acre area. Nearly 15 percent of the Carson River Basin's total area is located within the State of California, while the remaining 85 percent (3,360 square miles/2,149,680 acres) is located within the State of Nevada (Horton, 1996). The Carson River naturally flowed to its natural terminus in the Carson Sink. However, starting in 1915, the waters of the Carson River have been captured and stored in Lahontan Reservoir, constructed by the U.S. Bureau of Reclamation (Wilds, 2014).

Within a relatively small geographic area, the Truckee-Carson River System encompasses the major elements of water supply and demand issues facing communities throughout the intermountain western United States, including increased municipal water demand to support economic development, water allocation for agricultural irrigation as determined by historical appropriation doctrine, and increasing needs to protect stressed ecological systems (Wilds, 2014). In addition to the Lake Tahoe Basin watershed and ecosystems, the Truckee-Carson River System encompasses the municipalities of Reno-Sparks, Fernley, Fallon, Carson City, Dayton and Silver Springs; the largest industrial park in the nation; the Carson Sink; a federal wildlife refuge; and Pyramid Lake, a natural desert terminus lake that is located on the Pyramid Lake Paiute Tribe Reservation and home to an endangered species of fish called the Cui-ui and the threatened Lahontan cutthroat trout. The river system's water supply is critically dependent on the timing, form and amount of precipitation in the northern Sierra Nevada, and water releases from Lake Tahoe and Stampede, Boca and Prosser Creek Reservoirs.

Figure 1: The Truckee-Carson River System. Graphic by Ron Oden, 2016

As with many western river systems, water allocations are managed under a complex system of federal, tribal, state and local water-sharing agreements built on historic prior appropriation doctrine. Due to historical over-adjudication of water rights, western water supplies are currently oversubscribed. Most analysts predict water management in the American West will need to undergo profound changes to adapt to climatic changes and population increases anticipated for the region (Howells et al. 2013; Wiltshire et al. 2013; Ferguson & Maxwell, 2012; Overpeck & Udall, 2010; Barnett & Pierce, 2009; Brekke et al. 2009; Schempp, 2009).

Water use in the Truckee River Basin is currently regulated by the Truckee River Operating Agreement (2008, implemented in 2015). While 75 percent of the area of the basin lies in Nevada, most of the water storage exists in the snowpack, streams, and reservoirs of California. The 1971 California-Nevada Interstate Compact allocated 90 percent of the Truckee River's waters to Nevada. More than 80 years of litigation stems from agricultural diversions from the Truckee to the Carson River Basin, increased urban demands in the Reno-Sparks area, required flows for maintaining Pyramid Lake fisheries, periods of low precipitation and river flows during droughts, flood management during extreme weather events, use of unappropriated water rights during releases from reservoirs during flood periods, and decreasing water quality (Wilds, 2014).

The nation's first Bureau of Reclamation project, the Newlands Project, was constructed on the Truckee River. Completed in 1905, Derby Dam and the Truckee Canal diverted Truckee flows away from the river and Pyramid Lake to join Carson River flows at Lahontan Reservoir, providing agricultural irrigation supplies to the historic Newlands Project. These waters now also provide wildlife habitat to a federal wildlife refuge (Foley, 2008). Extensive periods of litigation and negotiation have produced the arrangements that govern the current system.

The Carson River water supply also originates from high alpine snowpack of the eastern Sierra Nevada in California, with a majority of water demand coming from downstream users in Nevada. As with the Truckee River, a compact between California and Nevada regulates interstate resource use. The Carson River involves the oldest litigation over water right adjudication in the United States, with one case alone spanning 55 years, being resolved through the Alpine Decree (1980), which today is the primary governance regime over that river's water rights allocation (Horton, 1996).

SURVEY METHOD

Survey Instrument

An interdisciplinary team of researchers, including climatologists, hydrologists, political scientists and economists, collaboratively developed a survey instrument to assess the climate resiliency of Truckee-Carson River System organizations with water management responsibilities and/or interests.[2] Twenty-five survey questions provided a framework for evaluating river system and organizational vulnerabilities in the context of each organization's interest or responsibility to manage water resources in the Truckee-Carson River System (Whateley, Steinschneider & Brown, 2014; Hinkel et al. 2013; Reed, 2008; Brooks, Adger & Kelly, 2005).

2 Instrumentation, data collection protocol and organizational survey research methodology received approval from the University of Nevada, Reno Office of Research Integrity and Institutional Review Board.

Survey responses identified normal, moderate/dramatic and severe/permanent water supply scenarios that might challenge daily operations, and subsequent organizational impacts and the current resources to adapt to these challenges.[3] Survey questions also asked organizational representatives to describe desired adaptations to climate change, to describe how the current water policy regime impacts their ability to function under water supply shortages, and to describe water management changes necessary to improve the system's ability to absorb water supply shocks posed by continued climate variability (Hinkel et al. 2013).

Survey Sampling Strategy

Two types of information are key to assessing the river system's resilience and adaptive capacity at the organizational level: 1) specific information about organizations that manage water in the Truckee-Carson River System, including perceived vulnerability to climate impacts and potential adaptive responses; and 2) information on overall river system function across human and natural systems. Sampling strategies were designed to obtain thorough information about the river system pertaining to its unique human and natural subsystems, from headwaters to terminus.

The sample was stratified by the two rivers that comprise the system (Truckee and Carson), and by river and river system segments (i.e., headwaters, middle reaches, lower reaches, natural terminus and man-made terminus). While the survey data collected are specific to Truckee-Carson River System organizations, this sampling strategy effectively captured a snow-fed river system's human and spatial vulnerabilities with respect to climate uncertainty.

Truckee-Carson River System Organizations Surveyed

Between March and August 2015, researchers conducted 66 face-to-face interviews with key representatives of a diverse set of organizations. These organizations were selected purposefully to achieve a reasonably normal spatial distribution across the Truckee-Carson River System as follows: Truckee River, 26 organizations; Carson River, 16 organizations; below the Truckee Canal, 9 organizations; and Truckee-Carson systemwide (both rivers), 15 organizations (see Figure 2).

Organizations surveyed hold significant regulatory or water management responsibilities and/or interests. Essentially, organizations were interviewed if they: a) consume, deliver, protect or supply a large quantity of water (such as irrigation or regional utility districts); b) can take action or pursue litigation that may have a significant impact on water management in the system; c) possess systemic expertise on specific issues, such as groundwater or fisheries; d) maintain roles that greatly enhance systemic capacity to adapt; or e) provide insight regarding the economic or jurisdictional impacts of location-specific water issues.

3 These survey data were used in part to establish threshold values for droughts and floods; these threshold values were used to construct plausible climate scenarios designed to stress the Truckee-Carson River System. Per the collaborative modeling research design tailored for Water for the Seasons, these climate scenarios provide inputs to a suite of hydrologic and operations models to further assess system resiliency and adaptive capacity.

Figure 2: Spatial distribution of the organizations surveyed.

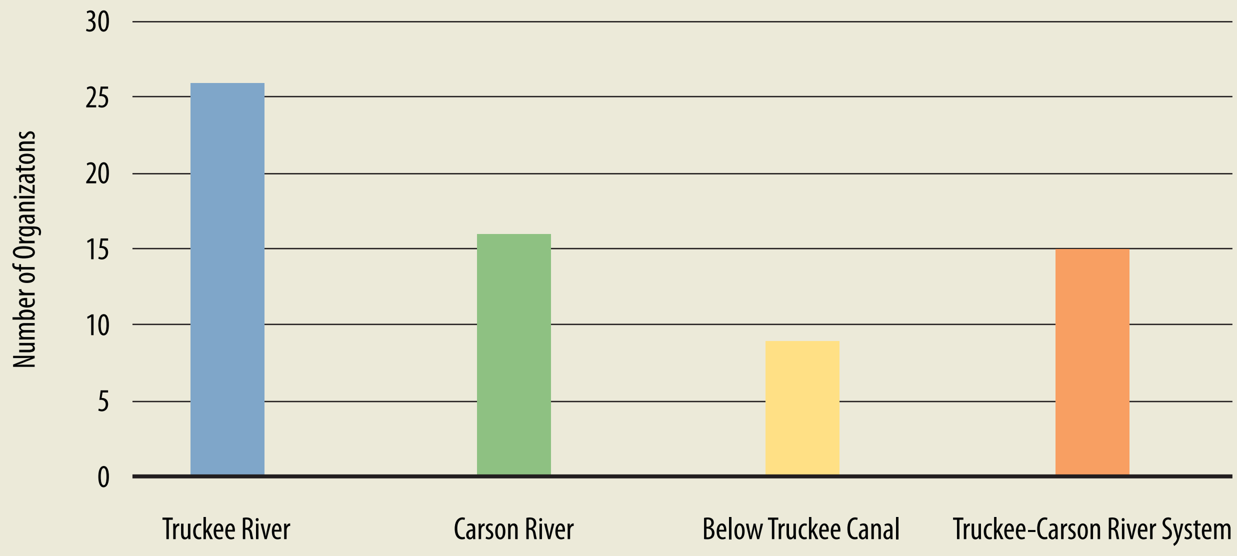
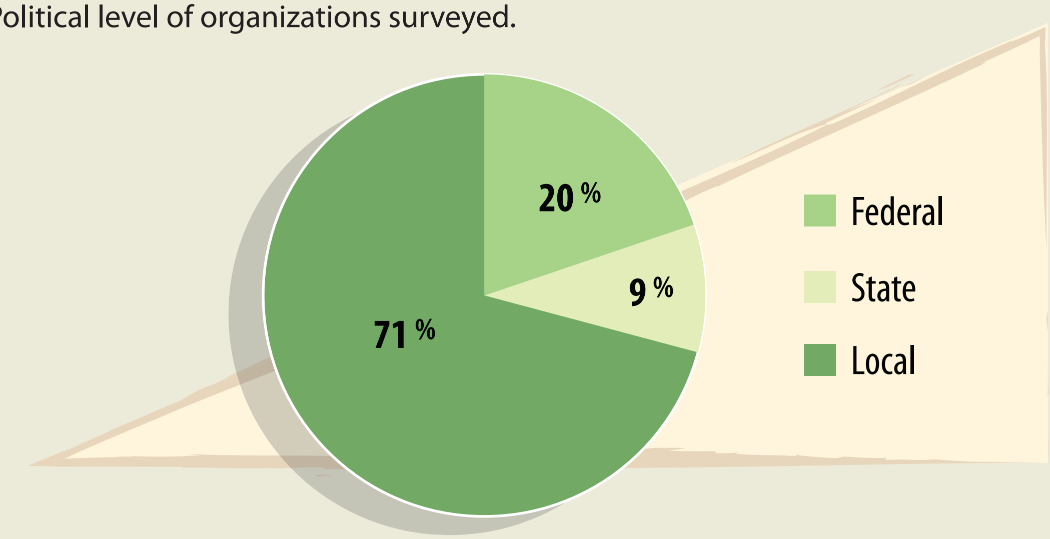


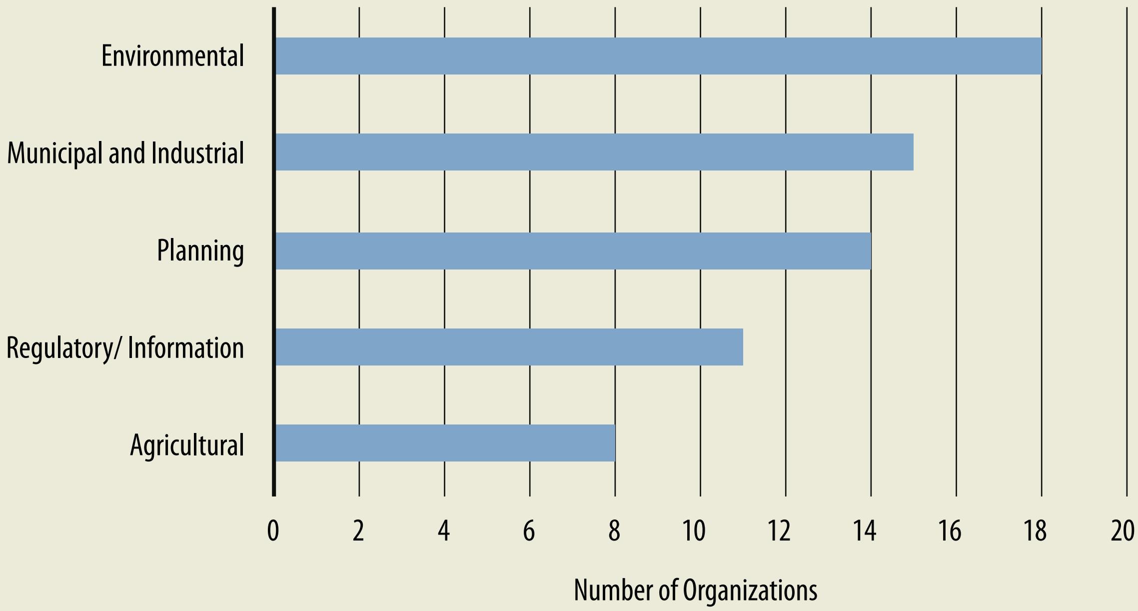
Figure 3 illustrates the political level of each of the organizations/agencies surveyed (n=66). The majority of organizations (71 percent) were classified as local, followed by federal (20 percent) and state (9 percent). Local organizations included county, municipal, public/private, tribal, water utility/treatment and nongovernmental organizations, including environmental interest groups.

Figure 3: Political level of organizations surveyed.



Researchers asked organizational representatives to describe their primary responsibilities in the Truckee-Carson River System, to categorize organizations by areas of primary responsibility. Organizational self-identified responsibilities (n=66) were aggregated and classified as belonging to one of five types (see Figure 4). The majority of respondents (n=18) described their responsibilities as pertaining to environmental, followed by municipal and industrial (n=15), planning (n=14), regulatory and information (n=11) and agricultural (n=8). Environmental responsibilities included water quality treatment and protection, and a wide variety of ecosystem services, including recreation, wildlife habitat, and riparian and restoration management. Municipal and industrial (M&I) organizations include public and private utilities and organizations that engage in related water supply functions. Organizations that described their primary responsibility as "planning" also include those that conduct economic development and related research activities. Regulatory and information organizations have systemwide oversight and/or engage in research and data collection activities at the systemwide scale. Agricultural organizations are those that either engage in irrigated agricultural production or provide support to agricultural production activities.

Figure 4: Organizations' primary responsibility.



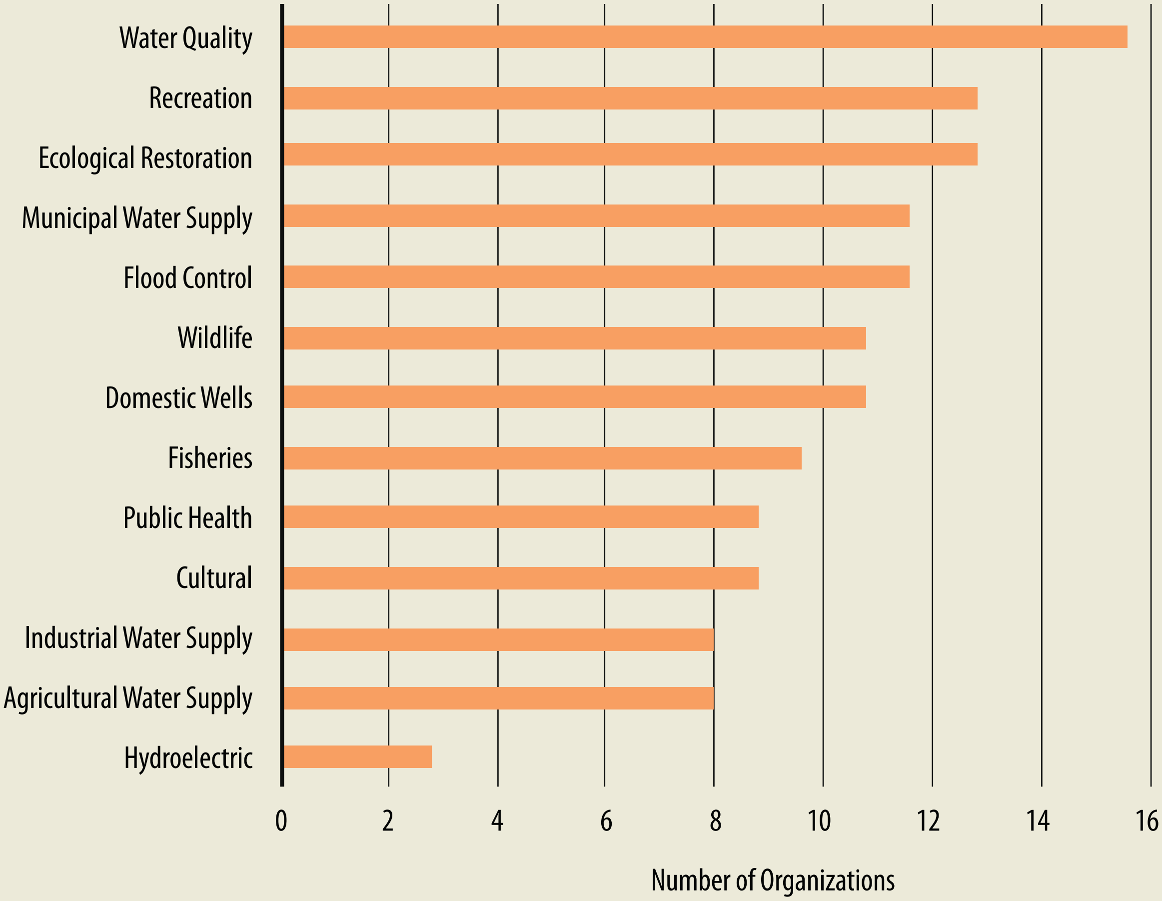
PRELIMINARY SURVEY RESULTS

Open-ended questions were analyzed using content analysis, a method commonly used to objectively document patterns and trends to obtain a quantitative description (Rossman and Rallis, 2017) and then descriptively coded (Saldaña, in press; Miles, Guberman & Saldaña, 2014). The coded data were analyzed using basic descriptive statistics. Per University of Nevada, Reno Office of Human Research Integrity Internal Review Board approved research protocol for this survey, only the de-identified cumulative results for each question are reported here.

Responsibilities and Priorities During Drought

To further understand key characteristics of the organizations selected for this survey, organizational representatives were asked to describe their water management responsibilities. Researchers presented a list of possible ecosystem services that the Truckee-Carson River System provides its communities, and asked them to self-identify services for which their organization is responsible (see Figure 5a). Of those who responded (n=58), the majority of respondents reported that their organization's major responsibility is to manage water supplies for water quality assurance (n=39). This was followed by ecological restoration (n=32) and recreation (n=32), municipal water supply (n=29) and flood control (n=29), and wildlife (n=28) and domestic wells (n=28).

Figure 5a: Ecosystem services of organizations.



Researchers asked organizational representatives to select from the list of self-identified water management responsibilities the top three (first, second and third) priorities during drought conditions when water supplies are low (see Figure 5b). Of those who responded (n=49), most respondents (n=15) assigned first priority to municipal water supply. This was followed by agricultural water supply (n=8), ecological restoration (n=7), and water quality (protection/maintenance) (n=6). Second priority was assigned by the most respondents to wildlife (n=8), followed by industrial water supply, water quality and ecological restoration (n=7, respectively).

The majority of organizations interviewed (61 percent, n=64) reported having water rights (see Figure 6a). Of the organizational representatives who answered the question (n=36), 53 percent indicated that these water rights make their organizations vulnerable during periods of water shortages (see Figure 6b).

Figure 5b: Priority ecosystem services during water supply shortages.

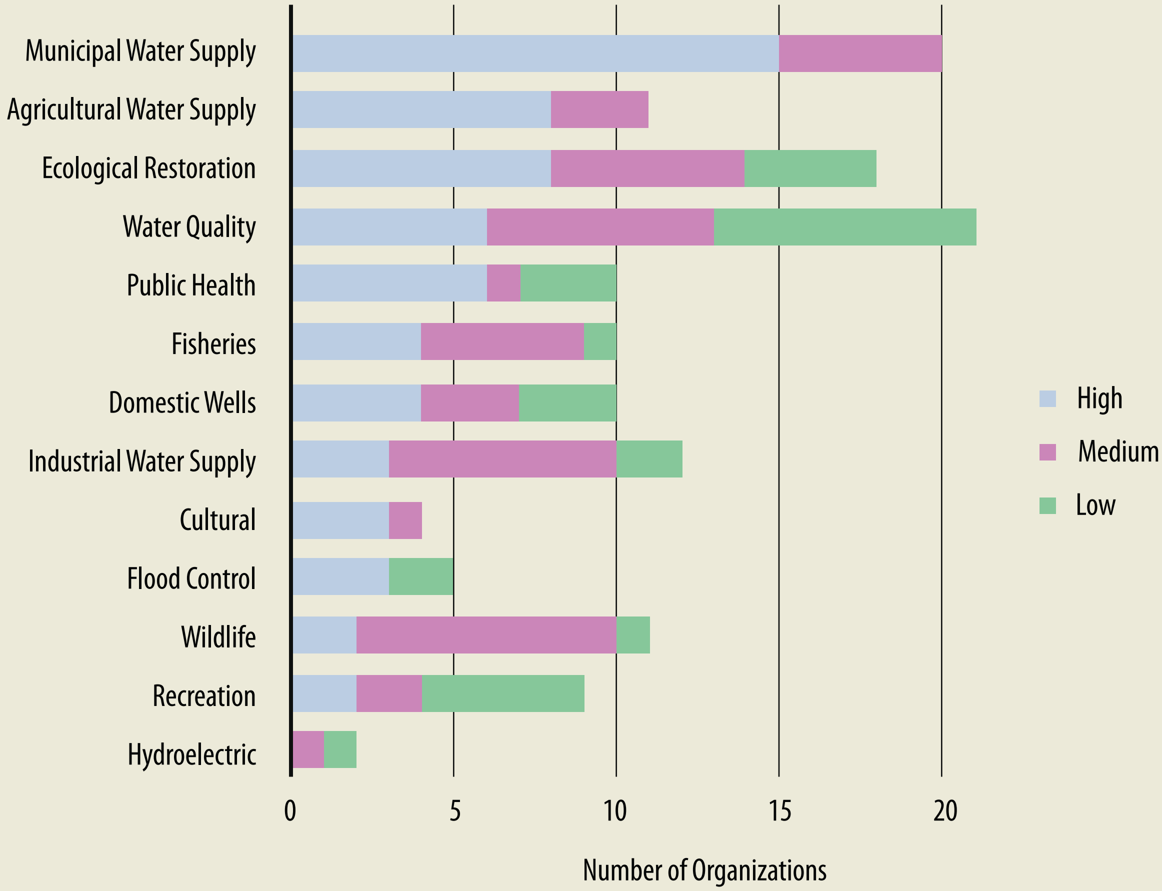


Figure 6a: Percentage of organizations with water rights.

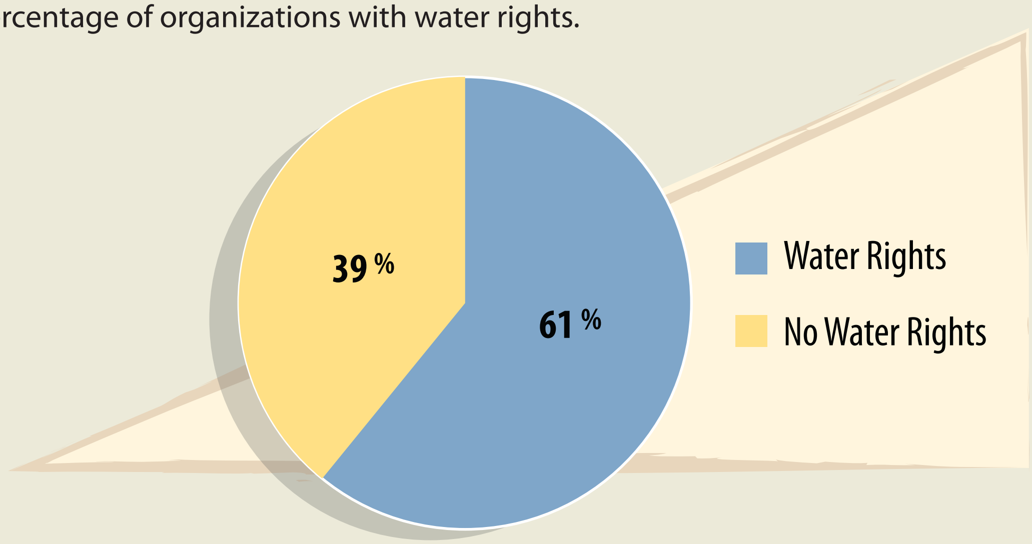
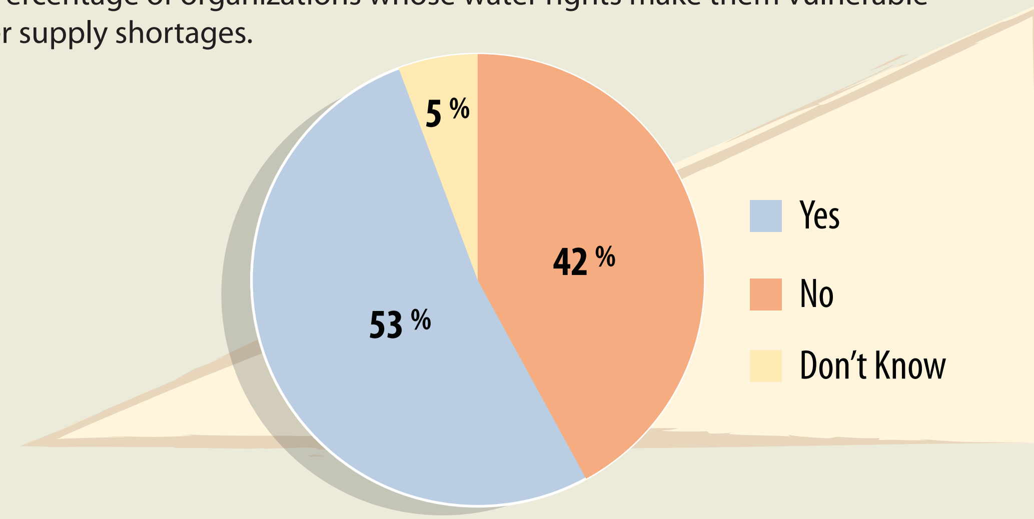


Figure 6b: Percentage of organizations whose water rights make them vulnerable during water supply shortages.



Normal Year Challenges and Perceived Worst Events

To evaluate vulnerability of the Truckee-Carson River System and its communities to climate variability and extreme events, organizational representatives were asked to describe climate impacts as a function of water supply shortages, such as those induced by recurring drought conditions, high-flow events (floods) and warming temperatures. Respondents were asked first if they experienced challenges during a normal water year. Then, respondents were asked to describe typical challenges their organizations face during a normal water year, followed by progressively worse water supply scenarios.

Depending on an organization's roles and responsibilities, a "normal" water year could be defined as a year when water supplies are at average flow, a year in which snowpack is measured at 100 percent of normal, or a year in which all water rights and allocations are met. The majority of respondents (67 percent, n=58) reported that their organizations faced water management-related challenges during normal years (see Figure 7a). As Figure 7b illustrates, respondents (n=39) described these challenges as associated most often with regulatory issues, followed by operational issues (water delivery and infrastructure), hydrologic issues (generally timing of supply and evapotranspiration), and ecosystem degradation (invasive species and undesirable land use changes). Additional issues described related to maintaining water quality and communication and coordination issues.

Figure 7a: Percentage of organizations facing water-related challenges in normal years.

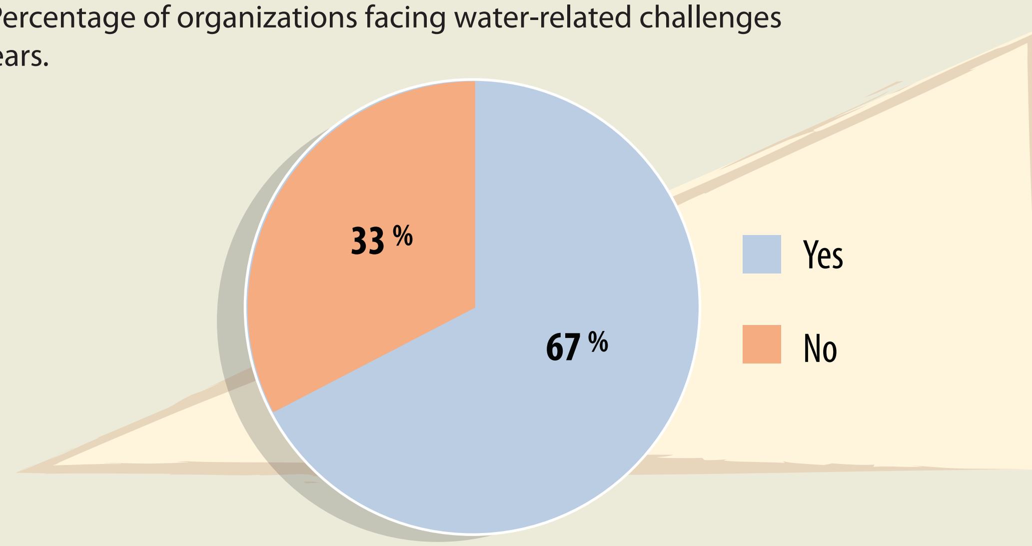
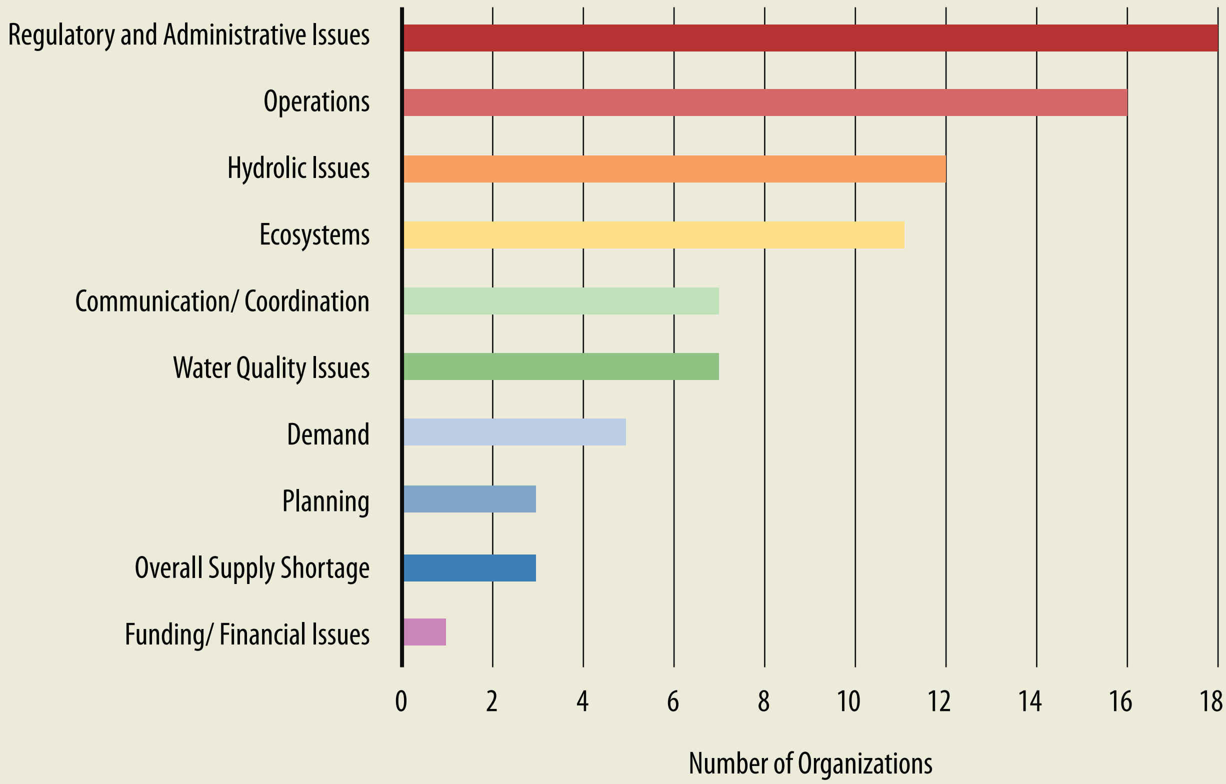


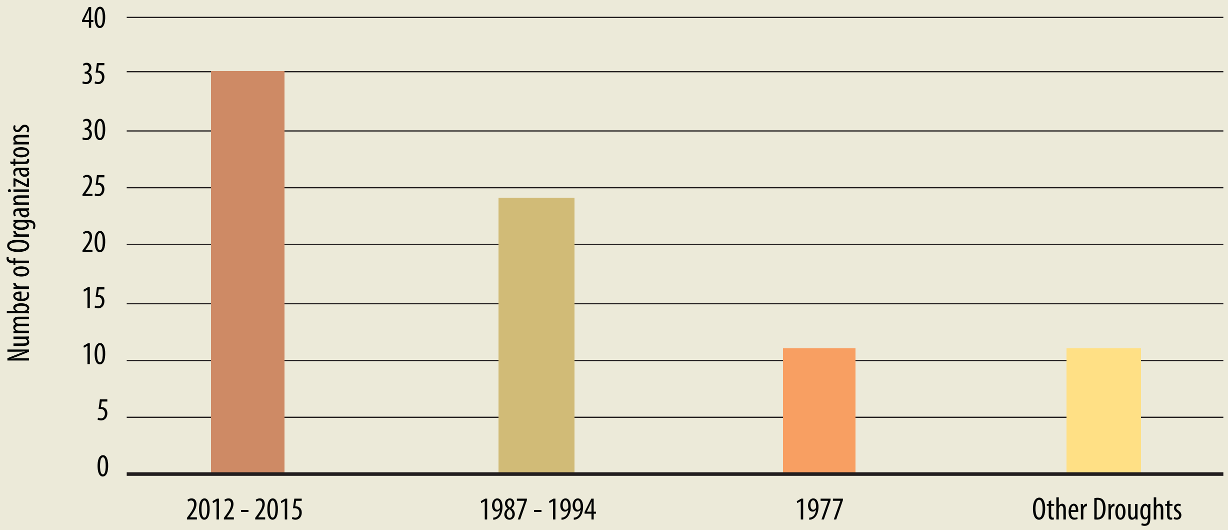
Figure 7b: Water-related challenges faced in normal years.*



*number of organizations that mentioned a water-related challenge at least once

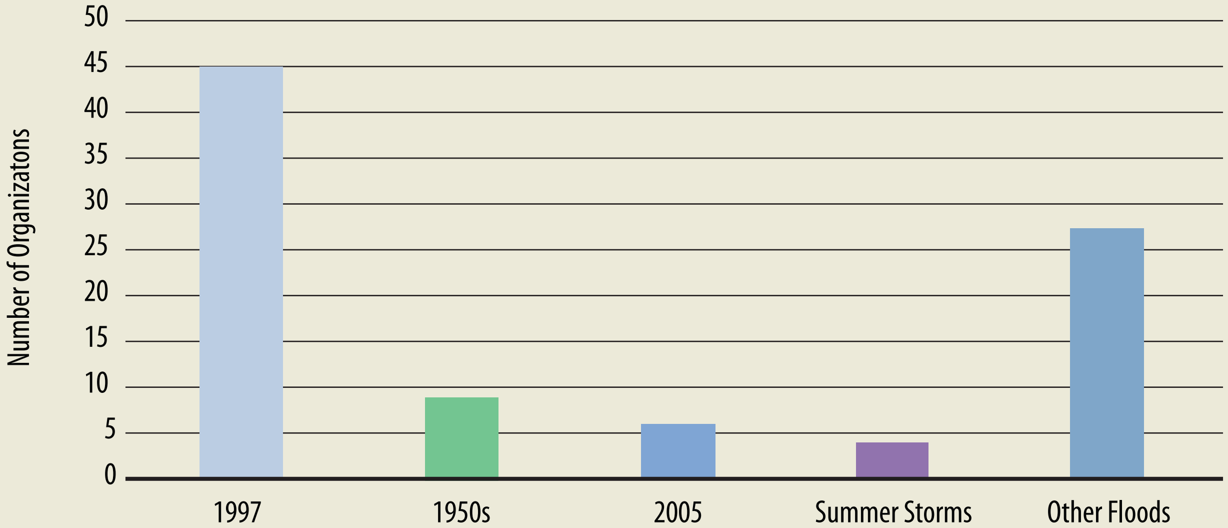
In order to set the context for questions about drought and high-flow thresholds, respondents were asked to identify the worst drought their organizations had faced. Responses to this question were consistent across the Truckee-Carson River System. Of those organizations who responded (n=57), most respondents (n=35) perceived the current drought (2012-2015) as the worst (see Figure 8a). When asked to recall the region's worst flood event, 45 participants (n=56) described the flood of 1997 (see Figure 8b). Additional notable climate events included the 1987-1994 drought and the 1950s flood. Organizational perceptions of worst droughts were more consistent across the system, while memories of worst floods varied by an organization's location on the river system, with vivid recollections of more recent events, such as localized flash flooding due to intense summer thunderstorms.

Figure 8a: Worst drought faced by organizations.*



* "don't know" and "not applicable" responses were omitted; organizations responded with up to three choices

Figure 8b: Worst flood in the Truckee-Carson River System.*



* "don't know" and "not applicable" responses were omitted; organizations responded with up to five choices

Identifying Thresholds Under Climate Variability

Managing and striving for resilience in the Truckee-Carson River System and its communities requires examining the river system's movement through various states of change, and proactively facilitating these transitions or changes toward ideal outcomes. Every transition in the river system involves crossing thresholds or tipping points that separate various system states (Resilience Alliance, 2010).

The following section reports responses by *type of organization* (n=66) to questions about climate variability, thresholds to drought and high-flow events, and subsequent impacts and adaptations (see Table 1). Recall that organizations' self-identified responsibilities are grouped as belonging to one of five types that include M&I, planning, environmental, agricultural, and regulatory/information (see Figure 5). For this analysis, M&I

organizations were combined with planning since these organizations conduct relatively similar activities, target similar populations and described similar thresholds, impacts and adaptations. Due to the complexity of their water management roles and responsibilities, tribal organizations were represented across multiple types of organizations.

Table 1: Types of organizations surveyed.

Municipal and Industrial M&I and Planning, 29 organizations ■ Economic development agencies ■ Planning agencies ■ County government ■ Tribal	Environmental, 18 organizations ■ Nongovernmental organizations ■ Tribal
Agricultural, 8 organizations ■ County government ■ Tribal ■ Conservation districts ■ Irrigation Districts	Regulatory and Information, 11 organizations ■ System experts ■ Federal and state agencies ■ Enforcement of decree and prior appropriation doctrine

Drought Thresholds

To develop a measure of drought vulnerability, researchers asked Truckee-Carson River System organizational representatives to identify drought thresholds by describing water supply shortages (as percent allocation received or percent of normal snowpack) that indicated moderate and severe drought. Organizations were asked to specify the number of years they could survive such a drought, to describe the types of impacts from these droughts, and to explain current adaptation tools that exist to help alleviate the impacts. The objective was to encourage respondents to consider and describe drought thresholds where daily operations might be critically challenged to tipping-point conditions, wherein the river system (natural components) and the communities it supports (human/wildlife components) experience a significant transition that might irreversibly alter the system. Permanently altered natural states challenge the sustainability of the river system and the human and wildlife communities it supports (Lenton et al. 2008).

Respondents were asked to define what would constitute a moderate supply shortage or drought for their organization, and specify the number of years they could survive such a drought. For example, an organization may have described a moderate drought as a drought in which they received 80 percent of their normal water allocation for three to four years. Respondents were asked next to describe a severe supply shortage or drought.

Table 2 illustrates a summary of responses to these questions and reports these drought thresholds by percentage of water allocation received, duration of drought in years, and other indicators as noted.
As illustrated earlier in Figure 8a, the majority of respondents (n=58) described the current (2012-2015) drought as the most severe the organization had ever faced. Several respondents also described the current drought as having the potential to push the river system to its tipping point.

Table 2: Moderate and severe drought thresholds by type of organization.

Organization Type	Moderate Drought	Severe Drought
M&I and Planning	10-50% 1-3 years	5-20% 2-10 years
Agricultural	40-90% 2-4 years	20-50% 1-4 years
Environmental	30-75% 2-3 years	10-50% 3-5 years
Regulatory and Information	As indicated via U.S. Drought Monitor	As indicated via U.S. Drought Monitor 15% snowpack for three years Lake Tahoe is below rim Groundwater drops 12-14 feet

For M&I and planning organizations, prolonged severe water supply shortages generally paired with a discussion of structural changes necessary in order to alleviate impacts. These changes included reducing the number of water-intensive industries and an "end" to irrigated residential and commercial landscapes. Currently, landscape irrigation comprises at least 50 percent of water demand in municipal settings. When compared with agricultural organizations, M&I and planning organizations reported being able to withstand longer periods of severe drought (two to ten years versus one to four years). It is possible that M&I and planning organizations allow for longer time horizons under severe drought conditions because their primary water demand is not as water-intensive as irrigated agriculture, and for M&I and planning organizations on the Truckee River, storage flexibility in the headwaters and groundwater reservoirs help to offset severe supply shortages for a period of time.

Comparatively, the majority of agricultural water use occurs in the Carson River and at the end of the river system in the Newlands Project. Yet these water users possess little storage flexibility. Additionally, during prolonged periods of severe drought, agricultural producers face sizeable financial risk and constrained operating capital. Organizational representatives reported that for agricultural water users, depending on the percent allocation received, even a one-year drought could be considered severe. For environmental users, a supply shortage that lasted three years and longer could be considered severe.

Concerns that surfaced consistently related to prolonged drought, regardless of organization type, included deteriorating water quality, irreversible economic impacts, and groundwater supply shortfalls due to increased groundwater pumping when surface supplies are insufficient. Impacts associated with moderate drought are exacerbated under severe drought for most organizations, regardless of type.

The impacts M&I and planning organizations described during moderate drought tended to fall within their planning boundaries, and respondents often stated that normal supply variation is to be expected in the arid West. During even moderate supply shortages, however, M&I and planning organizations reported water quality challenges, negative economic impacts, increased wildfire risk, increased reliance on groundwater, and challenges meeting demand and delivering supplies. Under severe drought conditions, M&I and planning organizations faced increased challenges in satisfying customer demand under the river system's current policy regime and regulatory structure.

The agricultural sector appeared to absorb impacts during moderate year shortages and cope with incremental water supply shortages using farm-level adaptation approaches. Organizational representatives noted that farm unit productivity degraded with an increase in duration of drought, due partly to lower soil moisture slowing water infiltration.

Underlying impacts independent of the degree of the water supply shortage include changes in farm productivity, economic stability, groundwater supply shortages due to increased pumping, and complexities related to changing place of use for water rights (e.g. prohibiting farmers from easily "stacking" water rights on their best and most productive parcels while fallowing marginal farm lands). Under severe shortages, additional impacts included challenges with delivering the full water duty due to dry soils in earthen delivery ditches absorbing water, and an increase in noxious weeds due to forced fallowing of fields.

Impacts to environmental organizations include maintaining native vegetation and riparian habitat, maintaining and protecting water quality, and watershed scale issues such as addressing the impact of fire and changes to ecological regimes. As water supply shortages become more severe, restoration and rehabilitation projects become more stressed and recreation use shifts.

Other types of organizations describe moderate year impacts as systemwide issues, especially impacts to water quality and increased concentration of contaminants. Under moderate shortages, it is often more difficult to track voluntary reductions in water use. Under severe shortages, systemwide issues and lack of information and monitoring become more apparent.

High-Flow Thresholds

Organizations were asked to identify high-flow thresholds, or tipping points, by describing high-flow events that posed dramatic and potentially permanent changes to daily operations. Unlike droughts, which are prolonged events with highly uncertain end dates, high-flow events are often forecasted and anticipated; yet the mechanisms to prepare are often outside the scope of an organization's toolbox, and the aftermath could destroy an organization's management resources, including water delivery infrastructure. To ensure that the challenges associated with climate variability were captured, researchers asked respondents to describe the impacts of high-flow events on their organizations, and how droughts punctuated with high flows impact daily operations.

Organizations of all types described similar levels of vulnerability in coping with high-flow events, so responses are reported by spatial location within the river system rather than by organization type (see Table 3). Respondents were asked to define what would constitute a "dramatic" versus a "permanent" (having permanent impacts on the system) flood event for their organization. For the Carson River, most survey respondents equated a "dramatic" high-flow event with a 100-year flood event, and a "permanent" high-flow event with a 100- to 200-year event. For the Truckee River, most survey respondents associated the 1997 flood with a "dramatic" high-flow event, and associated a 200- to 500-year flood event as being a "permanent" flood event. Looking at the Truckee-Carson River System as one system, a 50-year flood event was perceived as dramatic, and a 100- to 500-year event was perceived as permanent. At the river system terminus, "dramatic" events include Lahontan Reservoir spilling over, a canal breach or a flash flood.

Table 3: Dramatic and permanent high-flow event thresholds by location.

	Dramatic	Permanent
Carson River	▪ 100-year event	▪ 100- to 200-year event
Truckee River	▪ 1997 flood	▪ 200- to 500-year event
Truckee-Carson River System	▪ 1997 flood ▪ 50-year event ▪ 6,000 cubic feet per second at Reno ▪ Flash floods	▪ 1997 flood ▪ 100- to 500-year event ▪ Add 100 cubic feet per second to baseline ▪ Recurring summer storms
Below Truckee Canal	▪ Lahontan spills over, canal breaches or flash floods	No responses

Organizational representatives reported positive and negative impacts associated with such high-flow events. Table 4 summarizes these impacts by organization type. For M&I and planning organizations, negative impacts included damages to transportation and communication infrastructure, and damages to residential and other development located within the floodplain. Also noted were flood-induced threats to water supply and water quality.

Respondents from environmental organizations noted negative impacts including bank erosion, habitat destruction, spread of noxious weeds and degraded water quality. Municipal and industrial, planning and environmental organizations regard groundwater aquifer recharge as positive impacts.

Agricultural organizations expressed concerns about farm-level impacts, including damage to water delivery infrastructure, crop stress or loss and related financial losses, and insufficient funds needed to maintain fields and infrastructure. Additional negative impacts noted by other organizations include damages to stream gauges and other types of monitoring equipment, and the increased demand for information due to floods.

According to respondents, the timing of high-flow events is important and often determines the extent of impact (see Table 5). Winter (December to February) rain-on-snow events are associated with negative impacts, including reservoir storage challenges and limited capacity for water to infiltrate into the ground due to freezing temperatures. Summer thunderstorms and flash floods are also associated with negative impacts, as sedimentation, stormwater issues and damage to crops may occur. High flows during the period of late-spring runoff were perceived as manageable, and flooding during the growing season had both positive and negative impacts, depending on how much water was received.

Table 4: Impacts of high-flow events by type of organization.

M&I and Planning	Environmental
■ Transportation and communication challenges including electrical failure, washed out roads, and damaged infrastructure ■ Operational challenges including high spatial variability of impacts, impacts to developments within the floodplain and costs associated with cleanup after a flood ■ Threats to the water supply, such as dam and structure breaks and disruption of water services ■ Water quality issues such as increased sedimentation and turbidity ■ Recharge to the groundwater aquifers (+)	■ Bank erosion, habitat destruction, water quality problems, spread of noxious weeds ■ Aquifer recharge, the natural restoration of wetland and riparian areas, in-stream temperature regulation (+)
Agricultural	**Regulatory and Information**
■ Farm-level impacts including stress to crops, inundation of fields and canals, time and cost to repair fields after flooding ■ Contamination of water supply ■ Damage and destruction of water delivery infrastructure	■ Transportation and communication challenges due to washed out roads and damaged infrastructure ■ Water quality, sanitation and health problems ■ Lack of information due to damage to stream gauges and monitoring equipment ■ Increased demand for information

(+) indicates a positive impact; all other impacts are negative or neutral

Table 5: Issues of timing of high-flow events by type of event, including impacts and noted operational challenges.

Time of Year	Type of Event	Impacts	Operational Changes
Late December through February	Rain-on-Snow	Function of reservoir storage and infiltration capacity of the ground	Water is not needed this time of year, events challenge reservoir storage and release
October through April	Rain-on-Snow	Typically adequate space for floodwaters	Releasing water from reservoirs makes these events manageable
Late Spring	Runoff	Reservoirs fill and increases storage and supply (+)	Manageable
Spawning Period	Snowmelt Runoff	Erosion of spawning gravel, cold water temperatures threaten fisheries	Shift in timing from natural release
Growing Season	Flooding	Good for crops (+)	Too much water will damage crops
Summer	Flash Floods	Debris flows, gully washers, overworked treatment facilities, crop devastation	Impact is greater because increased recreation, tourism and farming this time of year
Late Summer (July/August)	Thunderstorms	Sedimentation and storm-water issues	Challenge increases as visitation increases

(+) indicates a positive impact; all other impacts are negative or neutral

Flood-Control Infrastructure

The Intergovernmental Panel on Climate Change (IPCC) projects increases in global average temperatures that will influence all aspects of the hydrological cycle. This is expected to result in more frequent and severe droughts as well as floods (Turral, Burke & Faures, 2011). To assess vulnerability to high-flow events and explore policy options related to risk reduction, researchers asked organizational representatives a series of questions focused on flood control in the Truckee-Carson River System. Figures 9a-9e illustrate the responses to these questions.

Slightly more than half of the respondents (51 percent, n=66) indicated that existing flood-control infrastructure was insufficient (Figure 9a). Roughly half of all respondents (n=31) elaborated on a potential location for additional flood-control infrastructure (Figure 9b). The majority of respondents (n=11) thought that new or additional infrastructure should be built on the Carson River, followed by the Truckee River (n=9), Carson headwaters (n=5), and below the Truckee Canal (n=5). Approximately one-third of organizations interviewed (n=22) specified the type of flood-control infrastructure desired. The majority (n=11) indicated reservoirs or dams as the preferred type of infrastructure, followed by waterways (n=6), and vegetation or natural Best Management Practices (BMPs) and storm drains (n=5) (see Figure 9c). When asked about the feasibility of increasing or upgrading existing infrastructure, of the respondents who answered (n=12), most indicated that feasibility was low (n=8) or medium (n=5) (see Figure 9d). Most respondents (66 percent, n=12) cited economic factors (costs) as the greatest barrier to constructing new or upgrading existing flood-control infrastructure, followed by regulatory (n=3), politically unpopular (n=2), public opposition (n=1), and environmental concerns (n=1) (see Figure 9e).

Figure 9a: Percentage of respondents who perceive existing flood-control infrastructure as sufficient.

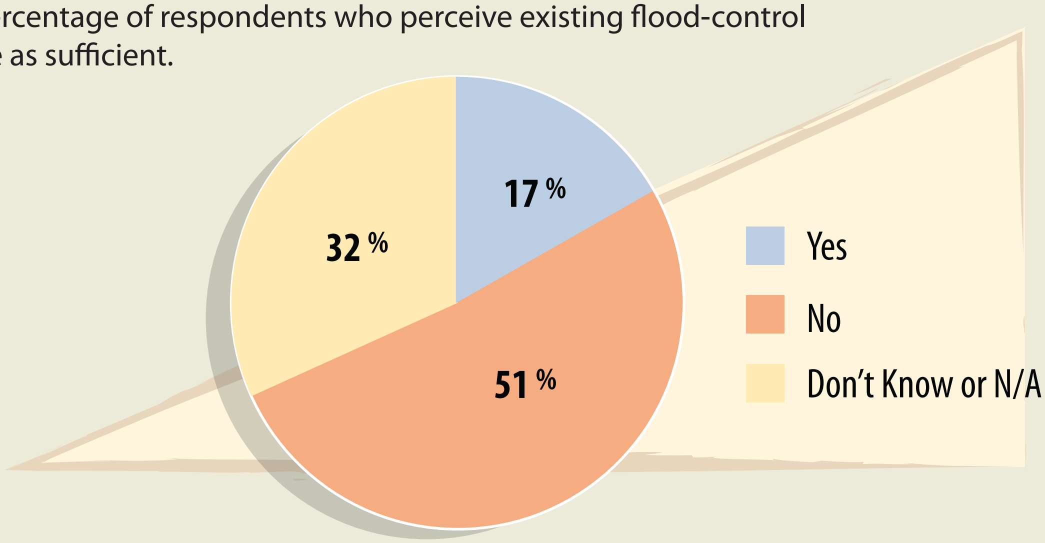


Figure 9b: Locations recommended for additional flood-control infrastructure construction or upgrades.

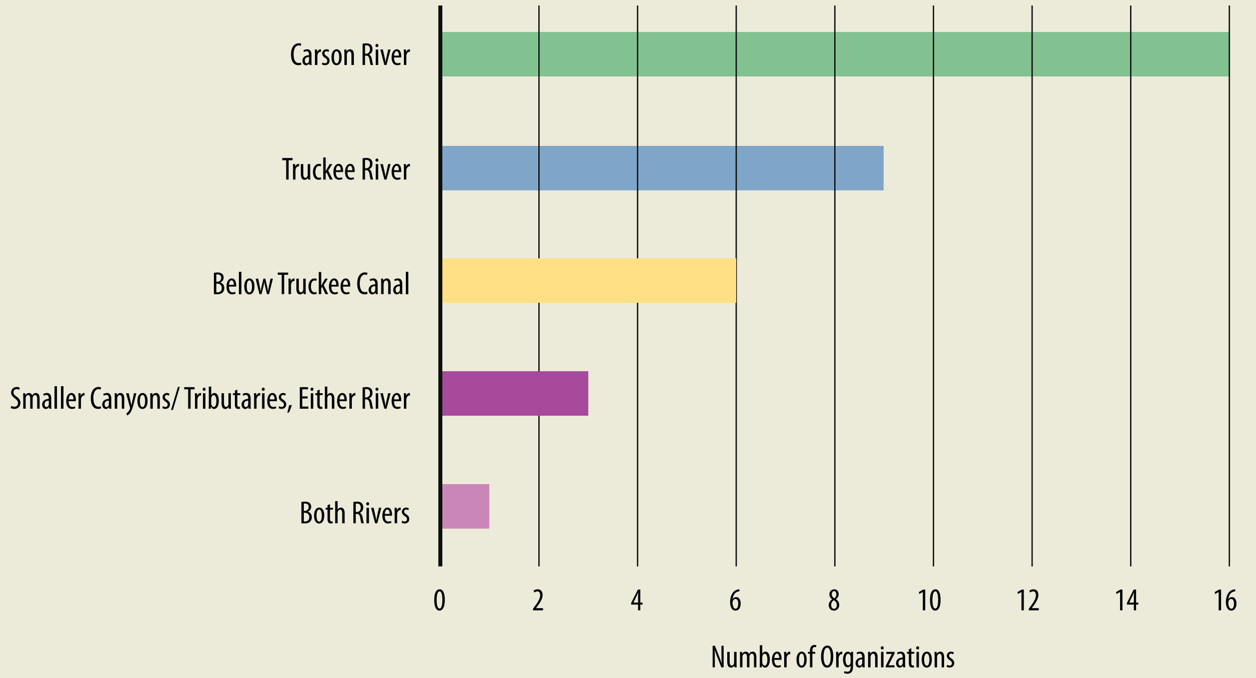


Figure 9c: Preferred type of future flood-control infrastructure.

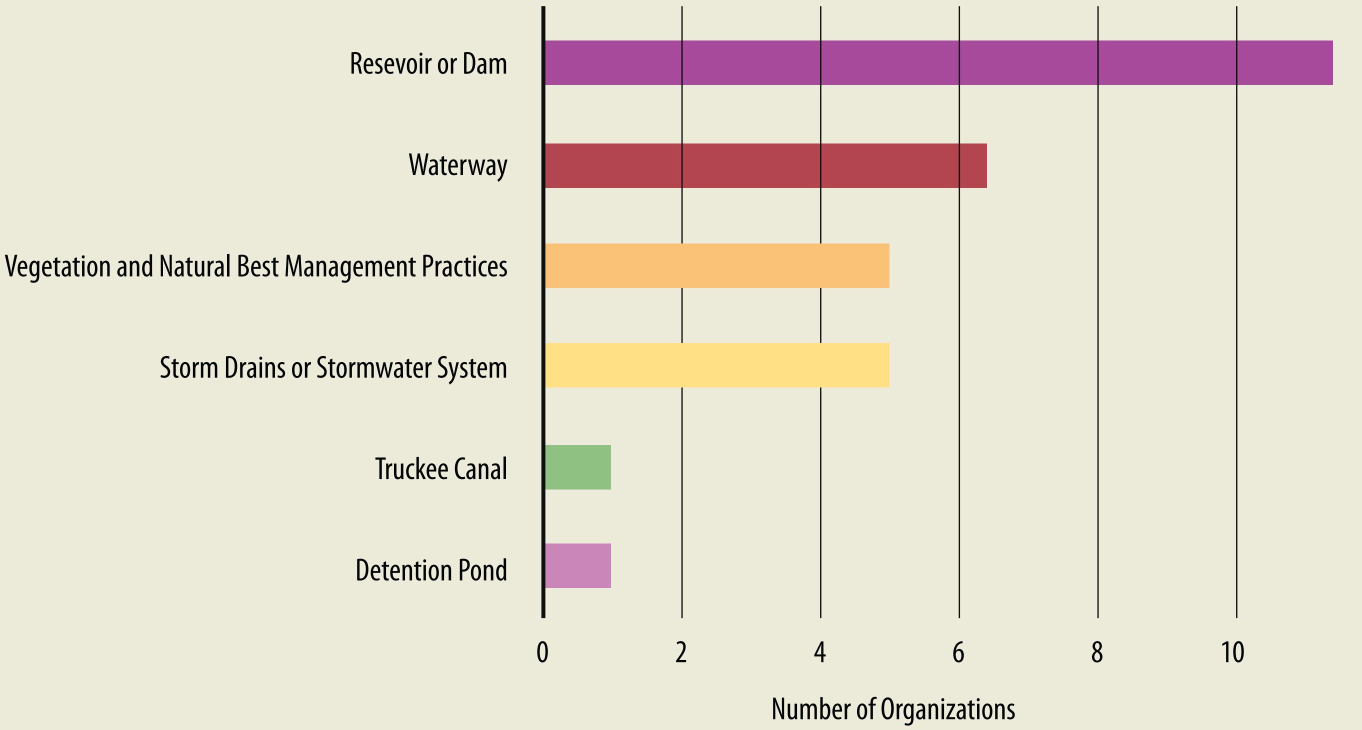


Figure 9d: Perceived feasibility of increasing or upgrading flood-control infrastructure.

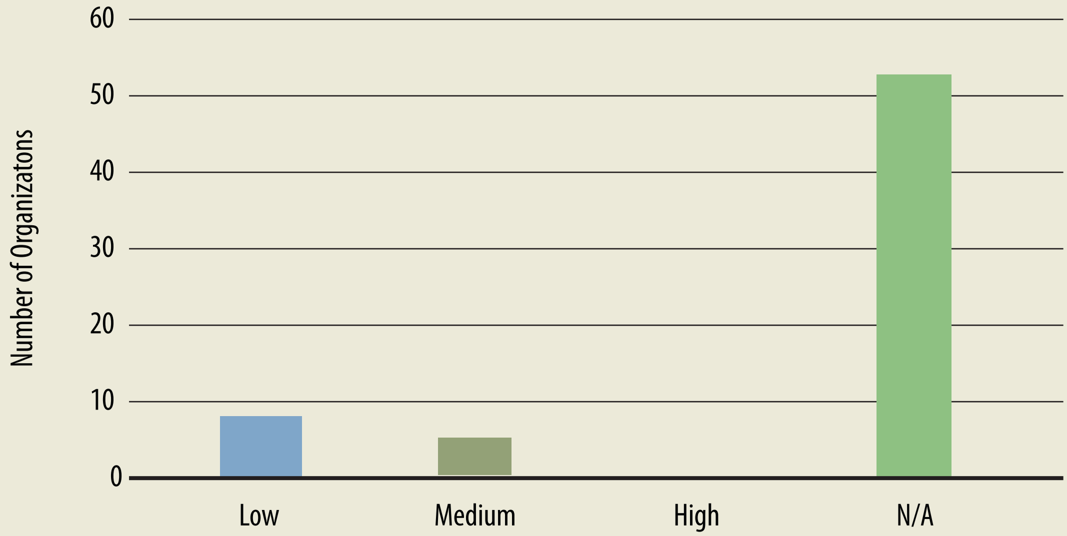
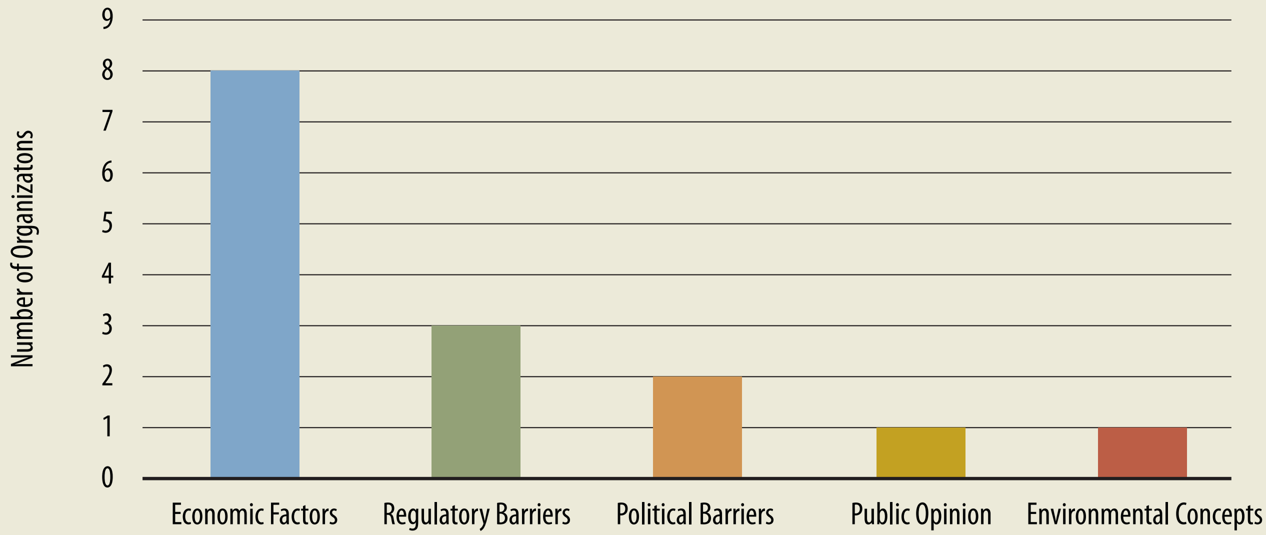


Figure 9e: Perceived barriers to constructing or upgrading flood-control infrastructure.



Using Floodwater to Recharge Groundwater Aquifers

Strategically using floodwater in wet years to recharge groundwater aquifers may be a viable adaptation strategy to address potential increases in water scarcity in snow-fed arid basins (Gale, 2000). Researchers asked organizational representatives if they believed that it was "reasonable" in wet years, to use floodwater to recharge Truckee-Carson River System groundwater aquifers. The majority of respondents (61 percent, n=66) indicated that it was reasonable. However only 50 percent of the respondents (n=66) indicated that it was desirable, and only 27 percent of respondents (n=66) indicated that it was feasible (see Figures 10a, 10b, 10c).

Figure 10a: Percentage of respondents agreeing that strategically using groundwater to recharge aquifers is a viable adaptation strategy during wet years.

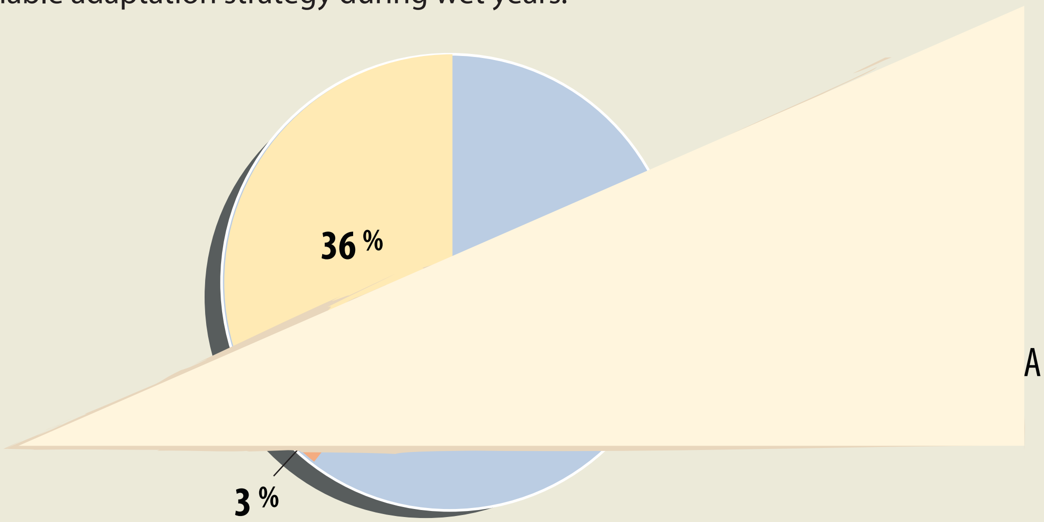


Figure 10b: Percentage of respondents who desired groundwater recharge during wet years.

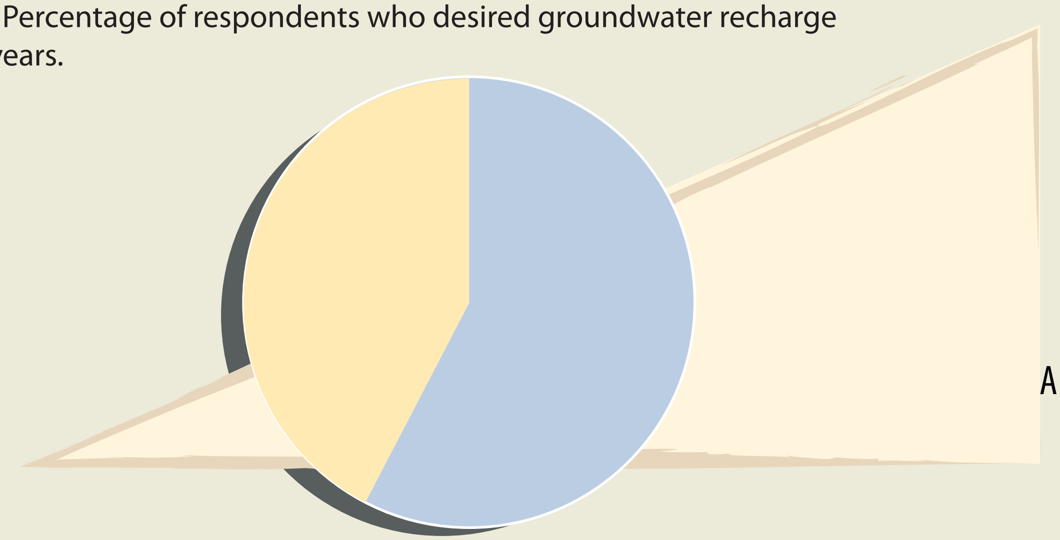
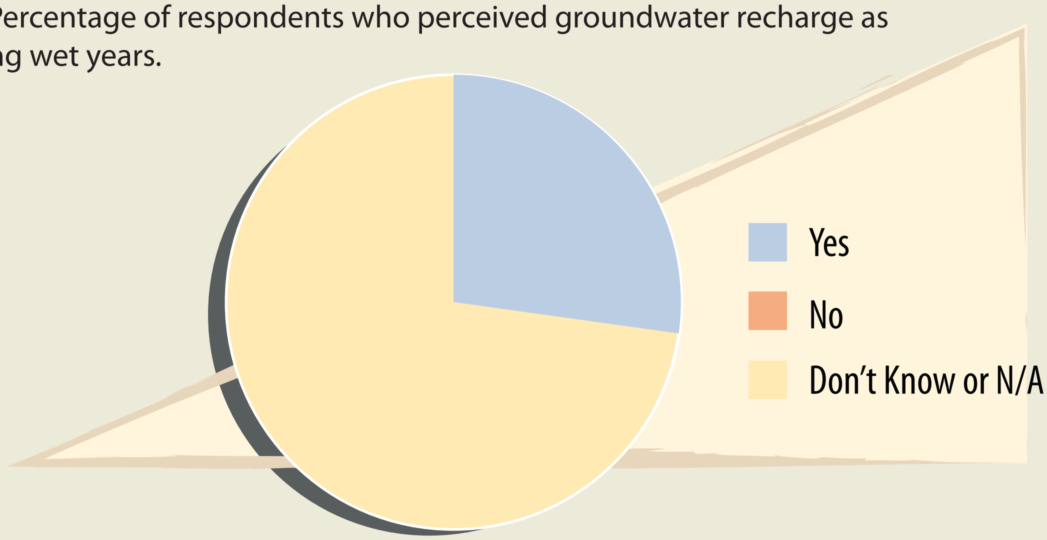
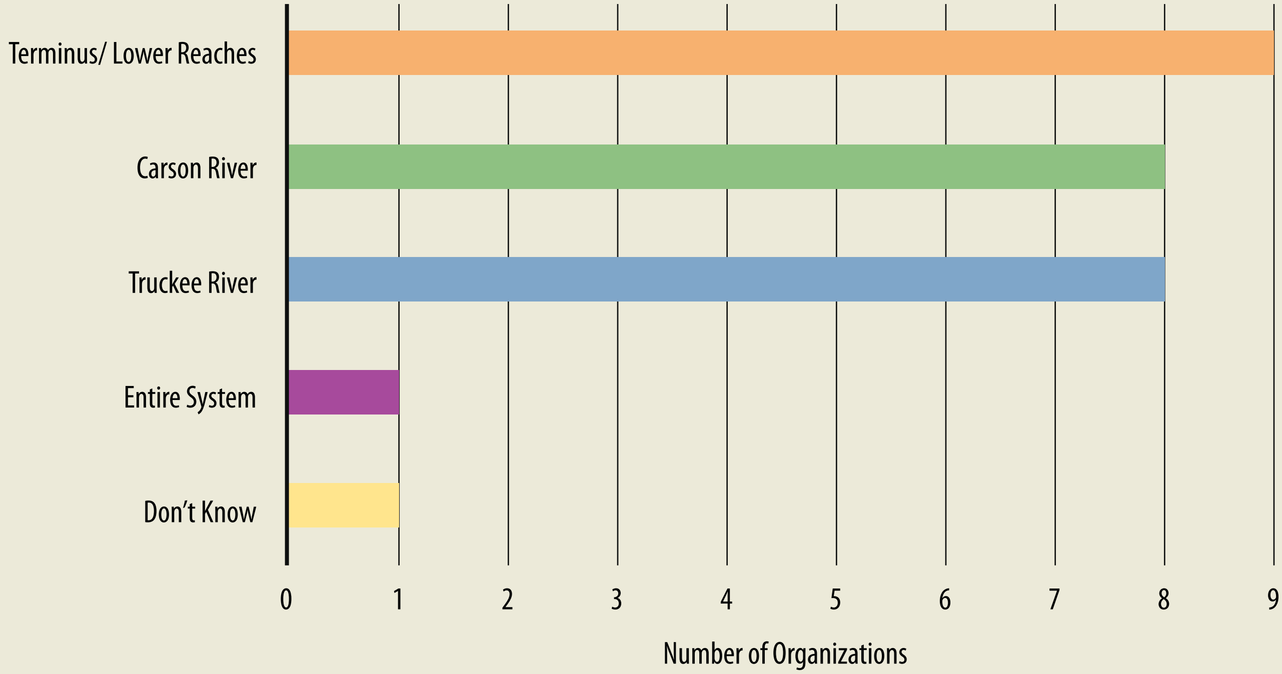


Figure 10c: Percentage of respondents who perceived groundwater recharge as feasible during wet years.



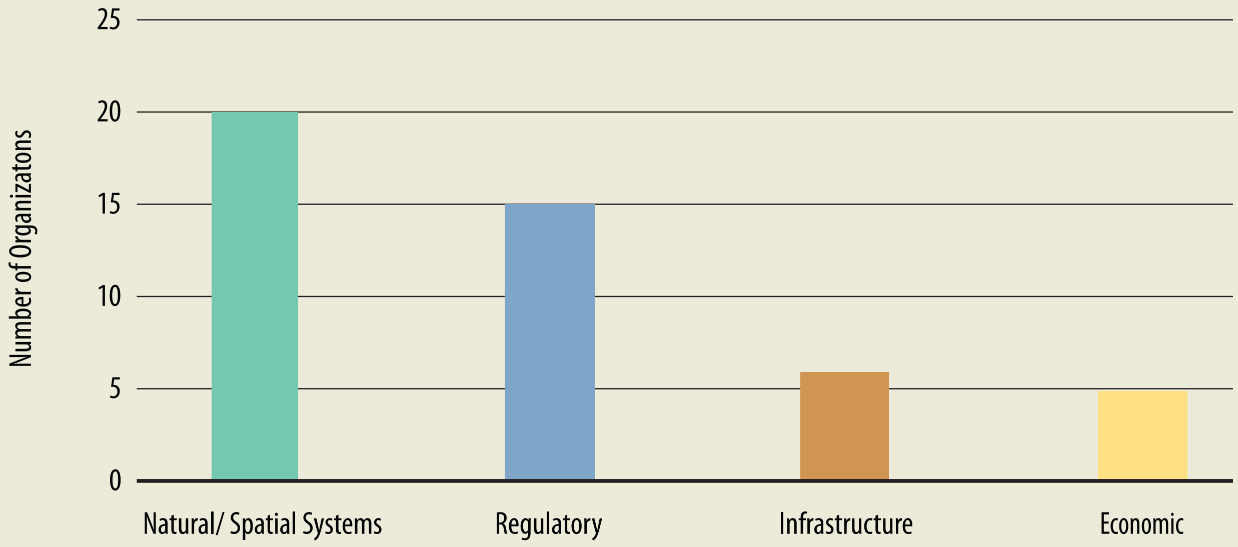
When asked where this strategy could or should be implemented in the river system, approximately one-third of organizations had a recommendation (n=24). The majority (n=9) recommended the terminus or lower reaches of the system. Others recommended areas located further upstream along the Carson (n=8) and Truckee Rivers (n=8) (see Figure 11).

Figure 11: Preferred location of groundwater recharge implementation.



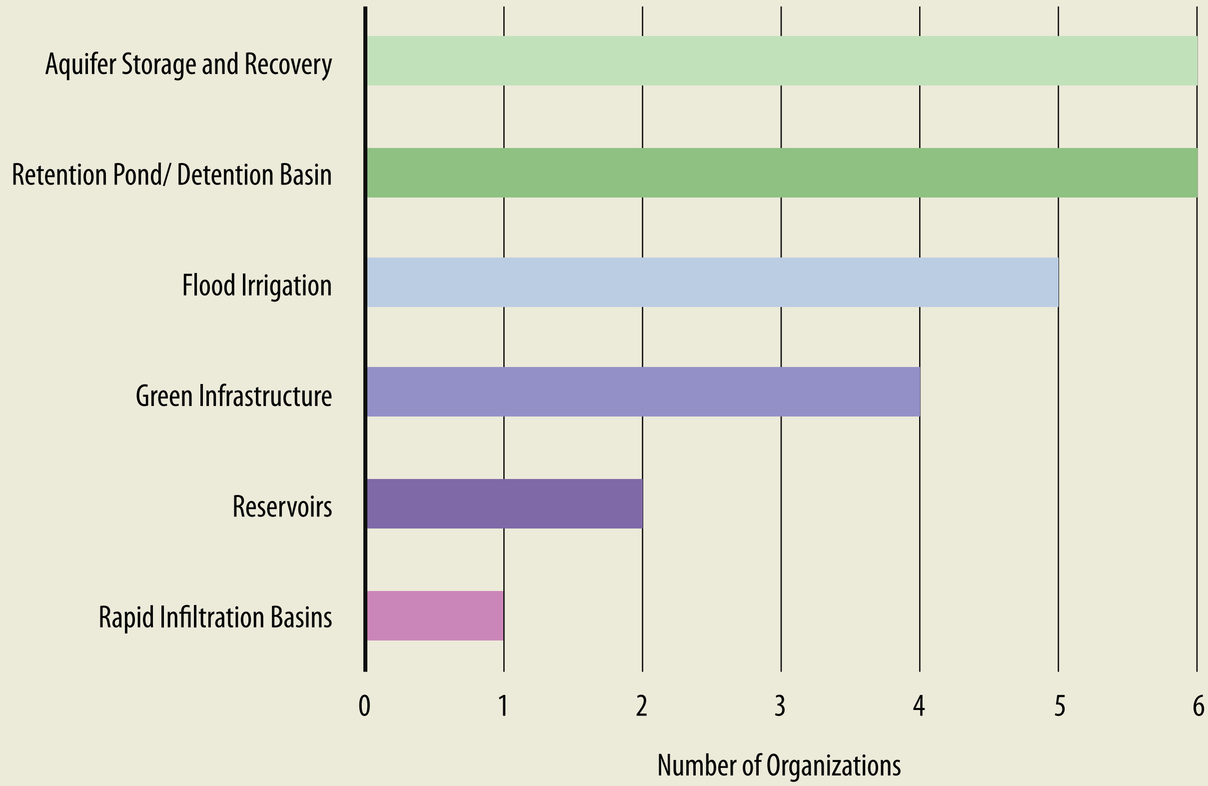
Perceived barriers to using floodwater to recharge groundwater aquifers focused primarily on reasons related to the natural and spatial attributes of the river system for roughly half of the organizations (n=31). These included: lack of appropriate physical conditions to allow for this action, concerns about flooding out others, and the difficulty of directing floodwaters to recharge areas due to the high velocity and volume of flows (see Figure 12).

Figure 12: Barriers to implementing use of floodwater to recharge groundwater.



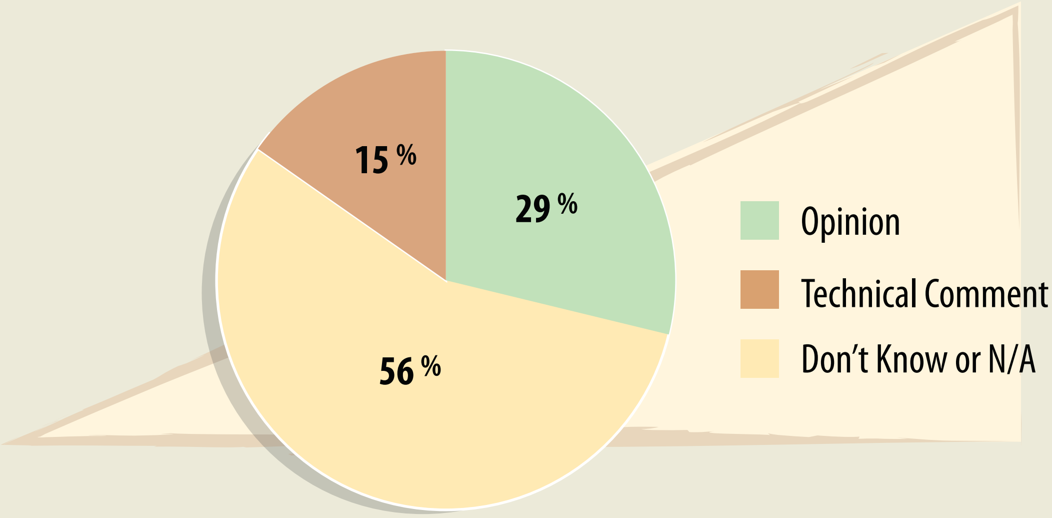
Of those that preferred infrastructure to provide for increased groundwater recharge (n=18), types preferred included aquifer storage and recovery, retention ponds or detention basins (n=6), flood irrigation (n=5), use of green infrastructure (vegetation, soils, natural processes) (n=4), reservoirs (n=2), and rapid infiltration basins (n=1) (see Figure 13).

Figure 13: Preferred type of infrastructure to facilitate groundwater recharge.



To clarify responses to the previous questions about groundwater recharge, researchers asked organizational representatives to elaborate on their familiarity and/or technical knowledge on the issue. The majority (56 percent, n=66) indicated familiarity and/or technical knowledge about the issue and use of groundwater recharge as a supply enhancement strategy, while roughly 29 percent provided an opinion on the benefits or caveats to this alternative. Only 15 percent of those who responded to this question indicated a lack of familiarity with or technical knowledge about the issue (see Figure 14).

Figure 14: Percentage of respondents who have a degree of familiarity with groundwater recharge.



Temperature Impacts

Global mean surface temperatures have warmed in recent decades, and the warming trend is expected to continue into the future (IPCC, 2013). To assess potential impacts to organizations in the Truckee-Carson River System, researchers asked respondents if temperature matters to their organization's water management, and if so, how it matters. The majority of respondents (76 percent, n=66) reported that temperature matters (see Figure 15a). Of those organizations who described specific impacts of change to temperature on water management (n=51), most respondents (n=39) noted concerns about increasing ambient (air) temperatures, which drives increased evapotranspiration, causing fields and lawns to dry at a faster rate (see Figure 15b).

Figure 15a: Percentage of organizations who indicated that temperature changes matter.

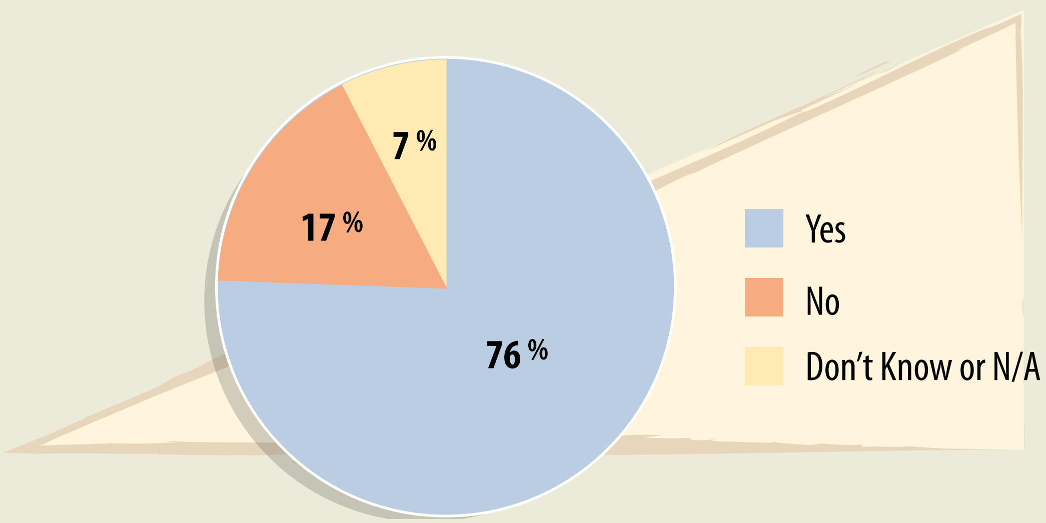
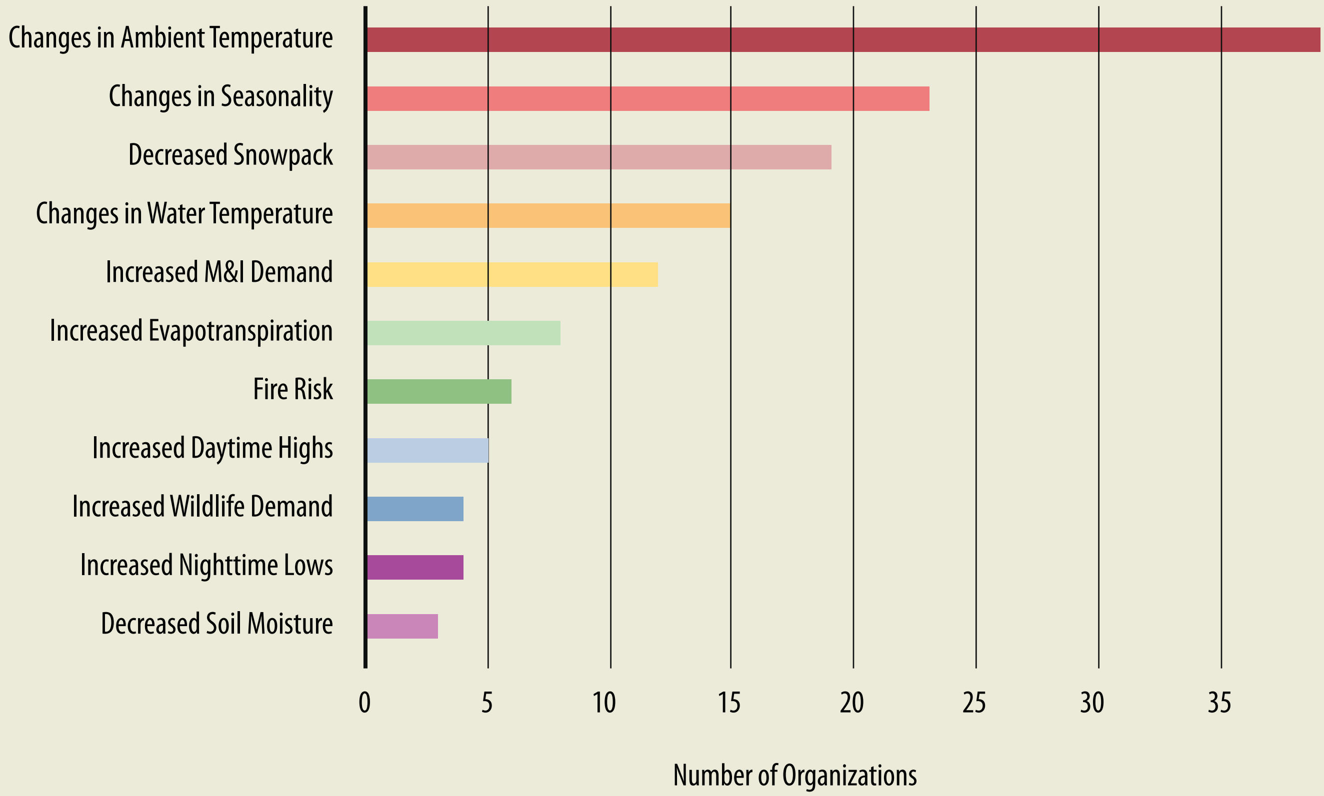


Figure 15b: Impacts of changes in temperature on organization's water management.



Other notable concerns directly related to increasing air temperature included: changes in seasonality (n=23), decreasing snowpack and subsequent loss of water supplies and snowpack as reservoir storage (n=19), increased water temperatures (harmful to water quality and wildlife habitat) (n=15), and increased M&I demand for water (n=12). Some (n=9) noted concerns regarding increases in daytime high and nighttime low temperatures. Impacts noted due to changes in seasonality as a result of warming temperatures included: increases in rain-on-snow events, summer rains causing monsoonal flows, and undesirable changes in the growing and harvest seasons. Additional impacts included decreased soil moisture, loss of snowpack as reservoir storage, increased risk of wildfire and increased wildlife demand for water.

Adaptation to Drought and High-Flow Events

Organizations were asked to describe specific adaptive strategies to drought and high-flow events that are currently being implemented (current adaptations), and strategies that would improve their ability to operate under drought and high-flow conditions in the future (desired adaptations). Many organizations described desired adaptations that present some barriers to implementation.

Current Adaptation to Drought

Respondents provided a number of examples of current drought adaptations (see Table 6). Many adaptations related to ongoing planning and preparedness, including implementation of state drought plans, increased emphasis on watershed restoration, and investing in people, projects and resources to enhance Truckee- Carson River System resiliency. Some recommended that information, research and monitoring efforts be heightened, with increased funding for research and conservation projects. Respondents requested more information about the effects on lake water quality of upstream discharges, improved forecasts of snowmelt and associated water supply, and information to improve their understanding of groundwater resource supply and sustainable yields.

Respondents expressed interest in learning about the effectiveness of demand management strategies, understanding behavioral changes in water use, attracting technology companies that use less water, and altering existing agricultural irrigation practices to conserve water. In urban areas, some respondents encouraged increased xeriscaping. Organizations also expressed interest in supply enhancement strategies, seeking alternative water sources with better water quality, investing in the development of aquifer storage and recovery, increasing water supply for river restoration projects and environmental protection, reducing forest density, and increasing gray water recycling. To better adapt to water supply variability, respondents described at length particular infrastructure and maintenance needs, with interest in the construction of new reservoirs and storage facilities, upgrades to treatment plants, improvements to water delivery systems, improvements to fish ladders and fisheries infrastructure, and removal of existing infrastructure such as Derby Dam.

Management and regulatory changes to increase adaptation were also discussed. Organizational representatives requested options for added flexibility in incorporating sustainable practices and drought planning. Other suggestions included adding new restoration projects along lower reaches of the river, shifting meteorological forecasting stations to higher elevations, obtaining more information and legal clarity on the location of groundwater aquifers and withdrawal rights, modifying Nevada water law and Total Maximum Daily Load (TMDL) regulations, and increasing communication and coordination among organizations. Respondents specifically requested increasing cooperation between upstream and downstream water users, and increasing public awareness of climate change predictions, water sources, water shortages, and the importance of soil moisture monitoring.

Table 6: Current drought adaptations by type of organization.

M&I and Planning	Environmental
▪ Demand management: develop conservation strategies, work to increase conservation, pursue residential water restrictions ▪ Supply enhancement: protect groundwater from overuse, seek better quality aquifers for growing communities ▪ Information and communication: gather data and information, communicate adaptation strategies, support new research ▪ Infrastructure: maintain and make improvements	▪ Monitoring and research: monitor water quality and stormwater runoff, document environmental conditions more frequently through ecosystem health assessments or other methods ▪ Operational changes: accelerate restoration efforts, increase frequency of small projects, adapt ecosystem management approaches
Agricultural	**Regulatory and Information**
▪ Planning and preparedness: develop and implement drought disaster programs, improve farm-level and farm business planning and preparedness ▪ Reduce acreage under cultivation ▪ Shift toward alternative crops that use less water, shift water use toward the most productive areas ▪ Improve efficiency by maintaining existing water delivery infrastructure	▪ Facilitate and expedite water rights exchanges ▪ Increase and improve public communication ▪ Improve data collection and provide better water supply forecasts ▪ Increase planning and preparedness to understand the information needs and priorities of the community

Desired Adaptation to Drought

Respondents described a range of desired adaptations to drought. These adaptations were consistent across all organizational types and across the river system. Systemwide desired adaptations included increased monitoring as well as improved planning and implementation to increase the adaptive capacity of the system. Desired adaptations stated during interviews are organized into eight categories in the following list:

List of Desired Adaptation Strategies

(1) Planning and preparedness

- Increase drought planning across all sectors
- Plan conservation efforts without political intervention
- Implement state drought plans
- Increase emphasis on watershed-scale restoration

(2) Information, research and monitoring

- Track tourist population to estimate seasonal water use
- Monitor water loss from infrastructure to incentivize improvements
- Increase funding for research and projects
- Improve understanding of upstream discharge impacts on lake water quality
- Improve forecasting to better predict timing of snowmelt and water supply
- Enhance monitoring of groundwater resource supply and sustainable yield

(3) Demand management

- Promote behavioral changes in water use
- Attract water-efficient industries that use less water
- Ban urban irrigation and incentivize xeriscaping design

(4) Supply enhancement

- Seek alternative sources of water
- Invest in research to develop aquifer storage and recovery systems
- Enhance supply for restoration projects and environmental protection
- Reduce forest density to increase drainage and reduce transpiration
- Increase recycling of gray water systemwide

(5) Infrastructure and maintenance

- Increase reservoir storage, including building storage on the Carson River
- Invest in temporary storage during drought years
- Improve water delivery downstream of the Truckee Canal
- Increase storage downstream of Lahontan Reservoir
- Increase pipe infrastructure and functionality between purveyors
- Upgrade water treatment plants
- Improve overall water delivery to the farm unit to prevent hydrologic loss
- Remove existing infrastructure (i.e. Derby Dam)

(6) Management changes

- Revise organizational missions to incorporate sustainable practices and drought-resistant planning
- Change delivery operations to increase efficiency
- Shift meteorological forecasting stations to higher elevations to understand "new snow conditions"
- Decrease releases from Stampede Reservoir to maintain storage later in the year
- Reduce hybridization of non-native fish

(7) Regulatory changes

- Develop legal clarity on groundwater aquifer locations and right to withdrawal
- Implement water law change to allow water-banking
- Curtail use by priority or issues
- Modify Total Maximum Daily Load (TMDL) to regulate high sedimentation

(8) Communication and coordination

- Increase public outreach to educate community on sources of water
- Increase education and awareness of water supply shortages and climate change predictions
- Increase cooperation and coordination with downstream water users
- Educate the public about the importance of soil moisture monitoring

Current Adaptation to High-Flow Events

When asked about how their organizations currently adapt to high-flow events, representatives listed numerous measures (see Table 7). For M&I and planning organizations, current adaptations included constructing catchment basins, protecting, maintaining and improving municipal drainage infrastructure, preventing floodplain development, developing flood plans, and improving emergency response. Some M&I and planning respondents stressed that current adaptations remain challenged by the spontaneity of flood events.

Agricultural respondents emphasized adaptations related to flood control, by utilizing wetlands, restoring riparian areas, and maintaining canals to carry away floodwaters. Additionally, agricultural organizational respondents emphasized the importance of developing regional flood plans and educating Farm Service Agency (FSA) disaster loan recipients about the risk of developing land in the floodplain.

Environmental organizations stressed the importance of maintaining the natural dynamics of the river system, and continuing with ongoing restoration projects (including bank stabilization, prioritization of restoration areas, and monitoring these areas prior to and following flood events). Respondents emphasized the importance of multi-agency collaboration to plan the capture of floodwater, and increased staffing and communications during flood events.

Table 7: Current adaptation to high-flow events by type of organization.

M&I and Planning	Environmental
■ Infrastructure: construct new catch basins; protect, maintain and improve sewers, storm drains, dams and driveway culverts ■ Planning and regulation: prevent development in the floodplain, develop flood plans, train personnel ■ Emergency response: improve emergency communication networks, install backup generators ■ Research and information: support research to understand aquifer recharge, map the floodplain, improve monitoring of contamination during high-flow events	■ Restoration projects: fund and plan projects related to restoration, bank stabilization, and stormwater runoff ■ Monitoring and research: use geomorphological studies to prioritize restoration areas, monitor riparian areas before and after flood events ■ Natural system dynamics: design restoration projects to help attenuate floodwaters
Agricultural	**Regulatory and Information**
■ Flood control: spread water to wetlands, rebuild and restore riverbanks, divert flows to prevent property damage, maintain canals that absorb and carry floodwaters ■ Planning and preparedness: develop regional flood plans, utilize Farm Service Agency disaster assistance and funding, educate loan recipients on proximity to the flood plain	■ Planning and coordination: collaborate with other agencies to plan for floodwater capture ■ Information: improve estimates of water storage capacity, improve technology, increasing staffing and communications during floods ■ Regulation: save space in reservoirs to capture floodwaters

Desired Adaptation to High-Flow Events

The most frequently described desired adaptations to high-flow events (see Table 8) were fairly consistent across the organizational types, and included: increasing storage reservoir space (including storage on the Carson River), deepening canals, maintaining infrastructure and removing constriction points, relocating infrastructure in the floodplain, and implementing the Truckee Meadows flood-control plan. Additional desired adaptations included improving forecasting and expanding communication and emergency response networks to remote areas. Environmental organizations indicated the need to fund restoration projects that will allow the natural system to absorb floodwaters, and to conduct research to define the new normal of extreme high-flow events.

Table 8: Desired adaptation to high-flow events by type of organization.

M&I and Planning	Environmental
■ Planning: improve flood control and stormwater planning ■ Infrastructure and maintenance: increase storage reservoir space; invest in flood-control berms, structures, and retention basins; update or restore existing infrastructure; prevent growth in the floodplain ■ Emergency response: improve or create evacuation safety plans and alternatives, communication systems, backup plans, and emergency response at treatment facilities	■ Monitoring and research: study the spread of invasive species, improve predictions about the "new normal" ■ Management and operations: promote flexibility in timing of water releases from reservoirs ■ Transportation and infrastructure: keep development out of the floodplain, protect critical roadways, maintain and improve canal infrastructure, remove unnecessary infrastructure ■ Restoration: fund in-stream restoration projects, restore floodplains and streams to absorb high flows
Agricultural	**Regulatory and Information**
■ Flood control: improve/create upstream storage on the Carson River, deepen canals, construct additional waterways and spill basins, maintain riverbanks ■ Management and operations: modify operation of Lahontan Reservoir, direct excess flows to Stillwater National Wildlife Refuge, make changes to Nevada water law ■ Planning and preparedness: invest in flood planning in the Lahontan Valley, increase education about flood impacts and flood assistance	■ Information and research: improve forecasting and knowledge of regional climates and extremes ■ Infrastructure: improve flood storage, increase riparian vegetation plantings in the floodplain, remove or prevent development in floodplains and waterways ■ Communication and coordination: Improve communication and coordination across the Truckee-Carson River System

Barriers to Desired Adaptation Strategies

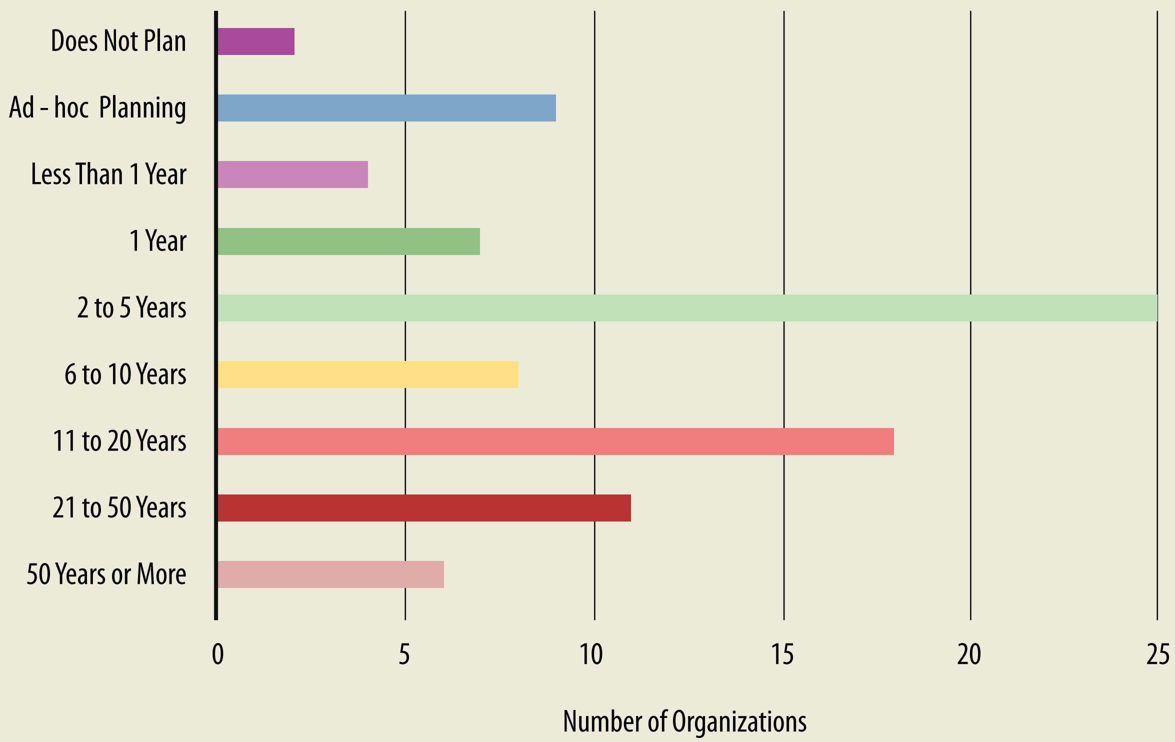
Respondents described barriers to desired adaptation and implementation that tend to characterize water supply-focused policies. According to survey responses, the top barriers to adapting to drought and flood events are:

- lack of funding;
- prohibitive cost of building infrastructure;
- uncertainty and spatial variability of flood events;
- diversity of issues, priorities and demand;
- lack of coordination from headwaters to terminus; and
- policy constraints.

Adaptive Capacity and Planning Horizons

To improve understanding of the current organizational adaptive capacity, researchers asked organizational representatives how far into the future their organizations plan water management goals and activities (see Figure 16a). Of the organizations who responded (n=63), many have multiple planning horizons (n=25). The majority of organizations interviewed reported planning two to five years into the future (n=25), for some activities. However, 18 organizations reported planning 11 to 20 years into the future, and 11 organizations reported planning 21 to 50 years into the future.

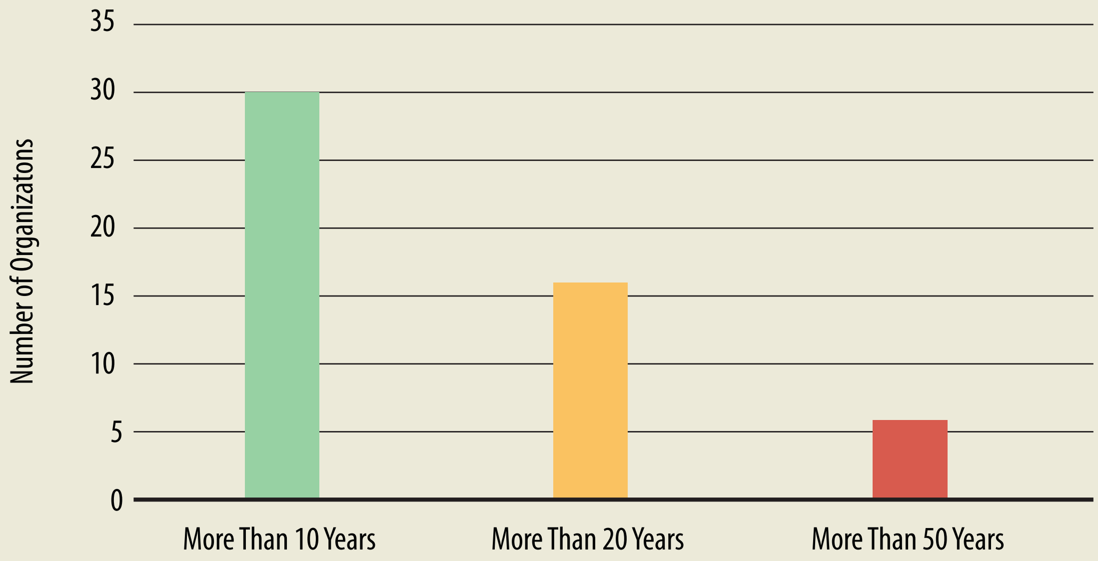
Figure 16a: Organizational planning horizons.*



*organizations selected as many as three responses

In terms of the longest planning horizon (see Figure 16b), 79 percent of organizations surveyed (n=52) indicated at least one planning horizon that extended 10 plus years into the future. About 33 percent of organizations had planning horizons that extended 20 plus years into the future (n=22), and 9 percent were planning more than 50 years into future for some activities (n=6).

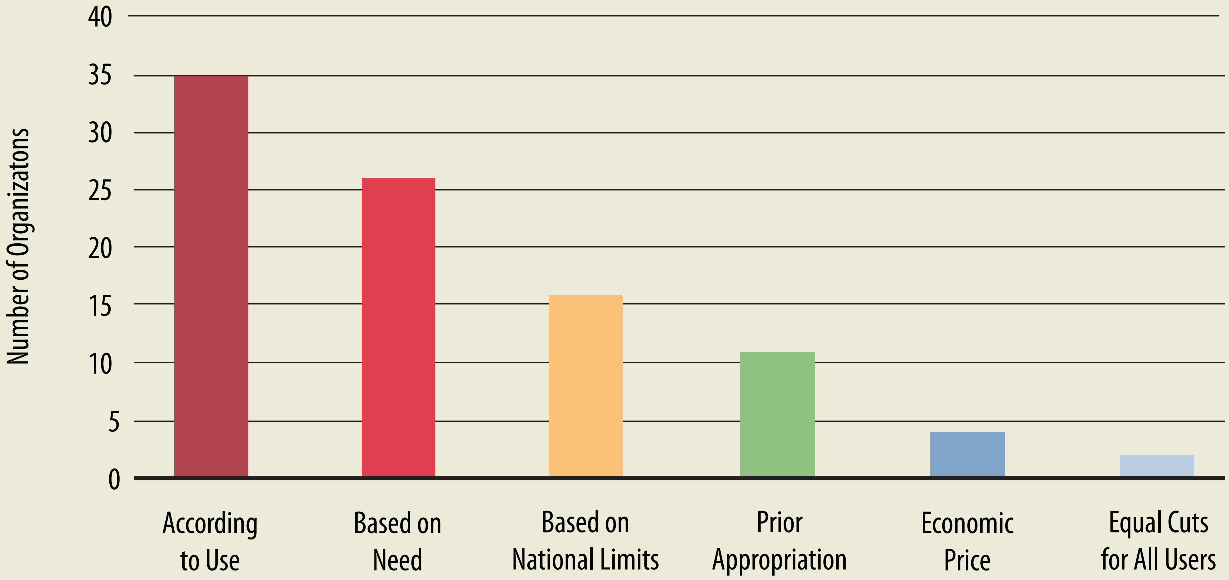
Figure 16b: Longest reported planning horizon.



Policy Preferences

To assess the role of policy in river system climate vulnerability and resiliency, organizational representatives were asked how water should be allocated during drought. Of those who responded (n=63), the majority indicated that water should be allocated according to use (n=35), followed by need (n=26), natural limits of the system (n=16) and through prior appropriation (n=11). Allocating water by price (n=4) or providing equal cuts for all users (n=2) were not frequently selected by the organizational representatives interviewed.

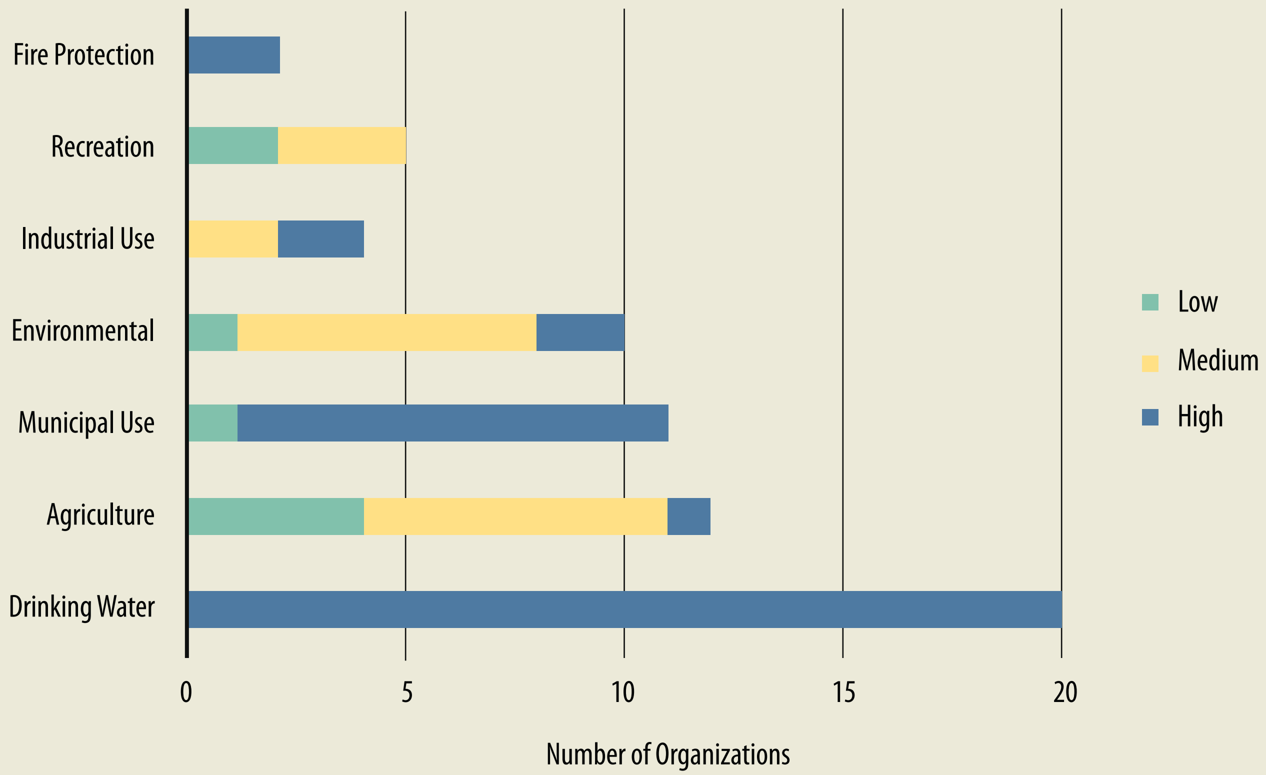
Figure 17: Preferred water allocation rule during drought.*



*organizations selected multiple responses

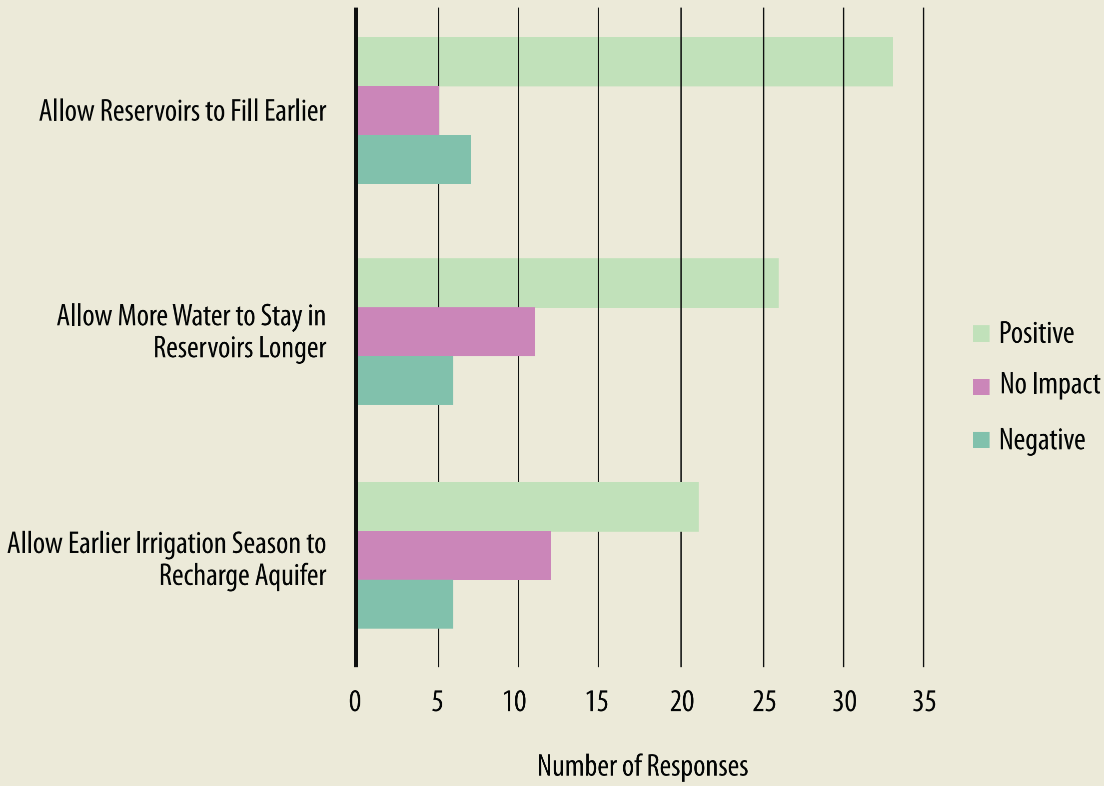
Organizations were asked to rank the most important uses of water during drought on a scale of low, medium and high. Of those who responded (n=35), the majority of respondents rated drinking water as the highest priority use (n=20) (see Figure 18). Municipal use also rated as a high priority (n=11). The remaining uses were rated predominantly as medium priorities and focused mainly on environmental use (n=7) and agriculture (n=7).

Figure 18: Ranking of preferred water uses/allocation during drought.



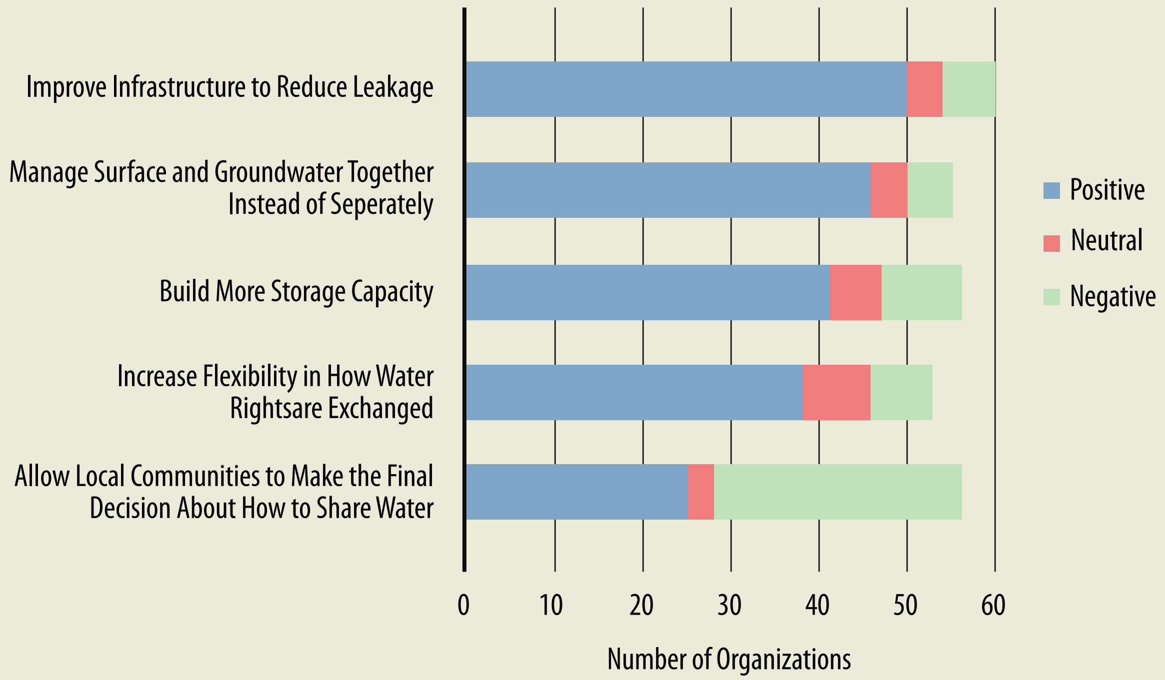
Respondents described how in the Truckee-Carson River System, drought is often followed by flood. Water storage and use policies within the system are tailored to balance against the possibility of both types of climate extremes. To explore opinions about these policies, respondents were asked to envision a scenario where several dry years were followed by a very wet year. The research team then asked them to assess changes to flood control policies that would increase storage in the system, based on that scenario. The policy options included: (1) allow reservoirs to fill earlier; (2) allow more water to stay in reservoirs longer; and (3) allow earlier irrigation season to recharge the aquifer. Respondents were asked to rate the impact of each using a five-point Likert-type scale, with 1 being very negative impact and 5 being very positive impact. These ratings were collapsed so that impacts were either negative, no impact or positive. The majority of respondents rated all three potential policy options as having a positive impact respectively with the majority preferring to allow reservoirs to fill earlier (see Figure 19).

Figure 19: Perceived impact of flood control policy options.



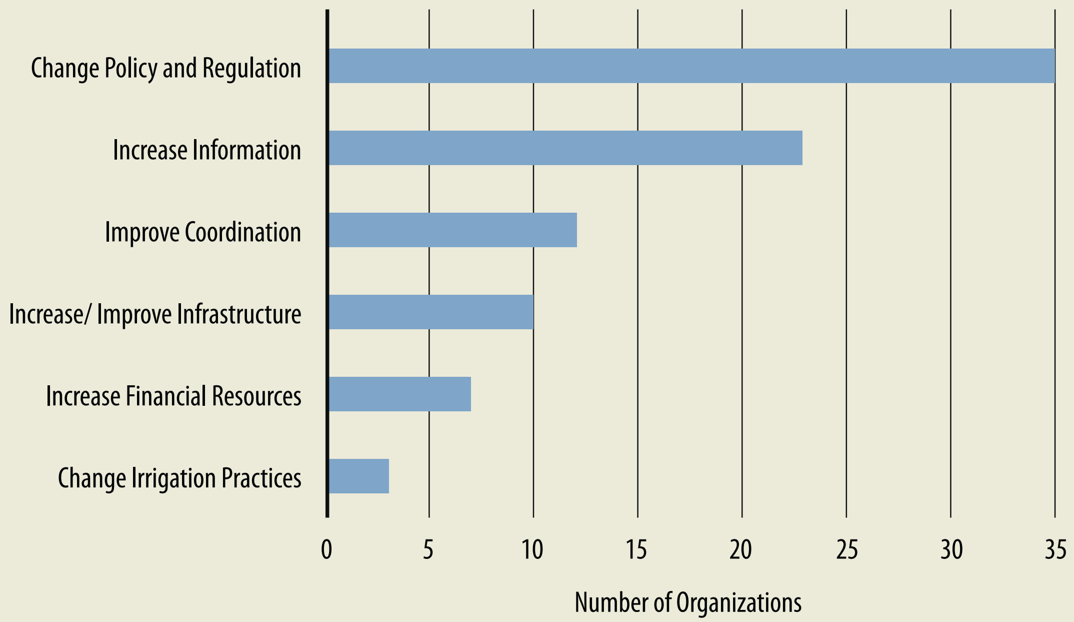
Researchers provided organizational representatives with five potential policy actions to manage water resources more effectively during drought conditions. These included: (1) improving infrastructure and reducing leakage; (2) managing surface and groundwater together instead of separately; (3) building more storage capacity; (4) increasing the flexibility in how water rights are exchanged; and (5) allowing local communities to make the final decision about how to store and share water. Respondents were asked to rate the impact of each using a six-point Likert type scale, with 1 being very negative impact, 5 being very positive impact, and 6 being don't know. For those who rated the impact (don't know responses were excluded from this analysis), scores were collapsed into three categories so that impacts were either negative, no impact, or positive (see Figure 20). Improving existing infrastructure and implementing conjunctive management of surface and groundwater were assigned the greatest positive rating. One respondent rated policy actions (2) and (4) as having both positive and negative impacts, and three respondents rated policy option (5) as having both positive and negative impacts.

Figure 20: Perceived impact on water management of proposed drought policy actions.



Organizational representatives were asked to describe the kinds of changes that might improve adaptive capacity to drought and flood (see Figure 21a). Most respondents expressed a desire to see changes to existing policy and regulation (n=35) and increased information about natural and human systems in relation to water (n=23). Twelve respondents wanted to see changes that would improve coordination and 10 respondents wanted to see improvements to or increased infrastructure.

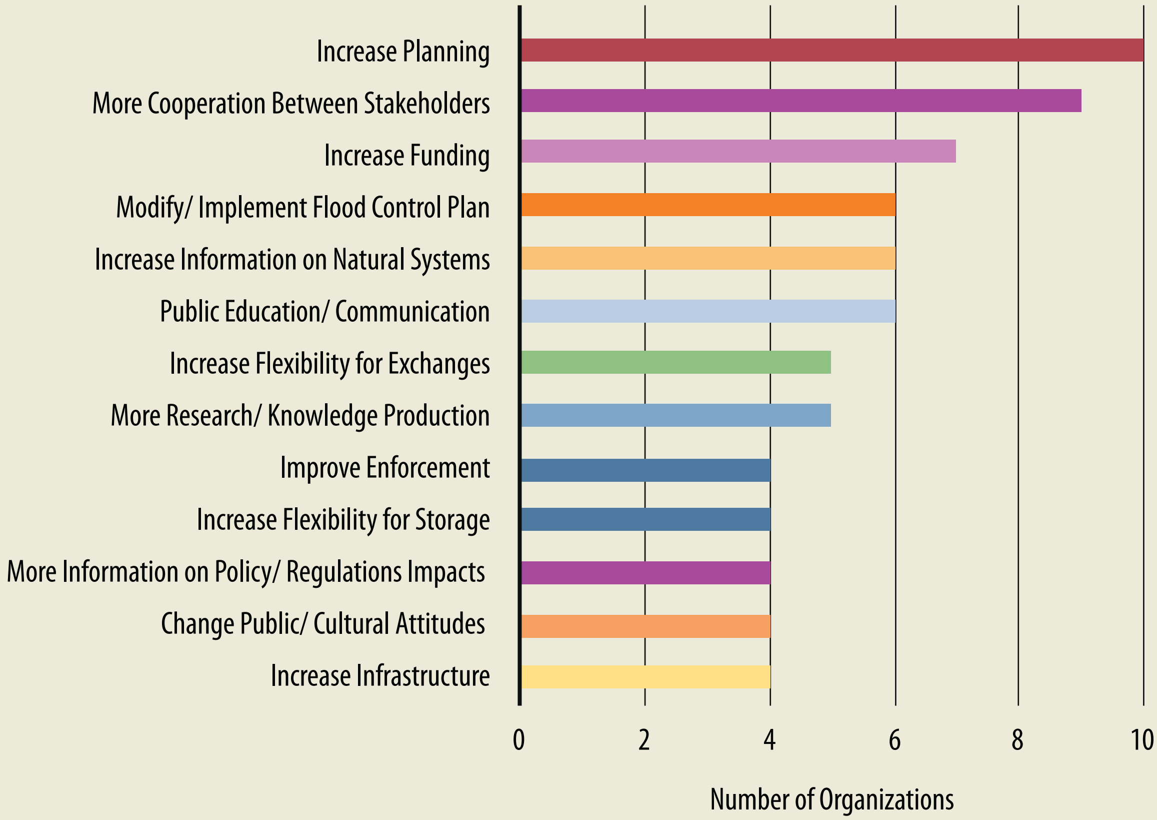
Figure 21a: Desired changes to improve adaptive capacity.*



*organizations selected up to seven preferences

Respondents identified more than 50 actions to improve adaptation. The largest number of respondents favored increased planning (n=10), followed by more cooperation between stakeholders (n=9), more funding (n=7), and more public education about water conservation and floodplain preservation (n=6) (see Figure 21b).

Figure 21b: Adaptation strategies identified by organizations.

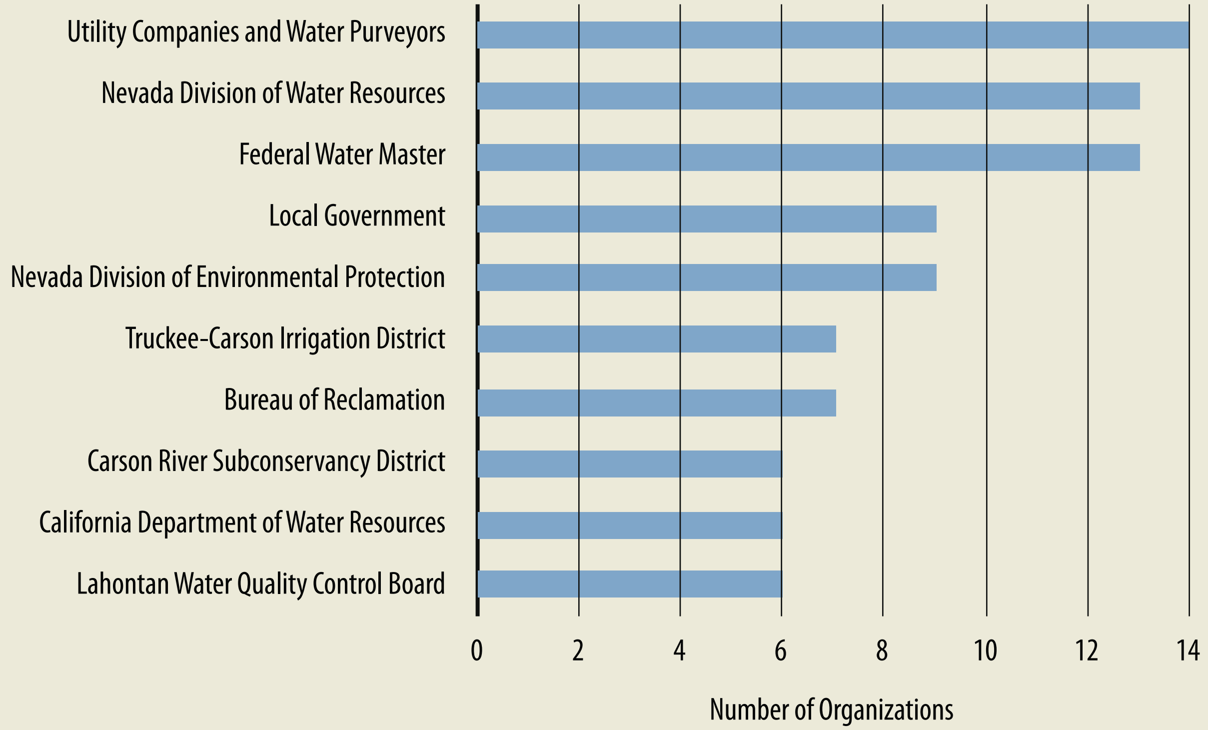


Communication and Coordination

Assessing options for future adaptation to climate change requires understanding the social networks that influence organizational decision-making on the Truckee-Carson River System. This involves examining which organizations other organizations reach out to routinely when water management or related issues arise. Understanding how organizations are connected through information exchange helps to identify communication patterns in the river system (Bharwani et al. 2013; Downing, 2012; Moser & Ekstrom, 2010).

Researchers asked organizational representatives a series of questions regarding existing communication networks in the river system to better understand and identify opportunities for improved adaptation. First, researchers asked: "Who do you call about water-related issues?" Figure 22 illustrates those organizations contacted most frequently and includes utilities and purveyors (n=14), Office of the State Engineer (n=13), Federal Water Master (n=13), Nevada Department of Environmental Protection (n=9), and local government (n=9).

Figure 22: Organizations called most often for information.



Organizational representatives were asked to describe the kinds of changes that might improve adaptive capacity to drought and flood (see Figure 21a). Most respondents expressed a desire to see changes to existing policy and regulation (n=35) and increased information about natural and human systems in relation to water (n=23). Twelve respondents wanted to see changes that would improve coordination and 10 wanted to see improvements to or increased infrastructure.

Figure 23: Percentage of respondents who perceived coordination problems in the Truckee-Carson River System.

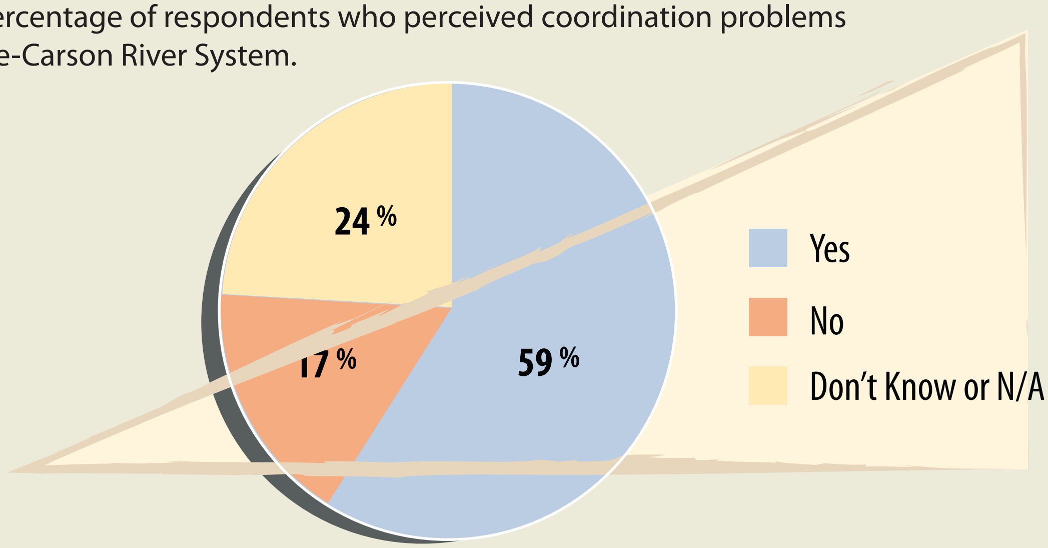


Figure 24: Perceived coordination problems on the Truckee-Carson River System.

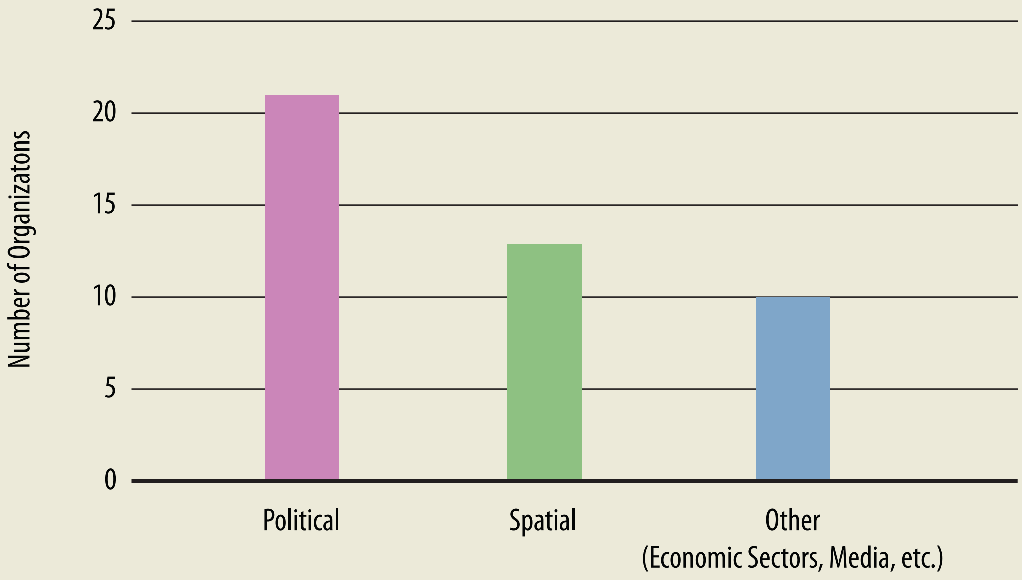
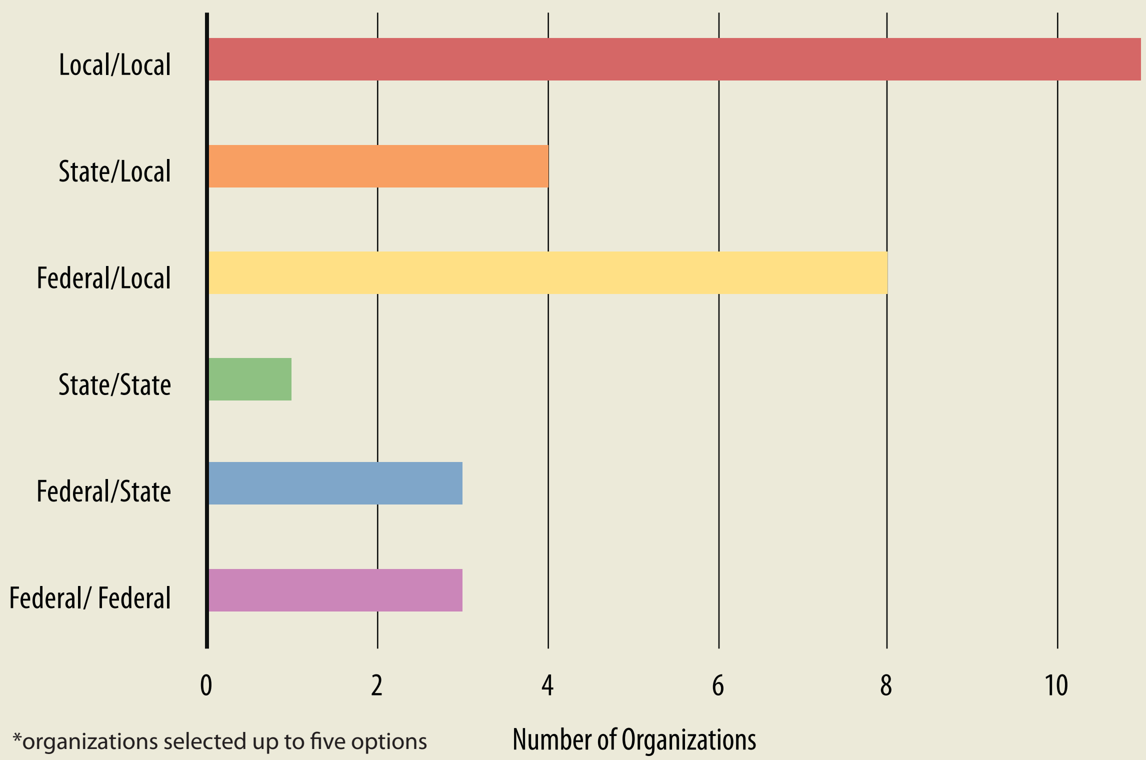


Figure 25a illustrates the various political levels across which coordination problems occur. The largest number of respondents indicated coordination problems among local or nongovernmental organizations (n=11), followed by problems among federal and local organizations (n=8). Local political levels include local actors, private sector, public agencies, utilities and nongovernmental organizations.

Figure 25a: Perceived coordination problems across political levels.*



*organizations selected up to five options

Figure 25b illustrates perceived coordination problems across the river system as described by a small set of organizations (n=13). The majority of respondents indicated coordination problems exist between upstream and downstream users (n=8), followed by coordination problems among downstream users (n=5). Several organizations (n=10) noted coordination problems involving the general public (n=6) as well across the various types of organizations or sectors (n=4) (see Figure 25c).

Figure 25b: Perceived spatial coordination problems across the river system.*

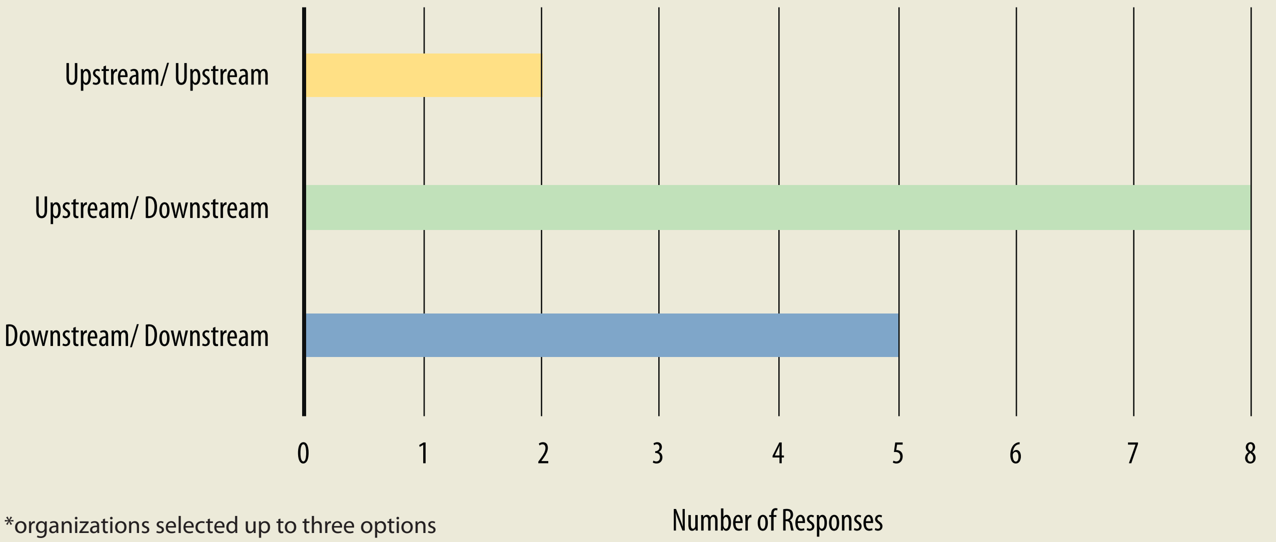
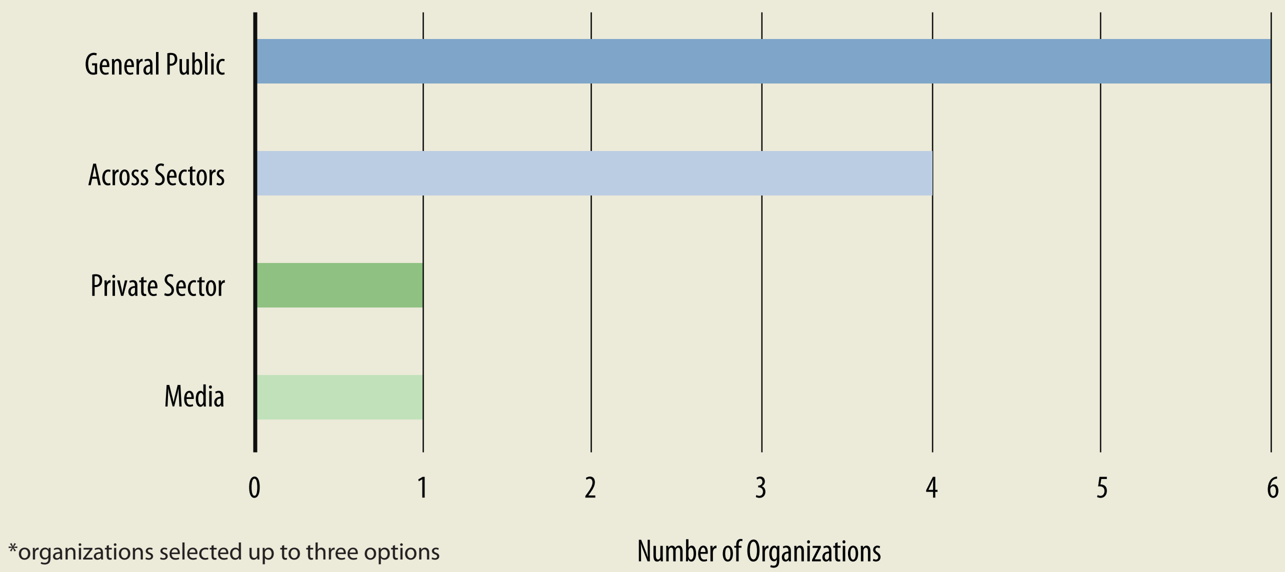
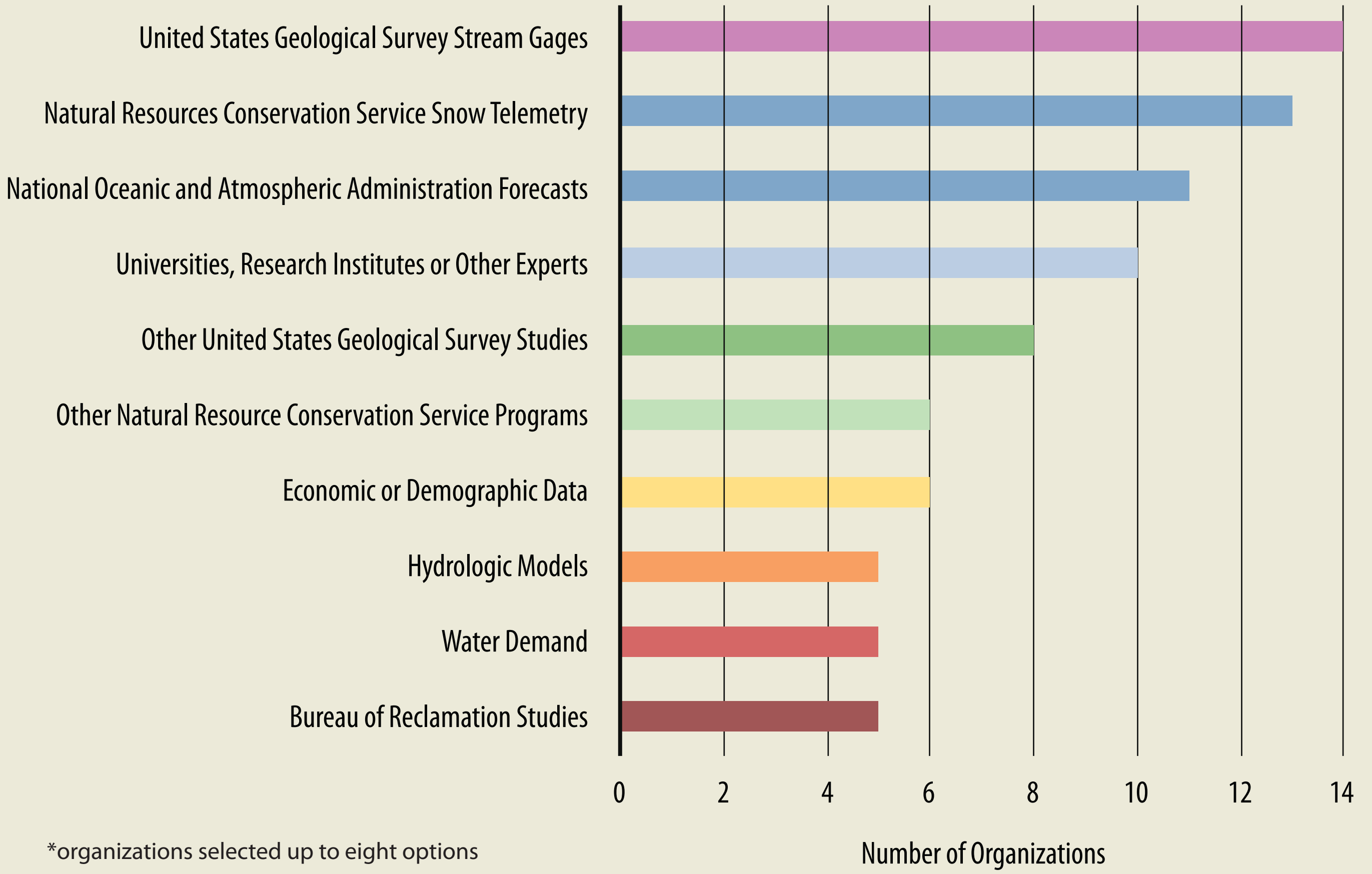


Figure 25c: Perceived coordination problems as a result of actions of other actors.*



When organizational representatives were asked where they get information used to make water-related decisions, nearly all described sources used (n=48). The majority reported using United States Geological Survey stream gages (n=14), followed by Natural Resources Conservation Service Snow Telemetry (n=13), National Oceanic and Atmospheric Administration Forecasts (n=11), and research findings from universities and systemwide experts. (n=10). Figure 26 illustrates the top 10 sources used by organizations.

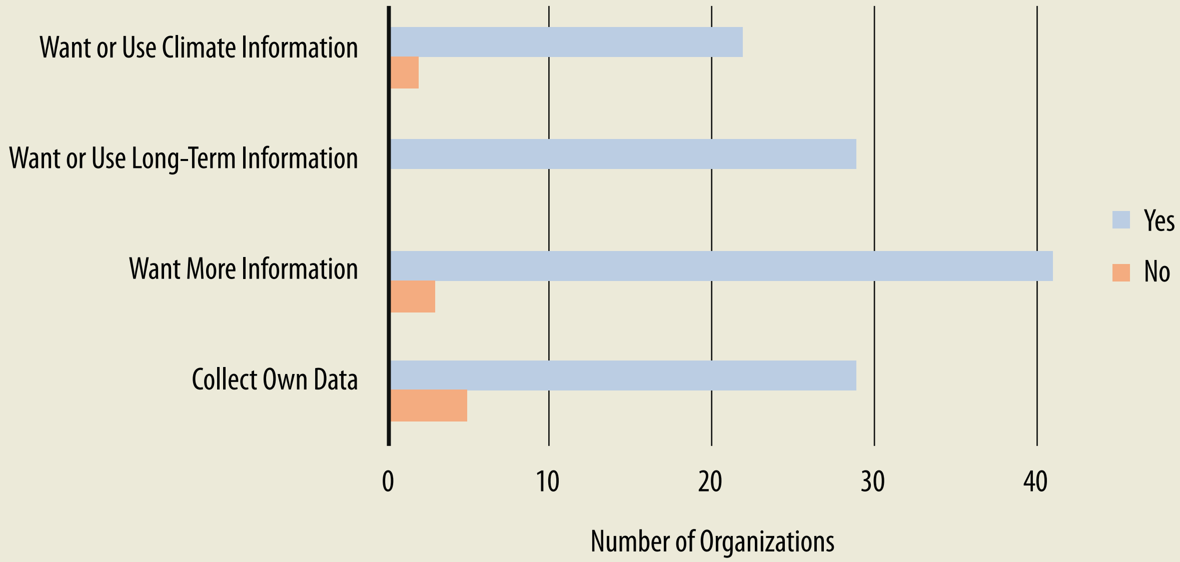
Figure 26: Sources information used by organizations to make water-related decisions.*



*organizations selected up to eight options

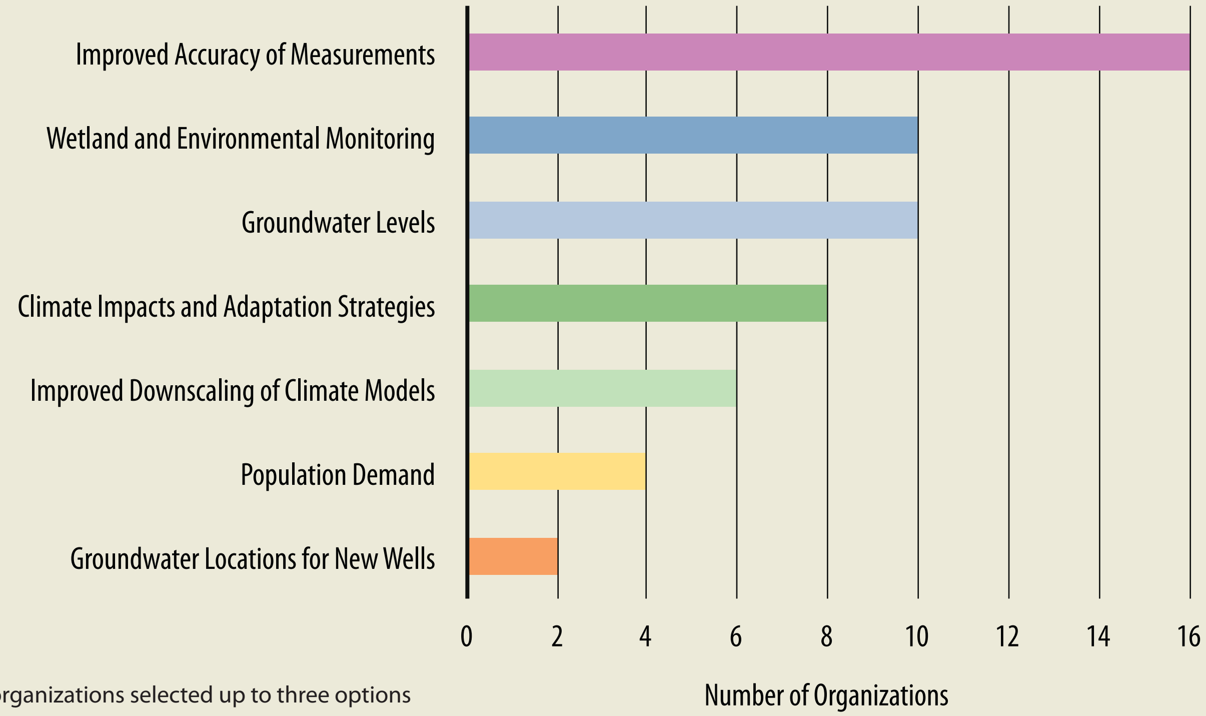
Most of the respondents reported that they collect their own climate information and data (n=29), and that they want more information than they currently have (n=41) (see Figure 27).

Figure 27: Information sought by organizations.



More specifically, respondents (n=35) described a desire for improved accuracy of measurements (n=16), as well as data on groundwater levels (n=10), wetland and environmental modeling (n=10), and climate impacts and adaptation strategies (n= 8) (see Figure 28).

Figure 28: Perceived missing information that would improve water related decisions.*



*organizations selected up to three options

Perceived Importance of Climate Change and Future Challenges

When asked how important climate change is to the river system, 79 percent of all respondents surveyed (n=66) reported it was very important, on a six-point Likert type scale with 1 being not very important, 5 being very important and 6 being don't know (see Figure 29). Nearly all respondents (n=60) commented on climate change adaptation currently being implemented within their organization. Many respondents reported that their organizations are already implementing adaptation strategies, which include improving communication, monitoring, or data collection and planning (see Figure 30). However, 13 of these respondents reported that their organization had not yet taken any action toward adaptation.

Figure 29: Perceived importance of climate change to the Truckee-Carson River System by organizations.

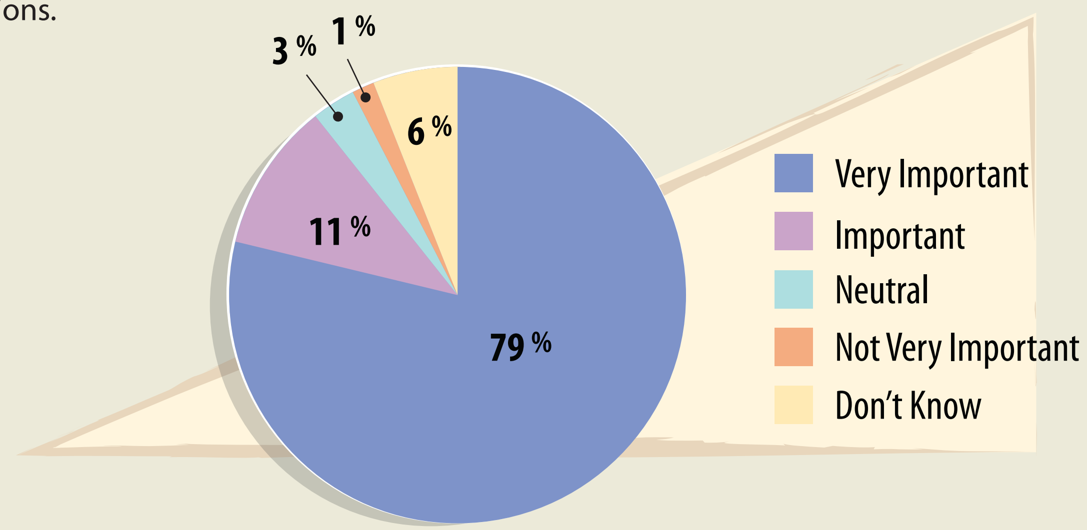
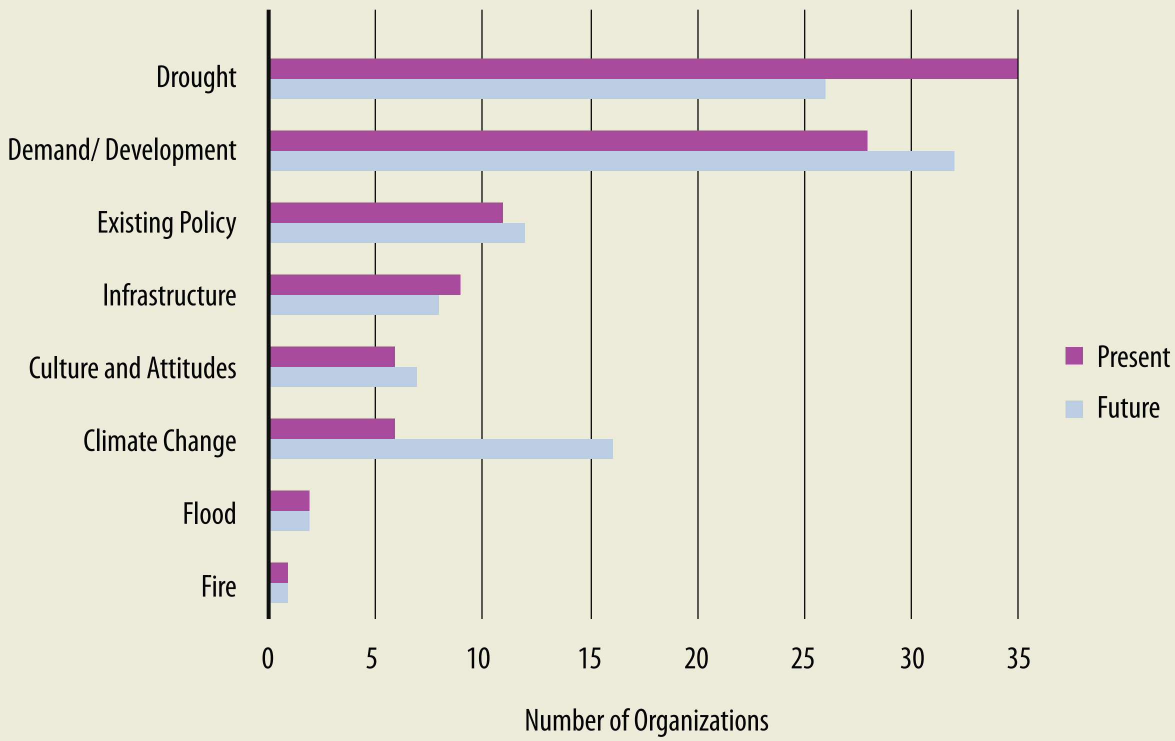


Figure 30: Climate change adaptation currently implemented by organizations.*

*organizations selected up to five options

When asked what the greatest stressors on the river system are presently and in the future, almost all organizations commented (n=65 for present, n=66 for future). The majority of respondents indicated that presently the greatest stressor is drought, and in the future the greatest stressor would be increased water demand due to increased economic and residential development followed by drought (see Figure 31). More respondents indicated that demand and development, climate change, issues related to operating environment and cultural attitudes would serve as important stressors in the future rather than in the present.

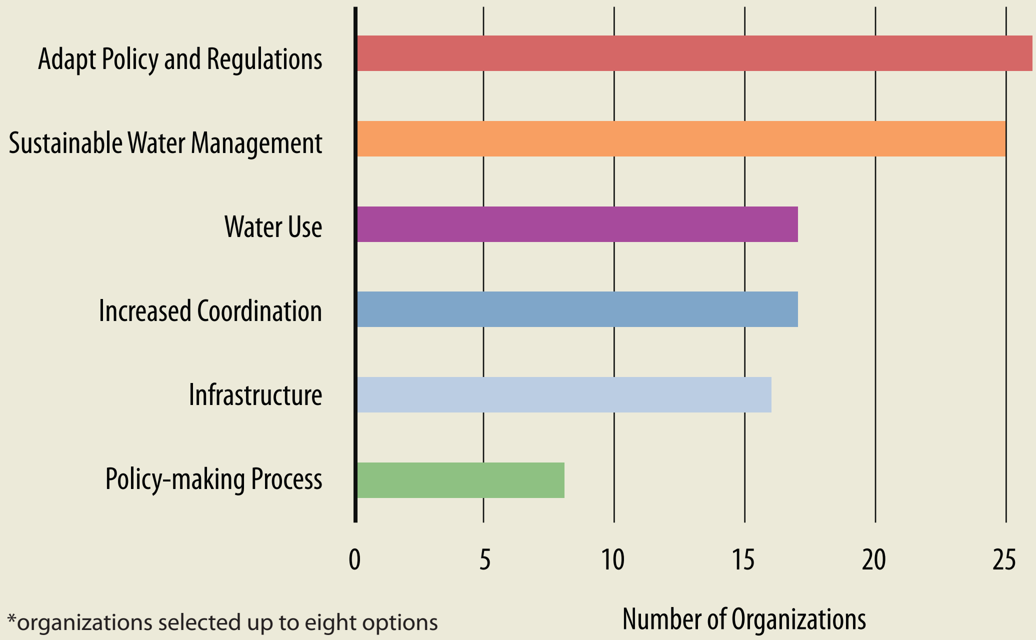
Figure 31: Present and future stressors on the Truckee-Carson River System.*



*organizations selected up to six options for present stressors, and up to five options for future stressors

To gage the potential for future adaptive capacity among Truckee-Carson River System organizations, researchers asked organizational representatives: "If you were King or Queen of the river and could make any changes you desired, what changes would you make to better manage water resources?" Nearly all organizations described desired changes (n=61) (see Figure 32). More than one third of respondents (n=26) indicated changes that required modification to prior appropriation doctrine to allow for greater flexibility and efficiency in using allocated water rights, such as temporary water leasing/banking programs or temporarily moving place and purpose of use to "stack" water rights to irrigate the most productive lands. Also suggested were structural changes (n=25), such as recruiting less water-intensive industry to the region. Altering current patterns of water consumption/use and increasing coordination and communication among Truckee-Carson River System stakeholders were indicated as necessary changes also (n=17), followed by improvements to water delivery infrastructure (n=16). Several comments (n= 7) indicated the need to revise the water policy making process.

Figure 32: Identified changes needed to better manage water resources in the region.*



*organizations selected up to eight options

SUMMARY

In snow-fed arid-land river systems such as the Truckee-Carson River System, the timing and duration of snowpack accumulation and spring runoff are critical factors driving the region's water availability throughout the seasons. Anticipated variability in these hydrologic processes may expose the region and its communities to increased vulnerability to prolonged drought, increasing temperatures and flood events. *Water for the Seasons* features a collaborative modeling research design that involves local stakeholders as participants in climate science research. Tailored to the Truckee-Carson River System and its communities, this program brings together scientists and stakeholders to examine the system's vulnerability to climate change and explore adaptation strategies to enhance resiliency at the watershed and community scales.

This publication reports the findings of a survey of 66 Truckee-Carson River System organizations with water management responsibilities and/or interests. The preliminary survey results reported here provide an initial framework for considering systemic climate vulnerabilities as well as opportunities for enhancing resiliency through adaptations. These findings also provide important information to direct future research in this program.

The majority of survey respondents noted the current 2012-2015 drought as the worst drought of memory. For M&I and planning organizations, coping with prolonged, severe water supply shortages would require necessary structural changes to alleviate impacts. These changes include reducing the number of water-intensive industries and deterring residential and commercial landscape irrigation. In the Truckee River, M&I and planning organizations called for increased flexibility in how water is stored in the Truckee headwaters (i.e., surface reservoirs) and in recharging groundwater reservoirs. Together, these strategies would help to offset severe supply shortages for a period of time. Agricultural and environmental organizations perceived little to no benefits from adding storage flexibility and groundwater reservoirs.

Agricultural organizations appeared to absorb drought impacts solely through farm-level adaptations, although farm unit productivity degraded with an increase in duration of drought, due partly to diminishing soil moisture slowing water infiltration. Underlying impacts independent of the degree of the water supply shortages included reduced farm productivity, reduced economic stability, groundwater supply shortages due to increased pumping, and complexities related to changing place of use to easily allocate water rights to only the most productive land parcels. During severe drought conditions, agricultural producers face substantial individual economic risks in order to sustain agricultural operations. For producers at the end of the system in the Newlands Project, depending on the percent allocation received, even a one-year drought could be considered severe, while for environmental users, a supply shortage that lasted three years and longer could be considered severe. Water quality degradation as a result of drought was a concern regardless of organization type. For all organization types, impacts associated with moderate drought are exacerbated under severe drought.

Organizational representatives suggested several changes necessary to improve resiliency to drought. Ideas included modifying prior appropriation doctrine to allow for greater flexibility and efficiency in using allocated water, reducing water-intensive industry and municipal and industrial landscaping, incentivizing water conservation, and increasing/improving coordination and communication among river system stakeholders. Preferred policy actions to manage water resources more effectively during drought conditions involved improving existing water delivery infrastructure and conjunctively managing surface and groundwater resources.

Since climate variability is also characterized by shifts in temperature, researchers asked organizational representatives if temperature mattered to their organizations water management and if so, how it mattered. Changes in temperature were notable among most organizations, especially in terms of changes in precipitation type (from less snow to more rain) and evapotranspiration rates. The 1997 flood, a rain-on-snow event, was described by most respondents as the worst high-flow event to date in the Truckee-Carson River System. However, for some municipalities, summer thunderstorms that produce flash floods overwhelmed existing stormwater infrastructure.

The most frequently identified desired adaptations to high-flow events were consistent across organization types. These focused on increasing storage reservoir space (including constructing new storage on the Carson River), deepening canals, maintaining and improving stormwater infrastructure, removing river constriction points, relocating infrastructure away from the floodplain, and implementing the Truckee Meadows flood- control plan. Additional desired adaptations included improved forecasting and expanding communication and emergency response networks to remote rural areas. Environmental organizations indicated that additional funding is required to restore the natural river and riparian system, to improve the system's capacity to absorb floodwaters, and to conduct research to define the new normal of extreme high-flow events.

Concerns related to increased evapotranspiration were explicitly linked to the cause of fields and lawns drying faster. Other notable concerns related directly to changes in seasonality (shorter winters, earlier springs, hotter summers), decreasing snowpack (loss of water supplies and snowpack as reservoir storage), increased water temperatures (harmful to water quality and wildlife habitat), and increased municipal and industrial demand for water.

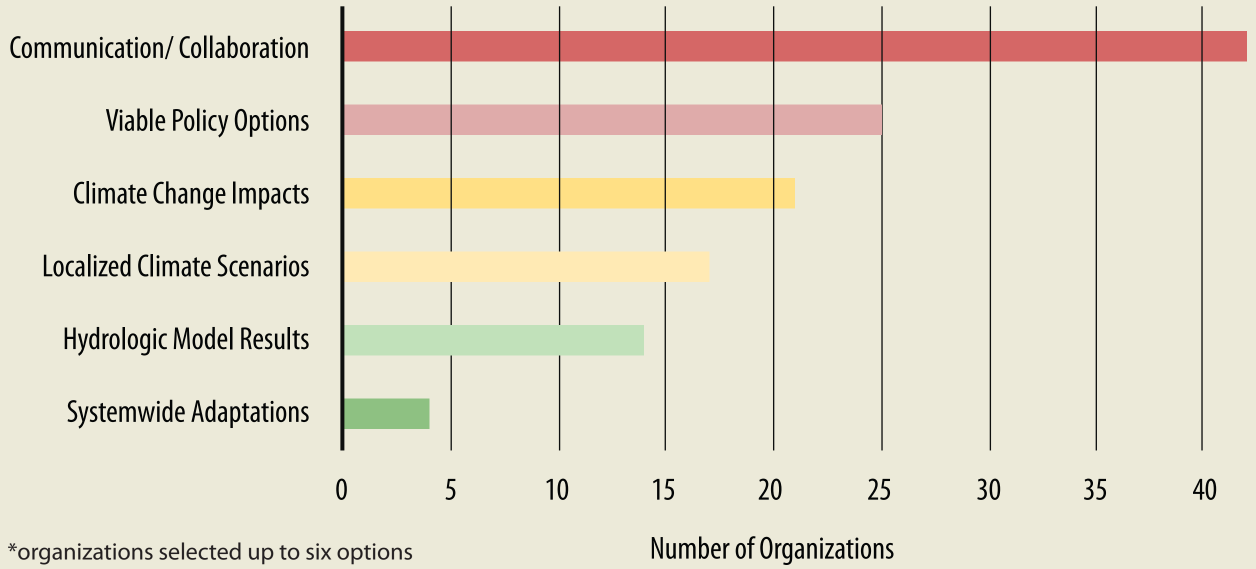
Most organizations surveyed expressed concerns about the future, due to pressures from steady population growth and economic development in the region driving increases in the demand for water under a seemingly static or decreasing water supply. The changes they suggested for better managing water resources into the future, provided no constraints existed, required modification to the prior appropriation doctrine to allow for greater flexibility and efficiency in using allocated water rights. Examples included adding temporary water leasing/banking programs, or allowing users to "stack" water rights by temporarily moving place and purpose of use to irrigate the most productive agricultural lands. Organizations also suggested structural changes, such as recruiting less water-intensive industry to the region, altering current patterns of water consumption/use, increasing coordination and communication among river system stakeholders, and improving water delivery infrastructure.

Finally, regardless of management responsibilities or location on the system, 79 percent of the organizations surveyed indicate that climate change is very important. Many respondents reported that their organizations are already implementing adaptation strategies and incorporating adaptation in their planning activities, with many organizations using 20- to 50-year planning horizons. However, survey respondents repeated frequently that coordination and communication among stakeholders is problematic, and needs to improve between and among upstream and downstream users to effectively enhance climate resiliency through systemwide adaptations.

Collaborative Modeling and Preliminary Survey Results

Organizational representatives surveyed listed several desired deliverables from the *Water for the Seasons* research program (n=65). By far the largest number of respondents (n=43) wanted to see improved communication and collaboration among stakeholders across the system (see Figure 33). The second most important program deliverable (n=25) included research information that provides viable policy alternatives to enhance Truckee-Carson River System climate resiliency. Also regarded as desired and important program outcomes were projected climate change impacts on the river system, and the results of hydrologic models based on climate scenarios tailored to the river system.

Figure 33: *Water for the Seasons* research program deliverables desired by organizations.

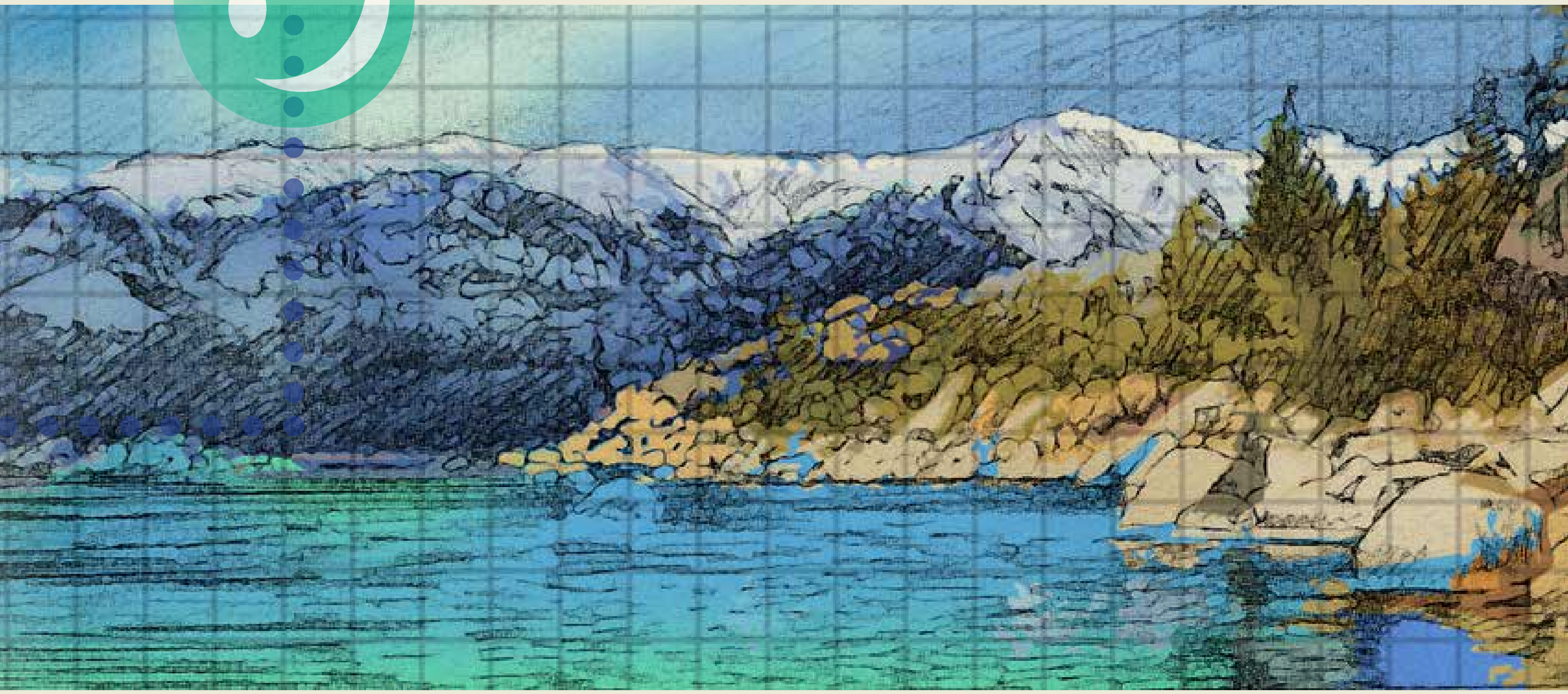


*organizations selected up to six options

Using the preliminary results

of this organizational survey and ongoing input from local key stakeholders, scientists have constructed plausible climate scenarios to simulate prolonged drought in the region, which account for a slight increase in temperature to replicate global warming trends. These climate scenarios provide data inputs to a suite of hydrologic models, tailored to the Truckee-Carson River System that simulate a range of possible hydrologic outcomes to surface and groundwater resources. Additionally, operations models are being used to determine if water rights are met when the resulting amount of water is distributed under the Truckee-Carson River System prior appropriation doctrine. The goal is for the scientists and stakeholders to explore the effects of climate scenarios on resulting water availability systemwide, and the potential impacts to specific organizations in the river system and the communities served. Additional discussions are occurring in order to understand adaptation strategies currently in place and the range of barriers to adapting to water supply variability in different reaches of the system.

Of note, the survey of organizations was the first step in gathering stakeholder input as part of this collaborative modeling research design. Researchers strive to interact with stakeholders as often as necessary to understand how water supply conditions and adaptations change as a function of time. By continuing to meet with stakeholder groups one-on-one, researchers are collecting spatially explicit data toward an assessment of vulnerability and resiliency systemwide. Researchers will continue to revise and document this process to incorporate ideas, input and information needs of Truckee-Carson River System stakeholders.



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