ARkStorm@Tahoe

Stakeholder perspectives on vulnerabilities and preparedness for an extreme storm event in the greater Lake Tahoe, Reno and Carson City region

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CNAP California-Nevada Climate Applications Program
Southwest Climate Science Center
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USGS science for a changing world

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Acknowledgments

The ARkStorm at Tahoe Team is very grateful to our agency partners for all their hard work, support, advice, engagement, facilities and willingness to participate in this non-traditional approach to catalyzing emergency response planning, ecological protection and resiliency planning for our communities. We are especially thankful to Aaron Kenneston (Washoe County, Director of Emergency Management and Homeland Security), Tim Cary (Nevada Division of Emergency Management), Ed Evans (Truckee River Flood Management Authority), Madonna Dunbar (Tahoe Water Suppliers Association), Chris Smallcomb (National Weather Service, Reno) and Gina Marotta (Inter-Tribal Emergency Response Commission) who brought their expertise and communities together and shared their facilities for the ARkStorm@Tahoe Expert Meetings and Tabletop Exercise.

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Executive Summary

Atmospheric rivers (ARs) are strongly linked to extreme winter precipitation events in the Western U.S., accounting for ~80% of extreme floods in the Sierra Nevada and surrounding lowlands. In 2010, the U.S. Geological Survey developed the ARkStorm extreme storm scenario for California to quantify risks from extreme winter storms and to allow stakeholders to better explore and mitigate potential impacts. To explore impacts on natural resources and communities in montane and adjacent environments, we downscaled the scenario to the greater Lake Tahoe, Reno, and Carson City region of Northern Nevada and California. This ArkStorm@Tahoe scenario was presented at six stakeholder meetings, each with a different geographic and subject matter focus, and discussions were facilitated by the ARkStorm@Tahoe team to identify social and ecological vulnerabilities to extreme winter storms, science and information needs, and proactive measures that might minimize impacts from this type of event. Information collected in these meetings was used to develop a tabletop emergency response exercise (TTX) and set of recommendations for increasing resilience to extreme winter storm events in both Tahoe and the downstream communities of Northern Nevada.

Over 300 individuals participated in ARkStorm@Tahoe stakeholder meetings and the emergency response exercise, including representatives from the emergency response, natural resource and ecosystem management, health and human services, public utilities, and business sectors. Interruption of transportation, communications, and lack of power and backup fuel supplies were identified as the most likely and primary points of failure across multiple sectors and geographies, as these interruptions have cascading effects on natural and human systems by impeding emergency response efforts. Other key issues that arose in discussions included contamination risks to water supplies and aquatic ecosystems, especially in the Tahoe Basin and Pyramid Lake, interagency coordination, credentialing, flood management, and coordination of health and human services during such an event. Mitigation options were identified for each of the key issues. Several science needs were identified, particularly the need for improved flood inundation maps. Finally, key lessons learned were identified and may help to increase preparedness, response, and recovery from extreme storms in the future.

Introduction

In fall 2013, the Tahoe Science Consortium (TSC), in partnership with the U.S. Geological Survey (USGS), and through grant support from the Federal Emergency Management Agency (FEMA), initiated the ARkStorm@Tahoe Project. The goal of the project was to work with communities in northern Nevada and California to plan responses to and recovery from extreme winter storm events. This report details findings from the effort, which included six information gathering sessions and a tabletop emergency response exercise. Further, this report includes a set of recommendations for emergency and natural resource managers that, if pursued, will help increase preparedness, response and resilience to major storms in the greater Lake Tahoe, Reno and Carson City region and in similar mountain communities elsewhere in the Western U.S.

The most extreme historical storms on the Pacific Coast have historically been the result of atmospheric rivers (ARs; Ralph and Dettinger 2012), which are long corridors of intense water vapor transport that carry warm wet air from the tropics to the Western U.S. (Fig. 1; Ralph and Dettinger 2011). Historically, these storms have had costly and long-lasting societal and ecological impacts, including flood inundation and damages to communities, risks of human casualties, damage to businesses, transportation networks and public utilities, disruptions of water supplies, and

Historically, these storms have had costly and long-lasting societal and ecological impacts.

disturbances of terrestrial and aquatic ecosystems. In 2010, the USGS developed the ARkStorm extreme storm event scenario for California to demonstrate and quantify risks associated with extreme storms, to provide better scientific and research focus regarding these events, and to allow emergency managers to explore and mitigate potential impacts from extreme winter storms in more informed ways (Porter et al. 2011). The name "ARkStorm" was coined to describe a large, hypothetical but scientifically plausible AR storm sequence that rivals but does not exceed the intense California winter storms of 1861 and 1862, which left the Central Valley of California flooded and the state's economy destroyed (Dettinger and Ingram 2013). The scenario was designed to exceed any single storm in the 20th century. To accomplish this, ARkStorm meteorologists stitched together two historic AR storms from 1969 and 1986, separated by only 4 days (Fig. 2; Dettinger et al. 2012), to form a 23-day sequence of intense and prolonged precipitation and (ultimately) flooding.

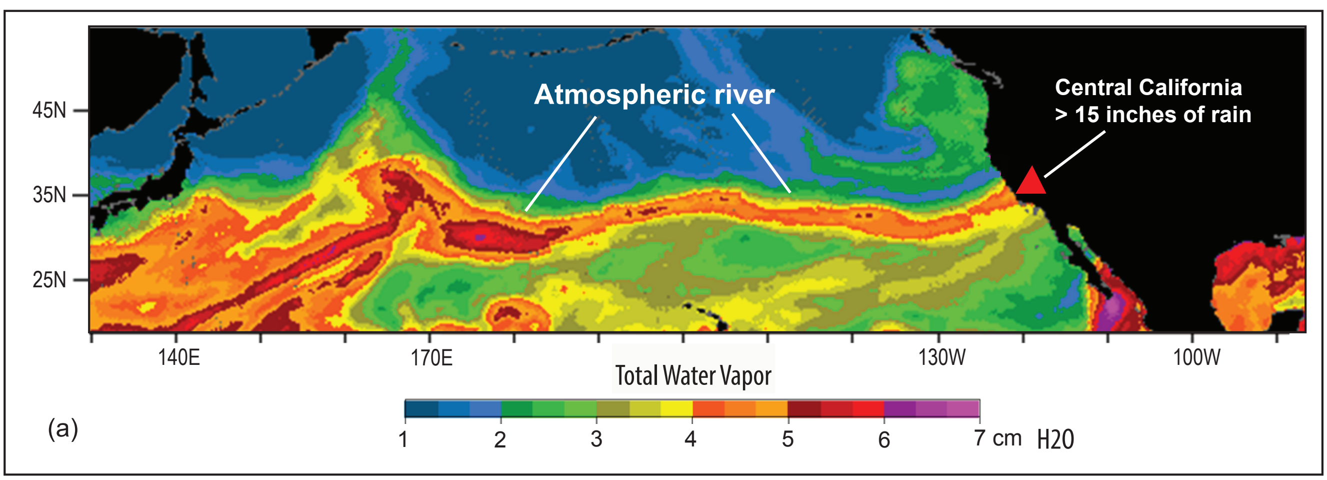


Figure 1. Total water vapor in the atmosphere on Oct. 13-14, 2009, with an atmospheric river indicated by warm-colored band of moist air extending across the whole North Pacific basin to central California coast (Ralph and Dettinger, 2011).

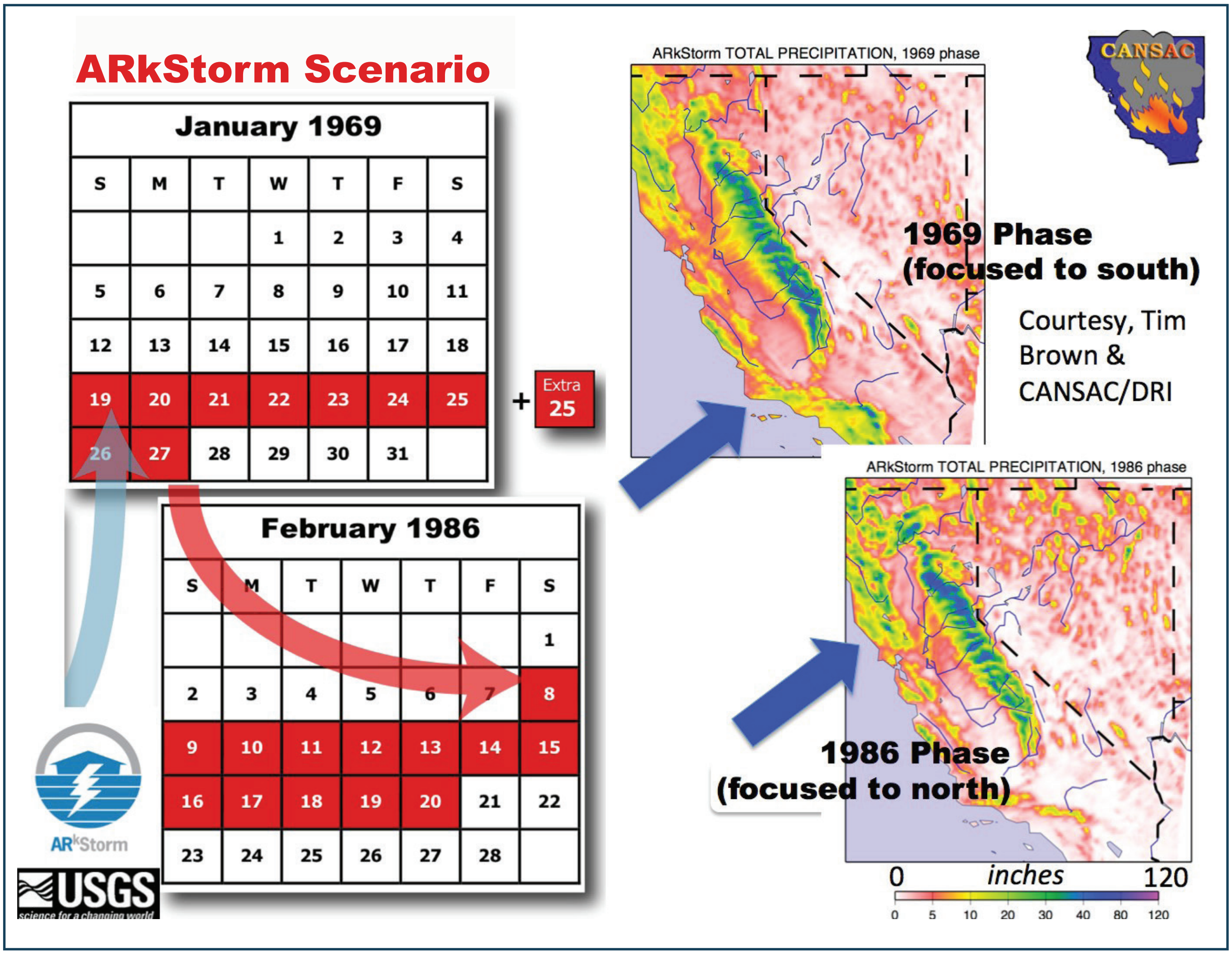


Figure 2. ARkStorm storyline (synthesis of two major historic storms in rapid succession) and simulated precipitation totals in the two phases.

Following development of the ARkStorm scenario, the USGS, with support from FEMA, initiated several community interaction efforts to identify approaches for increasing community preparedness to extreme storms. These included efforts with the U.S. Navy and NASA (in 2011), Ventura County (Hosseini et al. 2013), San Diego County (in 2012) and Sacramento (in 2013). The first three explored government and municipal impacts, and the latter was part of the California Office of Emergency Services (Cal OES) catastrophic flood planning effort.

The current effort, ARkStorm@Tahoe, was developed to explore the likely impacts of an ARkStorm in the Lake Tahoe region, including the Tahoe Basin; Truckee, California; and Reno, Sparks and Carson City, Nevada. Unlike previous ARkStorm exercises, which have primarily focused on impacts to lowland urban areas and the built environment, ARkStorm@Tahoe was intended to explore the impacts of an ARkStorm in an area with mountainous terrain, precipitation in the form of snow, large areas of non-urban land and relatively isolated communities in the mountains and on tribal lands.

Methods

The ARkStorm@Tahoe Project included three core elements: 1) development of technical products to simulate and describe the scenario in the study region, 2) six stakeholder meetings that included presentation of emerging technical results to spur extended facilitated discussions, and 3) a tabletop emergency response exercise that focused on the preparation, response and recovery phases of the storm. Results from stakeholder discussions are summarized by sector in the results section of this report and include issues identified, recommendations for future science and potential proactive measures that may be taken ahead of the storm to reduce vulnerability and impacts.

Technical Product Development

Several technical products were developed to provide a realistic description of the ARkStorm@ Tahoe scenario. First, the scenario was downscaled from coarsely resolved global weather data fields to 2-km resolution for the 150 km2 study area (including greater Lake Tahoe, Reno and Carson City) by weather forecasters at the Desert Research Institute's Program for Climate, Ecosystem and Fire Applications, California and Nevada Smoke and Air Committee (CANSAC). This downscaling was needed to obtain sufficient detail to clearly represent ARkStorm meteorology and impacts in the mountainous terrain. The storm was simulated using the Weather Research and Forecasting (WRF; Skamarock et. al. 2008) model nested within global weather-data fields from the NCEP/ NCAR Reanalysis program (Kalnay et al. 1996). This simulation provided hourly meteorological data every 2 km across the study region, which were the basis for maps and time series of temperatures, precipitation amounts, and wind directions and speeds that informed the expert discussions and design of the table-top exercise. Information was provided to National Weather Service (NWS) Reno Forecast Center staff, and they, in turn, developed a forecast timeline detailing how NWS would most likely respond to, and report on, the storm for presentation at stakeholder meetings. In addition, USGS developed maps of select variables used for weather forecasting for the Eastern Pacific/Western U.S. and NWS staff used these to develop detailed forecasts for specified dates in the scenario for use in the tabletop exercise. WRF model meteorological data were also input into existing hydrologic and ecological models to simulate streamflows at various locations within the Tahoe Basin (e.g., Fig. 3; USGS Nevada Water Science Center and DRI) and along the Truckee, Carson and Walker Rivers (NWS California-Nevada River Forecast Center; CNRFC) and to simulate potential long-term water quality impacts to Lake Tahoe (University of California, Davis).

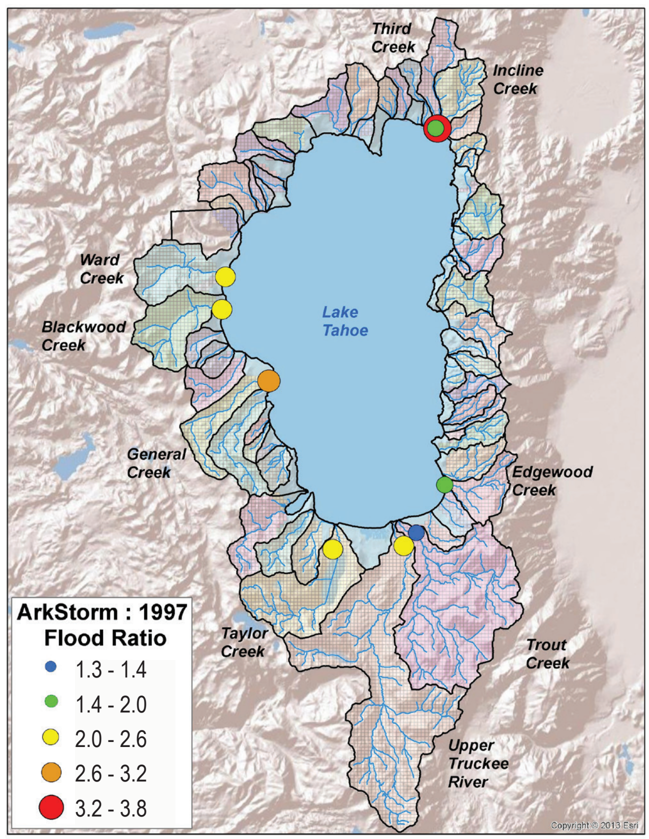


Figure 3. Ratio of simulated ARkStorm@Tahoe streamflows relative to measured streamflows during the 1997 AR storm sequence for select streams in the Lake Tahoe Basin based on simulation results provided by Richard Niswonger, USGS, and Justin Huntington, Desert Research Institute.

Spatial datasets of infrastructure, including public utilities, communications, transportation networks, hazardous materials, flood inundation areas, landslide and avalanche potential and many others were compiled by UC Davis and USGS, and entered into a geospatial database housed at USGS. Finally, a Google Earth flyover representation of the reservoir system of the Truckee River with overlays of pipelines and other infrastructure was developed by Bureau of Reclamation (USBR).

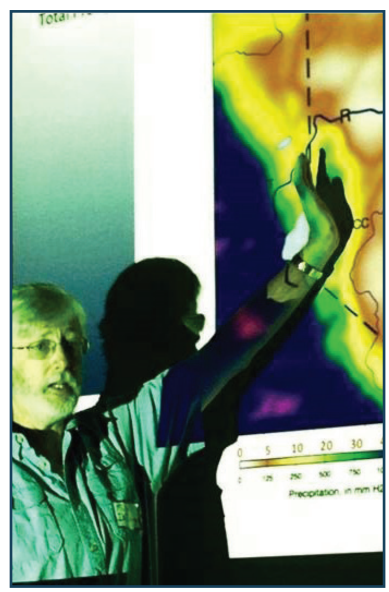
Stakeholder Meetings

The technical products described above were presented at six stakeholder meetings, each with a different geographic and subject matter focus (Table 1). In total, over 300 individuals participated in these meetings. The briefing portion of each stakeholder meeting typically included an overview of the goals and objectives of ARkStorm@ Tahoe, presentation of ARkStorm meteorology and hydrology, the NWS weather forecast and additional information appropriate to each group. Discussions were facilitated to identify social and ecological vulnerabilities to extreme winter storms, interdependencies, likely points of failure, potential injects for the tabletop emergency response exercise, science and information needs and proactive approaches that could help to minimize impacts from this type of event.

Stakeholder meeting in Carson City, Nevada. Photo credit: Dale Cox, USGS.

Table 1. Details of the six ARkStorm@Tahoe stakeholder meetings.

Focal Topic Areas	Location	Date	Number of Registered Attendees	Number of Organizations
Public Utilities/Water Supply	Incline Village General Improvement District, Incline Village, Nev.	12-Sep-13	31	22
Emergency Response/ Health and Human Services/ Business Community	Lake Tahoe Visitor's Authority, Stateline, Nev.	11-Oct-13	63	43
State/Federal Coordination	NV Division of Emergency Management, Carson City, Nev.	12-Nov-13	68	30
Truckee River Flood Management	Regional Emergency Operations Center, Reno, Nev.	5-Dec-13	138	69
Tribal Impacts	Reno-Sparks Tribal Health Center, Reno, Nev.	13-Jan-14	40	31
Natural Resource Impacts	Tahoe Regional Planning Agency, Stateline, Nev.	14-Jan-14	63	39



Scientist Mike Dettinger presents technical products describing ARkStorm@ Tahoe at a stakeholder meeting. Photo credit: Dale Cox, USGS.

Tabletop Emergency Response Exercise

The Tabletop Exercise (TTX) employed a non-traditional approach for emergency response exercise planning and was designed to maximize the interactive dialogue and engagement of diverse stakeholder communities. It was held following the stakeholder meetings and was structured to allow participants to discuss and respond to scenario injects in small diverse stakeholder groups. Participants were assigned to participate in small groups (8-10 individuals) selected by the ARkStorm Project Coordinator. The groups were comprised of a mixture of emergency responders, public safety and health officials, ecological managers, private sector infrastructure owner/operators, tribal communities and other participating organizations.

The scenario included three phases of the storm corresponding to days 8, 18 and 35 of the ARkStorm storm sequence (Fig. 4). During each of these respective phases, participants were encouraged to focus on issues related to preparedness (day 8), response (day 18) and recovery (day 35). At each stage of the storm, the National Weather Service and Truckee River Flood Project provided weather and flood forecast briefings, and maps of predicted flood extents and existing infrastructure were displayed.

Following a presentation of the stagesetter for each phase of the ARkStorm event, participants broke into their respective groups to discuss anticipated impacts, response actions and potential mitigation measures. Each phase included roughly ten injects (plausible situation that occurs in the scenario; e.g., a sewage pipeline bursts; the hospital is flooded), which were designed to focus discussions on key issues identified in the stakeholder meetings. The group discussions were facilitated and recorded by a designated member of the ARkStorm team. Two additional groups: a Senior Policy Group (SGP) and a Public Information Officer's (PIO) Group also held separate discussions. The SPG was led by Aaron Kenneston and comprised of senior policy makers and managers from the participating federal agencies and U.S. Department of Defense, Nevada and California State agencies, visiting emergency response managers from Wasatch County, Utah, and other observers. The PIO Group was led by Mike Wolterbeek (UNR, Public Relations) and was comprised of communication representatives from the participating organizations and local media. Key findings from each group were presented to the full group at the end of the TTX.

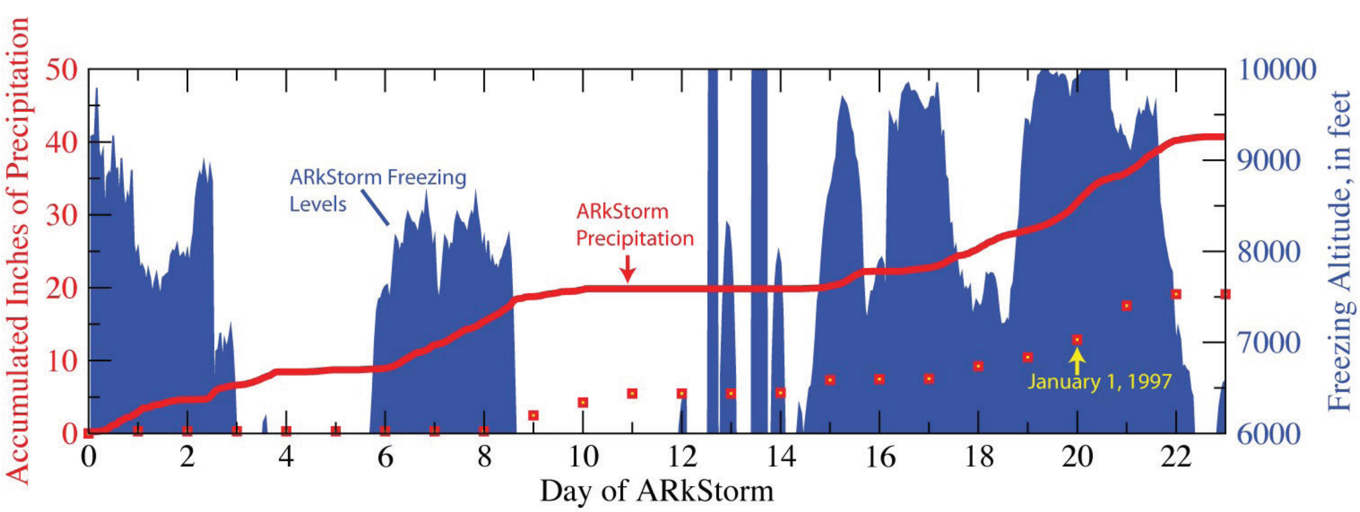


Figure 4. Accumulated precipitation and freezing altitudes in Tahoe City, Calif. during the ARkStorm sequence with accumulated precipitation during the 1997 AR storm sequence, as a reference. The first phase of the storm is colder, resulting in precipitation falling as snow at high altitudes, while the second phase of the storm (Day 12, onward) was warmer, resulting in precipitation falling as rain at altitudes up to 10,000 feet. The ARkStorm tabletop exercise included phases associated with Day 8 (preparedness), Day 18 (response) and Day 35 (recovery; not shown).

Diverse stakeholders worked together in groups during the ARkStorm@Tahoe tabletop emergency response exercise. Photo credit: Chris Smallcomb, NWS.

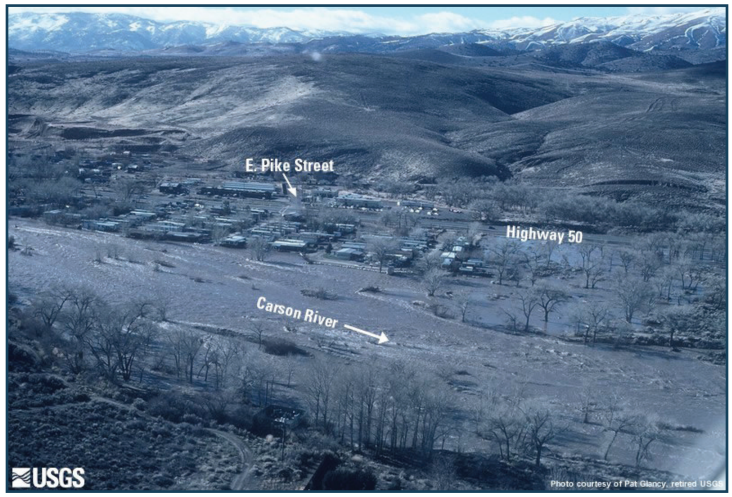
Stagesetter presentation by the National Weather Service of weather forecast for the ARkStorm@Tahoe tabletop emergency response exercise. Photo credit: Chris Smallcomb, NWS.

ARkStorm@Tahoe tabletop emergency response exercise. Photo credit: Michael Dettinger, USGS.

Results - Key Issues and Mitigation Options Identified

Transportation

Issues



Flooding of roadways along the Carson River in 1997. Photo credit: USGS

In all meetings, disruption of transportation corridors was identified as a key and likely point of failure and was at the heart of many of the other emergency response challenges discussed. Concerns were raised that rapid snow accumulation, flooding, avalanches and landslides were likely to occur in such a large storm, and would cut off major transportation routes affecting resupply, evacuation, sheltering, staffing and access to critical utilities or infrastructure. Existing datasets describing areas with high potential for flooding indicate that over 185 miles of major roads and 70 miles of rail would be inaccessible due to flooding alone (Fig. 5). In general, stakeholders expected that the Interstate 80 corridor west of Reno would be cut off by flooding in the Central Valley and snow at high altitudes during much of the storm, but there was less clarity as to how I80 east of Reno might be affected and whether that could be a potential route for bringing in support from areas to the east. In Tahoe and Carson City, stakeholders expressed significant concern about the fact that critical staff often do not live locally in the communities that they serve. One stakeholder mentioned that 70% of employees of the Carson City Fire Department live outside of Carson City. In Reno, the Truckee River essentially bisects the city from east to west, so that, even if critical staff do live locally, transportation routes to work and emergency response are likely to be cut off between north and south Reno during flooding associated with an ARkStorm. In the Tahoe Basin, few staff live in the basin, so that most commute over high elevation passes to get to work. Those passes would likely be closed in an ARkStorm.

Options Identified in the Stakeholder Meetings

- Preposition equipment such as dump trucks, loaders and excavators strategically to allow better coordination of opening roads. Consider potential for flooding, landslides, avalanches and especially the transportation disruptions that they will bring, in planning such prepositions.
- Develop MOUs (in advance) with private industry, including construction companies, to ensure that resources will be available to assist in providing emergency services and road clearing.
- Categorize and make available data about equipment resources according to size, weight and capabilities and identify in advance where they can be deployed (i.e., relative to road weight limits) for effective prepositioning
- Preposition staff and other resources (early in the storm sequence) needed to conduct critical functions, and plan to ensure that the families of critical staff members are well cared for in the ARkStorm emergency.

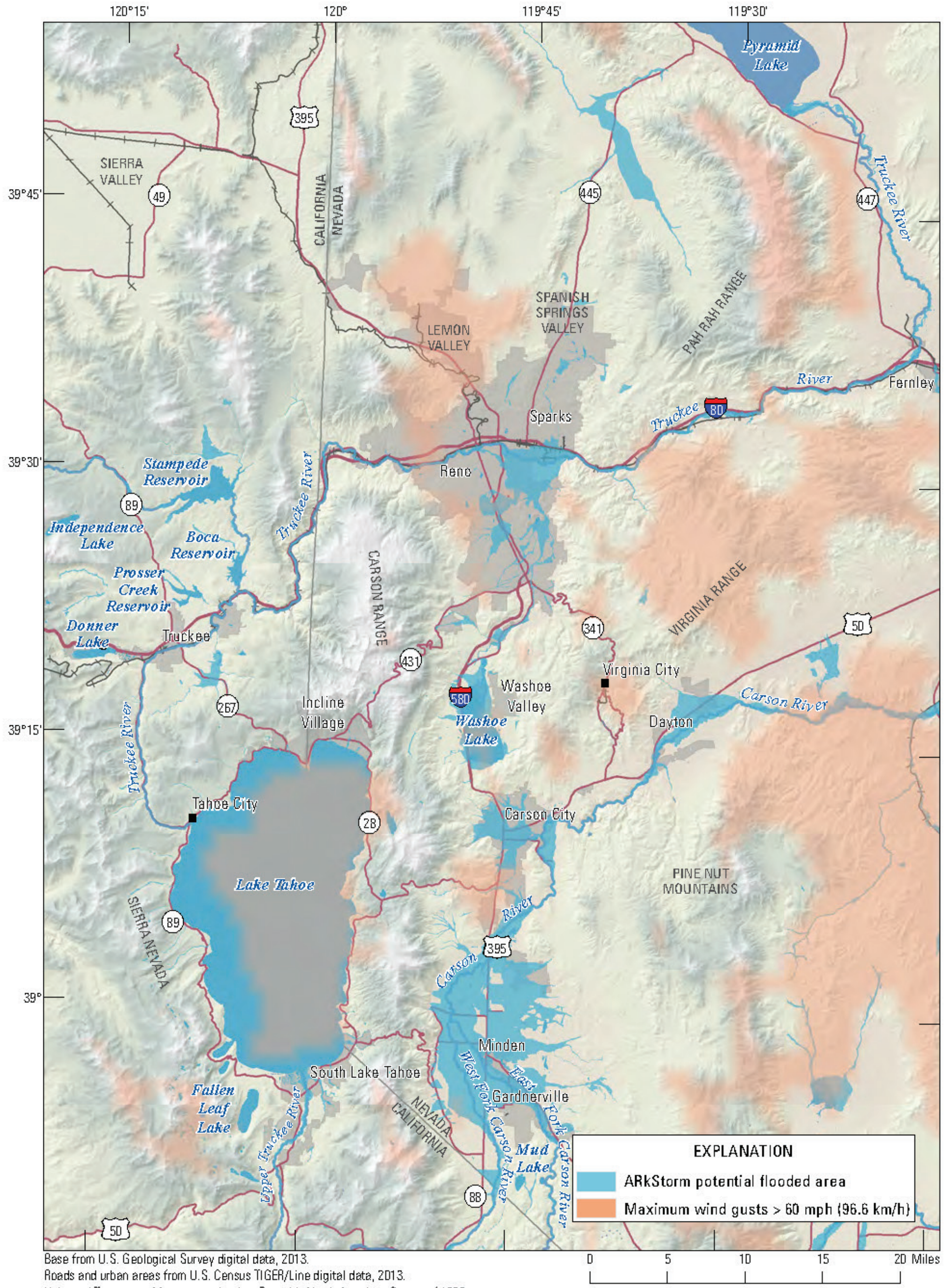
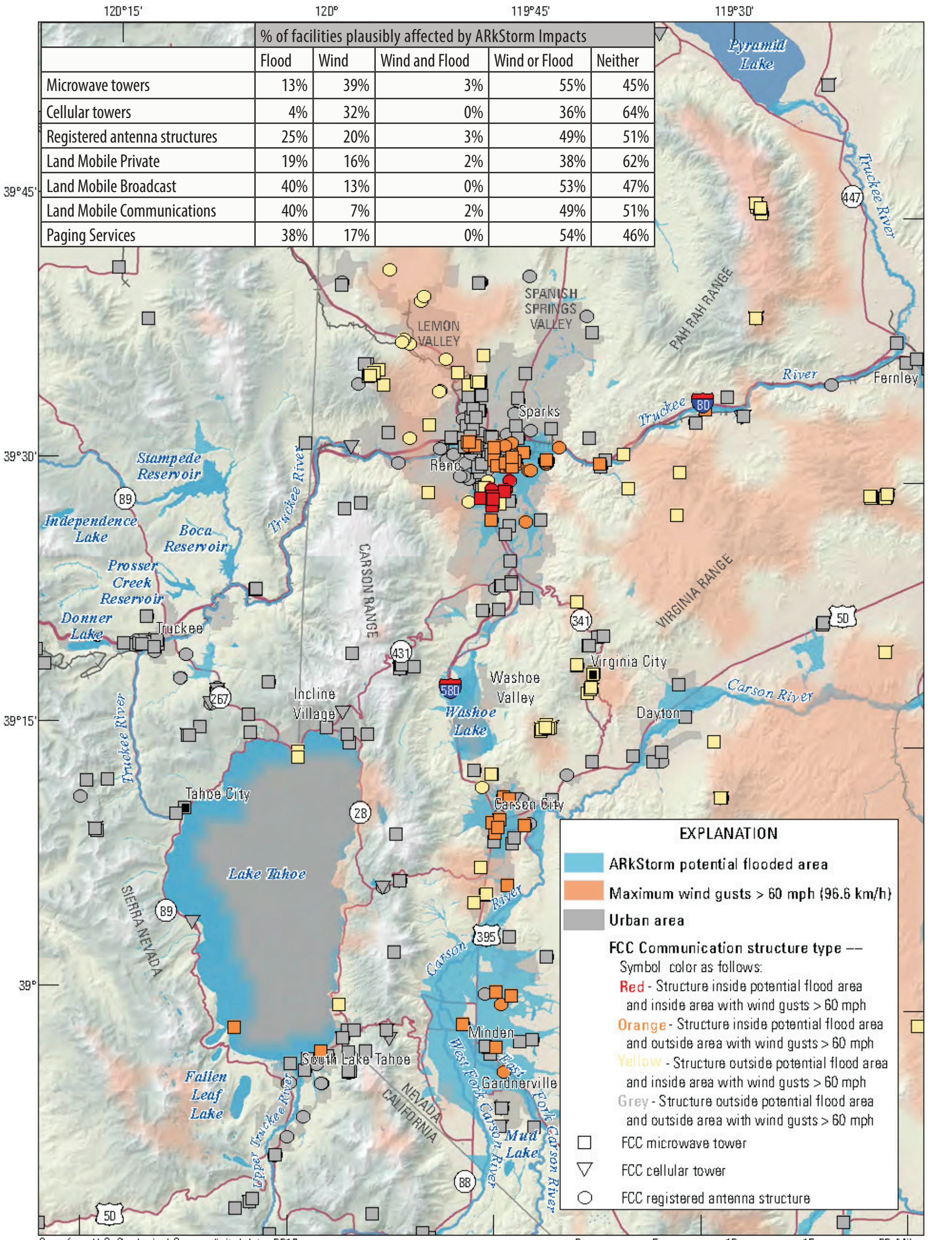


Figure 5. Locations of transportation corridors and ARkStorm potentially flooded areas and maximum wind gusts. Over 185 miles of road and 75 miles of rail fall within the potentially flooded areas. Potentially flooded areas are derived from the Federal Emergency Management Agency (FEMA) Digital Flood Insurance Rate Maps (DFIRM) 100- and 500-year flood boundaries (2010), the mapped extent of the 1997 New Year's Flood from Rigby et al. (1998) and the California Department of Water Resources (CDWR) Best Available Maps (BAM) (2014). Maximum wind gusts are downscaled model outputs from the ARkStorm@Tahoe scenario.

Communications



	% of facilities plausibly affected by ARkStorm Impacts				
	Flood	Wind	Wind and Flood	Wind or Flood	Neither
Microwave towers	13%	39%	3%	55%	45%
Cellular towers	4%	32%	0%	36%	64%
Registered antenna structures	25%	20%	3%	49%	51%
Land Mobile Private	19%	16%	2%	38%	62%
Land Mobile Broadcast	40%	13%	0%	53%	47%
Land Mobile Communications	40%	7%	2%	49%	51%
Paging Services	38%	17%	0%	54%	46%

Base from U.S. Geological Survey digital data, 2013.
Roads and urban areas from U.S. Census TIGER/Line digital data, 2013.
Universal Transverse Mercator projection, Zone 11, North American Datum of 1983.
Shaded-relief base from 10-meter National Elevation Data, 2012; sun-illumination from northwest at 45 degrees above horizon

Figure 6. Locations of microwave towers, cellular towers and registered antenna structures from the Federal Communications Commission (FCC) Antenna Structure Registration (ASR) database relative to areas of plausible ARkStorm@Tahoe impacts.

Issues

Discussion routinely revolved around the risks of communications disruptions due to weather, terrain, floods or landslides, as another key point of failure identified across all sectors. Although there are many redundancies in the region's communication systems, including cellular, Wi-Fi, broadband, satellite, microwave, fiber optics and amateur radio networks, the overall communications network is widely recognized as being vulnerable to disruptions during severe winter storms and floods. Indeed, GIS data that were compiled as part of the ARkStorm@Tahoe effort revealed that over half of all communications facilities could be impacted by winds or flooding (Fig. 6). Most sectors do not share a common radio platform, and other systems are of questionable or unknown reliability under ARkStorm conditions.

Disruptions of interstate communications also came up as a concern. NVDEM and CalOES have co-located microwave communications infrastructure near Reno but they currently lack a hardwire connection. There were also concerns about how the public would be notified regarding evacuation orders and potential routes and sheltering locations, or if their water supplies became contaminated. At Tahoe, there was additional concern as to how the large numbers of visitors that often flood the basin would be notified since they do not have permanent addresses or contact information in emergency-responder databases. Tribal communities were concerned about communications, given that communication infrastructures are limited and vulnerable in rural areas. Communications disruptions are likely to impact capacities to both recognize and respond to developing emergencies, by cutting stakeholders off from incoming monitoring and reporting data streams and by cutting responders and the public off from warnings, directives and communications from decision makers.

Options Identified in the Stakeholder Meetings

- Develop and distribute an assessment of communication technologies used by critical monitoring and response programs. This is needed to determine their vulnerabilities to weather, floods and landslides, including the potential for networks to be overwhelmed by extensive public use.
- Improve interagency communications and develop an emergency alert system for the Lake Tahoe Basin. This includes testing real-time sensor and communications systems, establishment of common emergency radio frequencies and phone-tree and group text-messaging systems that will provide key stakeholders in the basin options to communicate on multiple platforms.
- Leverage social networking and crowd-source information sharing capabilities to enhance situational awareness for emergency responders and the public, especially the visitors who have few other connections to information originating in the area. An example application that was suggested was the web-based, crowd-sourced tool used by Boulder County, Colorado to gather damage reports and upload photographs from individuals during the 2013 floods (https://boulderflood2013b.crowdmap.com/).
- Coordinate with Washoe County Amateur Radio Emergency Services to identify alternative (or "last resort") communication capabilities for the Lake Tahoe Basin and surrounding areas.
- Identify and coordinate radio frequency bands used by emergency responders among the various tribes and emergency responders in Tahoe.
- Connect with, and expand, the existing telemetered communications backbone of seismology towers of the Nevada Seismological Laboratory Reno/Tahoe Area Monitoring Network (http://www.seismo.unr.edu/Monitoring#renotahoe) as a backup for the everyday emergency-responder communications systems.
- Establish a hard wire connection between NVDEM and CalOES microwave communications systems above Reno.

Power failures and fuel supplies

Issues

Electrical power outages, coupled with fuel supply limitations for emergency generators, were regularly identified as key vulnerabilities by multiple sectors. The issue was also identified as a key point of failure across sectors. Most stakeholders have short-term capabilities to work around power outages, but longer-term outages would yield significant cascading impacts. At a localized scale, this was a concern for public utilities and hospitals, given energy-dependence of essential functions such as water and wastewater transport, medical care and sheltering and fuel pumping stations (which have high power demand because they are electronically operated). Most public utility managers and hospitals said they have backup generators, but typically only 2-7 days' worth of backup fuel supplies. One stakeholder mentioned that gas stations typically have no backup power because systems that would accommodate demand would be expensive to install. There were also concerns about whether backup generators (e.g., those supplied by FEMA) would be compatible with connection points at hospitals and whether alternative fuel types (e.g., diesel vs. compressed natural gas vs. aviation fuel) could be used for critical facilities. Once backup fuel supplies are exhausted, many stakeholders do not have clear plans for where fuel can be obtained (though schools, public transportation or waste management fleets, gas stations and fire stations were mentioned as possibilities). Similarly, it appears that there are no settled plans as to how these "additional" supplies would be managed and prioritized. In terms of overall fuel availability, northern Nevada relies on northern California for fuel, and in the absence of help from the east, has 4 days of gas, 3 days of jet fuel, and ½ day of aviation fuel. Additional fuel could be brought in to airports or military bases (e.g., Fallon, Stead or Reno International) as long as they remain open, but fuel distribution beyond those hubs relies on ground transportation routes being open.

Options Identified in the Stakeholder Meetings

- Develop and enforce standards for minimum size of fuel reserves for different sectors in communities that are likely to be isolated in the event of an ARkStorm scale emergency
- Develop plans and MOUs among local communities for accessing, allocating and prioritizing fuel reserve supplies in event of transportation closures that prevent resupply from outside sources
- Develop a set of criteria and options for prepositioning fuel supplies for critical functions. Use inundation maps to guide strategic prepositioning.

Health and human services

Issues

Continuation of medical services, sheltering and care for vulnerable populations are a significant concern. Hospital and health care workers indicated that their key concerns were ability of staff to get to work and disruptions of power, fuel and water supplies. Several medical facilities in Reno and Carson City are located in the 100-year floodplain (Fig. 8) and would likely need to be evacuated and operations relocated to higher ground in an ARkStorm event. Participants identified the need for information on where to locate evacuation, shelter and staging areas as well as potential routes for transporting staff and supplies to these locations. Concerns about how to alert and potentially relocate vulnerable populations, including residents in assisted living or skilled nurse facilities and individuals with special needs (e.g., dialysis units, hearing impaired) were raised. Maintenance of access to prescription medications under emergency conditions is also a concern. Tribal stakeholders as well as agencies in the Tahoe Basin were concerned about limited medical facilities and capabilities in these areas that are most likely to be isolated. For example, the Pyramid Lake Paiute Tribe clinic in Nixon was cut off for several weeks in 1997. In Tahoe, the only large hospital is on the south shore, while the north shore and elsewhere have limited medical facilities and capabilities. Availability of sufficient shelter space to support tourists and potential influx of people from California looking for higher ground is also a serious concern.

Options Identified in the Stakeholder Meetings

- Assess vulnerability of critical hospital infrastructure such as heating and cooling systems or diagnostic equipment facilities to flooding and evaluate whether such facilities can be moved to better protect them from floodwaters.
- Proactively identify options for relocating care facilities, including establishment and staffing of one or more emergency mass-care facilities.
- Develop MOU's for temporary housing of care-facility staff at hotels and resorts.
- Preposition staff and extra fuel and other supplies at medical and prospective sheltering facilities that are not in danger of flooding.
- Reassess emergency shelter and evacuation locations for catastrophic flooding events.

Wastewater management and water contamination

Issues

Sewage and wastewater treatment and disposal systems are vulnerable to failure during flooding associated with an ARkStorm, as are other toxic disposal sites, many of which are located in areas with high potential for flooding (Fig. 7). Effluents from these and other sources of contamination pose important risks to environmental and public health. These vulnerabilities were identified as high priority concerns at all meetings, but the concerns differed between Tahoe and downstream areas. In the Tahoe Basin, when systems are operating correctly, virtually all wastewater is transported out of the basin using a system of gravity fed lines and pumping stations. In several areas (depending on public utility district) wastewater is not treated prior to transport. Because the sewage lines are largely gravity-fed, they are located at low elevations and are vulnerable to becoming overwhelmed by huge amounts of storm water flow. In addition, many pumping stations have only a 3-4 day fuel supply that may not be sufficient if prolonged road closures prevent delivery of backup supplies. One participant mentioned anecdotally that the South Lake Tahoe public utility district was on the brink of a sewage overflow during the 1997 storm and the only reason it didn't happen was because community members were asked to severely restrict their inside water uses.

Flooding of Sparks industrial area in 1997. Photo credit: Pat Glancy, USGS.

The wastewater treatment plant for the Truckee Meadows area is located along the Truckee River in the floodplain and is vulnerable to flooding. Emergency management staff commented that there are problems with the plant nearly every time the river floods. In addition, flooding of feedlots and industrial areas located in the floodplain have a history of, and potential for, introducing biological and chemical contaminants in the river, floodplain and ultimately areas downstream (including Pyramid Lake). The University of Nevada, Reno, reported that a plan with triggers is in place to move its feedlot animals in advance of major floods. In contrast, other stakeholders were unaware of whether inundation maps are available for much of the industrial area in Sparks, suggesting there isn't a clear sense of what flood risks are at many sites with hazardous materials. Because the Truckee River empties into Pyramid Lake, the Pyramid Lake Paiute Tribe was also concerned about the potential for long-term contamination.

Options Identified in the Stakeholder Meetings

- Develop and enforce standards for minimum size of fuel reserves for different sectors in communities that are likely to be isolated in the event of an ARkStorm scale emergency
- Develop plans and MOUs among local communities for accessing, allocating and prioritizing fuel reserve supplies in event of transportation closures that prevent resupply from outside sources
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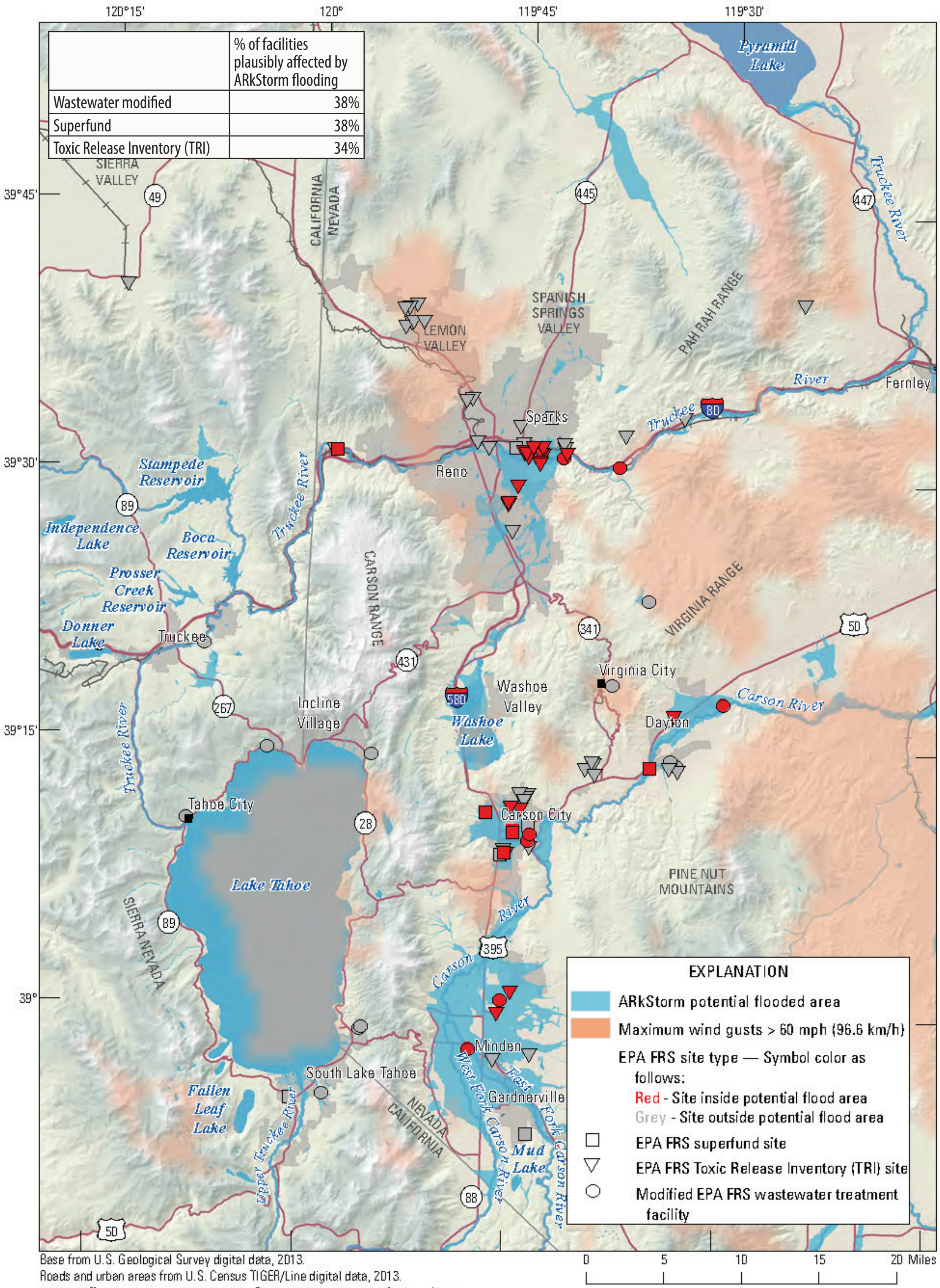


Base from U.S. Geological Survey digital data, 2013.
Roads and urban areas from U.S. Census TIGER/Line digital data, 2013.
Universal Transverse Mercator projection, Zone 11, North American Datum of 1983.
Shaded-relief base from 10-meter National Elevation Data, 2012; sun-illumination from northwest at 45 degrees above horizon

Figure 7. Locations of superfund sites, Toxic Release Inventory (TRI) sites and wastewater treatment facilities from the Environmental Protection Agency (EPA) Facility Registry Services (FRS) database relative to areas of plausible ARKStorm@Tahoe impacts. Wastewater treatment facility locations have been modified based on local knowledge.

Water supply

Issues

Many of the communities around Lake Tahoe depend on the lake for their water supply. Water supply intakes from Lake Tahoe might be severely impacted by sediment and contaminant influxes due to extreme stormwater runoff and spills from wastewater treatment plants located along the lake shore. This risk is greatly aggravated by the lack of sediment filtration systems on those intakes, and would result in damage to water supply systems, violation of water quality standards for drinking water supplies, and thus public-health risks in the basin. Some water systems are interconnected and may be able to replace disrupted neighboring systems, however many are not. These represent points of failure—existing groundwater wells are not sufficient to supply primary needs in many places. Other communities, including several of the tribal communities, where groundwater is the primary water supply were similarly concerned about interruption and contamination of drinking water sources. Several water suppliers in the Tahoe Basin indicated a potential need to shut down systems if they become overwhelmed with contaminants or the system breaks. However, fire agencies voiced concern about how shutting down water supplies would be communicated and how they could perform their fire-suppression functions in such an event, as they rely on operational water systems, rather than tanker trucks, for their operating water supplies.

Options Identified in the Stakeholder Meetings

- Explore inter-agency mutual aid agreements for sharing of key staff across agencies to maintain water-supply operational capabilities in the event transportation corridors are cut off. Public utility districts could conduct familiarization sessions with each other's systems to enhance emergency response capabilities in event that critical staff members are unable to get into the basin.
- Encourage the public to store personal water supply prior to event in case of water supply contamination or disruptions during storms or other emergencies.
- Examine the relative costs and benefits of shutting down water systems around Lake Tahoe to mitigate environmental damage from compromised sewage transport systems before events require such a decision. Identify clear lines of authority for such shut downs and consider establishment of pre-determined thresholds and conditions under which these actions would be expected to be taken.

Credentialing

Issues

Concerns about credentialing came up in several of the meetings. Road access to critical public utility infrastructure is often limited by first responders who bar access to everyone, including utility workers and others who may need access to shut down systems or make repairs that will prevent even worse impacts from developing. Public utilities staff identified this as a significant problem that has occurred in the past. An established and widely recognized (within the region) credentialing system to identify those personnel (both public and private) who can be allowed special passage into emergency settings would reduce these problems while protecting the broader public and first responders.

Flooding in 1997. Photo credit: Pat Glancy, USGS.

Options Identified in the Stakeholder Meetings

- In the Tahoe Basin, develop credentialing process for critical staff with Washoe County Sheriff's Office. Include guidelines for information flow and chain of communications to Nevada Highway Patrol and other law enforcement agencies. Develop corresponding processes in the Reno and Carson City jurisdictions.
- Design and distribute placards for critical staff vehicles to clearly demonstrate credentials.
- Create databases of critical personnel from utilities and other organizations that will need access to key infrastructure during emergencies

Flood management

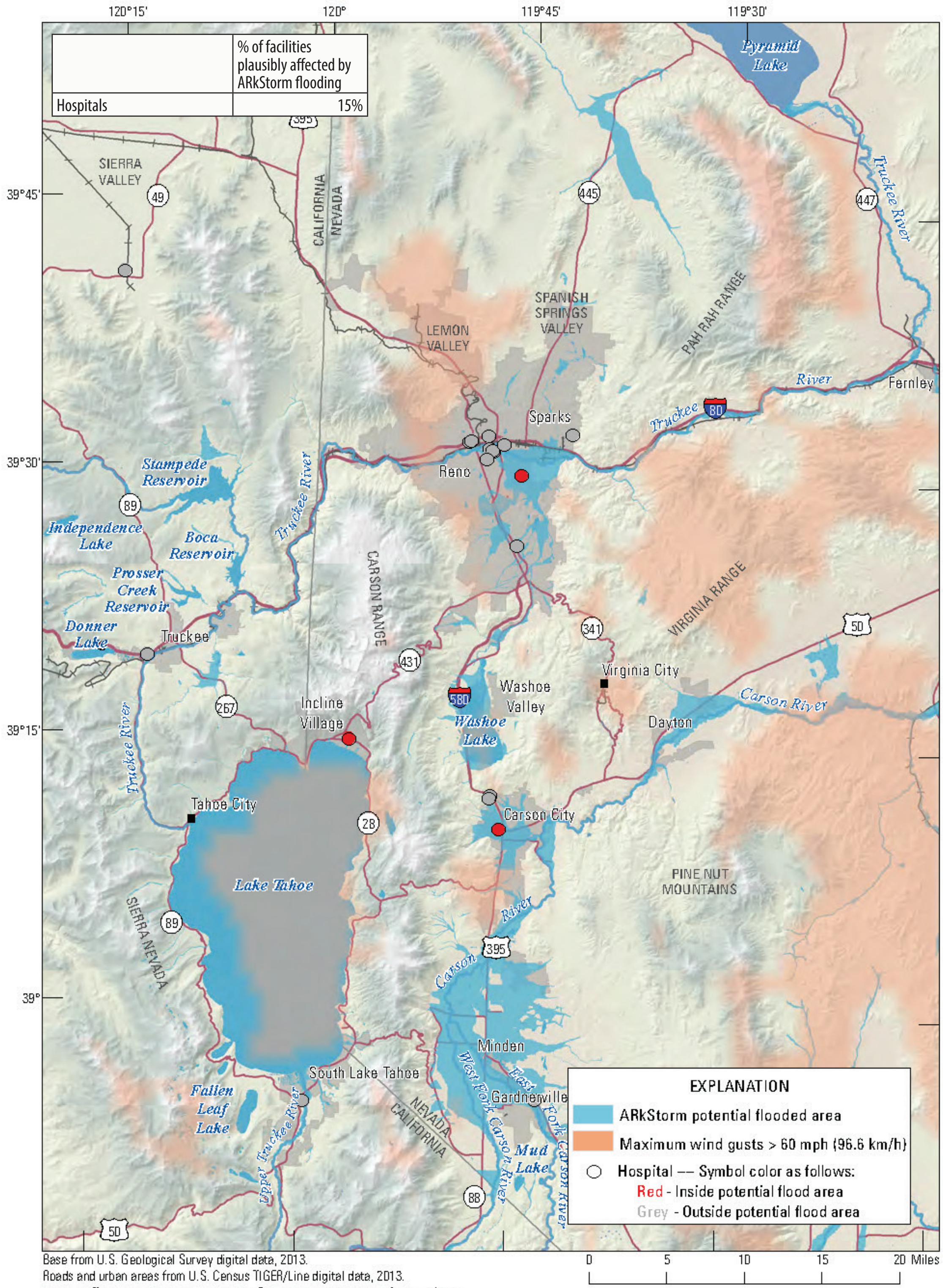
Issues

Several reservoirs exist along the Truckee River and have potential to ameliorate flood impacts. However, there are significant concerns about the capacity of dams along the Truckee River to withstand an event as extreme as the ARkStorm scenario. Most of the dams along the Truckee River are earthen dams and thus have the potential to fail if overtopped. Such failures could result in massive losses of life and property. Forecasts enable water to be released in preparation for storms if dams are near capacity, but releases are limited to outflow capacity, which may not be sufficient to accommodate rapid inflows that an ARkStorm would produce if the dams are already full. Moreover, predicted wave heights associated with ARkStorm could exceed the height of the dam at Lake Tahoe if lake levels rise too much (or started too high). Flood management involves significant coordination and communication between the NWS, USBR, the Army Corps of Engineers and water masters and effective flood management is dependent upon functional communications between these groups, which may be disrupted during an ARkStorm.

Truckee River at Derby Dam during the 1997 flood. Photo credit: Pat Glancy, USGS.

Options Identified in the Stakeholder Meetings

- Evaluate costs and benefits of constructing a spillway at the Lake Tahoe dam
- Raise dam heights while maintaining current water storage limits at vulnerable locations
- Evaluate possible expansions of real-time meteorological monitoring networks to increase time available for response



Base from U.S. Geological Survey digital data, 2013.
Roads and urban areas from U.S. Census TIGER/Line digital data, 2013.
Universal Transverse Mercator projection, Zone 11, North American Datum of 1983.
Shaded-relief base from 10-meter National Elevation Data, 2012; sun-illumination from northwest at 45 degrees above horizon

Figure 8. Locations of hospitals from the California Department of Public Health (CDPH) and Nevada Department of Health and Human Services (DHHS) relative to the areas of plausible ARkStorm@Tahoe impacts.

Public flood awareness and preparedness

Issues

One of the most effective ways of reducing harm to the public, to responders and to property in a situation like an ARkStorm is to have a public that is informed and prepared to reduce its own risks. Thus, concerns about public information, situational awareness and preparedness came up in several meetings. One stakeholder remarked that because floods don't occur as often as is the case in coastal areas, there is less public awareness and preparedness for such events in this region. Thus there is a continuing need for wide-reaching and engaging flood awareness programs for the public. Concerns were also expressed regarding potential public confusion caused by flood inundation maps that are overly complicated and due to inconsistencies in maps from different times, sources or methodologies. A particular public-awareness difficulty in the Tahoe/Reno/Carson City region is how to reach the large numbers of tourists and short-term visitors who regularly pass through the area.

Options Identified in the Stakeholder Meetings

- Develop public programs that increase awareness of flood risks, preparedness, and planning resources. Notably, the University of Nevada, Reno cooperative extension is planning a major program of flood awareness events in fall 2014.
- Tailor public awareness programs to target sectors most at risk or most likely to provide critical functions during flood emergencies.
- Develop special awareness campaigns and plans to target tourist venues and short-term visitors who may be unfamiliar to potential evacuation routes and locations.
- Develop an outreach plan for lessons learned from ARkStorm@Tahoe.
- Reconcile conflicting inundation maps and simplify them for public dissemination.
- Develop education programs to disseminate the best available information regarding the risks of floodplain development.
- Expand the scope of public flood awareness programs to other potential impacts of winter storms related to issues such as multi-day snow closures, wind damages or power outages.

Interstate coordination

Issues

Given an ARkStorm-type scenario, a general consensus believed that the state of California would not be able to provide significant emergency management support to Nevada because resources would be stressed in dealing with large storm impacts and disruptions in California. Stakeholders raised significant concerns about the availability of, and competition for, a variety of resources given likely significant requirements and federal declarations elsewhere in California. Indeed, in such an event, California populations would be expected to evacuate into the Reno/Tahoe region, adding to the emergency conditions and requirements there. Thus, the regional capability to absorb significant self-evacuees traveling to Reno/Tahoe from impacted areas of California is a major concern. Nevada and California regularly conduct joint emergency-response exercises with each other, and less often with other states.

Options Identified in the Stakeholder Meetings

- Conduct extreme winter storm and flooding emergency response exercises with neighboring states besides California and Nevada.
- Develop direct communication links (with backup capabilities) between the Nevada Department of Emergency Management and the California Office of Emergency Services.
- Develop plans and agreements for leveraging inmate work forces for emergency responses and recovery actions.

Photo credit: Krissy Clark

Tribal

Issues

Several of the tribes have only 1-2 emergency response staff, and otherwise rely on volunteers and outside resources. Tribal members were concerned about limited emergency response resources and supplies. They also voiced the perception that they are often at the end of the line when it comes to assistance or resources. Tribes were also concerned that they are not always explicitly mentioned in mutual aid agreements, although utility operators and state and county emergency responders indicated that they would not hesitate to support tribes, as would be the case for any constituency. The 1997 flood resulted in severe economic impacts to some tribal communities. Businesses upon which tribes rely (e.g., Walmart, Reno-Sparks Tribal Health Clinic) are located near or adjacent to the floodplain, representing a significant vulnerability with potentially long-lasting economic impacts. The Pyramid Lake Paiute Tribe was particularly concerned about flood refuse and pollution from the entire Truckee watershed that washed into Pyramid Lake in 1997 and that would likely wash in under ARkStorm conditions. Pyramid Lake is a source of subsistence and revenue for their tribe. Some of the tribes do not have adequate backup fuel supplies or equipment for critical functions, and their communities are relatively remote and likely to be isolated. These communities have limited modes of communication, some of which may not be functional in a storm emergency, leading to further isolation.

Options Identified in the Stakeholder Meetings

- Establish amateur radio communications opportunities for Shoshone, Washoe and other tribes with vulnerable communication lifelines.
- Identify and coordinate radio frequencies used for emergency communications by individual tribes.
- Engage tribes in developing and updating Emergency Management Assistance Compacts (EMAC and Nevada EMAC (NEMAC) agreements.
- Increase fuel and provision reserves in communities most likely to be isolated
- Develop and implement standards and thresholds for prepositioning resources such as sandbags, commodities and fuels.
- Foster additional opportunities for interaction between tribal, county, state and federal emergency managers to help develop relationships and interactions that facilitate interagency communications and assistance during emergencies.

Environment

Issues

Flooding, avalanches, landslides and water contamination due to flooding of wastewater systems, feedlots and hazardous materials from an ARkStorm would be expected to have long-term environmental impacts. Environmental managers (most of whom were from the Tahoe Basin) were particularly concerned that wastewater systems in the Tahoe Basin could be compromised and could undo many years of efforts to prevent contamination of the lake. Land disturbances (and changes in the Lake) arising from an ARkStorm could increase opportunities for spread and establishment of aquatic and terrestrial invasive species, and managers felt that recently disturbed areas such as restoration sites, vegetation treatment sites or recently burned areas would be particularly vulnerable to these impacts. Managers were also concerned that infrastructures, such as road culverts, and restoration-project design requirements are based on short-duration flood-recurrence intervals and current flow regimes may not be sufficient given the significant role that extreme events (like an ARkStorm) play in the geomorphology of the basin and the likelihood that weather extremes will become more common and severe under climate change (e.g., Das et al. 2013). Also, in the Tahoe Basin, managers would have to wait until flows subside, snow melts and soils dry out before they could begin repairs or even begin to assess many of the damages. Finally, managers were concerned about declines in resources for monitoring and emphasized the need for high temporal resolution monitoring to better capture and manage extremes before, during and after they occur.

Options Identified in the Stakeholder Meetings

- Evaluate emergency-response approaches and restoration plans in terms of their capacities, during large storms like ARkStorm, to protect water sources and the Lake from pollutant inflows, such as diversion of sewage overflow to retention basins or marshes.
- Revisit cost/benefit considerations regarding upsizing and better stabilizing culverts, and formulate plans to deploy machinery to regularly maintain them and to protect them in extreme storm situations.
- Explore relative costs and benefits of upgrading or moving sewage lines and pumping stations to lessen their vulnerability to flood impacts.
- Identify needed monitoring locations, establish additional meteorological and stream monitoring stations, and harden existing monitoring systems and their communications links.
- Explore opportunities to leverage real-time monitoring networks to measure meteorological variables (e.g., University of Nevada, Reno seismology network).
- Develop a long-term ecological recovery plan for the Tahoe Basin that is relevant to a variety of types of disturbances and contains benchmarks for monitoring recovery.
- Install short-term mitigation measures at sites with known vulnerabilities at beginning of winter season.

Business/Private Sector

Issues

Stakeholders from the business and private sectors such as hotels and casinos expressed a desire to help but were concerned about how long they would be able to sustain operations with adequate food, power and heat, and capacity for housing tourists, residents and potential evacuees from California in such an event. The potential liabilities that might be incurred by private-sector actors who come to the aid are also a concern.

Options Identified in the Stakeholder Meetings

- Conduct legal analysis of "Good Samaritan" laws and applicability of other laws during disaster or emergency situations.
- Extend integration of public and private plans and resources for addressing major catastrophes where possible.

Recovery

Issues

Reestablishment of infrastructure and services, opening main transportation routes, reopening businesses and restoring the character of the community (including its attractiveness to tourists and sportsmen) would be key recovery issues following an ARkStorm. Stakeholders also identified the need to conduct damage assessments with potential approaches including crowd sourcing and use of social media. Stakeholders wanted to know how long transportation routes might be closed and what would be the added burdens (distance and time) from reroutes. The Pyramid Lake Paiute Tribe remarked in one meeting that they closed out the last of their federal recovery projects from the 1997 flood in 2013, indicating that recovery would very likely be an extended process for a very long time.

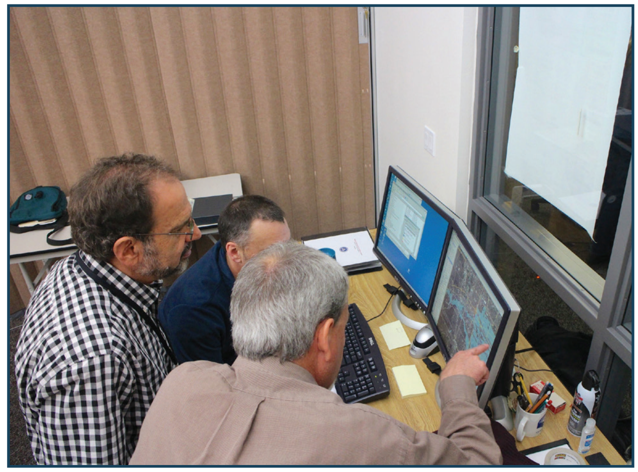
Options Identified in the Stakeholder Meetings

- Conduct rapid damage assessments to collect information on critical infrastructure and number of people affected.
- Establish and leverage social media outlets to compile and centralize real-time, crowd-sourced, and geo-referenced information on conditions.
- Recovery programs last long enough so that audits and accounting eventually reassert themselves as crucial factors in these programs. As a result, proper paper trails need to be developed early in the process and maintained to ensure successful funding streams and public investments in the region's recovery.
- Public/private plans and coordination during recovery should be promoted and, if possible, anticipated before, during and after the emergency.

Results – Key issues identified in the tabletop exercise

Phase One: Preparation

In Phase One, there has been significant precipitation over several days and there is a forecast for a potentially large, warm storm on the horizon. Activities in this phase focused on preparedness for the potential upcoming storm. Public information, advance preparation of shelters and hospitals, activation of emergency plans, identifying locations of staging areas and access routes, and advance preparation for evacuations were identified by multiple groups as key activities. Critical to all of these activities was establishing a Unified Coordination Group to make responses effective.



Stakeholder examine maps showing flood inundation areas. Photo credit: Chris Smallcomb, NWS.

Phase Two: Response

In this phase, participants are in the throes of the height of the storm, 18 days in, and on the verge of record flooding on the Truckee and Carson Rivers. Preservation of life and safety was identified as the primary concern during this phase and all activities and responses identified were a means to this end. Prioritization of existing resources for evacuation and maintaining roadways, utilities, life lines and other critical infrastructure necessary for evacuation and response was emphasized, as was the need for coordinated communications within the Incident Command System (ICS) organizational structure, particularly with dam managers, who would likely be releasing water from the dams to prevent them from being breached. In addition, the need to have an effective and centralized Joint Information Center (JIO) that is well-staffed and continued warnings and communications with the public was expressed.

Stakeholder groups participating in the tabletop exercise report key concerns and priorities identified during discussions. Photo credit: Chris Smallcomb, NWS.

Phase Three: Recovery

Phase Three, the recovery phase, takes place a week following the storm. During this phase, participants were asked to think retrospectively about what actions they might have taken at various stages of the event to mitigate the impacts, and prospectively about what trigger actions they might implement in their current plans in anticipation of an event of this magnitude, and what opportunities might exist for a shift in regional planning following this type of event. Overall, it was recognized that better preparedness and response is the best way to facilitate rapid recovery. There was widespread recognition that Stead Airport would likely be an important staging area during this type of event and there is additional opportunity to examine and reevaluate plans to incorporate Stead as well as other strategic locations. There was also a recognized need to incorporate these locations into training and exercises, and to establish triggers for their use. Further, there was discussion of the importance of having cross-agency coordination and assistance agreements in place prior to an event. There was continued emphasis of the importance of early and frequent communications with the public, particularly at-risk populations such as those in the most remote or most vulnerable areas. There was also discussion of the need to proactively reach out to private industries that may be able to provide resources and to policy makers to ensure they understand and are willing to support on-the-ground actions deemed important by operations staff. Finally, there was discussion of the need to be proactive in documenting damages, and increasing awareness of the public and policy makers of storm impacts to facilitate the flow of resources. To a similar end, determining how to most efficiently manage resources through training and exercises, being prepared to develop grant proposals, manage volunteer resources, manage temporary housing, and recognize (and act on) opportunities to re-establish critical infrastructure and developments such that they are more robust to future events (e.g., rebuilding outside the floodplain) is also needed.

Results - Science needs identified in stakeholder meetings

Avalanche, debris flow, landslide vulnerability modeling and mapping

Stakeholders expressed a desire to understand where avalanches and other geomorphic hazards such as debris flows, mudslides, rock-falls or landslides may occur. Several data sources are available that provide a rough estimation of where these may occur in California and in the Lake Tahoe Basin based on factors such as slope, geology or vegetation cover, but no such datasets exist for Nevada outside of the Tahoe Basin and there is a need to develop this information for subsequent risk analysis. Moreover, the maps and models that do exist have not been translated to quantify risk to critical infrastructure.

Forecast modeling

Currently, forecast models allow for detection of atmospheric rivers 7-10 days out, and reasonable estimates of precipitation amounts can be identified 3-5 days out. Stakeholders expressed a need for higher resolution forecast models that enable better prediction and more lead time to prepare for an ARkStorm-type event. NWS experts suggested that model improvement requires both an increase in computing power and scientific knowledge of atmospheric dynamics, which may be improved with increased offshore and ocean monitoring.

Flood inundation mapping

Several needs related to flood inundation mapping were identified. Publicly available flood maps include FEMA insurance maps (FEMA 2014) and maps showing inundation areas during the 1997 flood event for the Reno area (Rigby et al. 1998). Stakeholders identified the need for more comprehensive mapping, maps for larger flood recurrence intervals (i.e., 300-500yr maps), and mapping with greater specificity (e.g., by sub-watersheds draining into Reno/Carson) so that more accurate inundation estimates can be derived based on the location and form (rain vs. snow) of precipitation. The ability to produce inundation maps on the fly based on a hydrologic forecast was also expressed as a key science need. In addition, the issue of map standardization was discussed at length. Inundation maps from different sources, times or using different methods can give conflicting information which hinders response and stakeholders agreed that standardization of methods and maps is an important issue to address.

Hydrologic modeling

A key science need that was identified is the development and application of models that can accurately predict extreme flows such as those that may be experienced during an ARkStorm-type event; these models can in turn provide estimates of relative flood vulnerabilities. In addition, stakeholders were interested in flow and flood predictions based on a range of storm scenarios and antecedent conditions.

Sediment loading and dynamics modeling

Given the potential for sediment inputs to affect water supplies in Lake Tahoe, stakeholders identified the need to estimate relative vulnerability of water supply intakes to sediment loading based on proximity to inputs and potential for sediment transport based on winds and water currents. Stakeholders were also interested in impacts of an ARkStorm to short- and long-term water quality conditions in Lake Tahoe and suggested that models of shoreline erosion potential that includes effects of wind action on turbidity and shoreline erosion would be useful. They were also interested in estimation of flood effects on Total Maximum Daily Loads for sediment and other pollutants, and testing of bioengineering techniques that would help to limit pollutant loading into the lake.

Monitoring

Several monitoring needs were articulated, including establishment of additional meteorological stations where gaps currently exist, and leveraging real-time monitoring networks to collect meteorological data. Stakeholders also identified the need for a centralized clearinghouse for monitoring data or, at a minimum, a database that includes what data exist and where they may be found. There was significant discussion of the need for additional offshore and ocean monitoring that would provide for improved forecast modeling and response lead times.

Alternative scenarios/antecedent conditions

Recognizing that the ARkStorm scenario is one of an infinite number of possibilities, stakeholders were very interested to know how results of meteorological and hydrologic models used to quantify ARkStorm impacts would differ based on different storm temperature scenarios, antecedent conditions related to soil saturation, snowpack and reservoir levels.

Lessons Learned

- The major flooding event that occurred in 1997 was relatively fresh in people's minds, and this event served as an effective focal point for understanding the scale and potential impacts of an ARkStorm. Emergency managers have significantly improved emergency response planning since 1997 and are better prepared for an ARkStorm because of lessons learned in the past but there is still ample opportunity to improve resilience to this type of event. For example, approximately one-half of communications infrastructure, one-third of EPA-registered waste facilities, one-eighth of hospitals, and nearly 300 miles of roads and railways could plausibly be affected by an ARkStorm, suggesting significant vulnerabilities still exist.
- Interruption of transportation, communications and power were the key points of failure across sectors and geographies as emergency response and recovery efforts are highly dependent upon continuity in these three sectors. Focusing efforts to improve preparedness, response and recover in these areas has the potential to improve overall resilience of the study area, given the cascading effects of failures in these areas.
- The resiliency of transportation of goods and services from beyond the study area was a recurring theme in discussions. An especially important decision point may eventually be the management of alternative airfields: that is, identifying under what circumstances and how might Stead, Fallon and even Carson City air fields be used to maintain the flow of people and supplies to the region.
- Weaknesses or failures of interagency coordination are an important source of "friction" that is likely to limit responsiveness before, during and after an ARkStorm event. Examples include: road closures that limit vital access to failing facilities by utility workers (the credentialing problem); and potentially weak government agency communications with tribes, vulnerable populations, healthcare facilities, the region's large tourist (and, in the event, refugee) populations, and across the state lines. Communications is probably the area that might most readily be proactively strengthened to reduce unnecessary ARkStorm impacts.
- Being at the terminus of the Truckee River drainage, the Pyramid Lake Paiute Tribal communities are especially vulnerable to having their livelihoods contaminated by polluted runoff and harmed by flooding. Other tribes are isolated and/or without adequate emergency response personnel and the means to communicate during an ARkStorm-sized event. Tribes in general feel they are at the end of the line when it comes to emergency response, despite assurances to the contrary from emergency response officials.
- Planning and emergency response resources exist but many public utilities and other non-emergency response stakeholders did not seem to be aware of their existence. This was evidenced by comments that related to needing an evacuation plan, needing to know where shelters could be located, or what evacuation routes should be, despite the existence of some of this information on county and state websites. Improved public outreach and extreme storm or flood awareness programs would help to rectify this situation.

- During the TTX, a number of hypothetical environmental damages occurred, particularly related to contamination of water resources. It was clear that addressing these impacts was a lower priority during the response phase as compared to evacuation and protection of life and safety. During the recovery portion, some respondents suggested that in retrospect, they wish they had done more to protect water supplies. For example, it became clear that the management of water supplies in the Lake Tahoe area during the crisis will be inextricably tied to, and eventually dictated by, the wastewater situation. Increased awareness of the potential long-term impacts of an ARkStorm on water resources may help utilities and responders be more proactive about this issue.
- Limitations to accessing geospatial information considered to be sensitive (e.g., locations where hazardous chemicals are housed, wells and water supply intakes, utility lines) that may be relevant to public and environmental health may constrain emergency preparedness and response. For example, Homeland Security Infrastructure Program (HSIP) Gold is a highly useful dataset of critical infrastructure. However, these data can only be utilized after a federal emergency designation has been declared. Securing legal agreements would facilitate the sharing of critical information for local emergency planning purposes and during emergency events. If data are deemed truly sensitive, location information can be generalized and sensitive attributes can be removed to allow emergency management the use of information to make generalized decisions or to provide situational awareness. Additionally, these data rely on national and private databases that may not have utilized local knowledge for geospatial or temporal accuracy. Local coordination to create, update and maintain geospatial data and a central repository with offsite backups for critical infrastructure data is very important for local emergency management decisions to be made. The identification of either a local agency to identify and maintain this data would help facilitate the use of up-to-date and accurate geospatial data for planning processes or when an emergency occurs.
- Geospatial results from various environmental studies are very site specific or stop at state, county or other political boundaries (e.g., landslide probability maps exist for California but not Nevada). Often the results of these studies stay within the scientific community. Better communication of the existence of environmental studies and their relevance to the emergency community need to be facilitated. Although data are in some cases incomplete, having some information, and knowing the limitations of that information, may be better than having no data at all. Being able to show the relevance of good data and the importance of what may otherwise be considered academic or esoteric work is critical to ensuring use of the data. This also helps identify where data gaps exist, where the quality of data needs to be improved, and where multiple entities and agencies in the scientific community can work together to data that fits the various regulatory, planning, and emergency needs.
- After the exercise, several groups mentioned coordination between emergency managers and planners concerning development areas and access routes. A regional or basin-wide planning approach from both community/urban planning and transportation planning that is coordinated with the emergency planning community, or where there is some dialog between local planning efforts and their regional ramifications, seems like a potential positive outcome that would help foster more sustainable communities, transportation routes and emergency plans.

Lessons Learned continued...

- Although a great deal of work is being done regionally concerning flood inundation, these projects tend to be focused on short stretches of river and there are liability concerns associated with making final data products available to the public. An overarching mechanism that allows the release of "best available data" from scientifically sound studies for public awareness and for emergency management decisions without the threat of litigation would help to address this need. This work also highlights the need for a basin-wide approach for the release of data, to help identify data gaps, and to provide a wider range of information for decision making and to provide an immediate feedback for the potential ramifications, both upstream and downstream, of events or management decisions.
- Many of the vulnerabilities and recommendations identified for ARkStorm are applicable to other types of emergencies (e.g., earthquakes). Situational awareness (real-time monitoring and communications of developing storm, impact and response conditions) may prove to be unusually vulnerable in this area, given the blanketing of many crucial areas (especially around the Lake) by thick obscuring snowpacks, difficult terrains (for travel, transport and even communications), and the many widely separated populations and infrastructures. Continued hardening of communications, monitoring equipment and lines of authority in anticipation of catastrophes of ARkStorm's magnitude is crucial.

Truckee River White Water Park in Downtown Reno, Nev. Photo credit: Valerie Lykes

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Appendix 1 – Stakeholder Meeting Summaries

Meeting 1: Incline Village, NV (Public Utilities/Water Supply)

Stakeholders expressed a desire to understand where avalanches and other geomorphic hazards such as debris flows, mudslides, rock-falls or landslides may occur. Several data sources are available that provide a rough estimation of where these may occur in California and in the Lake Tahoe Basin based on factors such as slope, geology or vegetation cover, but no such datasets exist for Nevada outside of the Tahoe Basin and there is a need to develop this information for subsequent risk analysis. Moreover, the maps and models that do exist have not been translated to quantify risk to critical infrastructure.

Meeting 2: Stateline, NV (Emergency response/health and human services/ business community)

Currently, forecast models allow for detection of atmospheric rivers 7-10 days out, and reasonable estimates of precipitation amounts can be identified 3-5 days out. Stakeholders expressed a need for higher resolution forecast models that enable better prediction and more lead time to prepare for an ARkStorm-type event. NWS experts suggested that model improvement requires both an increase in computing power and scientific knowledge of atmospheric dynamics, which may be improved with increased offshore and ocean monitoring.

Meeting 3: Carson City, NV (State/Federal coordination)

The third meeting was held on November 12, 2013, at the NV Division of Emergency Management office. Over 60 individuals from 43 different organizations (see table 3) signed in, though over 90 individuals were observed at the meeting. The core concerns related to transportation, communications, power and fuel supplies, and locating shelters were discussed in great depth, as were concerns about the resiliency of reservoirs along the Truckee River and evacuation and relocation of essential medical services that exist in the floodplain. Discussions also touched on emergency response coordination among state and federal agencies. Although CA and NV conduct interstate emergency response exercises on an annual basis, it is likely that CA would be unable to assist NV and both states will likely need to coordinate with states farther to the east. The opportunity to immediately leverage federal assets such as the National Guard was also discussed. The group also identified approaches for increasing public awareness and flood preparedness and key issues related to recovery such as reestablishment of facilities and infrastructure and damage assessment.

Meeting 4: Reno, NV (Truckee River/flood management)

The fourth meeting was held on December 5, 2013, at the Regional Emergency Operations Center in Reno, NV. Over 135 individuals from 69 different organizations were in attendance. The discussion covered additional facets of key issues identified in previous meetings and included in-depth discussion of flood management, including balancing water supply conservation with flood management, and related science needs including more comprehensive and detailed flood inundation mapping. The availability and options related to regional fuel resupply was also discussed in depth. Northern Nevada depends on northern California for fuel, and since this supply could be cut off, potential approaches for bringing fuel reserves in from the east were identified.

Meeting 5: Reno, NV (Tribal issues)

The fifth meeting was held on January 13, 2014 at the Reno-Sparks Tribal Health Center in Reno, NV in conjunction with the Intertribal Emergency Response Council board meeting. Over 40 people from 31 organizations, including seven different tribes were in attendance. The meeting was intended to focus specifically on concerns of tribal members. Many of the concerns expressed were consistent with those expressed in past meetings but the tribes had several unique concerns, including limited tribal emergency response staffing, severe economic impacts, isolation of rural communities during emergencies, prolonged recovery periods, and a perception that tribes are often at the end of the line when it comes to assistance or resources. The Pyramid Lake Paiute Tribe was particularly concerned about flood refuse and pollution from the entire Truckee watershed washing down into Pyramid Lake, which is source of subsistence and revenue for their tribe. Tribes were also concerned that they are not always explicitly mentioned in mutual aid agreements, although utility operators and state and county emergency responders indicated that they would support tribes as they would any constituent.

Meeting 6: Stateline, NV (Natural resource impacts)

The last meeting was held on January 14, 2014 at the Tahoe Regional Planning Agency in Stateline, NV. Over 60 individuals from 39 organizations were in attendance. Most of the attendees had jurisdictions within the Tahoe Basin, so discussions were naturally biased toward issues relevant to this geographic area. This meeting had a slightly different focus from previous meetings, which were largely focused on emergency response. Instead, discussions in this meeting were targeted toward understanding both short- and long-term impacts to natural resources and potential management strategies for minimizing impacts of an ARkStorm. The vulnerability of wastewater systems and the potential to contaminate Lake Tahoe and surrounding waterways was identified as a key concern. Other concerns included flooding, impacts on water quality, spread and establishment of invasive species, and interactions with other disturbance types (e.g., fire, landslides). Science and monitoring needs as well as management strategies including infrastructure restoration and design specifications were identified.

Appendix 2 – Participating organizations

Organization	Incline Village, NV 9-12-13	Stateline, NV 10-11-13	Carson City, NV 11-12-13	Reno, NV 12-05-13	Reno, NV (Tribal) 01-13-14	Stateline, NV (Natural Resources) 01-14-14
Flood Management						
Bureau of Reclamation			X	X	X	X
Truckee River Flood Project				X	X	
Government - City						
Carson City			X			
Carson City Emergency Management			X			
City of Reno				X		
City of South Lake Tahoe						X
City of Sparks				X		
Reno Fire				X		
Reno Police				X		
Sparks Fire				X		
Town of Truckee						X
Truckee Police Dept						X
Government - County						
Douglas County		X				X
Douglas County Sheriff's Office	X	X	X			
East Fork Fire/Douglas County		X				
El Dorado County Sheriff's Office, Tahoe Division						X
Northern Nevada Regional Intelligence Center				X		
Regional Emergency Operations Center				X		
Storey County			X	X	X	
Washoe County				X	X	X
Washoe Amateur Radio Emergency Services				X	X	
Washoe County Emergency Management	X				X	
Washoe County School District		X	X	X		
Washoe County Sheriff's Office	X	X		X		

Organization	Incline Village, NV 9-12-13	Stateline, NV 10-11-13	Carson City, NV 11-12-13	Reno, NV 12-05-13	Reno, NV (Tribal) 01-13-14	Stateline, NV (Natural Resources) 01-14-14
Washoe County Technology Services				X		
Government - Federal						
Department of Homeland Security				X		
Federal Bureau of Investigation, Tahoe Division		X				
Federal Emergency Management Agency			X			
National Weather Service			X	X	X	X
Government - State						
California Office of Emergency Services		X	X	X	X	
CalFire						X
California Highway Patrol						X
Nevada 211 Crisis Call Center			X	X	X	
Nevada Administration			X			
Nevada Attorney General's Office					X	
Nevada Clean Energy			X			
Nevada Division of Emergency Services		X	X	X	X	
Nevada Emergency Alert System				X		
Nevada Governor's Office of Energy			X	X	X	
Nevada Highway Patrol				X		
Nevada Threat Analysis Center			X			
Health and Human Services						
American Red Cross	X	X	X	X	X	X
Barton Memorial Hospital		X				
Carson City Health and Human Services				X		
Carson Valley Medical Center		X				
Nevada Center for Disease Control				X		
Life Care Reno		X		X		

Organization	Incline Village, NV 9-12-13	Stateline, NV 10-11-13	Carson City, NV 11-12-13	Reno, NV 12-05-13	Reno, NV (Tribal) 01-13-14	Stateline, NV (Natural Resources) 01-14-14
Nevada Division of Public Health			X	X	X	
Nevada Dept. of Health and Human Services		X	X			
Pyramid Lake Tribal Health					X	
Regional Emergency Medical Services Authority				X		
Renown Health				X		
St. Mary's Regional Medical Center				X		
Washoe County Health District				X		
Washoe County Public Health				X		
Military						
Naval Air Station, Fallon				X		
Nevada Air National Guard			X	X		
US Army National Guard				X		
US Air Force National Guard		X				
US Marine Corps				X		
Natural Resource Management						
Bureau of Land Management				X		
California Conservation Corps			X			
California Regional Water Quality Control Board, Lahontan Region						X
California Tahoe Conservancy						X
California State Parks						X
Environmental Protection Agency		X				X
Nevada Division of Forestry			X			
Natural Resource Conservation Service						X
Nevada State Lands Dept						X
Nevada Tahoe Conservation District	X					X

Organization	Incline Village, NV 9-12-13	Stateline, NV 10-11-13	Carson City, NV 11-12-13	Reno, NV 12-05-13	Reno, NV (Tribal) 01-13-14	Stateline, NV (Natural Resources) 01-14-14
Tahoe Regional Planning Agency	X	X				X
US Forest Service						X
US Fish and Wildlife Service						X
Non-profit						
California Water Network						X
League to Save Lake Tahoe						X
Sustainable Community Advocates						X
Trout Unlimited				X		
Private Sector Engineering/Consulting/Insurance						
Ascent Environmental						X
Atkins Global				X		
Belfor Property Restoration					X	
Bently Enterprises		X				
Cardno Entrix						X
Employers Insurance				X		
HDR Engineering				X		
Resiliency Partners	X	X	X	X	X	
RO Anderson						X
Sound Watershed						X
Wildscape Engineering Services						X
Willis Group				X		
Private Sector Tourism/Commodities						
Carson Valley Inn		X				
Circus Circus, Reno		X		X	X	
Harrah's Tahoe		X				
Hyatt Lake Tahoe	X					
Peppermill Casino				X		
Sienna Hotel Casino				X		
Walmart					X	
Public Utilities						
Calaveras County Water District		X				
Douglas County Public Works	X	X				

Organization	Incline Village, NV 9-12-13	Stateline, NV 10-11-13	Carson City, NV 11-12-13	Reno, NV 12-05-13	Reno, NV (Tribal) 01-13-14	Stateline, NV (Natural Resources) 01-14-14
ElDorado County Public Works		X				
Incline Village General Improvement District	X					
Kingsbury General Improvement District	X	X				
Liberty Utilities		X				
Lakeside Park Association	X					
Marlette Water District		X				
North Tahoe Public Utilities District	X	X				
Reno Public Works				X		
Round Hill General Improvement District	X					X
South Tahoe Public Utilities District	X					
Tahoe City Public Utilities District	X					
Tahoe Stormwater Engineering Division						X
Research/University						
Desert Research Institute		X				X
Sierra Nevada College	X	X				
Tahoe Science Consortium	X	X	X	X	X	X
University of California, Davis	X	X	X	X	X	X
University of Nevada, Reno	X	X	X	X	X	X
University of Nevada, Reno Cooperative Extension			X	X	X	
US Geological Survey	X		X	X	X	X
Tahoe Fire Protection Districts						
Meeks Bay Fire Dept		X				
North Lake Tahoe Fire	X					
South Lake Tahoe Fire						X
Tahoe Douglas Fire		X				X
Transportation						
CalTrans			X			
Nevada Dept. of Transportation			X	X		
Reno Tahoe Airport Authority				X		

Organization	Incline Village, NV 9-12-13	Stateline, NV 10-11-13	Carson City, NV 11-12-13	Reno, NV 12-05-13	Reno, NV (Tribal) 01-13-14	Stateline, NV (Natural Resources) 01-14-14
Regional Transportation Commission				X		
Transportation Security Administration				X		
Tribal						
Duckwater Tribe					X	
Elko Band Council					X	
Ely Shoshone Circle					X	
Intertribal Emergency Response Commission	X			X	X	
Nevada Urban Indians				X		
Reno-Sparks Indian Colony		X		X	X	
Walker River Paiute Tribe					X	
Washoe Tribe		X	X		X	

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