Colorado Water

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Theme

Natural Hazards

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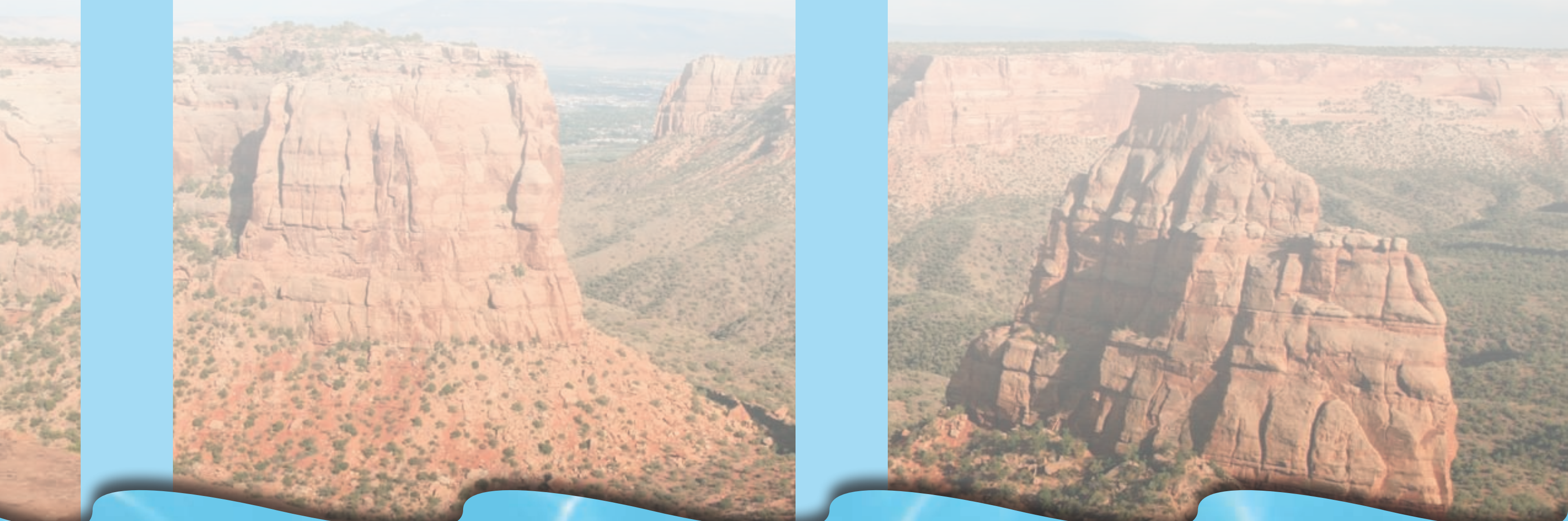
Highlights

In Every Issue



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Front Cover: Seasonal snowmelt rushes down Glacier Creek in Rocky Mountain National Park
Inside Front Cover: Colorado National Monument near Grand Junction
(Photos by Laurie Schmidt)

Editorial

by Reagan Waskom, Director, Colorado Water Institute

Living in a place such as Colorado, we tend to think of natural disasters as events that happen somewhere else—hurricanes, earthquakes, volcanoes, tsunamis, etc. But in reality, we have our share of natural hazards here, and the majority of them have something to do with water. Drought, flood, tornadoes, avalanches, hail, blizzards, and flash floods all occur in Colorado. The question is simply when and where the next water-related hazard will strike, and how severe the impacts will be.

As long as there has been water on this planet, extreme hydrologic events have occurred, and they are an important aspect of the hydrologic cycle. Natural disasters, however, didn't come along until human civilization got in the way of these extreme events. On a global scale, about 50% of "water disasters" are related to flood, 28% to waterborne disease, 11% to drought, 9% to landslides and avalanches, and 2% to famine.

The cumulative impacts of growth, poor planning, and floodplain development mean that many events we call "natural" hazards are actually human-induced hazards. What might have been an unrecorded extreme hydrologic event just a few hundred years ago becomes a major human disaster today. Research shows that the occurrence, severity, and cost of natural disasters have increased in proportion to human population. Population growth simply increases exposure to extreme hydrologic events. But where we choose to live also increases our vulnerability—80% of the world's population and 15 of the planet's 18 megacities are found on or near coastlines. Changing climate scenarios make this statistic even more sobering.

The current human tendency to develop our civilizations in hazardous areas, such as floodplains, increases our exposure to risk, yet we continue to make ourselves vulnerable by building and living in these areas. Private and federal insurance buffers individual financial risk and often substitutes for better planning decisions. Given human nature, expanding population, and changing climate, how can society increase resiliency and the ability to withstand surprises?

This issue of *Colorado Water* focuses on some current research and thinking on risk assessment, adaptation, and response to natural hazards. Eve Gruntfest's research on flash floods points out that 50% of fatalities due to flash floods are vehicle related and largely avoidable. She found that middle-aged workers are most vulnerable, due to a work ethic that propels them to go to work regardless of road or weather conditions. Something as simple as better communication of emergency protocols and expectations at work could reduce these poor choices. Melinda Laituri describes how the integration of GIS technology with human observation networks can create enhanced online communication and information networks to greatly improve disaster response. Drought research described by NOAA scientist Roger Pulwarty evaluates the changing impact of drought as a function of increasing population and a changing climate.

As long as humans live on planet Earth, we will always experience the impacts of hydrologic extremes. How we plan, forecast, monitor, and respond to these extremes determines our vulnerability or resiliency. Colorado water managers typically operate their systems somewhere between flood and drought, but they must incorporate both extremes in their planning and infrastructure. In the past, the best engineered solution to these extremes was to build more capacity and redundancy into stormwater and water storage systems. Today, we must also incorporate better planning and early warning systems with more robust decision tools to help society weather these storms.

Colorado Floods: A Hydrology Perspective

by Neil S. Grigg, Professor, Department of Civil and Environmental Engineering

One of the ironies of our geographically diverse state is that big floods can occur in such a dry climate. Our mid-continent climatic position contributes to this irony because it sometimes encourages formation of large thunderheads that create large and intense rainfall amounts. Another cause is the rain-on-snowmelt phenomenon that can occur during spring runoff. Whatever the cause, Colorado flooding can be severe, and it is a threat to be respected. This short article provides an overview of the underlying phenomena that cause flooding across Colorado.

Big Floods in Colorado and Their Causes

To set the stage, it is useful to study big floods that have occurred in Colorado. Paleo-hydrologists (who examine geologic records) tell us that the state has experienced great floods in the past. Among the many events on record, a few that come to mind are the 1864 (May 19) Cherry Creek flood, the 1864 (June 9) flood that devastated the military camp at Camp Collins, the 1904 (August 12) and 1921 (June 3) floods in the Pueblo region, the 1935 (May 30) storm that dropped 24 inches of rain northeast of Colorado Springs, the 1965 floods along the Front Range, the 1976 Big Thompson flood, the 1983 Colorado River flooding, and the 1997 Fort Collins flood. Each flood was somewhat different, but most involved heavy rainfall that occurred quickly, causing tributary and main streams to rise rapidly.

Flooding can also occur on the Western Slope, but the climatic regime, the mountainous terrain, and the lower population density have enabled the region to escape the disastrous floods that afflict the Eastern Slope. The 1983 Colorado River snowmelt flooding was different from most Eastern Slope floods, in that it was caused by large quantities of snowmelt water that built up in the downstream reservoirs.

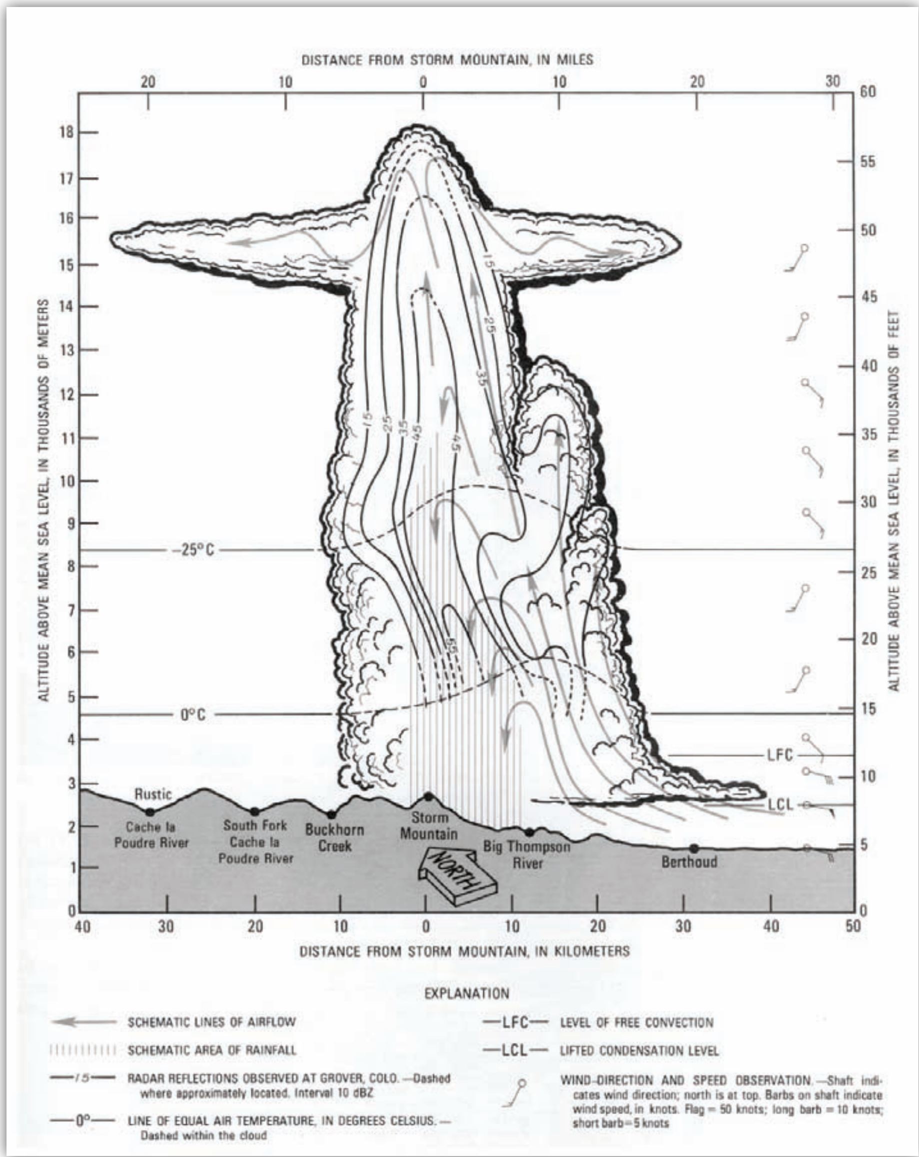
Some Colorado floods have had devastating effects on life and property. The 1904 Pueblo-area flood killed about 100 people when it toppled a trestle and swept away a Denver and Rio Grande passenger train. The train crashed on a bridge over Dry Creek, eight miles north of Pueblo. In the big flood of 1921 on the Arkansas River and Fountain Creek, over 200 people were killed or reported missing.

Over a three-day period in 1965, flooding occurred on the Platte, on the eastern plains, and on Fountain Creek, causing large losses in a widespread area. The storms followed a wet period and dropped as much as 14 inches of rain in a few hours. The peak on the South Platte at

The 1976 Big Thompson flood left a house precariously undercut by lateral scour a quarter of a mile below Glen Comfort. (Courtesy of USGS, photo by by R.R. Shroba)

Denver was 40,300 cubic feet per second (cfs), compared to the previous high of 22,000 cfs in a period dating back to 1889. The peak would have been even higher, but all flow from Cherry Creek was stored in its reservoir. Six persons drowned, and two other flood-related deaths occurred. About 75% of the $500 million in damage occurred in the Denver metro area. If you convert that to 2009 dollars, it amounts to about $3.3 billion.

The devastation wrought by the 1976 Big Thompson flash flood is well known, as it caused the greatest loss of life in a natural disaster in many years. In 1997, a short-duration flood caused tremendous property damage in Fort Collins and claimed four lives. Colorado State University organized a conference to discuss that flood, and some 400 people attended—many with emotional stories about danger and hardship. The flood caught everyone by surprise when waves of water appeared from the west, creating havoc in the city and at the university and causing significant property damage. The powerful flood waters along Spring Creek washed over the railroad trestle and College Avenue and caused several deaths in a mobile home park.



This drawing illustrates the rainstorm that triggered the Big Thompson flood in 1976. (Courtesy of Neil S. Grigg)

Anyone who studies these Colorado floods understands their tremendous power. The floods did not result from days and days of heavy rain, as you might see in the East, South, or Midwest. With the exception of the snowmelt floods, they occur from cloudbursts that drop large amounts of rain on small areas in a short period of time. The quantity of water involved in a Front Range flash flood could be, say, 25,000 acre-feet that resulted from a 10 x 10-mile storm with a maximum rainfall depth of 10 inches, but tapering off to only an inch or two at the edges of the storm. In contrast, a large storm in the eastern or southern U.S. might be hurricane-induced and could easily fill a 100 x 100-mile area with rain and drop 2.5 million acre-feet of water and more.

Hydrology of Floods in the State

So, the combination of the mid-continent climate, the snowpack, and the terrain explains the causes of Colorado floods. The state's East Slope climate cycle starts with snow buildup in the winter and early spring, followed by spring runoff, then by summer and a drier fall. It differs on the West Slope due to different climatic zones. Atmospheric moisture can arrive from the Pacific, the Gulf of California, the Gulf of Mexico, and the Mississippi Valley. The climate forces vary by season, but rainfall floods seem to occur from May through September.

Hydrologists who study Colorado flooding divide the state into four or five regions. A 1976 study by McCain and Jarrett looked at gage data for the South Platte, Arkansas, Rio Grande, and Colorado River Basins and divided the state into plains, mountains, northern plateau, and southern plateau zones. In a 1999 report, Vail used five regions: mountain, Rio Grande, southwest, northwest, and plains.

Each region has distinct flood characteristics. Front Range flooding gets the most attention due to the large population base, but plains floods can be equally large. Rainfall floods on the Western Slope seem to have lower peaks than snowmelt floods, but some rainfall peaks can approach snowmelt flood levels. Large rainfall floods in southwest Colorado occur mainly in the early fall as a result of decayed hurricanes from the west coast of Mexico, and large ones occurred in 1911, 1970, and 1972. A large rainfall flood in the Southwest and Rio Grande zones occurred in the 1920s. Small basin flash floods cause heavy local flooding with debris and mud slides.

Perhaps a good way to summarize Colorado's flood hydrology is to describe scenarios of floods that can and do happen. While scenarios do not represent actual floods, they are the avenue to predict probable floods and seek to mitigate them.

The first scenario is an urban event of, say, a 10 to 25-year recurrence interval. Floods of this magnitude cause disruption in cities and require large and expensive storm drainage systems to handle them. They can be caused by rainfall events of one to two inches in an hour, for example. The Urban Drainage and Flood Control District, located in Denver, publishes a criteria manual with detailed rainfall curves for events such as these. There has been a tendency for cities to build increasingly large management systems for urban runoff events, and over the past two decades water quality has been integrated with stormwater in many of the cities as a program objective.

Next, we might see a larger event; say, a 100-year storm that also flooded the main streams. Now, the flood takes on a different scale and includes not only significant urban flooding but also threats to property and infrastructure in the floodplain. Floods like this have important environmental implications as well, as they can nourish flood plains, clear out pollution, and generally refresh riparian areas.

Then, really big floods—like the one on the Big Thompson in 1976 and on Spring Creek in 1997— take on larger proportions and may be labeled as "500-year floods" or even higher. For example, the 1997 Fort Collins flood was caused by extraordinary rainfall amounts that exceeded 14 inches in a little over 30 hours. Maximum amounts occurred just next to the foothills. Floods of this magnitude cannot be handled by underground storm drainage pipes and require open space for flows to run above ground without excessive damage.

Finally, the large-scale snowmelt floods, like the 1983 Colorado River flooding, can occur from combinations of heavy snowpack and rapidly rising temperatures, perhaps exacerbated by rainfall that adds heat energy and accelerates the melting. If floods like this occur in a small watershed, they can cause local and tributary flooding, but they can also occur over large-scale areas and even multi-state regions, as in 1983. That year, due to record runoffs from late spring snows, the Colorado River peaked at 120,000 cfs. When the spillways at Glen Canyon Dam were opened to accommodate the inflows, the pressure of the water was so great that it carved a 50-foot-deep hole in the sandstone at the tunnel plug.

Colorado has experienced enough floods to become keenly aware of its need to mitigate the flood hazard threat. Above all, this requires vigilance that prevents putting people and property in harm's way. Floodplain management programs have valid goals to manage land use with flooding in mind, but tributary floods and small-scale urban floods can also threaten people. It can be expensive to repair dams and expand spillways to accommodate maximum probable events, but the high consequences of such low-probability events warrant significant societal concern and investment.

Social Impacts of Flood Events: Learning from Hurricane Katrina

by Laurie Schmidt, Colorado Water Institute

For those who haven't personally experienced a major natural disaster, it is difficult to fully grasp what victims all too often endure—the loss of a home, the death of a loved one, an extended stay in a shelter, or separation from a child during rescue or evacuation. But for Lori Peek, assistant professor in the Department of Sociology at CSU, understanding and learning about those kinds of experiences are a primary focus of her research.

Since 2005, Peek has made several trips to New Orleans, Louisiana, to interview child and adult survivors of Hurricane Katrina. Katrina slammed into the U.S. Gulf Coast as a Category 5 storm on August 29, 2005. It was to become the costliest natural disaster in U.S. history, largely due to the breaking of the levees and floodwalls, which sent the waters of Lake Pontchartrain pouring into New Orleans neighborhoods.

The Human Side of Flood Disasters

Peek's research focuses on the role that social inequality and vulnerability play in determining how a disaster will affect individuals and entire communities. Her recent projects include a longitudinal study of children in Louisiana affected by Hurricane Katrina, and an examination of the relocation experiences of parents and children who were displaced to the state of Colorado in the aftermath of Katrina. Both studies look at the impact of a natural disaster on the human environment, rather than just on the physical landscape.

"Disasters are fundamentally social events," said Peek. "Yes, they're forces of nature, but they're also forces of society. Human decisions shape who is living at risk in our society and in other societies around the world." Although Katrina left an indelible mark on the terrain—gutted homes and properties, flooded streets, piles of debris—it left an equally devastating imprint on the residents of New Orleans, many of whom were displaced by the storm.

"Katrina was massively instructive on several different levels. It really made us think about what happens when large swaths of our population are displaced for long periods of time, and what that means for communities and their potential to rebuild," said Peek.

Disasters like Katrina can also exacerbate the injustices of social inequalities. For example, wealthier people tend to have more social networks to draw support from after a disaster. "If you're middle class, it's likely that you have more extensive social networks across the country, so you can draw upon the resources of others or share their homes," said Peek. "Or you can tap into your own personal wealth and pay for a hotel room to be in a more comfortable setting, as opposed to ending up in the cramped and uncomfortable conditions of shelters, temporary trailer homes, etc. Those sorts of trauma become cumulative when combined with the most immediate effects of the disaster itself," said Peek.

During Katrina, thousands of people were rescued from rooftops, and Peek says this sort of trauma is precisely what leads to a prolonged recovery period after a disaster. As part of a research project, she recently interviewed an 18-year old African American boy in New Orleans, who, she said, still breaks down in tears four years after Katrina. "He was only 14 when Katrina struck. He lives with the memory of evacuating his grandmother in a wheelchair and carrying his baby sister in his arms, and then waiting for five days for somebody to rescue them," said Peek. "He was displaced to three different cities in three different states after Katrina, and ultimately never returned to school. So his experience of Katrina was profoundly different than someone who may have also lost their home,

Lori Peek (left) and co-researcher Alice Fothergill survey the devastation in New Orleans four weeks after Hurricane Katrina made landfall in 2005. (Courtesy of Lori Peek)

Lori Peek and co-researcher Alice Fothergill interview school children in New Orleans about their experiences with Hurricane Katrina. (Courtesy of Lori Peek)

but who was able to self-evacuate, get out of harm's way, and return to a more stable routine soon after the disaster."

Almost 30 years before Katrina, on July 31, 1976, a flash flood roared through Colorado's Big Thompson Canyon, during which U.S. Army helicopters rescued 850 people from rooftops, canyon walls, and rocks in the middle of the flooded river. Although warning times and evacuation procedures during a hurricane certainly differ from those that take place during a flash flood, Peek says that in terms of social impacts—there are parallels to be drawn between the two disasters. "It's important to be aware of the trauma involved with having to be picked up from a rooftop," she said. "So, what procedures can we implement that would minimize suffering?" One important strategy, she says, is ensuring that there is an efficient system for tracking victims after they have been rescued. For example, having one designated drop-off point for rescued people would help facilitate the reunion of family members, especially parents and children who may have been separated during the chaos of the disaster.

Human Responses to Natural Hazards

Educating people who live in high flood risk areas about the realistic potential for disaster is also important, particularly when considering the natural human tendency to keep hazard risks "out of sight, out of mind." For example, consider how most people respond if asked how often a 100-flood event can occur. "Once every 100 years, of course." Yet in reality, every single year there is a 1% chance that a flood event of that magnitude could occur—even if it just happened last year. "Humans are not trained to think in terms of long-term averages, and as a society we're not taught to speak the language of mathematical probabilities," said Peek. In addition, changing climate is affecting flood recurrence intervals, as are human impacts on the environment, so what used to be a "100-year" flood might now be a "50-year" flood.

Peek also refers to the phenomenon that psychologists call "optimistic bias." For example, even if you know you live in a floodplain, you don't think a flood will happen to you. "Survey after survey has revealed this bias," said Peek. "We know that planes go down, we know that car crashes happen every day—but we don't think it's going to happen to us." After interviewing more than 200 Katrina survivors, Peek says that nearly every person said they only took enough clothes for two days when they evacuated. "Nobody thought Katrina—referring to both the size of the storm and the overtopped floodwalls and broken levees—would be as bad as it was."

Although the optimistic bias serves as a protective mechanism, in that it enables us to sometimes take necessary risks, it doesn't serve us well when it comes to judging the potential for natural hazards. "Optimistic bias and the failure to think probabilistically are dangerous companions, because they result in humans making decisions to build in and occupy high-risk hazardous areas," said Peek.

Lori Peek helps a displaced child with her homework after Hurricane Katrina. (Courtesy of Lori Peek)

Then there is, quite simply, the human tendency to forget. "Disasters become these historical markers, where we talk about life before 9/11 and life after 9/11, or life before Katrina and life after Katrina, for example," said Peek. But unless the event was large enough to be of national significance, the impacts are too-soon forgotten. In Colorado, the 1997 flash flood disaster on Spring Creek in Fort Collins occurred just 23 years after the Big Thompson flood, yet many people were surprised that "this could happen." Peek says that memorials can play a role in keeping residents aware of the hazard risk. "Memorials can help people to remember, but they usually are more about acknowledging loss than about getting people to be prepared for disaster," she said.

Colorado Flood Events

Peek says that one big question for Colorado to consider, especially in light of what happened in Katrina, is: what evacuation and sheltering plans are in place? Compared to hurricanes, flash flood events often have very little warning time. And if the warning time is short and people don't receive the information and are left behind—what plans do we have in place to get survivors off rooftops? And once people are out of harm's way, where are they evacuated to, and how do we ensure that survivors are reunited with loved ones? "Where people end up in the immediate aftermath of a disaster shapes their trajectory of recovery," said Peek. "This variable, and many others, have a ripple effect on people's lives several years after the disaster."

Without a doubt, the scale of Hurricane Katrina's devastation was much greater than that of the Big Thompson or Spring Creek floods in Colorado, yet these more localized flood events impact victims' lives just as severely as a Category 5 hurricane.

"We have to learn the lessons from Katrina," said Peek. "Think about the fact that 850 people were rescued from canyon walls and rooftops after the Big Thompson flood—it's going to happen again, and next time there will be more victims because there are more people living in high-risk areas."

See Lori Peek's faculty profile on page 35 of this issue.

USGS science for a changing world — Recent Publications

Assessment of In-Place Oil Shale Resources of the Green River Formation, Piceance Basin, Western Colorado by R.C. Johnson, T.J. Mercier, M.E. Brownfield, M.P. Pantea, and J.G. Self http://pubs.usgs.gov/fs/2009/3012/

Nahcolite Resources in the Green River Formation, Piceance Basin, Northwestern Colorado by M.E. Brownfield, R.C. Johnson, J.G. Self, and T.J. Mercier http://pubs.usgs.gov/fs/2009/3011/

National Streamflow Information Program: Implementation Status Report by M.J. Norris http://pubs.usgs.gov/fs/2009/3020/

Transient Electromagnetic Soundings Near Great Sand Dunes National Park and Preserve, San Luis Valley, Colorado (2006 Field Season) by D.V. Fitterman, F. de Sozua, and A. Oderson http://pubs.usgs.gov/of/2009/1051/

Acoustic Doppler Current Profiler Applications Used in Rivers and Estuaries by the U.S. Geological Survey by A.J. Gotvald, and K.A. Oberg http://pubs.usgs.gov/fs/2008/3096/

Analytical Results for Municipal Biosolids Samples from a Monitoring Program Near Dear Trail, Colorado (U.S.A.), 2008 by J.G. Crock, D.B. Smith, T.J.B. Yager, C.J. Berry, and M.G. Adams http://pubs.usgs.gov/of/2009/1090/

Digital Data from the Great Sand Dunes and Poncha Springs Aeromagnetic Surveys, South-Central Colorado by B.J. Drenth, V.J.S. Grauch, V. Bankey, and New Sense Geophysics, Ltd. http://pubs.usgs.gov/of/2009/1089/

Geographic Information Systems, Remote Sensing, and Spatial Analysis Activities in Texas, 2008-09 by U.S. Geological Survey http://pubs.usgs.gov/fs/2009/3039/

Nutrient Trends in Streams and Rivers of the United States, 1993-2003 by L.A. Sprague, D.K. Mueller, G.E. Schwarz, and D.L. Lorenz http://pubs.usgs.gov/sir/2008/5202/

Revised Comparison of Simulated Hydrodynamics and Water Quality for Projected Demands in 2046, Pueblo Reservoir, Southeastern Colorado by R.F. Ortiz, and L.D. Miller http://pubs.usgs.gov/sir/2009/5083/

U.S. Geological Survey Colorado Water Science Center: http://co.water.usgs.gov

Learning from Colorado Flash Floods: Driver Behavior in High-Water Conditions

by *Eve Gruntfest, Director, Social Science Woven into Meteorology, University of Oklahoma*
Isabelle Ruin, Post-Doctoral Scientist, National Center for Atmospheric Research, Advanced Study Program
Cedar League, Research Assistant, Center for Collaborative Adaptive Sensing of the Atmosphere, University of Colorado, Colorado Springs

What have we learned from our deadly Colorado flash floods in the past 33 years? July 31, 2009, marks the 33rd anniversary of Colorado's Big Thompson Flood, which took more than 140 lives, and July 28, 2009, marks the 12th anniversary of the Fort Collins flood, when five people were killed along Spring Creek. As summer begins and we await the cool, refreshing afternoon thunderstorms and the seasonal summer monsoon, it is important to reflect on our current vulnerability to flooding.

Since the 1976 Big Thompson Flood, early warning systems have advanced and now include emergency call-back systems, Doppler radar, satellite imagery, and automated stream and rain gauge networks. The emphasis on the "detection" rather than "response" part of the warning system, however, does not solve many of the problems identified in 1976. Unfortunately, flash floods often occur in catchments too small for the rainfall signal to appear on Doppler radar, leaving the public unwarned and vulnerable. Are campers today more aware that a severe thunderstorm can produce catastrophic flash flooding in the middle of the night? Probably not.

Even if rain can be detected on radar, it is still difficult to notify campers and other non-residents (e.g., tourists) about short-fuse flash floods. Cell phone reception is not very good in mountain canyons. Publicizing information about flash flood recurrence intervals is also problematic—the recurrence interval for the Big Thompson River varies from 500 to 10,000 years in the scientific literature. Experts call for a comprehensive integration of social and natural sciences to improve the understanding of public responses and target loss reduction. This article focuses on social science initiatives that have the potential to increase our capability to reduce vulnerability.

Flash floods are characterized by their sudden onset and fast and violent movement. They are particularly difficult to forecast accurately, and they leave very little lead time for warnings. Flash floods can surprise people who are in the midst of their daily activities, and they have particularly severe consequences for people who travel across flooded roads. Several studies show that a large number of flood-related deaths occur among motorists on the road, and in the United States 50% of flash flood fatalities are vehicle related.

The Big Thompson Flood in Colorado

In 1976, over 140 people were killed on the night of Colorado's Big Thompson flood. Of the approximately 2,500 folks who were in the canyon, which is located 35 miles northwest of Boulder, most received no official warning that a catastrophic flash flood was about to shatter their lives. Seven of the victims reacted by "doing the right thing"—aware of the flood's approach, they immediately moved to higher ground. However, they then miscalculated the flood's actual moment of arrival and returned to lower ground to move a vehicle or collect something from a dwelling. They paid for that decision with their lives.

Eve Gruntfest studied the Big Thompson disaster in hopes of deriving lessons for the many officials along Colorado's urban front range who realized that the 14 inches of rain in less than three hours could have similarly affected them.

A warning sign at the entrance of Colorado's Big Thompson Canyon instructs drivers to climb to safety in the event of a flood.

In 1976, flash floods were not recognized as a separate category of flood, but much has changed in 33 years. Gruntfest's geography thesis focused on the behavior of people during the Big Thompson flood. She identified which activities led to survival and which did not. Clearly, climbing to safety was the best action to take, and those who stayed in a car or did nothing were more likely to die in the flood.

Most flash flood warning research, including the National Science Foundation project Gruntfest recently completed, focuses on public perceptions of warnings rather than analyses of actual behavior. After 33 years, Gruntfest's current work is based on human response, and she and her colleagues are confident they can learn more from what people do than from what they say they would do.

2002 Flash Floods in France

Much more is known now about the hydrologic and geologic science of flash floods, which contributes to improved understanding of flood seasonality. New work by Isabelle Ruin and her colleagues at the Laboratoire d'études des Transferts en Hydrologie et Environnement (LTHE) and the Laboratoire PACTE at Joseph Fourier University in Grenoble, France, examines the consequences of different response timescales for the river, the public, and forecasters. Ruin studied a catastrophic September 2002 flash flood event in southern France that took 23 human lives in 16 distinct sub-catchments. She combined analysis of the physical and human response to Mediterranean storms by using both the results of hydrometeorological simulations and qualitative research tools for interviews of flood victims. An interesting finding from this research is that middle-aged workers in cars are most vulnerable to flash floods. They often believe they must get to work—that they do not have the discretion to cancel their trip, even if they perceive the risk posed by a flash flood as being high.

YouTube Flood Video Study 2009

In her geography master's thesis work at the University of Colorado, Colorado Springs, Cedar League observed actual driver behavior through YouTube videos to understand what people were thinking when they were crossing flooded roads. The majority (61%) intentionally decided to cross flooded roads for fun or to film the flood. The minority (39%) had a specific place to get to, such as driving to/from work. Most were males between the ages of 18 and 35 driving trucks or SUVs who said they are not influenced by education campaigns, they pay attention to weather warnings to some degree, and that they would drive again in similar conditions. Many subjects in the YouTube videos indicated that a greater presence of emergency officials and/or warning signs in flood areas may deter them in the future.

Based on Ruin and League's research findings, the key to reduced loss of life in flash floods may not lie in improving the warnings or being sure people understand the warnings. Rather the key may be ensuring that administrators and "bosses" acknowledge the flash flood threat facing their employees and allow employees to come to work an hour later, based on local conditions. Otherwise, employees may take driving risks even though they know about the warnings because they fear losing their jobs and feel they "have to get to work."

Collaborative Program: National Weather Service and National Center for Atmospheric Research

Another research project focused on developing better ways to reduce flash flood deaths is collaboration between the National Weather Service, the National Center for Atmospheric Research, and faculty and students from the geography department at Missouri State University.

The project team, which includes Isabelle Ruin, is developing a GIS database that incorporates data from recent floods; reports from flood risk reduction agencies; information about streams, rivers, and basins (with specific reference to the location of low-water crossings); topography; and geo-coded summaries of 911 calls. Traffic counts used by local transportation departments also highlight whether people change their behavior in light of forecasts or local conditions.

Recent investigations are leading to new ways of understanding warning response; for example—finding out what motivates drivers to change their routes or the timing of their trips in light of potentially deadly high water along their regular route. Examining behavioral patterns in response to warnings and to flash flood conditions involves asking several questions. What does it take to change driver behavior when faced with flooded roads? How can we improve warning messages to convey our knowledge with the longest lead time and most geographic specificity? Can warnings be issued for specific low-water crossings rather than for counties or polygons?

In summary, there is no "one-size-fits-all" answer to more effective flood warnings. People need different information at different times of the day, which presents a serious challenge for weather forecasters who shoulder warning responsibilities. By building on traditional flash flood research by meteorologists and hydrologists that focuses on rainfall, streamflow, radar, and satellite forecasts, collaborations between social scientists and practitioners from the National Weather Service offer potential for substantially reducing public vulnerability to flash flooding.

CWCB's Role in Statewide Flood Hazard Mitigation and Floodplain Management

by Tom Browning, Section Chief, Colorado Water Conservation Board

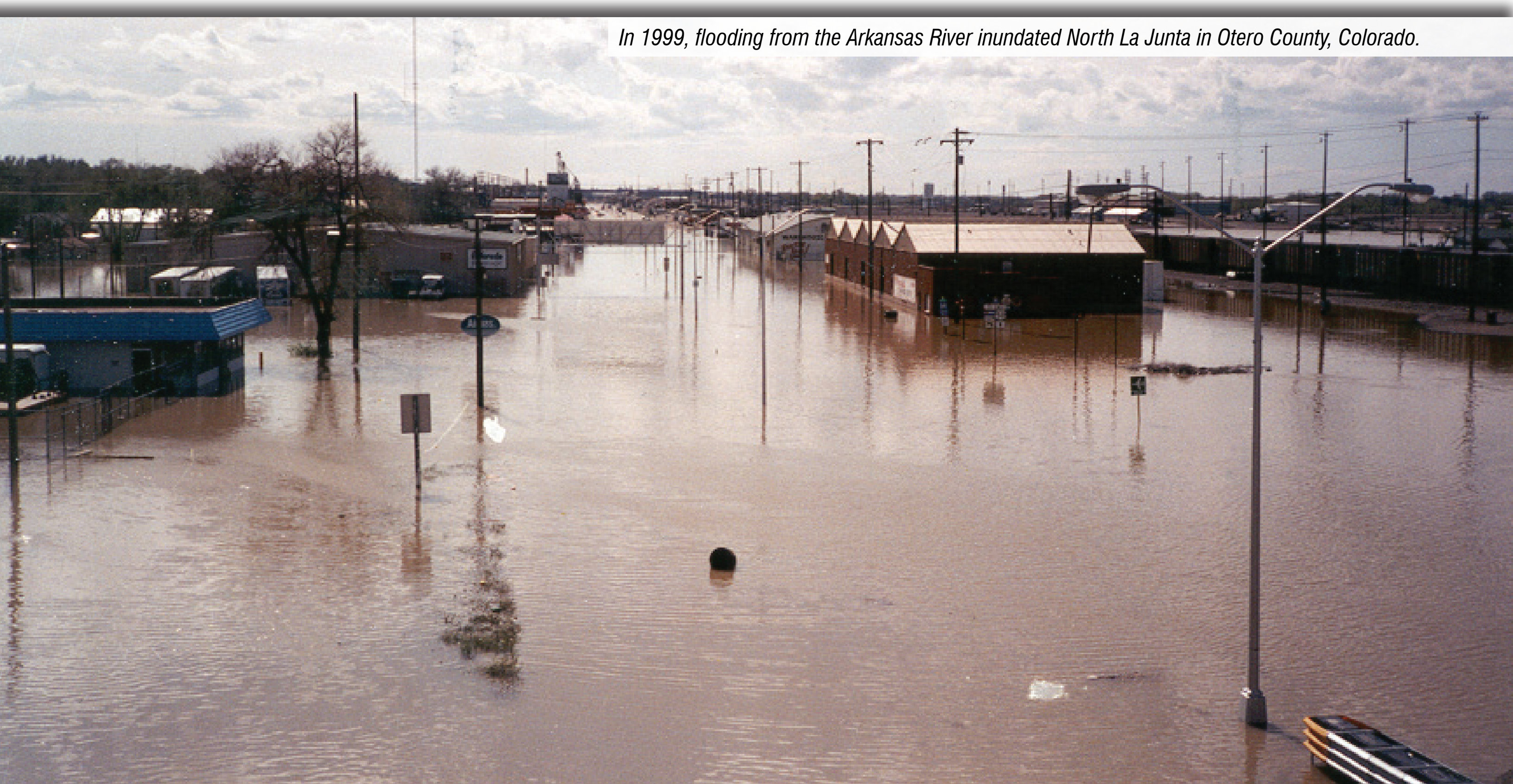
In the system of floodplain management today, the Colorado Water Conservation Board (CWCB) works closely with its federal and local partners to help ensure that wise land use practices are occurring in harmony with applicable laws, regulations, and policies. The CWCB engages in several programmatic activities to assist in flood loss reduction:

- Managing the process for new and revised FEMA floodplain mapping studies
- Completing flood hazard mitigation projects
- Conducting flood outlook and research tasks to assist in the prediction of snowmelt flooding
- Providing post-flood technical assistance to flood-damaged communities
- Furnishing pertinent information to decision makers and the public (through various education and outreach initiatives) regarding future protection measures
- Implementing multi-objective watershed restoration projects to benefit public safety, water supply, recreation, and the environment

Colorado is known to have one of the largest and most respected professional floodplain management associations in the nation, and the Denver metropolitan area is also fortunate to have the internationally recognized Urban Drainage & Flood Control District and its positive influences on flood loss reduction.

Looking back in history, the 1976 Big Thompson flood event stands as an important reminder that major flooding does occur in Colorado. Two additional examples that occurred during the first half of the 20th century include an enormous flood on the Arkansas River in 1921 that killed many people and left behind a swath of destruction in Pueblo, followed by another large flood in 1935 on Fountain Creek that left its powerful mark on Colorado Springs.

During the second half of the century, the Great Flood of June 1965 was not only deadly, but it also wreaked enough havoc in Castle Rock and Denver to cause nearly $1 billion in damage (2006 dollars). My grandfather lost nearly everything when his entire business was washed away in the raging waters of the '65 flood. Later, in 1984, extreme high water from rapid snowmelt in western Colorado resulted in widespread damage and a multi-county disaster declaration. In



In 1999, flooding from the Arkansas River inundated North La Junta in Otero County, Colorado.

The 1997 flood on Pawnee Creek in Colorado washed out the Holyoke Railroad bridge.

more recent times, the 1997 flood on Spring Creek in Fort Collins caused five fatalities and triggered a presidential disaster declaration when approximately $200 million in property damage occurred in the city.

I have personally witnessed the immediate and long-term impacts of several devastating floods, including the 1996 Buffalo Creek flash flood in Jefferson County, the 1997 Spring Creek flash flood in Fort Collins, the 1997 Pawnee Creek flood near Sterling, and the 1999 Arkansas River flood at North La Junta. Those major events were not among the first in Colorado history, and they certainly won't be the last.

Many lessons have been learned from past flood disasters, most of which have guided the way engineers, government planners, and flood specialists think about public health, safety, and welfare when it comes to the awesome power of rushing water. Those lessons relate to how humans react during frightening emergency situations, and how extreme events should be analyzed to improve peak flow computations for other streams in the region. Land development practices can be tailored to interface better with the natural environment as well.

Technological advances since the time of the earlier floods have also greatly assisted in carrying out the mission to help protect life and property. One specific tool that water management officials make use of now is an extensive network of automated streamflow and rainfall gages located throughout the state. Those instruments report valuable data on a real-time basis—through satellite telemetry—for immediate use by decision makers. Additionally, the National Weather Service uses Nexrad Doppler radar and rainfall algorithms to assess storm threats and to issue flood "watches" and "warnings" when specific counties may be at risk for potential or actual flooding. Furthermore, a communication tool known as "Reverse 911" has been successfully used to warn residents about looming danger and was recently put to the test in Douglas County to notify people about flooding along West Creek, which ripped apart a 10-mile section of Highway 67. Other warning methods include obvious means such as cellular phones, pagers, and email messages. The Division of Emergency Management activates its Emergency Operations Center, when needed, to coordinate emergency situations and to disseminate pertinent information to incident responders.

Even with all of the great work being done and the available technologies, damaging floods continue to occur across the country. One reason for this is that current standards allow for development (e.g., homes, businesses, and infrastructure) to occur in areas that are prone to some risk of high water. The level of risk has been deemed to be acceptable for a certain recurrence interval, or frequency, that allows people to make use of their land to a reasonable degree while simultaneously assuming some amount of risk. Flood-producing rainstorms and related phenomena can cause rivers, streams, and creeks to rise beyond their regulatory flood levels.

The existing regulatory standard that is commonly accepted in Colorado and nationwide is the "100-year flood event," which is a term that is often misunderstood by the general public. The 100-year flood event actually indicates a flood having a 1% chance of being equaled or exceeded in any given year, rather than a flood that occurs only once every 100 years. Therefore, the 1%-chance flood is truly based on probability, which means that it is not impossible for a community to experience back-to-back 100-year floods in two consecutive years. Along those lines, the CWCB strongly advocates that critical infrastructure (hospitals, fire stations, schools, etc.) be located outside of the 500-year floodplain for added protection.

The cost of public works projects is another important consideration for explaining why flood damages are still occurring. For example, what if all new roads and bridges were required to withstand or pass much larger flows than what they currently can handle? One can imagine that many taxpayers would not be willing to swallow the very expensive pill that would be required to replace infrastructure in order to accommodate the higher design standards. The public generally understands that we live with some amount of risk in our everyday lives, and that there is a cost to reducing that risk.

The general public can protect itself from the impacts of flooding in the following ways:

- Purchase a flood insurance policy for your home, since regular homeowners' policies do not cover flood damages.
- Avoid driving over bridges or into flooded streets where moving water exists over the roadway.
- Understand that multiple hazards can occur simultaneously, and one hazard can lead to another (for example wildfires in forested areas can greatly increase storm runoff, flooding, and debris flows)
- Be aware of changing conditions if you are living, traveling, or camping in canyons and along waterways, since "walls of water" moving swiftly down a stream can develop in a matter of moments.
- Climb to safety by seeking high ground if water is rapidly rising or if flood danger is imminent, even if it means leaving your car on the side of the road until the danger passes.

The CWCB continues to strengthen its partnerships with local governments, interested agencies, and non-profit organizations in order to help reduce Colorado's vulnerability to flooding. Increased growth and population, as well as new development along floodplain corridors, emphasize the need to remain diligent in supporting sensible floodplain management activities across the state.

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where has all the water gone?
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The WateReuse Association is a nonprofit organization whose mission is to advance the beneficial and efficient use of water resources through education, sound science, and technology using reclamation, recycling, reuse, and desalination for the benefit of our members, the public, and the environment. Across the United States and the world, communities face water supply challenges due to increasing demand, drought, depletion and contamination of groundwater, and dependence on single sources of supply. WateReuse addresses these challenges by working with local agencies to implement water reuse and desalination projects that resolve water resource issues and create value for communities. The vision of the WateReuse Association is to be the leading voice for reclamation, recycling, reuse, and desalination in the development and utilization of new sources of high quality water.

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For more information and registration visit: http://www.watereuse.org/

Drought, Climate, and Early Warning

by Roger S. Pulwarty, NOAA/National Integrated Drought Information System

Drought refers to a deficiency in long-term average precipitation over a period of time, resulting in a water shortage that has an adverse impact on the environment, agriculture, industry, recreation, or domestic consumption. There is no single definition of drought that meets all local needs. Over the past few years, the impacts of drought have been brought home by several significant events. The southeast United States, including parts of Virginia, North and South Carolina, Tennessee, Georgia, Alabama, Mississippi, and Florida, has been in the midst of a historic drought for the past two years. This drought also nearly shut down some power plants because of the unavailability of water to provide cooling, or because potentially high-temperature releases into already-warm streams were affecting endangered species.

Researchers at NOAA and elsewhere have identified the period from January 2007 through December 2008 as being the most severe two-year drought for the state of California since at least 1895. Most importantly, precipitation in 2007-2008 has not been the lowest on record. Warm temperatures—especially in northern California—have combined with low precipitation to produce record-low indicator numbers, as evidenced by the Palmer Drought Severity Index. Drier-than-normal conditions appear to be continuing through 2009. The climatic drivers of these droughts are not identical and can be complex. Internal variability of the atmosphere can produce major shifts in regional conditions (such as occurred during the 1930s), or can be linked to colder sea surface temperatures in the Pacific (such as during the 1950s), reducing moisture flow to the southern Plains. In addition, drought conditions can be exacerbated by other factors, including land surface feedbacks, that intensify after onset. Identification and development of relevant drought management triggers and indicators requires active engagement among researchers, information brokers, and stakeholders in various affected sectors.

The Status of Drought Planning

At least eight states have drought mitigation plans in place. Colorado, Illinois, and Washington have expressed intent to revise their existing plans by incorporating mitigation actions. Drought mitigation planning has also taken place in other jurisdictions within the United States. In the southwestern U.S., the Navajo, Hualapai, Hopi, and Zuni tribes, as well as the Taos Pueblo, have all recently drawn up mitigation plans. More municipalities, counties (four counties in Hawaii have drought mitigation strategies), and regional organizations (river basin commissions) are developing drought plans, and drought planning is now

The white "bathtub ring" in Lake Mead (Nevada) shows the dramatic change in water level due to drought. (Courtesy of Ken Dewey, High Plains Regional Climate Center)

The boat ramp leading into Colorado's Barr Lake was stranded quite a distance from the water due to drought conditions in 2002. (Courtesy of Ken Dewey, High Plains Regional Climate Center)

being recognized as an important criterion for hydroelectric plant licensing.

The drought that began in the western U.S. in 1999 has served as a significant focusing event for planning among states and communities. In 2004, five years of unprecedented drought, coupled with increased water use, led to increased tensions among the basin states. There had never been a shortage declared on the Colorado River in the Lower Basin, and there were no shortage guidelines in place. Operations between Lake Powell and Lake Mead were coordinated only at the higher reservoir levels (through "equalization"). As a result of ensuing negotiations and federal pressure, operations are now specified through the full range of operations for Powell and Mead[1]. The strategy for shortages in the Lower Basin now includes a provision for additional shortages, if warranted, and is in place for an interim period (through 2026) to gain operational experience. Most importantly, the basin states have agreed to consult before resorting to litigation. This landmark agreement represented an opportunity to develop robust strategies for adaptation without wholesale changes in the system.

While the above-average years of 2005 and 2008 have alleviated some pressure, the storage of Lake Mead and Powell is still only averaging about 50%. Studies have shown that by 2050, the average inflow to the Colorado could decline 5 to 18% due to temperature increases. These studies have not yet included the impacts of such declines when combined with periodic occurrence of severe drought. As climate varies and changes, early warning information meant to provide input into meeting triggering criteria for managing Mead and Powell is critical, especially through the next 17 years.

After the severe years of 2000-2004 in the Colorado Basin, it was clear that an improved process was needed to integrate federal, state, and local risk assessment with early warning needs for drought impact mitigation—across timescales from seasons to multiple years. A key gap was that information on physical states and impacts were not optimally integrated into a coherent overall narrative, in real-time, to meaningfully characterize drought conditions. Most critically, these plans usually do not contain formal processes for conducting post-audits of drought response and impacts. It was widely recognized that improving integration of such information into planning and implementation would create improvements in mitigation decision support.

The National Integrated Drought Information System (NIDIS)

As envisioned by the Western Governors Association and codified in the NIDIS Act of 2006, NIDIS is being developed to consolidate federal, state, and tribal physical/hydrological and socio-economic impacts data on an ongoing basis; to develop a suite of usable drought decision support tools focused on critical management indicators and triggers; and to enable proactive planning across temporal and spatial scales. NIDIS draws on the experiences and networks of the NOAA Regional Climate Centers, Regional Integrated Sciences and Assessments Program, the National Drought Mitigation Center in Nebraska, and the state climatologists. There is significant leveraging of existing system infrastructure, data, and products produced by operational agencies (e.g., the USDA Natural Resources Conservation Service SNOTEL network, reservoir and streamflow levels from the Department of the Interior and the Army Corps of Engineers, and the River Forecast Centers of NOAA). NIDIS also facilitates the transfer and adaptation of successful drought management innovations identified in one area to other regions in need.

To provide guidance on system implementation, a team was assembled from representatives of over 40 federal, state, and tribal agencies, as well as the non-governmental organization (NGO) and private sectors. The key NIDIS system components are public awareness and education, drought response networks, integrated monitoring and forecasting, interdisciplinary research and applications, and an interactive web-based drought portal. The Drought Portal was publicly released in 2007 (www.drought.gov) and has broad reception.

NIDIS has since conducted the first-ever assessment of the status of drought early warning systems across the country. This assessment compared lessons across drought-affected regions and states. Other workshops assessed the contribution of satellite-based information to soil moisture monitoring, monitoring gaps in the Upper Colorado Basin, and the impacts of drought and climate change on Western tribal lands. NIDIS has begun the deployment of soil moisture sensors in over 100 sites as part of the NOAA Climate Reference Network. Research on climate change attribution relative to drought has also been supported under NIDIS.

Knowledge assessment meetings (to determine the state of knowledge of a particular component of drought risk assessment), held in partnership with the National Drought Mitigation Center in Nebraska and the NOAA Regional Integrated Sciences and Assessments Programs, among others, have stressed the urgency of integrating drought monitoring and information delivery by:

- Improving fundamental understanding of drought, including potential changes in drought frequency, severity, and duration
- Improving understanding of changes in societal vulnerability to drought resulting from population growth/demands, urbanization, land use changes, and other factors, including the linkages between water supplies and energy
- Improving regional and local drought risk management through enhancements in technology and information communication use, including impacts assessments and communication
- Developing national drought policies that help manage vulnerability through interagency and interstate coordination

Specifically, NIDIS has convened a series of workshops with water managers/resource specialists from federal, state, municipal, and tribal governments in the Upper Colorado Basin. Three critical problems emerged as NIDIS priorities:

1. Coordinated reservoir operations: low flow shortage triggering criteria (Powell/Mead)
2. Inter- and intra-basin transfers (Front Range)
3. Ecosystem services

Over the next year, NIDIS will build on the successes of the U.S. Drought Monitor, Seasonal Outlooks, and other tools and products through coordination of relevant monitoring, forecasting, educational, and impact assessment efforts tailored to watersheds (the Colorado Basin, in particular), regions (southeast Georgia, Alabama, Florida, the Carolinas, and the Lower Great Plains), and individual states facing ongoing drought-related challenges, such as California. NIDIS Early Warning System Pilots will help define the network of activities needed to maintain well-structured paths from observations, modeling, and research to the development of relevant place-based knowledge and usable information.

Climate variability and change, together with increasing development pressures, can result in drought impacts that may be beyond our institutional experience and will significantly exacerbate conflicts among water users. As planning baselines change in response to changing climate, managing our nation's farmlands, waterways, reservoirs, and ecosystems to provide economic and environmental benefits requires an ongoing framework for collaboration between resource managers and research communities. NIDIS offers the region and the nation a mechanism for the development of information services in support of adaptation as climate varies and changes.

[1] Issued in Record of Decision, dated December 13, 2007; available at http://www.usbr.gov/lc/region/programs/strategies.html

Internet GIS and Online Disaster Response

by Melinda Laituri, Professor, Department of Forest, Rangeland, and Watershed Stewardship
and Kris Kodrich, Associate Professor, Department of Journalism & Technical Communication

Multiple, large-scale disastrous events continually occur: the 2004 Indian Ocean tsunami, the twin events of Hurricanes Katrina and Rita in 2005, the 2006 record flooding of the Danube in Europe, the 2007 California wildfires, and the 2008 earthquake in Sichuan, China. Effective disaster management and response demands rapid utilization of information and data from many sources. The suite of geospatial technologies (GIS, remote sensing, GPS, and the Internet) plays an increasingly important role in disaster management, response, and preparation, with particular emphasis on water resource management. One form of disaster response is the online disaster-response community (ODRC), which is composed of formal and informal networks of people acting as sensors collecting, processing, and delivering information where it is needed.

We are interested in the development and use of the Internet coupled with GIS (Internet GIS) by the ODRC with a focus on participatory responses and activities from novel networks of users during and after disasters. Internet GIS is the network-based geographic information services that can use wired or wireless internet to access geographic information, spatial analysis tools, and GIS web services and allow for broad dissemination of data and analysis results. The notion of "people as sensors"—people collecting information to aid in the recovery process and posting this information for broad dissemination outside of the established traditional channels of emergency response—is becoming a key part of disaster response.

The combination of internet technologies, the open source movement, the rise of citizen journalism (or blogging), and mobile technologies create a network of various participatory activities. These include identifying locations where people need to be rescued, as in the case of floods and high water events, tracking road closures and storm surge advances due to hurricanes, and posting missing persons information post disaster. Disasters have provided a unique trigger, consolidating technological advances with democratizing influences operating outside the traditional brokers of information and aid. An aspect of online disaster response is the use of GIS and the Internet to provide rapid information about locations that are experiencing the disaster. Identifying and understanding the lessons from these key events may facilitate a better understanding of disasters and the role of geospatial technologies in improving our management and response.

The integration of mapping, global positioning systems, satellite imagery, and interactive GIS provides important opportunities for developing and sharing information and techniques. In some instances, special licensing arrangements for satellite imagery and GIS software ("technological gift giving") has resulted in innovative sharing and development opportunities during disasters. After the Indian Ocean tsunami, remotely sensed data were made available that identified areas of coastal inundation and damage to farmlands, infrastructure, and resort areas. Other innovative developments take best advantage of online resources. Mashups, the mixing of hybrid Web applications from multiple sources but appearing seamless to end users, combine satellite imagery with maps and geospatial data to provide local information using the open Application Programming Interfaces (APIs), for example, of Google Map™ and Google Earth™.

An outcome of the Indian Ocean tsunami and Hurricane Katrina is the recognition of the "first responders of the wired world." These first responders are a crucial part of the ODRC and contribute through innovative uses of existing technology: blogs, message boards, and web portals. Wiki software was used as an organizational tool to create web portals (http://katrinahelp.info/wiki/index.php) to pages such as those identifying immediate shelter needs (ShelterFinder) and family tracing (PeopleFinder) after flooding. These outputs exemplify what has been termed "social source"—the coupling of nonprofit technology with the open source movement explicitly for social missions.

Internet GIS for disasters or digital disaster systems are rapidly evolving in the face of ongoing, back-to-back disasters. In response to the multiple disasters, volunteer organizations, citizen GIS, participatory GIS, and civic web mapping have formed to provide hands-on expertise in developing location-specific GIS applications. These organizations form in cyberspace to solicit assistance in times of need development and implementation of socio-technological networks for disaster response: Examples include:

- **GISCorps:** http://www.giscorps.org
  Operating under the auspices of the Urban and Regional Information Systems Association (URISA), GISCorps coordinates short-term volunteer GIS services to underprivileged communities worldwide in response to disasters such as flooding, earthquakes, and hurricanes.

- **Mercy Corps:** http://www.mercycorps.org
  Mercy Corps has created the Geospatial Relief & Development Team. A volunteer base of more than 50 GIS and remote sensing professionals in the Pacific Northwest has mobilized to apply geospatial technologies to expedite the flow of aid and accelerate disaster recovery.
- **MapAction:** http://www.mapaction.org
  Based in the United Kingdom, MapAction is a non-governmental organization (NGO) dedicated to providing time-sensitive information during a disaster.

The combination of mapping tools, geospatial data, and web applications provide an avenue of empowerment for people to self-organize in response to disaster. While emergencies vary widely in scale, severity, and duration, they are inherently local. Oftentimes, information that is needed from a GIS for immediate emergency response is simple and does not require complex analytical procedures, but rather reliable and adequate data (e.g., escape routes, shelters, locations outside the flood event).

The nature and scope of crises, emergencies, and threats to the public have changed dramatically to now include terrorism, war, and human-caused disasters. Effective communication, such as effective GIS activities, must begin long before the disaster event erupts and continue long after the immediate threat has subsided. Internet GIS for disaster management reveals the power of intersecting networks to create new organizational and networking arrangements for addressing disaster and valuing the role of "people as sensors," to collect information about their locality and disseminate to those in need. It reveals the relationship between geography, communication, and technology. However disaster management that includes Internet GIS must include an evaluation that demonstrates its utility and success. The grim reminder of helpless victims stranded on rooftops after Hurricane Katrina is juxtaposed with the satellite images of the Louisiana coastline. The critical requirement is to provide assistance to those who need help and to discern the role of Internet GIS in this capacity.

This article was adapted from: Laituri M., Kodrich K. On Line Disaster Response Community: People as Sensors of High Magnitude Disasters Using Internet GIS. *Sensors*. 2008; 8(5):3037-3055.

Hydroclimatic Variability in the Upper Colorado River Basin:

Water Supply Forecasting and Management

by Margaret A. Matter, PhD Candidate, Department of Civil and Environmental Engineering

Summary

Meeting future water demands in the Colorado River Basin (CRB) depends in part on understanding the underpinnings of hydroclimatic variability. Increasing variability adversely impacts accuracy of water supply forecasts in the CRB and violates the assumption of stationarity, which is fundamental to many methods used in water resources engineering design, planning, and management. While increasing hydroclimatic variability during the 20th century is often attributed to anthropogenic climate change, variability also stems from climate cycles. Three climate cycles occurred in the CRB during the 20th century and were influenced by anthropogenic climate change and other external forcings, including air pollution, and modifications to land use, land cover, and water use. Thus, climate cycles are a reasonable basis on which to characterize hydroclimatic variability.

An innovative methodology was applied to each of the three climate cycles (cool/wet, warm/dry, cool/wet climate cycles) in two tributaries in the Upper CRB, the Gunnison River near Gunnison, Colorado (GRG), and the Yampa River at Steamboat Springs, Colorado (YRS), to characterize patterns in temperature, precipitation, and streamflow associated with climate cycles, and to determine changes in the patterns over the 20th century.

The methodology entails:

- Characterizing patterns in temperature, precipitation, and streamflow accompanying the three climate cycles during the 20th century
- Developing complementary temperature and precipitation (T&P) patterns between September and March that are associated with upcoming annual basin yield (ABY) for each climate cycle
- Building regression models using key components of the complementary T&P patterns to predict ABY and Apr-Jul flow volumes for each climate cycle
- Applying the same methodology to develop regression models to predict ABY and Apr-Jul flow volumes for WY 2002-2008, the ongoing warm/dry climate cycle of the 21st century
- Comparing model predictions with actual ABY, and when possible, with National Weather Service (NWS) Jan 1 and Apr 1 forecasts

Results show that hydroclimatic variability is more deterministic than previously thought and entails annual complementary temperature and precipitation patterns that are specific to climate cycle type, unique to each river basin, and are influenced by external forcings. The complementary temperature and precipitation patterns establish by fall, are detectable as early as September, persist into spring, and are related to magnitude of upcoming precipitation and ABY. Thus, while much of the water supply in the CRB originates from winter snowpack, significant and reliable indicators of the magnitude of upcoming precipitation and ABY are evident in the fall, well before appreciable snow accumulation.

Margaret Matter (far right) with former CWI director Robert Ward and his wife Brenda.

Climate Cycle Patterns and Changes over the 20th Century

In general, temperature and precipitation exhibit patterns that are characteristic of climate cycles. For example, temperatures are cooler and fall precipitation decreases and shifts earlier in the season during the cool/wet climate cycles at both sites. Opposite patterns tend to prevail during the warm/dry climate cycle. In addition to cyclic patterns, long-term and seasonal changes over the 20th century include the following:

- Warmer temperature conditions during both seasons at both sites, which is consistent with anthropogenic climate change
- Cooler maximum daily temperature in September and October, which is consistent with effects of irrigation (urban and agricultural)
- Cooler maximum daily temperature between December and March in the Upper Yampa Basin, which may be related to cooling effects of aerosol emissions from regional coal-fired power plants, vehicles, and other sources, combined with winter temperature inversions
- Median ABY decreases at both sites between the cool/wet and warm/dry climate cycles in the first half of the 20th century (but this is also a period of substantial land and water resource development)
- Oct-Dec and Jan-Mar seasonal flow volumes decrease steadily over the century at the YRS site, perhaps due to upstream water storage and use during that time
- Median annual precipitation decreases at both sites (but the decreases occur at different times during the century). Causes may include anthropogenic climate change or other external forcings, such as aerosol emissions affecting rainfall efficiency.

In summary, variations in temperature, precipitation, and streamflow over the 20th century involve cyclic changes coinciding with climate cycles and long-term and seasonal effects of external forcings, including anthropogenic climate change, air pollution, and modifications to land use, land cover, and water use, on climate cycles.

Model Predictions and Comparisons with Actual Flow Volumes and NWS Forecasts

Complementary T&P patterns that are associated with upcoming ABY during each climate cycle were developed from statistically significant temperature correlations with precipitation and with ABY. The complementary T&P patterns illustrate the evolution of hydroclimatic conditions between September and March that are related to extreme (i.e., wetter or drier) conditions. Key components of the complementary T&P patterns were used to develop regression models to predict ABY and Apr-Jul flow volumes. The Sep-Dec regression model uses temperature and precipitation characteristics for September-December, and model predictions are compared to NWS Jan 1 forecasts. Likewise, the Sep-Mar models are based on temperature and precipitation characteristics for September-March, and predictions are compared to NWS Apr 1 forecasts.

Table 1 summarizes:

- Regression model characteristics for the three climate cycles of the 20th century and for WY 2002-2008 at the YRS
- Accuracy of the regression models and of NWS forecasts were determined by comparing the percent of predictions and forecasts that are with 15% and 20% of actual flow volumes

Briefly, results in Table 1 for the YRS site show:

- Regression models are reasonably accurate at predicting ABY
- Sep-Dec regression models outperform NWS Jan 1 forecasts
- Sep-Mar regression models are often equally as or more accurate than NWS Apr 1 forecasts during the 20th century
- Both regression models outperform NWS forecasts for WY 2002-2008

While the WY 2002-2008 models are reasonably accurate and outperform NWS forecasts, the current warm/dry climate cycle is ongoing and may continue to evolve, and consequently, the regression models would also change. To test whether the conditions of the current warm/dry climate cycle have changed, the WY 2002-2008 regression models were used to predict Apr-Jul flow volumes and ABY for WY 2009. The Sep-Dec and Sep-Mar model predictions of Apr-Jul flow volume at the YRS site are 178,114 and 456,622 ac-ft, respectively, compared to NWS Jan 1 and Apr 1 forecasts of 470,000 and 290,000 ac-ft, respectively.

Conclusions

Increasing variations in temperature, precipitation, and streamflow over the 20th century are neither entirely due to anthropogenic climate change nor are they completely random, but rather are more deterministic and entail: (a) cyclic patterns in temperature and precipitation accompanying climate cycles, (b) complementary T&P patterns that are associated with upcoming precipitation and ABY, and (c) effects of external forcings, including anthropogenic climate change, aerosols, and modifications to land cover and water use, on climate cycles and related complementary T&P patterns. The results provide new insights into the hydroclimate of the Upper Yampa and Gunnison River Basins, which may be used to develop new or improve existing climate models to more accurately predict and to help water managers and users prepare for effects of anthropogenic climate change and other external forcings on regional climate and water resources.

Regression model results demonstrate that:

- Hydroclimatic conditions influencing upcoming precipitation and ABY establish by fall, are detectable as early as September, and persist into spring
- Most of the predictive information about upcoming ABY is detectable in the fall
- Complementary T&P patterns are specific to each climate cycle and unique to each river basin
- Complementary T&P patterns establish early in climate cycles, but may evolve over the climate cycle

Results suggest alternative strategies that may be integrated into existing water supply forecast procedures to help improve forecast accuracy and advance lead time by as much as six months: from April 1 to October 1 of the preceding year. Results may also have applications in downscaling climate models, improving water resources engineering methods that assume stationarity, and in river restoration and management.

Table 1. Yampa River at Steamboat Springs, CO (YRS Site)

Percent of Predicted Annual and Apr-Jul Flow Volumes that are within 15% and 20% of Actual Flow Volumes for the Three Climate Cycles During the 20th Century and the Ongoing Climate Cycle of the 21st Century								
Climate Cycle and Period of Record (WY)	**Sep-Mar Regression Variables**	**Sep-Mar Model r^2**	**Percent of Predicted within 15% of Actual ABY[1]**	**Percent of Predicted within 20% of Actual ABY**	**Sep-Dec Regression Variables**	**Sep-Dec Model r^2**	**Percent of Predicted within 15% of Actual ABY**	**Percent of Predicted within 20% of Actual ABY**
Unimpaired Cool/Wet 1911-1942	Sep Prec[2] Nov Prec Dec Tmax[3] Jan Prec	0.76	72	86	Sep Prec Oct Tmax Nov Prec Nov Tmax	0.69	66	79
Impaired Warm/Dry 1943-1974	Oct Tmax Nov Tmax Dec Prec Jan Prec	0.59	61	81	Oct Tmax Nov Tmax Nov Tmin[4] Dec Prec	0.58	58	74
Impaired Cool/Wet 1975-2001	Sep Prec Oct Prec Dec Prec Jan Prec	0.77	70	78	Sep Prec Oct Prec Oct Tmax Dec Prec	0.76	74	78
21st Cent. Warm/Dry 2002-2008	Sep Tmin Jan Prec	0.76	67	83	Sep Tmin Dec Prec	0.85	67	83
		Precent w/i 15% of Actual Apr-Jul Q Vol				**Perecnt w/i 15% of Actual Apr-Jul Q Vol**		
Period of Record	**Sep-Mar Regression Variables**	**Sep-Mar Prediction**	**NWS Apr 1 Forecast**		**Sep-Dec Regression Variables**	**Sep-Dec Prediction**	**NWS Jan 1 Forecast**	
1991-2001	Sep Prec Oct Prec Dec Prec Jan Prec	65%	36%		Sep Prec Oct Prec Dec Tmin Dec Prec	65%	na	
2002-2008	Sep Tmin Jan Prec	67%	43%		Sep Tmin Dec Prec	67%	20%	

[1] ABY = Annual Basin Yield
[2] Prec = Precipitation
[3] Tmax = Maximum Daily Temperature
[4] Tmin = Minimum Daily Temperature

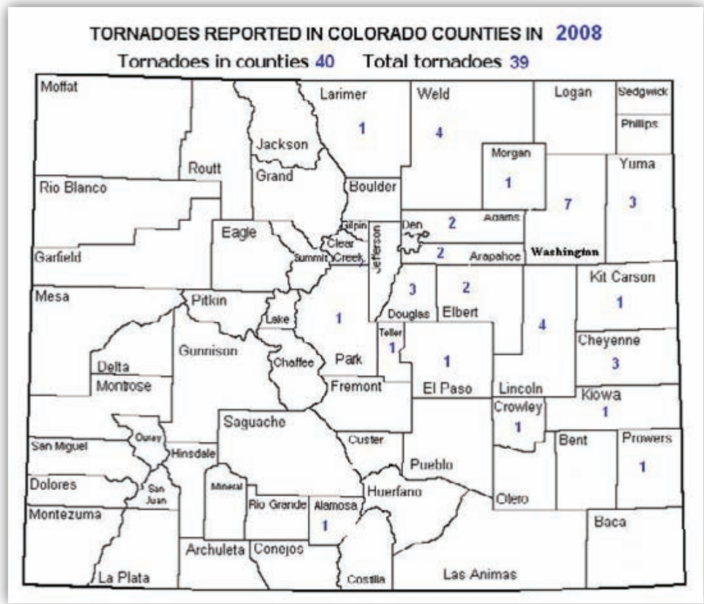
Tornadoes in Colorado

by Robert Glancy, *NOAA National Weather Service*

June 7, 2009. It is a Sunday afternoon in June that starts with sunny skies, and then the clouds gather. A friend of mine is in the checkout line in a store at the Southlands Mall in southeast Aurora. Large hail begins to fall, and store management tells everyone to go to the fitting rooms or restrooms in the back of the store because of a reported tornado. The ceiling pulses, a large glass door at the front of the store shatters. After the tornado the wind lessens but large hail continues to fall, and shoppers are advised to leave the store due to a possible gas leak. My friend leaves without her purchases.

Variations on this story can be told by thousands of people who were at the mall around 2 p.m. on the 7th of June. This was one of six tornadoes that were reported in northeast Colorado that day, but this one caused the most damage as it trekked nearly six miles across southeast Aurora, Colorado—damaging houses, condos, an outbuilding at a high school, a pool, and numerous businesses. The National Weather Service is responsible for rating tornadoes by the extent of their damage, and this tornado was rated EF1 on the Enhanced Fujita Scale, with estimated wind speeds of around 100 miles per hour (mph).

Was this unusual? Should people be surprised when tornadoes develop? Not really. Over the past 20 years Colorado has experienced an average of 50 tornadoes each year. The bulk of these occur east of Interstate 25 during the months of May and June, although tornadoes have been reported as late as October. The number of tornadoes that occur in Colorado is highly variable from year to year, and the good news is that the vast majority of tornadoes that



strike our state are relatively weak, with winds to 110 mph. Less than 10% of our tornadoes are strong tornadoes, with destructive winds between 111 and 167 mph. The Windsor tornado of May 22, 2008, is an example of an EF3 tornado with estimated winds of 140 mph. Across the United States, about a dozen violent tornadoes occur each year, with winds over 167 mph. Fortunately, these very rarely visit the state of Colorado.

Colorado residents need to know where to go when a tornado develops. The safest location is in the lowest level of a building, where you can put walls between you and the flying debris kicked up by tornadic winds. Basements are best, or on the first level of a building in a small room such as a bathroom or closet. Always get away from windows, because even a weak tornado can break a window. If you live in a mobile home, have a plan to get to a better shelter, as mobile homes are easily damaged by strong winds.

The National Weather Service issues tornado warnings to alert you of tornadoes. These can be received on NOAA Weather Radio, through the Emergency Alert System on radio and television, and on the Internet at www.weather.gov. Some towns and cities also alert their citizens through siren systems. Another way to be prepared is to attend severe weather spotter training next spring to learn more about how tornadoes develop and the thunderstorm signatures that indicate the potential for a tornado.

Have a safe summer, and remember thunderstorms can also produce other hazards such as flash floods, large hail, and lightning.

This tornado occurred near the Southlands of Denver on June 7, 2009. View is looking east. (Courtesy of NOAA)

Colorado's Weather and Water: Spring 2009

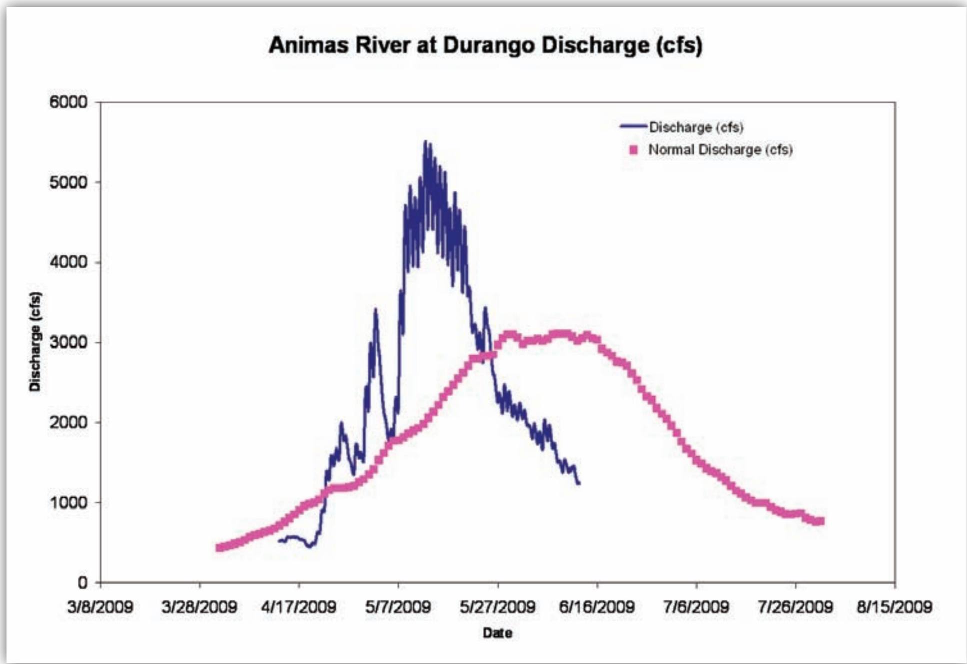
by Nolan Doesken, Colorado Climate Center

The Colorado Climate Center at Colorado State University tracks the state's temperature patterns, precipitation, and snow accumulation and melting every year. This is my 32nd "Water Year" watching our seasonal climate patterns and the water they provide us with. Every year is similar in some ways—snow accumulates in the Colorado mountains in late fall, winter, and early spring. That snow then melts in late spring and early summer, causing our rivers to surge and our reservoirs to fill (most years). Then, for a few lovely but frantic summer months we grow our crops, enjoy our yards and gardens, and frolic on and in our rivers, streams, lakes, and reservoirs—using and enjoying the water that we received. Then the cycle starts again.

A 1.70-meter-deep snowpit at Senator Beck Study Plot in the San Juan Mountains, Colorado, shows dust that was deposited on April 3 and April 8, 2009. (Courtesy of Center for Snow and Avalanche Studies)

The 2009 snowmelt and runoff season has definitely been an attention grabber. December dropped enough snow in parts of southwest Colorado to carry them for nearly the entire winter. Spring moisture in that part of the state this year didn't amount to much. As usual, the northern mountains had more frequent snows spread out over a longer snow season. Here, especially in the South Platte Basin, we lagged behind our long-term average for much of the winter until storms in April propelled us to mountain snowpack that was at or above the average—and a relief for many water users.

Then came May. Snow melted fast and early in the mountains, resulting in high water in many watersheds, but no major flooding. Was the rapid, early melt the result of the several layers of dust from late winter and spring dust storms over the southwestern part of the state? Or was it due to the persistently warm May temperatures, especially over western and southern parts of Colorado? It was probably a combination of both. Ongoing and forthcoming studies are examining the role of dust, both its causes and implications.



This graph shows April-June 2009 and normal (1897-2008) discharge (cfs) for the Animas River at Durango. Notice the early peak in discharge due to the early snowmelt.

More recently, weather patterns changed again. Since a few days before Memorial Day into mid-June, waves of clouds and moisture have moved into Colorado from the west and southwest, while several cold fronts have slipped down from the north

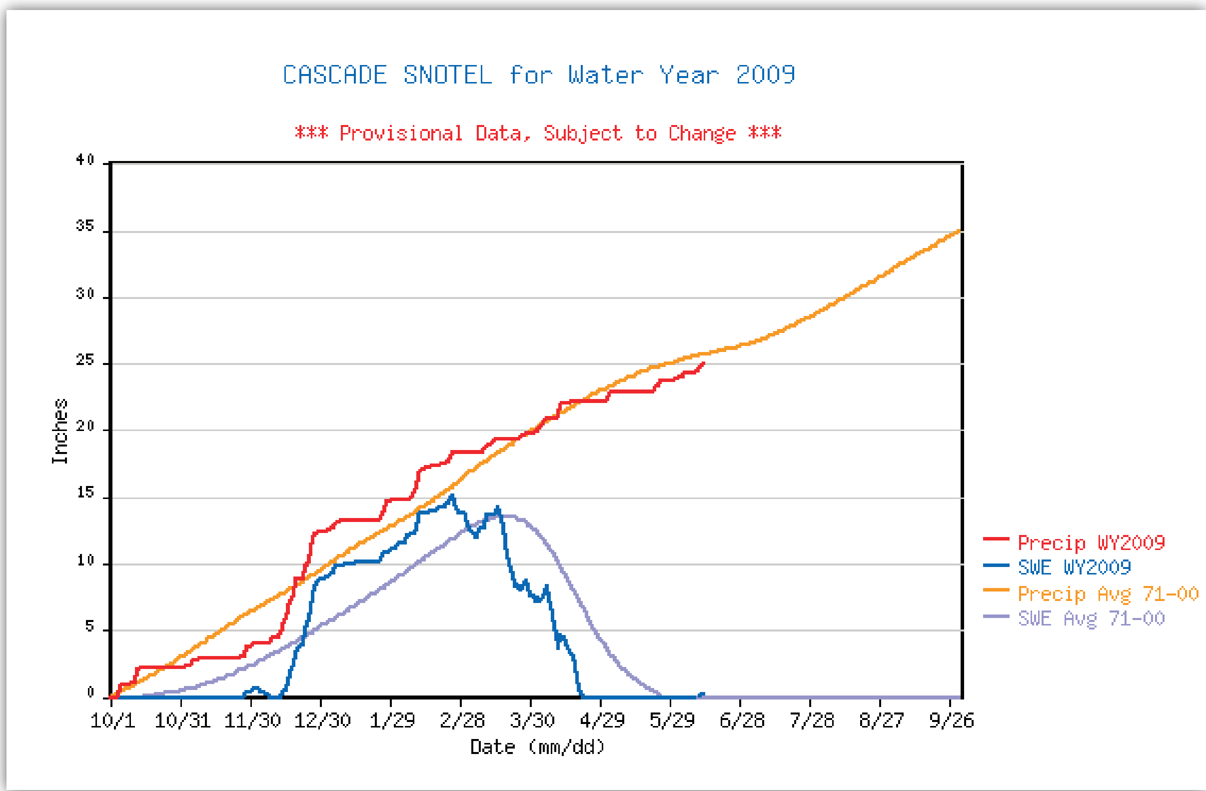
Graduate student Annie Bryant holds a sample of one of the dust layers from the 2.25-meter-deep Rabbit Ears Pass snow pit. Dust layers deposited on March 22, March 29, and April 3, 2009, are visible. (Courtesy of Center for Snow and Avalanche Studies, Silverton, Colorado)

and humid air from the Midwest has drifted into eastern Colorado. The last phases of the spring snowmelt slowed in the northern mountains, and almost daily rains have dampened many areas. Even places like Durango picked up nearly three inches of unexpected rains at a time of year that is normally sunny and dry in that area.

For northeastern and east-central Colorado, late spring rainfall has been more abundant than at any time since the wet 1990s. Almost daily storms have soaked parts of northeastern Colorado with over five inches of rain from late May through mid-June. For the first time this decade, there has been relatively low demand for May-June irrigation water—both for crops and for municipal use—in this part of the state, which has resulted in full and rapidly filling reservoirs.

The cool, moist weather and frequent clouds have been pleasant to some and annoying to others. Along with the clouds have come more frequent and widespread hail storms than we've seen for at least a decade. While the wheat crop looks great in many areas, hail damage has been frequent and widespread. Severe thunderstorm and tornado watches and warnings have been an almost daily occurrence in June.

As we move into July, weather patterns will almost certainly change again. Summers have been hotter than the long-term average for eight of the past ten years for most areas of Colorado. This has been especially true in July. So sit back and prepare for summer.



This graph shows Water Year 2009 and average (1971-2000) precipitation and snow water equivalent for the Cascade SNOTEL site. Notice the early melt out of the snow-water equivalent for 2009, as compared to the 1971-2000 average melt out period.

Gilbert Stamm and Teton Dam

by Patricia J. Rettig, Head Archivist, Water Resources Archive, Colorado State University Libraries

Sometimes archival collections help a researcher get inside the mind of a historical figure. Sometimes they don't. But they can always be counted on to provide unique documents that provide insight into the past.

The Water Resources Archive at Colorado State University holds the archival materials of Gilbert G. Stamm. An interesting set of documents, the papers certainly give insight into the activities of this 1970s-era Bureau of Reclamation commissioner; however, they don't reveal much in the way of his thoughts and feelings on the events of his time. Yet even with this aspect absent—not entirely atypical of a person's professional papers—the collection still sheds light on one of the Bureau's most significant events, which occurred during his leadership.

The Event

On June 5, 1976, the Bureau of Reclamation's Teton Dam on the Teton River in eastern Idaho failed. A leak in the dam discovered that Saturday morning could not be repaired, and by noon the dam collapsed, releasing 80 billion gallons of water. The water roared downstream as a 15- to 20-foot wall filled with debris, reaching speeds of 15 to 20 miles an hour and destroying everything in its path. Not only were thousands of acres of farmland ruined, an entire town was wiped out. Evacuation alerts had been issued in advance, but still 11 people died, as did 13,000 head of livestock.

Construction of Teton Dam had begun in February 1972 and suffered through many delays. The reservoir eventually began filling on October 3, 1975, and was raised to full capacity on June 1, 1976. Four days later, the dam failed. It was the Bureau's first dam failure in its nearly 75 years of building more than 300 dams.

Gilbert Stamm, commissioner of the Bureau of Reclamation at the time, flew to Idaho the next day to inspect the damage. He witnessed nearly a third of the 305-foot-high, 3000-foot-long embankment dam having been washed away. The investigations that followed the failure concluded that a number of factors had contributed to the disaster.

Sugar City, Idaho, was left under water after the 1976 Teton Dam failure. (Image from Stamm Papers, Water Resources Archive, Colorado State University)

This image shows the Teton Dam on June 6, 1976, after its failure. (Image from Stamm Papers, Water Resources Archive, CSU)

This image shows the Teton Dam before its collapse in 1976. (Image from Stamm Papers, Water Resources Archive, CSU)

The Commissioner

Gilbert Stamm, born in Denver in 1911, had become commissioner in 1973 after nearly 30 years climbing the Bureau's ladder. He received his education at the University of Denver and Colorado Agricultural College (now Colorado State University), graduating from the latter in 1935 with a bachelor's degree in economics and sociology. During his college days he participated in a number of organizations, including serving as editor of the campus newspaper.

Stamm became involved in Western water development projects after graduation, going to work for the U.S. Department of Agriculture's Land and Water Resources Office in 1936. He worked there for ten years before moving to the Bureau, where he held several different positions, including nine years as assistant commissioner.

As Congressman Leo J. Ryan of California stated during a House of Representatives subcommittee hearing on the Teton Dam disaster, "In every organization there is a point at which the long chain of responsibility starts. It is the desk where the buck stops. In the Bureau of Reclamation, that desk is the commissioner's desk." Stamm was responsible for the agency's policies and thus testified at Congressional hearings in the months following the disaster.

The Bureau learned some lessons and made some changes to their policies and practices following the Teton disaster. Improved dam safety programs were the biggest result, but it wasn't Stamm leading the way anymore—he had resigned in February 1977.

The Papers

Stamm's papers at the Water Resources Archive contain the text of his hearing testimony on Teton, as well as speeches on the subject of Teton Dam. These show his defense of and support for his employees and the Bureau, but it is hard to tell from these documents what he really thought or felt about the situation. However, as the commissioner, he was expected to relay facts and to carry his agency through the troubling times. If he kept a diary or wrote personal letters during this time, they do not survive in the materials donated by his family after his death in 1989.

Stamm's nearly 200 speeches and statements, which dominate the archival collection, span the years 1958 to 1984, covering time both during and after his service at Reclamation. The materials reveal that he frequently spoke to professional water-related organizations about Reclamation projects, as well as at numerous project dedications and opening ceremonies.

The collection also contains files on some of the projects he worked on throughout the West earlier in his career, mostly in California. In addition to a smattering of publications, correspondence, and awards, there are numerous slides and photographs of Bureau projects and events, including of his flight over the Teton Dam disaster area.

The materials are contained in just nine boxes, so they are clearly not comprehensive of Stamm's long career. Archives, however, can only contain what people create and save and so are rarely comprehensive. (And, of course, the official records of Stamm's work would be part of the Bureau of Reclamation's archives.) But, as the Stamm collection shows, something is better than nothing when trying to see into the past.

To keep unique documentation of important events and people from slipping away, the archive is interested in preserving collections of historical importance. For more information about the Stamm papers and other collections in the Water Resources Archive, as well as how to donate materials, see the web site (http://lib.colostate.edu/archives/water/) or contact the author (970-491-1939; Patricia.Rettig@ColoState.edu) at any time.

Restoring the Purgatoire River Watershed System

by Shelly Van Landingham and GayLene Rossiter, Colorado State Forest Service

Since 2004, Tackling Tamarisk on the Purgatoire (TTP) project partners have worked to improve native riparian communities along the Purgatoire River Watershed in southeast Colorado by removing non-native, invasive woody plant species, such as tamarisk (salt cedar) and Russian olive. In doing so, the project helps protect Colorado's native riparian areas, water resources, watersheds, and communities, as well as the wildlife and agriculture that depend on these resources.

The lower Purgatoire River Watershed encompasses more than 275 river miles, including the river and its tributary feeder streams. The main stem of the Purgatoire flows east from the 14,069-foot Culebra Peak high in the Sangre de Cristo Mountains to Trinidad, Colorado. From there, the river flows northeast to Las Animas, Colorado, where it converges with the Arkansas River.

The watershed supports one of the most intact native fisheries in the Central Shortgrass Prairie east of the Rocky Mountains. Fortunately, many areas in the Purgatoire Watershed still exhibit remarkably intact and vigorous native riparian vegetation, making restoration efforts more successful and sustainable. Currently, the tamarisk infestation is fairly manageable, especially in the upper reaches of the river. Removing the invasive plant will cost substantially less at this point than it will if the plant is allowed to spread. Getting a head start on the tamarisk infestation has been critical to the control and long-term project success of the TTP partnership.

The tamarisk invasion threatens significant riparian vegetation and degrades the ecosystem in the Purgatoire River Watershed in numerous ways by:

- Significantly increasing non-beneficial water consumption
- Crowding out native plant species
- Increasing salinity of the surface soil, which renders it unsuitable for other plants to grow
- Providing less diverse and lower-value habitat for wildlife
- Widening floodplains, clogging stream channels, and increasing sediment deposition
- Diminishing human enjoyment of and interaction with the river environment

Salt cedar and other invasive trees, such as Russian olive, also compromise the livelihood of Colorado's agricultural community by consuming valuable water required for farming and ranching.

The lower Purgatoire River Watershed encompasses more than 275 river miles in southeast Colorado.

Wildlife use of tamarisk is very limited to nonexistent, as its seeds are too small for most wildlife to use, and the plants do not provide adequate nesting habitat. Tamarisk grows so thick in some areas that wildlife can hardly pick their way through the dense thickets—this is also true for people and livestock.

In many riparian forests, such as those in southeast Colorado, tamarisk has become a ladder fuel. This puts the forests and people who live in these watersheds at risk of unnaturally severe wildland fires, because tamarisk ignites easily and exhibits extreme fire behavior, including intense heat and rapid spread.

TTP Partners

TTP partner representatives include a broad range of public agencies, non-profit organizations, and individuals who have joined in this collaborative effort. Active partners include the Branson-Trinchera Conservation District, Colorado Department of Agriculture, Colorado Division of Wildlife (CDOW), Colorado State Forest Service, Colorado Water Conservation Board, Natural Resources Conservation Service (NRCS), Purgatoire River Water Conservancy District, Rocky Mountain Bird Observatory, Southeastern Colorado Water Conservancy District, Spanish Peaks-Purgatoire River Conservation District, Tamarisk Coalition, The Nature Conservancy, Trinidad State Park, U.S. Bureau of Reclamation, U.S. Fish and Wildlife Service, private landowners, and many others.

Purgatoire River Tamarisk Map and Infestation Inventory

In 2005-2006, the Tamarisk Coalition, a non-profit alliance working to restore riparian lands, completed a comprehensive map for the Colorado Water Conservation Board that illustrated tamarisk infestations on the Purgatoire River Watershed. The map has allowed the TTP partners to identify and strategically attack the establishment and spread of tamarisk and other invasive plant species. To see the *Purgatoire River Mapping Summary*, visit http://www.tamariskcoalition.org/tamariskcoalition/Mapping.html.

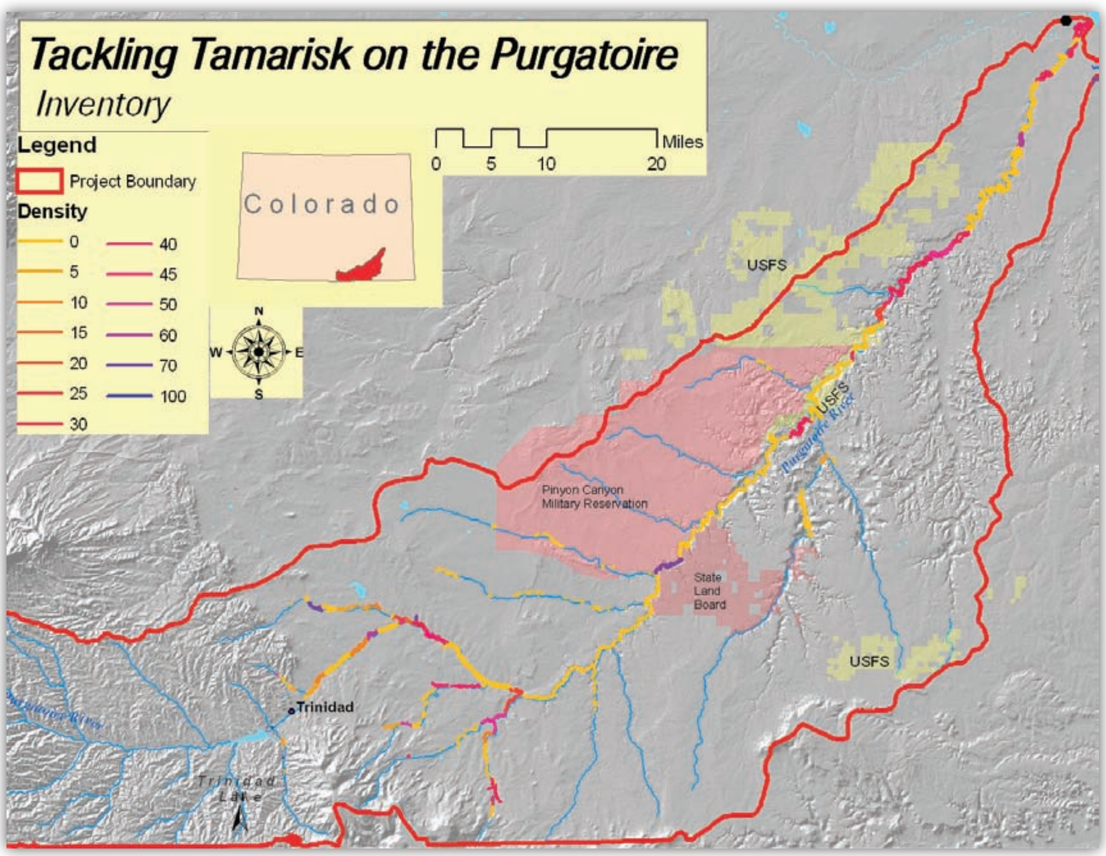
TTP Strategic Plan

A comprehensive strategic management plan for Tackling Tamarisk on the Purgatoire was completed that addresses issues in the watershed from Trinidad Lake in Las Animas County to the John Martin Reservoir, where the river converges with the Arkansas River in Bent County. The Consolidated Woody Invasive Species Management Plan for Colorado's Purgatoire Watershed was approved by the Colorado Department of Agriculture Weed Coordinator and is available at http://arkwipp.org/purgatoire-plan.asp.

Project Implementation

In 2005, TTP partners were awarded NRCS Environmental Quality Incentives Program (EQIP) Invasive Plant Program funding. Three landowners currently are working under 10-year contracts with the NRCS. To date, 20 acres of tamarisk mitigation have been completed, with a total treatment goal of 100 acres.

Treatment methods used will be very site specific. In the upper end of the Purgatoire watershed, the project will mostly employ the cut-stump method (i.e., using a saw crew that includes a sawyer, sprayer, and stacker). After cutting all stems of a plant, herbicide is applied to the cut stumps within 10 minutes. This is a very low impact treatment method that spares existing vegetation. The cut stems are then stacked for disposal as determined by the landowner. Other methods used within the watershed's upper reaches will include mechanical mulching, followed by foliar application after a season's worth of growth.



One other very promising option for control is the tamarisk leaf beetle (*diorhabda elongata*). These beetles have been very successful on Colorado's west slope, and the Colorado Department of Agriculture is currently working towards the release of a sub-species of the beetle that may have success on the eastern slope. The beetles do not outright kill tamarisk, but continually stress it, giving native vegetation the advantage and eventually causing death of tamarisk. Bio-control should be considered wherever feasible, as it causes no

The image below shows Chacuaco Creek, the major tributary to the Purgatoire River, before tamarisk treatment.

The image above shows Chacuaco Creek, the major tributary to the Purgatoire River, after tamarisk treatment.

disturbance to soils or native vegetation and is the least costly of all control methods once established. (For more information on tamarisk leaf beetle, please visit http://www.usbr.gov/uc/albuq/library/eaba/saltcedar/pdfs/tamarisk.pdf)

Trinidad State Park, one of the TTP partners, is located on the eastern section of the watershed. With the partnership's assistance, the park has treated nearly 170 acres along the waterways at Trinidad Lake. After treating the majority of tamarisk in the park, this partner annually monitors the areas for re-growth.

Chacuaco Creek is the largest tributary of the Purgatoire River and is located between the towns of Kim and Branson. The project goal is to control tamarisk and Russian olive within the entire drainage. The Colorado Division of Wildlife Wetlands Program awarded a grant to the Branson-Trinchera Conservation District (B-T CD) to initiate the effort, and 160 acres were treated in 2009. B-T CD recently was awarded two additional grants for 2010-2011: a CDOW Wetlands Grant for 2010, as well as a grant from the Colorado Water Conservation Board. The goal of the Branson-Trinchera Conservation District and the TTP partners is to treat 400 acres by 2011.

Riparian Restoration is the Ultimate Goal

Understanding how tamarisk and Russian olive function and respond to treatment within different environments will provide long-term success with removal and control efforts. Keys to success for the TTP project are to: identify goals to remove, control, and plan for restoration; develop a long-term plan that employs best management practices and control methods for individual sites; identify other invasive weeds that exist on individual sites; and incorporate monitoring and maintenance of re-growth into the TTP plan.

Recognizing that private landowners are instrumental to the success of the project, the team continues to work with landowners to provide them with the information they need to make informed decisions about how best to control tamarisk on their land.

The many partners recognize that this is a long-term effort, and sustainability of the Purgatoire River Watershed and its native fisheries, rare riparian plant species, agriculturally based communities, and recreational users relies on TTP's success.

For more information about the Tackling Tamarisk on the Purgatoire Project, please contact Shelly Van Landingham, La Junta District, Colorado State Forest Service, at (719) 384-9087.

CSU Professor Receives NSF Award

Thomas Borch, assistant professor of environmental soil chemistry in the Department of Soil and Crop Sciences at Colorado State University, has received a Faculty Early Career Development (CAREER) Award from the National Science Foundation. The honor is considered one of the most prestigious for up-and-coming researchers in science and engineering.

Borch will use the nearly $500,000, five-year grant to investigate how climate change, and especially the projections of increased precipitation and flooding, may impact important biogeochemical cycles, such as those related to iron. Iron minerals are among the most important reactive solids in earth surface environments, acting as natural filters of inorganic contaminants and nutrients, sorbents for organic matter, and poising the redox potential of groundwater. Lack of biologically available iron in soils can also lead to iron deficiency anemia which is a major public health and financial problem in Central Asia, with primary impact on woman and children.

Iron minerals are responsible, in part, for stabilization of organic matter in soils. Consequently, any changes in iron chemistry may also result in changes in the atmospheric carbon dioxide concentration and the global climate. In high-elevation watersheds of the Rocky Mountains, more than 95% of spring snowmelt infiltrates through soils and moves along shallow groundwater flow paths before merging with stream water. In fact, one-sixth of the world's population depends on water released from seasonal snowpacks and glaciers, so an improved understanding of the soil processes that sustain the supply of clean water from mountain headwaters is critical to current and future human natural resource demands.

"This award will allow us to initiate a new important research area in environmental biogeochemistry at CSU; attract high-caliber postdoctoral researchers, graduate, and undergraduate students; and develop a set of new courses targeting undergraduate students interested in environmental biogeochemical processes from the molecular scale to field scale," said Borch.

Borch earned his doctorate degree in environmental soil chemistry from Montana State University and his Master of Science and Bachelor of Science degrees in environmental chemistry from the University of Copenhagen. He joined Colorado State University in 2005 to initiate a program in environmental soil chemistry.

This article adapted from a June 5, 2009, CSU news release.

Salazar Waives National Parks Fees for Three Summer Weekends

Secretary of the Interior Ken Salazar announced on June 2, 2009, that the National Park Service will offer three fee-free weekends this summer to encourage Americans to visit these national treasures. The 147 National Park Service sites that charge fees for entry will waive the fees during the weekends of July 18-19 and August 15-16 (the first fee-free weekend was on June 20-21).

"During these tough economic times, our national parks provide opportunities for affordable vacations for families," said Salazar. Most Americans live less than a day's drive from a national park, Salazar noted. Nationwide, parks attracted more than 275 million recreation visits last year, and spending by non-local visitors provided $10.6 billion to local economies.

The entrance fees being waived range from $3 to $25. The waiver does not include other fees collected in advance or by contractors, such as fees charged for camping, reservations, tours, or use of park concessions.

Colorado parks included in the fee waiver:

- Black Canyon of the Gunnison National Park
- Colorado National Monument
- Dinosaur National Monument
- Florissant Fossil Beds National Monument
- Great Sand Dunes National Park & Preserve
- Hovenweep National Monument
- Mesa Verde National Park
- Rocky Mountain National Park

Colorado's Gunnison Tunnel Celebrates 100 Years

by Denis Reich, Water Resource Specialist, Colorado State University Extension

If you've ever sat in ski traffic or waited for roadwork stoppage near Loveland Pass on I-70, you may have caught yourself contemplating the engineering behind the Eisenhower and Johnson memorial tunnels. And if someone told you that two tunnels in Colorado have been designated as National Civil Engineering Landmarks (by the American Society for Civil Engineers), it would seem obvious that it must be these two tubes of asphalt and concrete burrowing through the Rockies.

Not even close. In fact, the two landmark tunnels were built many decades before I-70 was even a serious consideration. The Moffat tunnel was completed initially as a trans-mountain railroad tunnel in 1926 and now also serves as a water diversion for Denver Water. But the first was the Gunnison Tunnel, one of the first five federal projects in the West, which was completed in September of 1909 to augment irrigation flows in the fertile Uncompahgre Valley. Construction took five years of around-the-clock excavation through almost six miles of western Colorado's gneiss, schist, and shale. Perhaps because you can't ride a train or drive an automobile through it, most Coloradoans don't even know it's there, but its story is probably one of the more inspiring in Colorado's history.

The story of the Gunnison Tunnel begins with a splintered community of ex-miners, railroaders, and first-generation homesteaders. Western Colorado, and particularly the small populations of the lower Uncompahgre, were struggling to define their identity in the late 1800s. Out of 170,000 acres of irrigable land, less than 30,000 acres were being farmed. The soils of the valley were clearly productive, but due to the unpredictable availability of irrigation water, making a living from agriculture during this time was a difficult task. Although runoff from the San Juan Mountains would threaten the Uncompahgre River with flooding in May or June, by late July the river bed would often be mostly exposed. Irrigating a crop to full term in these parts was no business for the sweaty palmed producer.

The Gunnison Tunnel was completed in September 1909.

The Gunnison River was a more substantial river than its sibling the Uncompahgre, and irrigators were aware of its tendency to produce flows deeper into the irrigation season. As producers began to build canal networks and form local ditch companies, such as the Montrose, Uncompahgre, and Delta Ditch companies, it was only a matter of time before tapping the Gunnison to supplement local irrigation was considered.

Legend has it that a local, F.C. Lauzon, was visited in a dream by the idea for a tunnel diverting water into the valley. Dream or not, this industrious Frenchman began to advocate strongly for the project in 1890. Sometimes he would spend entire days on Montrose street corners preaching to any who would listen about the obvious benefits of a tunnel full of Gunnison River water emptying its wet wealth into the Uncompahgre Valley. In 1894, his persistence paid off, and Colorado legislature backed the project to the tune of $25,000. The U.S. Geological Survey (USGS) agreed to a reconnaissance survey of the project under the direction of Frederick Newell, an MIT-trained engineer who would ultimately become the Bureau of Reclamation's first director. After mapping the region and likely tunnel routes, all that prevented the digging from starting was a full survey within the Black Canyon to accurately locate the proposed tunnel's eastern portal.

In the summer of 1900, a party of five, including William W. Torrence, set out from Montrose to boat the Gunnison through the Black Canyon and determine a suitable inlet point for the tunnel. Additional men were sent to watch from the cliffs above and relay updates back to family. After spending three weeks in the canyon, losing one of their two boats, and running out of food, they abandoned the survey short of their objective at the "Fall of Sorrows."

Torrence, who had a reputation for getting things done, placed an advertisement in the newspaper seeking a survey companion of "adventurous spirit" and "strong constitution" with "no family" to help him keep the Gunnison Tunnel project alive. In August 1901, he returned with Abraham Lincoln Fellows, an engineer from the Cortez canal system (now the Montezuma Valley Irrigation Company). After retracing the steps of the 1900 expedition, they swam the treacherous Black Canyon Narrows, a short segment of wild river bracketed by sheer rock faces only 40 feet apart. After riding the Gunnison's whitewater for 10 days, mostly without boat or raft, they emerged from the mouth of the canyon battered but successful; the tunnel project could proceed.

The state commenced construction in the fall of 1901. Unfortunately, this first attempt was soon abandoned as the project quickly outgrew its limited funding. As the first attempt was faltering, Colorado Congressman James Shafroth, a member of the House Committee on Irrigation, began meeting regularly with Representative Newlands of Nevada, who was probably in the early stages of composing the 1902 Reclamation Act. The fact that recently inaugurated President Roosevelt was a vocal advocate for western irrigation was of no harm to this congressional alliance either.

In the wake of the Reclamation legislation, the USGS recommended the Uncompahgre Valley as one of the suitable locations to begin spending this new pot of federal funds. The Gunnison Project was officially authorized by then Secretary of the Interior Ethan A. Hitchcock in March 1903, along with four other projects in Wyoming, Montana, Nevada, and Arizona. In keeping with the Act's requirements, local landowners also merged the valley's major ditch companies, forming the Uncompahgre Valley Water User's Association. The "Water Users" became the beneficial entity responsible for managing and maintaining the project and for repaying the government for the costs of its construction.

Construction on the tunnel began in earnest in late 1904. To expedite the process, tunnel excavation was attacked from four locations: the western portal, eight miles east of Montrose near the Cedar Creek railroad point, the eastern or river portal that included a 12-mile access road of double digit grades, and two shafts. About 500 men worked on the tunnel, many of whom came from the Appalachian coal mines. Work wasn't easy and turnover was high, with the average stay being about two weeks. After five years of persistent toil that included navigating a fault-line, uncorking an underground hot spring, and 26 fatalities, the tunnel was finally completed nearly 20 years after Mr. Lauzon's legendary dream. Remarkably, when the tunnels met in the middle they were offset by only 18 inches (the Eisenhower tunnel missed by 40 feet). The finished tunnel was 32,650 feet long, which at the time was the longest irrigation tunnel in the world. It was 11 x 13 feet at the mouth with a capacity of 1,300 cubic feet per second, which is still the case today.

The Gunnison Project was officially opened by President William Taft on September 23, 1909. As the President pressed a golden bell to a silver plate, water began flowing through the tunnel and into the South Canal. The surrounding community responded by ringing bells in reply, and the sound simulated the Uncompahgre's new water supply as the ringing moved down the valley from Montrose to Delta. The 11-mile South Canal was also completed in 1909 and diverts water to the Uncompahgre River just north of Colona. Some project water is also sluiced over the river at this point via the West Canal to feed the western side of the Valley. Even today, engineers worldwide still marvel at how the nearly 800 miles of canals, laterals, and drains work over 1,000 feet of fall in concert with the Uncompahgre River and pre-existing arroyos to irrigate the valley.

The impact of the Gunnison Tunnel diversion on the Uncompahgre Valley community was swift and dramatic. By 1923, the Valley's population had doubled to over 6,000, and the irrigated acreage within the project expanded from 37,000 acres in 1913 to 64,180 acres in 1933. Producers quickly capitalized on the improved irrigation conditions, and at various times in its history the Uncompahgre has provided some of the most productive land in the country for potatoes, apples, peaches, sugar beets, alfalfa, onions, dry beans, and livestock. Today, the Uncompahgre Project irrigates over 66,000 acres around Montrose, Olathe, and Delta, and is renowned for its sweet corn and a wide variety of agriculture that includes melons, specialty vegetables, and beef cattle.

The Uncompahgre Valley Water Users Association took control of the renamed Uncompahgre Project in 1932, and its headquarters are still located on Park Avenue in the original Bureau of Reclamation office building. The Water Users are managed by Marc Catlin, who is passionate about the legacy of the tunnel and deeply concerned that it is being taken for granted. "Most people in this area don't realize they are having an experience with Gunnison River water in the bed of the Uncompahgre River," he said. Catlin's comment strikes at the heart of the primary tension around water in the area. The Valley is beginning to test its limits with rapid population growth and a stressed agricultural economy and, as 2001 and 2002 proved, there is high potential for droughts to cause serious problems.

Dan Crabtree, operations manager with the Bureau of Reclamation who works closely with Catlin on managing water delivery to the tunnel, expresses his awe for the Uncompahgre Project's longevity. "Who would have thought we'd be here 100 years later with the tunnel still fully intact, operating much like it did in 1909?" he asks. To help celebrate the centennial of this profound achievement, Catlin and the Uncompahgre Valley Water Users Association are organizing a special "Tunnel Days" celebration for Saturday, September 26, 2009. "I want people to be proud of the foresight and fortitude it took to make this Valley what it is today," Catlin said.

CWI Announces Funded Student Projects

The Colorado Water Institute is pleased to announce the funding of six student projects this year. This program is intended to encourage and support graduate and undergraduate research in disciplines related to water resources and to assist Colorado institutions of higher education in developing student research expertise. The purpose of the funding is to help students initiate new research projects or to supplement existing student projects focused on water resources research. The FY09 funded projects and funding recipients are listed below:

James Cullis
Department of Civil, Environmental, & Architectural Engineering, University of Colorado

Faculty Sponsor: Diane McKnight

Understanding the Hydrologic Factors Affecting the Growth of the Nuisance Diatom *Didymosphenia Geminata* in Rivers

Didymosphenia geminata, also known as "didymo" or "rock snot," is a nuisance algal species that occurs in many mountain streams in the western U.S. It tends to produce large amounts of extracellular stalk material, and while it is not considered to be toxic, the growth of these large algal mats has a significant impact on the aesthetics of a stream and on the sustainability of stream ecosystems and water supply infrastructure. Not much is known about this species, as it has only become a significant problem in the past 10 to 15 years. This research will look specifically into the hydrologic factors affecting the growth of this nuisance species at a number of study sites in Boulder Creek, Colorado, with a particular focus on the role of flood-induced bed disturbance as a primary control of growth. The overarching research hypothesis is that high levels of shear stress and bed disturbance due to flood events are necessary to control the growth and bloom tendency of *D. geminata*, and that these levels can be provided through environmental flood releases from reservoirs to maintain functioning stream ecosystems and water supply systems.

Bear Creek Watershed Project

Kimberly Gortz-Reaves, College of Architecture and Planning, University of Colorado (Faculty Sponsor: Charlie Chase)

Bear Creek watershed encompasses four counties and more than eight cities and towns. The extent to which public and private land use managing agencies or organizations involved with the watershed offer "on-the-ground" projects for young people and community groups to participate in (e.g., habitat restoration, stream bank stabilization, or other watershed conservation projects) is unknown. Furthermore, there is no existing system to provide coordination for watershed-wide projects. The purpose of this research project is to identify stakeholders and potential partners operating in the Bear Creek watershed and their needs, resources, and capacities. The project will be facilitated by the Bear Creek Watershed Partnership (BCWP), which is aimed at connecting youth-based stewardship and leadership programs to opportunities offered by Bear Creek watershed stakeholders. To date, facilitating partners include City of Denver Parks and Recreation, University of Colorado at Denver, National Park Service RTCA, AmeriCorps, FrontRange Earth Force, and Groundwork Denver. To date, there has been limited program coordination among municipalities and other public and private agencies within the Bear Creek watershed. The objective is to contact agencies and associations, build a database of information based on conversations with contacts, create a stronger partnership effort, and develop a GIS-web based interactive map with the gathered information. The long-term goal is to create a forum in which partners will be able to share or coordinate their objectives, improve management strategies, and post stewardship projects for youth.

Jason F. Smith
Department of Horticulture and Landscape Architecture, CSU

Faculty Sponsor: James E. Klett

Impact of Limited Irrigation on the Health of Four Common Shrub Species

The shrub water study was started in 2005 in response to the 2002 drought to evaluate the actual water requirements of some commonly used landscape plants. Currently, most water use statements for landscape plants are based on personal opinions or observations, and few studies have evaluated the water use of landscape plants. This research involves determining the water use values for some common landscape shrubs from a replicated study. The research is continuing in 2009 and will evaluate the growth of Redosier dogwood, smooth hydrangea, Diablo ninebark, and arctic blue willow when subjected to four different amounts of irrigation (0%, 25%, 50%, and 100%), based on the evapotranspiration rate of Kentucky bluegrass. By the end of 2009, accurate water requirements for these four species will be determined after a season of collecting various types of data. If the study results show that these shrubs do well with 0% or 25% of the evapotranspiration rate of Kentucky bluegrass, then they would be well suited for planting in many Colorado landscapes that require little to no irrigation. However, if these shrubs are found to need 50% or 100%, then the use of these shrubs could be limited for landscape use in Colorado.

Potential Changes in Groundwater Acquisition by Native Phreatophytes in Response to Climate Change

Throughout western North America, arid regions are likely to experience changes in the timing and amount of precipitation as global surface temperatures increase. Altered rainfall and runoff patterns will exacerbate current stresses on water resources from growing human demands and could produce long-term changes in water availability for ecosystems, agriculture, and municipalities. In Colorado's arid San Luis Valley (SLV), competing water interests will be particularly sensitive to climate change. The SLV receives only 180-250 mm of precipitation annually; yet, a shallow unconfined aquifer recharged by snowmelt supports over 600,000 acres of irrigated agriculture, substantial water transfers out of the valley, and native rangeland for livestock grazing. The dominant native plants in the SLV are phreatophytes, plants that use groundwater. Evapotranspiration by phreatophyte communities accounts for more than one-third of the total annual groundwater consumption. Some SLV phreatophytes can also utilize predictable pulses of summer monsoon rain to reduce or supplement their groundwater use. Thus, changes in monsoon rainfall patterns may produce changes in groundwater acquisition of phreatophytes, which could have considerable effects on the SLV groundwater budget and regional agriculture. Our research investigates the response of four native phreatophytes to changes in growing season precipitation using a rainfall manipulation experiment. Our goal is to understand how plant community adjustment to climate change in the SLV would affect regional groundwater resources, and to incorporate this understanding into the Rio Grande Decision Support System groundwater management model.

Julie Kray
Department of Forest Rangeland and Watershed Stewardship, CSU

Faculty Sponsor: David J. Cooper

Chengmin Hsu
Department of Civil Engineering,
University of Colorado Denver

Faculty Sponsor: Lynn E. Johnson

High-Resolution Soil Moisture Retrieval in the Platte River Watersheds

An accurate estimate of soil moisture is necessary for various hydrometeorological, ecological, and biogeochemical modeling and applications. Unfortunately, continentally available soil moisture data (AMSR-E) are currently derived using passive remote sensing technology that has a very rough resolution (i.e., 25 km). This rough resolution character of the AMSR-E products makes them difficult to use for hydrological and ecological purposes at the watershed scale. In this project, I propose to: (1) improve and update the AMSR-E soil moisture products by assimilating the AMSR-E products into the NOAH land surface model, (2) downscale the coarse resolution soil moisture outcome to a higher resolution product (e.g., 240-meter resolution), and (3) validate the final product with the joint soil moisture observations obtained from NRCS Soil Climate Analysis Network (SCAN) and from soil moisture monitoring stations in Nebraska by the High Plains Regional Climate Center (HPRCC). The study area will include portions of the North and South Platte River Basins and a portion of the Republican River Basin. The work proposed in this project constitutes a first attempt to understand the spatial structure of brightness temperature and soil moisture images when applied at a higher resolution. It will also test the capability of the NOAH land surface model to generate high-resolution surface soil moisture. More importantly, the work will be a foundation for the future estimation of root-zone soil moisture.

Developing Barriers to the Upstream Migration of New Zealand Mudsnail (*Potamopyrgus antipodarum*); Phase II: Laboratory and Field Evaluations of Mudsnail Response to Copper-based Materials under Varied Water Quality Conditions

The objective of this research is to evaluate the ability of copper-based substrates to prevent the upstream spread of the invasive New Zealand mudsnail (*Potamopyrgus antipodarum*). Over the last 20 years, mudsnails have spread rapidly across the western U.S., prompting management agencies to close several streams and fish hatcheries. There is currently a need for effective methods to prevent further invasion into novel waterbodies. Preliminary research results suggest that several copper-based substrates may be useful in stopping the upstream spread of this organism. I am currently studying how physicochemical parameters, including pH, temperature, and water hardness, affect the mudsnail's response to the copper materials. We are hopeful that copper-based substrates can eventually be integrated into mudsnail management plans once the barrier ability of each of the materials has been evaluated.

Scott Hoyer
Department of Fish, Wildlife, and Conservation Biology, CSU

Faculty Sponsor: Christopher Myrick

Faculty Profile

Lori Peek, Assistant Professor, Department of Sociology

I joined the faculty in the Department of Sociology at Colorado State University (CSU) in the fall of 2005. I am also a faculty affiliate with Women's Studies at CSU and the Natural Hazards Center at the University of Colorado-Boulder. For the past three years, I have served as the associate chair for the Social Science Research Council (SSRC) Task Force on Hurricane Katrina and Rebuilding the Gulf Coast. The main responsibility of the Task Force has been to oversee a program of research on the effects of that catastrophic event. The research has been supported by grants from the MacArthur, Russell Sage, Ford, Rockefeller, and Gates Foundations.

My research focuses on marginalized populations, social inequality, and disasters. I am interested in exploring the ways in which various forms of inequality—such as those based on race, religion, gender, class, and age—play out in people's everyday lives and during extraordinary times. In particular, my work examines how unequal access to power and resources contributes to vulnerability before, during, and after disaster. My most recent research projects include an exploration of the backlash against Muslim Americans after the September 11 terrorist attacks, a longitudinal study of children's experiences in Louisiana following Hurricane Katrina, and an examination of the relocation experiences of parents and children who were displaced to the state of Colorado in the aftermath of Hurricane Katrina.

Since I have been at CSU, I have undertaken several productive and gratifying research projects. My research has appeared in a number of journals, including *Child Development*, *Sociology of Religion*, *Disasters*, *International Journal of Mass Emergencies and Disasters*, and the *National Women's Studies Association Journal*. I am currently finishing a book on the post-September 11 backlash (tentatively titled *Behind the Backlash*, forthcoming with Temple University Press in 2010). In 2008, I finished editing a special issue on children and disasters for the journal *Children, Youth, and Environments*. The issue contains a collection of 20 papers from around the world that explore children's reactions to drought, tsunamis, hurricanes, volcanic eruptions, climate change, and the HIV/AIDS pandemic. Some of the contributions also consider the experiences of children who live in a constant state of disaster as a result of chronic poverty, violence, or unsafe living conditions.

My published work addresses questions concerning vulnerability and crisis, such as: What are survivors' experiences in disaster situations? Who is most vulnerable in a disaster and why? How do individuals and families cope with acute and chronic crisis situations? How do disasters affect the mental and physical well-being of survivors? In what ways are intentional human-induced disasters similar to, and different from, natural disasters? How does post-disaster displacement influence the recovery process for children and adults? While the contexts and populations I have studied vary, the questions have common threads related to understanding the challenges people face and the ways in which they cope with disaster events. All of these projects also have a policy component, with the hope that the research will improve people's lives and the ability of communities to prepare for and respond to disasters.

I began to address these research questions and policy issues as a doctoral student working at the Natural Hazards Center at the University of Colorado-Boulder. While disaster work was less recognized at that time, the September 11 terrorist attacks, the 2004 Indian Ocean earthquake and tsunami, Hurricane Katrina, and other catastrophic events have brought the work of disaster scholars to center stage for the general public, the media, policy makers, and the academic research community. With population growth, unsustainable development and human settlement in hazardous areas, environmental degradation, global warming, deforestation, and increasing economic and social inequalities, human populations in the developed—and especially the developing—world will continue to suffer significant loss of life, land, health, security, and culture throughout the 21st century. It is my goal to contribute to our theoretical and applied understanding of the major factors that shape society's growing vulnerability to disasters.

I teach courses at CSU in the areas of race and ethnic relations, contemporary theory, qualitative research methods, and the sociology of disaster. In 2007, I was honored to receive the Best Teacher Award from the CSU Alumni Association and the Excellence in Teaching Award from the College of Liberal Arts. I am very proud to be at a university that has a national and international reputation for water-related research. It provides all of us here with such a valuable network of people working in different strands of water.

Lori Peek, Ph.D.
Assistant Professor

Colorado State University

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Colorado State University

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Water Research Awards

Colorado State University (April 15 to June 14, 2009)

Abt, Steven R, USDA-USFS-Rocky Mountain Research Station, Bedload Transport in Gravel-bed Rivers & Channel Change, $75,063

Bestgen, Kevin R, DOI-BLM-Bureau of Land Management, Hornyhead Chub Distribution, Abundance, and Habitat Use in the Lower Laramie River Drainage, $20,000

Bestgen, Kevin R, DOI-Bureau of Reclamation, Abundance Estimates for Colorado Pikeminnow in the Green River Basin, Utah and Colorado, $14,115

Bestgen, Kevin R, DOI-Bureau of Reclamation, Evaluating Effects of Non-Native Predator Fish Removal on Native Fishes in the Yampa River, $23,967

Bestgen, Kevin R, DOI-Bureau of Reclamation, Yampa and Middle Green CPM & RBS Larval Survey, $44,000

Bestgen, Kevin R, Wyoming Game & Fish Department, Big Sandy River Larval Dispersal, $96,643

Bestgen, Kevin R, Wyoming Game & Fish Department, Hornyhead Chub Investigations, $63,580

Bledsoe, Brian, NSF - National Science Foundation, Field Characterization of the Hydraulics of Steep Channels, $49,532

Cabot, Perry Edmund, Colorado Water Conservation Board, The Effect of Land Fallowing and Water Rights Leasing on Corn Yield, Nutrient Needs, and Economics in the Lower Arkansas River Valley of Colorado, $80,349

Cabot, Perry Edmund, Lower AR Valley Water Conservancy District, The Effect of Land Fallowing and Water Rights Leasing on Corn Yield, Nutrient Needs and Economics in the Lower Arkansas River Valley of Colorado, $2,320

Chavez, Jose L, Monsanto, Remote Sensing-based Crop Water Stress Determination of Limited Irrigated MON87460 Transgenic Drought Tolerant Corn Hybrids, $43,677

Davies, Stephen P, New Mexico State University, Afghanistan Water, Agriculture and Technology Transfer Program (AWATT), $1,025,655

Fausch, Kurt D, DOI-BLM-Bureau of Land Management, A Field Test of Effects of Grazing Management Systems on Invertebrate Prey that Support Trout Populations in Central Rocky Mountain Streams, $15,600

Fausch, Kurt D, The Nature Conservancy, Review of Water Management Scenarios for the North Fork Poudre River, $10,000

Fiege, Mark T, DOI-NPS-National Park Service, Environmental History of the Kawuneeche Valley and the Headwaters of the Colorado River, Rocky Mountain National Park, $49,994

Garcia, Luis, Various "Non-Profit" Sponsors, Developing a Decision Support System for the South Platte Basin, $10,000

Gates, Timothy K, Colorado Dept of Public Health and Environment, Data and Models for Planning of Nonpoint Source Selenium Management in the Lower Arkansas River Basin, Colorado, $501,735

Goodridge, Lawrence, Scientific Methods, Inc., Rapid Concentration of Viruses from Drinking Water, $23,539

Hansen, Neil, DOI-Bureau of Reclamation, Demonstrating Limited Irrigation Technology as an Approach to Sustain Irrigated Agriculture While Meeting Increasing Urban Water Demand in Colorado, $68,465

Hawkins, John A, DOI-Bureau of Reclamation, Middle Yampa Smallmouth Bass and Northern Pike, $55,200

Johnson, Brett Michael, DOI-Bureau of Reclamation, Chemically Fingerprinting Nonnative Fishes in Reservoirs, $36,504

Lee, Brook L, USDA-USFS-Rocky Mountain Research Station, Effects of Mountain Pine Beetle and Forest Management on Water Quantity, State Forest, $56,825

Myrick, Christopher A, DOI-USFWS-Fish & Wildlife Service, A Pilot Project Testing the Use of Copper and Copper-Based Compounds to Prevent the Upstream Movement of New Zealand Mudsnail, $25,647

Myrick, Christopher A, DOI-USGS-Geological Survey, Developing Barriers to the Upstream Migration of New Zealand Mudsnail Phase III, $5,000

Niemann, Jeffrey D, DOI-Bureau of Reclamation, Implementing a Framework to Assess Uncertainty in Hydraulic and Hydrologic Models, $35,000

Oad, Ramchand, New Mexico State University, Afghanistan Water, Agriculture and Technology Transfer Program (AWATT), $755,567

Pilon-Smits, Elizabeth AH, NSF-Biological Sciences, Ecological Aspects of Plant Selenium Hyperaccumulation: Below and Beyond, $124,651

Reardon, Kenneth F, University of Colorado, Bioconversion of Extracted Algal Biomass into Ethanol, $50,000

Roesner, Larry A, ACR, LLC, Graywater - Wetlands Monitoring and Recycling for Urban Watersheds, $49,900

Schneekloth, Joel, Monsanto, Response of Drought Tolerant Genetics to Water Stress, $65,071

Snyder, Darrel E, DOI-Bureau of Reclamation, Identification and Curation of Larval and Juvenile Fish, $99,332

Spencer, William P, USDA-Foreign Agricultural Service, Cochran Fellowship Training Program in Irrigation/ Algeria and Tunisia/July 2009, $19,946

Waskom, Reagan M, USDA-CSREES-Cooperative State Research Education and Extension, Coordinated Regional Water Resources Programming for the Northern Plains and Mountains Region, $67,000

Westra, Philip, Monsanto, Field Production of Tissues and Grain from Drought Tolerant Corn, $47,880

Wohl, Ellen E, National Science Foundation, ARRA RAPID: Pre-Disturbance Surveys of Wood Loads in Headwater Streams of the Colorado Front Range, $30,435

University of Colorado

Abdalati, W, NASA, Summer Melt Contributions of the Greenland Ice Sheet to the High-Latitude Water Budget: A Multi-sensor Investigation, $75,247

Greenberg, A, FR-SDS Ltd., New Desalination Process for Enhanced Recovery from Brackish Water: Smart System Utilizing Ultrasonic Reflectometry (UR) and Flow Reversal (FR), $180,137

Greenberg, A, Middle East Desalination Research Center, New Desalination Process for Enhanced Recovery from Brackish Water: Smart System Utilizing Ultrasonic Reflectometry (UR) and Flow Reversal (FR), $100,683

Linden, K, WateReuse Foundation, Water Reuse 2030: Identifying Global Challenges, $110,000

Michl, J, National Renewable Energy Laboratory, New Molecular Chromophores Exhibiting Exciton Multiplication and Electron and/or Hole Injection into Water to Photolyze Water to Hydrogen and Oxygen, $66,261

Pellegrino, J, Blue Sun Biodiesel, Bench Scale Studies of Algae Dewatering-Lysing-Oil Extraction and Water Reuse via Membrane Hybrid Processes, $33,522

Schaefer, K, Clark University, Carbon and Water Flux Responses to Extreme Weather and Climate Anomalies: A Fluxnet Synthesis, $51,765

Smyth, J, National Science Foundation, Water in the Mantle: Effects of Hydration on Physical Properties of Mantle Minerals - Accomplishment Based Renewal, $107,241

Tolbert, M, NASA, Laboratory Studies of Aerosol Optical Properties, Water Uptake, and Phase Transitions, $141,022

Weimer, A, Sandia National Laboratories, High Efficiency Generation of Hydrogen via Solar-thermal Chemical Water Splitting Cycles (STCH), $318,791

Zagona, E, U.S. Department of the Interior/Bureau of Reclamation, Decision Support Program for Management of the Truckee-Carson Watersheds and River System, $82,000

Calendar

July

22-24 **Colorado Water Workshop 34th Annual Meeting; Mt. Crested Butte, Colorado**
Legal, biological, ecological, historical, and economic aspects of non-consumptive use.
http://www.western.edu/water/

August

4-7 **EmCon 2009; Fort Collins, Colorado**
Discuss findings in emerging contaminants in ecosystems and drinking water.
http://www.emcon2009.com

13 **2009 Rocky Mountain Water Reuse Workshop; Golden, Colorado**
This year's theme is "Purple Mountain Majesties — Water Reuse in the Rockies."
http://www.watereuse.org/sections/colorado

16-20 **StormCon 2009; Anaheim, California**
The world's largest stormwater pollution prevention conference.
http://www.stormcon.com

16-22 **World Water Week; Stockholm, Sweden**
The leading annual global meeting place for the planet's water issues.
http://www.worldwaterweek.org

19-20 **2009 Colorado Water Congress Summer Convention; Steamboat Springs, Colorado**
http://www.cowatercongress.org/default.asp

30-2 **Distribution Systems Symposium & Exposition (DSS); Reno, Nevada**
http://www.awwa.org/index.cfm

30-2 **2009 Annual Water Symposium; Scottsdale, Arizona**
This year's theme is "Managing Hydrologic Extremes."
www.hydrosymposium.org

September

12 **Ag Day 2009; Fort Collins, Colorado**
The 28th Annual Ag Day at Hughes Stadium, hosted by agricultural organizations and associations.
http://agday.agsci.colostate.edu

13-16 **24th Annual WateReuse Symposium; Seattle, Washington**
The world's preeminent conference devoted to water reuse and desalination.
http://www.watereuse.org/conferences/symposium/24

26 **Tunnel Days; Gunnison, Colorado**
Centennial celebration of the Gunnison Tunnel.

October

2-5 **2009 Theis Conference—Ground Water and Climate Change; Boulder, Colorado**
Addresses groundwater and climate change.
https://info.ngwa.org/servicecenter/Meetings/Index.cfm?meetingtype=cf

6-8 **H20-XPO for Water and Wastewater; Louisville, Kentucky**
http://www.nrwa.org

7-9 **Sustaining Colorado Watersheds Conference; Vail, Colorado**
4th Annual Watershed Conference with the theme "Thriving in Challenging Times."
www.coloradowater.org

14-15 **Platte River Symposium; Kearney, Nebraska**
A review of research and innovative programming related to the Platte River.
http://watercenter.unl.edu/archives/PlatteRiverSymposium2009.asp

21-22 **20th Annual South Platte Forum; Longmont, Colorado**
www.southplatteforum.org

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Vehicles were left stranded in the aftermath of the 1976 Big Thompson flood. (Image courtesy of Water Resources Archive, CSU)