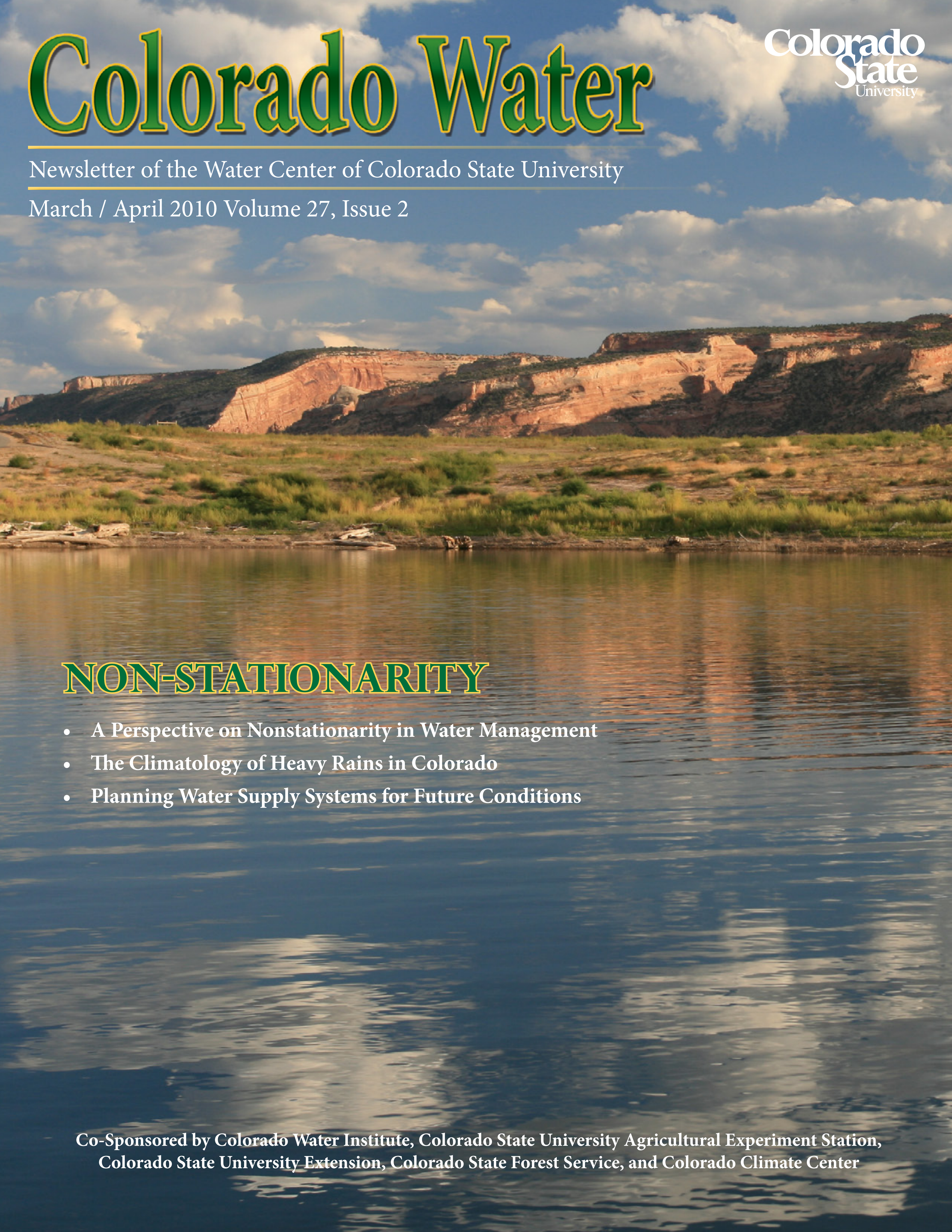

Colorado Water

Colorado State University

Newsletter of the Water Center of Colorado State University

March / April 2010 Volume 27, Issue 2

NON-STATIONARITY

- A Perspective on Nonstationarity in Water Management
- The Climatology of Heavy Rains in Colorado
- Planning Water Supply Systems for Future Conditions

Co-Sponsored by Colorado Water Institute, Colorado State University Agricultural Experiment Station, Colorado State University Extension, Colorado State Forest Service, and Colorado Climate Center

Highlights

In Every Issue

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Cover photo: The red rocks of Colorado National Monument are a backdrop for reflections in the Colorado River. (photo by Laurie J. Schmidt)

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Editorial

by Reagan Waskom, Director, Colorado Water Institute

In their 2008 paper in the journal *Science*, Milly and his colleagues proclaimed, "Stationarity Is Dead" and went on to ponder, "Whither Water Management?" Their thesis was that climate change undermines a basic assumption that historically has facilitated management of water supplies, demands, and risks.

Most statistical forecasting methods are based on the assumption that a series can be rendered approximately stationary through the use of mathematical transformations. A stationarized series is relatively easy to forecast: you simply predict that statistical properties will be the same in the future as they have been in the past.

Water managers have always known our world is inherently nonstationary, and they routinely deal with this in management and planning. Changes in land use, declining groundwater levels, and urbanization are all examples of nonstationarity within a watershed. The relevance of this problem depends on your time horizon—operational decisions occur on a very short interval, while water supply planning may have a 50-year or longer time scale.

The point is that as climate varies and changes, planning for the long-term average yield and the past 100 years of hydrologic extremes may result in failed or unsafe systems. Uncertainty is a given in water planning; we have always planned for both tails of the distribution, both floods and droughts. As we approach the limits of the water resource, these perturbations become more expensive and disruptive, requiring us to develop a broader understanding of the range of hydrologic futures that we may face.

System planners must consider both safety and optimization. To do this they need flexibility and adequate margins of safety. Robust planning gives us the ability to deal with change or surprises from any source, not just climate or growth. Given nonstationarity, what are the correct decision rules and best planning guidelines? This is not a rhetorical question, but one that water supply managers and planners must find a solution for. What guidance can climate and water scientists give these professionals?

Downscaling general circulation models (GCMs) may represent cutting-edge climate science, but that does not guarantee reliable results that water planners can use now. The difficulty lies partially in the handoff of uncertain climate projections to hydrologic models. The recent Water Utilities Climate Alliance report indicated that current coupled models do not currently provide reliable water supply planning information. This does

not mean the models are not useful or that we should not downscale GCMs—it just means you cannot rely on the predictions. Modeling is essential for understanding a system as large and complex as global climate, but direct measurement of snowpack, stream flow, and groundwater levels are critical for robust planning.

Another interesting dimension of nonstationarity is the way that we communicate this information to the media and general public. For example, scientists and planners understand that the single line that puts a property either in or out of the 100-year floodway is not truly binary in reality, but is a continuum that incorporates uncertainty and risk. The public sees this differently, in part because of the way it affects their wallets, and in part because of how we communicate these concepts.

Healthy skepticism is an important aspect of any scientific process. However, recent public survey data point to a crisis of public confidence in climate science. These surveys indicate that a large segment of the public questions climate scientists' interpretation of the data and models, as well as their motives. Scientists understand that there is always uncertainty and error terms; in our minds this does not invalidate the observations and model output. The public understands this differently.

Climate and water scientists must become more sophisticated in how they communicate to reverse this loss of public confidence. Not only does our science need to be robust, but we must also take responsibility for accurate, clear, and non-advocacy communication of complex science concepts.

Planning Water Supply Systems for Multiple Future Conditions

by Marc Waage, *Manager of Water Resources Planning, Denver Water*

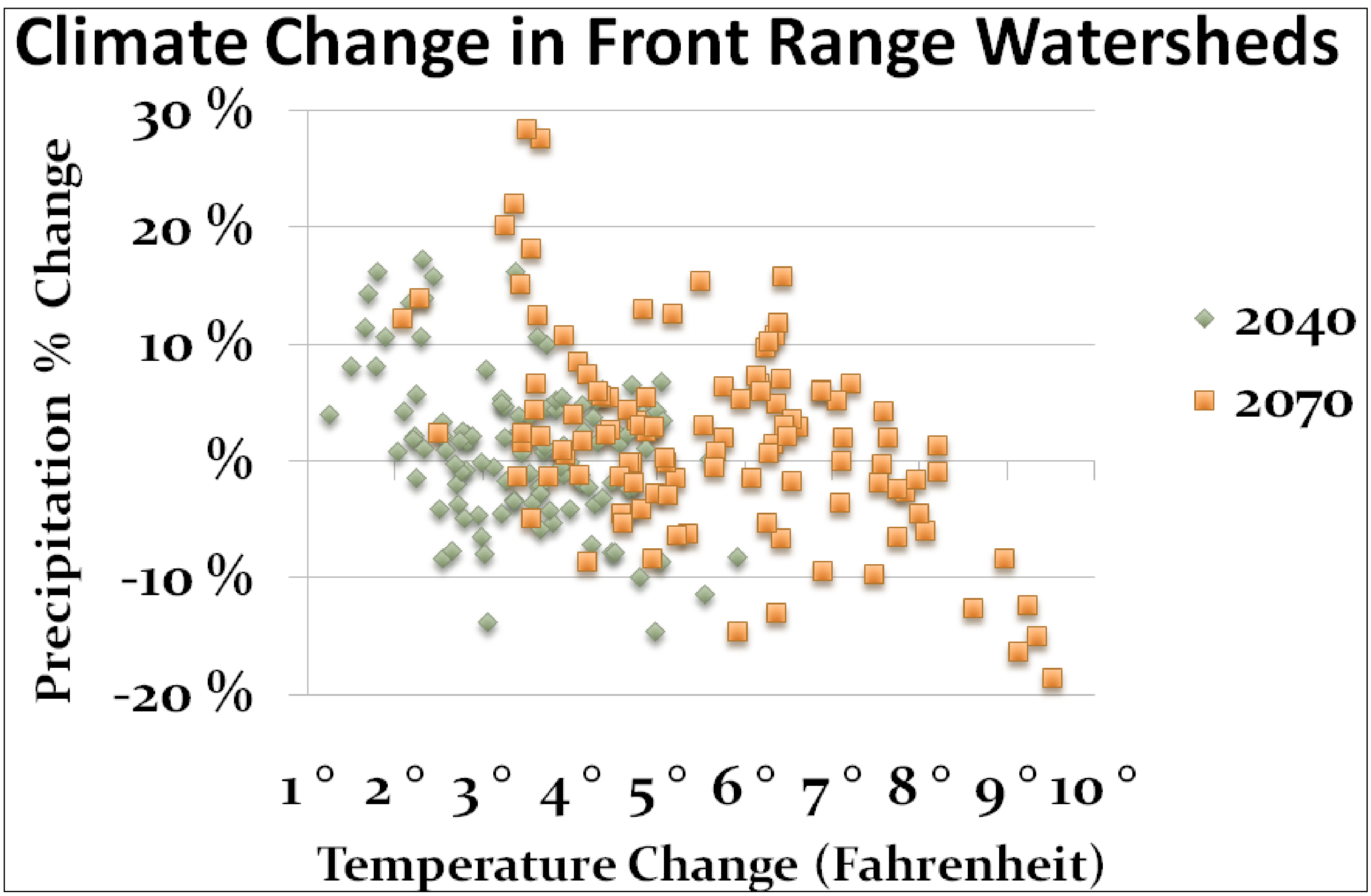
and Laurna Kaatz, *Climate Adaptation Coordinator, Denver Water*

In Colorado, water supply planners rely on the past to predict future water conditions. Many parts of the state have more than 100 years of streamflow and weather data (or hydrology data) that water supply planners use to understand and prepare for the state's highly variable hydrology. But climate change threatens that practice. With climate change, hydrologic patterns are expected to fundamentally shift, and, unfortunately for Colorado, there is a wide range of possible shifts. Water planners now must prepare for past hydrologic variability, as well as the possibility of future shifts in hydrologic patterns. To accomplish this, water suppliers need to consider new planning techniques to prepare for multiple possible future conditions.

Why We Need to Plan for Multiple Outcomes

Past hydrologic records are still our best guide to future water supply conditions. Many water suppliers use sophisticated techniques for analyzing and reconstructing hydrologic records, including growth rings from old trees to estimate streamflow from hundreds of years ago. These techniques have helped water providers prepare for the state's highly variable climate, but it only prepares utilities for one outcome—the repeat of past hydrologic patterns, also known as climate stationarity. In order to prepare for a changing climate, planners need new techniques that incorporate multiple possible climatic conditions.

Figure 1 shows projected temperature and weather changes for the upper portions of the South Platte, Colorado, and Arkansas Rivers. Most of Colorado's municipal water supply comes from this area. Weather records show that this area is warming, and climate models project even more warming. But climate modelers do not agree on how much and how quickly it will warm, and the stakes are high. A simple analysis of Denver's mountain watersheds showed a warming



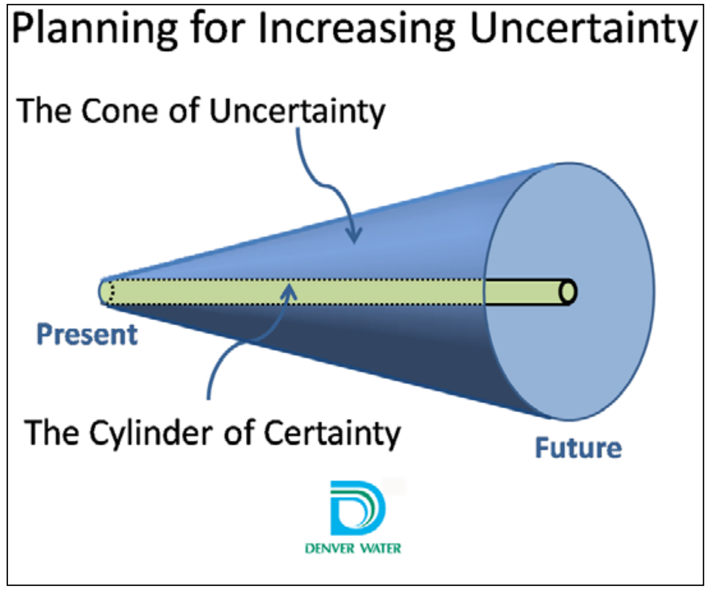
The above illustration shows climate model projections of the average change in precipitation and temperature by 2040 and 2070 for Denver's watersheds. The projections are 30-year averages taken from 112 statistically downscaled projections from 16 climate models used to simulate low, medium, and high emission paths and are compared with 1950-1999 averages. (Information courtesy of the Joint Front Range Climate Change Vulnerability Study) of 5 degrees Fahrenheit would cause a 14 percent decline in water supply—roughly the amount of water used by 100,000 Denver households. But the real wild card is what will happen with precipitation. As shown in Figure 1, about half of the climate models project declining precipitation, while the other half project an increase. Declines in precipitation can cause much greater losses of supply than can warming.

By assuming climate stationarity, the largest variable Colorado municipal water providers have planned for is the state's intense but sporadic population growth and changing water use patterns. Climate change is now a key planning variable, and several others are emerging. For example, in the last decade, Denver's watersheds underwent fundamental changes. In 2002, a severe drought caused streamflow in the South Platte River to dip to the lowest levels on record. And the 2002 Hayman Fire, the largest forest fire on state record, destroyed thousands of acres of forest in an area already damaged by the 1996 Buffalo Creek Fire. Those fires caused sediment problems in the South Platte watershed, and managing those problems now costs Denver Water tens of millions of dollars. In the West Slope watersheds, pine beetles have killed nearly all of the lodgepole pine trees, which increases the risk of wildfires and quality degradation. Along with continuing changes to the state's climate and watersheds, many water suppliers in Colorado now grapple with how to prepare for shifting social, political, regulatory, environmental, and economic conditions. With so many variables, water providers need new techniques to prepare for a much greater range of possible future conditions.

Four Promising Multiple Outcome Planning Methods

The Water Utility Climate Alliance, in an effort led by Denver Water, identified and evaluated municipal water planning methods specifically designed to prepare utilities for many possible future conditions. In January 2010, the Water Utility Climate Alliance published a guide for water utilities, titled *Decision Support Planning Methods: Incorporating Climate Change Uncertainties into Water Planning*. The report found that while some water utilities have been using multi-outcome methods for many years, most are not. The following five methods were evaluated for their use in municipal water planning:

- Classic decision analysis uses estimated probabilities of future events to mathematically evaluate and rank decision alternatives against multiple, and potentially conflicting, decision objectives and to determine strategies that minimize expected future cost.
- Traditional scenario planning seeks to identify near-term actions that prepare a utility for several different plausible, and often provocative, future scenarios.



- Robust decision-making uses complex modeling processes and combines features of both decision analysis and scenario planning to develop adaptation hedging strategies for a large number of plausible future conditions.
- Real options helps water managers identify water supply strategies that adjust over time and balance risks.
- Portfolio planning is used in the financial world to select a portfolio containing a mix of assets or strategies that minimizes financial exposure due to future market scenarios.

Figure 2 demonstrates the difference between planning for a repeat of the past and planning for a growing range of possible future conditions. The *Cylinder of Certainty* represents a projection of the future from the past, particularly in terms of repeating hydrology. The cylinder contains variability, but that variability is limited to what has happened in the past. The *Cone of Uncertainty* represents uncertainties that grow over time, such as climate, social, environmental, regulatory, political, and economic changes. Scenario planning tries to identify several points on the end of the cone and develops near-term strategies to simultaneously prepare utilities for those future conditions. Using complex modeling, robust decision-making tries to identify 100 or more points on the end of the cone and develops hedging strategies to prepare utilities for those conditions. Both methods seek no-regret (or low-regret) strategies that provide the utility with flexibility to react to a range of future conditions. Decision analysis, real options, and portfolio planning estimate the probabilities of reaching various points on the cone and determine strategies that minimize expected future costs.

Examples in Colorado

There are several examples of water planning processes in Colorado that use multi-outcome techniques. Denver Water has added scenario planning to its integrated resource planning process. As part of that process, planners identified five planning futures to represent various plausible changes in social, regulatory, environmental, economic, and climatic conditions and treated each planning future as equally likely to occur. Planners are now seeking near-term strategies that simultaneously prepare the utility for each of the planning futures.

Denver Water also is conducting a pilot project on robust decision-making to determine if modeling processes can be developed to support this computational planning technique. Front Range water utilities are using a scenario process to evaluate a range of possible climate changes to their watersheds. The Colorado Water Conservation Board (CWCB) uses the same scenario process to evaluate possible effects of climate change on water available to the state under the Colorado River Compact. The CWCB is also using a simple scenario process to represent uncertainties about future supply and demand conditions in its statewide water planning effort.

Evaluation of Methods

There is no "one-size-fits-all" method. Every planning process must be tailored to the needs and capabilities of the water utility. For utilities that are not interested in methods requiring sophisticated computing or modeling, scenario planning is fairly intuitive and can be accomplished with minimal external resources. On the other hand, utilities looking for, and confident in, a probabilistic assessment may look to decision analysis. Utilities that want to invest more resources and rigor into planning efforts may want to consider more advanced computational methods or hybrid methods, such as robust decision-making, real options, or portfolio planning.

As water utilities plan for a greater range of future conditions, they are no longer developing plans for one projection of the future. They are seeking robust strategies that may not be optimum for any one projection of the future, but in the long run, they will provide water utilities with better options and more flexibility to adapt to changing conditions.

We Need Your Help

Only a handful of water utilities have reported using multi-outcome planning methods. Denver Water and the Water Utility Climate Alliance are interested in promoting more research, evaluation, and development of multi-outcome water planning methods, as well as encouraging more use of these methods by the water industry and sharing utilities' experiences through case studies. We encourage you to read our guide, found at www.wucaonline.org, and give us your feedback.

USGS science for a changing world

Recent Publications

Anthropogenic Organic Compounds in Source Water of Selected Community Water Systems that Use Groundwater, 2002-2005 by J.A. Kingsbury http://pubs.usgs.gov/sir/2009/5200
Comparison of 2006-2007 Water Years and Historical Water-Quality Data, Upper Gunnison River Basin, Colorado by P.A. Solberg, B. Moore, and D. Smits http://pubs.usgs.gov/ds/462
Development, Testing and Application of a Coupled Hydrodynamic Surface Water / Groundwater Model (FTLOADDS) with Heat and Salinity Transport in the Ten Thousand Islands / Picayune Strand Restoration Project Area, Florida by E.D. Swain and J.D. Decker http://pubs.usgs.gov/sir/2009/5146/
Evaluation of LiDAR - Acquired Bathymetric and Topographic Data Accuracy in Various Hydrogeomorphic Settings in the Lower Boise River, Southwestern Idaho, 2007 by K.D. Skinner http://pubs.usgs.gov/sir/2009/5260
GWM - 2005 - A Groundwater management Process for MODFLOW 2005 with Local Grid Refinement (LFR) Capability by D.P. Ahlfeld, K.M. Baker, and P.M. Barlow http://pubs.usgs.gov/tm/tm6a33
Occurence of Volatile Compounds in Selected Urban Streams in the United States, 1995-2003 by D.A. Bender, G.C. Delzer, C.V. Price, and J.L. Graham
Analysis of Dissolved Selenium Loading from Surface Water and Groundwater to Sweitzer Lake, Colorado, 2006-2007 by J.C. Thomas http://pubs.usgs.gov/sir/2009/5048

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

A Perspective on Nonstationarity in Water Management

by Robert M. Hirsch, Research Hydrologist, U.S. Geological Survey

Hydrologic frequency analysis is central to the planning and operations of virtually all water resources projects. These projects are designed and operated to "trim the tails" of the frequency distribution. The flood control aspects of the project trim the upper tail, and the water supply or navigation aspects trim the lower tail. Design and operating strategy choices are based on evaluation of trade-offs between the residual risk (flood risk or water supply shortage risk) and the cost of risk reduction. All of these methods are predicated on the idea that we use available historical hydrologic data to estimate the relevant frequency distributions and simulate the impact of the project design and operating strategies on the relevant hydrologic variables (e.g., the annual peak discharge frequency curve or the annual 7-day low flow frequency curve). The implicit assumption in all such analyses is that the hydrologic record of the past is the best guide to what can be expected in the future. In statistical terms, the system is stationary. But it is widely recognized and accepted in the hydrologic community that the stationarity assumption may be invalid in many cases. Below are three categories of reasons why the assumption may be invalid:

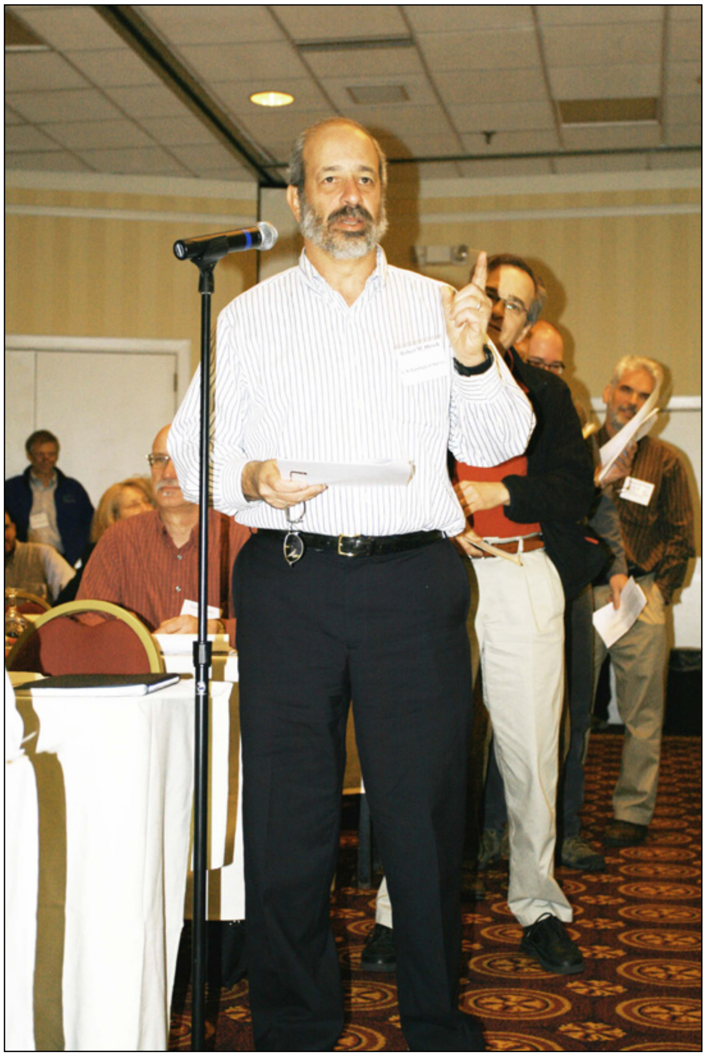
> "We cannot afford such a rigid view of the scientific enterprise. The only way to figure out what is happening to our planet is to measure it, and this means tracking changes decade after decade and poring over the records."
>
> Ralph Keeling, author of *Recording the Earth's Vital Signs*

1. Human modifications to the hydrologic system upstream of the project.

These modifications include urbanization (increased impervious surfaces), land-use modification such as conversion of forest land to crop land, or groundwater development leading to decreases in base flow to streams. The good news is that the physical processes that drive the hydrologic change are reasonably well understood, and there are reasonably accurate predictive models that can adjust the past hydrologic record to a state that represents (assumed) future conditions of the watershed. The challenges involve the accuracy of the model that translates the watershed change into changes in hydrologic response and also the accuracy of the forecasted changes in watershed conditions. These problems are relatively tractable, but they do present significant scientific challenges, particularly for some of the processes with long lag times, such as deforestation-reforestation or groundwater depletion.

2. Natural climate phenomena are quasi-periodic and lead to high degrees of hydrologic persistence.

This category centers on phenomena such as El Niño Southern Oscillation, Pacific Decadal Oscillation, and Atlantic Multidecadal Oscillation. All of these phenomena have characteristic temporal scales, and all have documented impacts on temperature, precipitation, and hydrologic conditions on land. For example, El Niño years are likely (but not certain) to produce wetter than normal conditions across large parts of the southwestern United States. However, at present, the ocean and atmospheric science communities are not able to provide long-range predictions of the timing of these phenomena, their intensity, their duration, or their specific impacts on weather over land. One reason that these quasi-periodic phenomena are important to planning is that some parts of the United States appear to get "stuck" in a particular climate state for many decades. Thus, the sample of hydrologic values collected may represent mostly one state, but the future operations may take place in another state. Examples of this include the a on a few decades of very wet conditions about a century ago. Another example is the Red River of the North, which experienced a highly persistent pattern of very high precipitation in the late 19th century and in the late 20th and early 21st centuries. Flood-control projects were designed based on a period of much smaller floods that covered the first half of the 20th century. Hydrologic science, since the work of Hurst, has attempted to provide a clear mathematical construct to understand and model these phenomena. Regardless of whether this is called "non-stationarity," it points to the importance of hydrologic analysis making maximum use of a wide range of information sources to help characterize the system. These include historic records, paleo-records, and linkages to distant land or ocean systems for which better records are available.



Robert M. Hirsch, research hydrologist with the U.S. Geological Survey, poses a question to panelists at the Workshop on Nonstationarity, Hydrologic Frequency Analysis, and Water Management held in Boulder on January 13-15, 2010. (Colorado Water Institute photo)

3. Climate change induced by human-driven changes in the global atmosphere, primarily the enrichment of greenhouse gases.

The third category is climate change, as driven by human activity on a global scale. The modeling and theoretical climate literature contains a rich discussion about the expected impacts of enhanced greenhouse forcing on hydrologic conditions in general and on hydrologic extremes in particular. The general view from the climate modeling community is that enhanced greenhouse forcing is likely to lead to greater hydrologic variability (bigger floods and deeper and longer droughts). Many climate researchers suggest that very intense precipitation events are becoming more common, and that prolonged periods of low precipitation are also becoming more common. However, when it comes to the response of rivers and groundwater to these changing climate phenomena, the results are much less clear.

Given that continued increases in greenhouse gases is a virtual certainty for many decades to come, and given the plausible linkage between greenhouse gases and hydrologic frequency distributions, there is a need for guidance on how practitioners should proceed. The evaluation of this linkage must proceed on dual tracks—one based on climate system simulations, attempting to test and improve the aspects of the models that are important to hydrology; and the other an empirical track, which views the past century as an unplanned experiment. With that in mind, we must collect and analyze the data on the hydrologic system to see if we can tease out signals that indicate what greenhouse forcing is doing to the hydrologic system. The availability of long records (at the scale of a century) is vital to this enterprise, given what we know about the high degree of persistence in hydrologic records. What is needed is not so much data at many locations, but continuity of data and continuity of data analysis. Analysis of precipitation data is important, but it is not a substitute for analysis of streamflow data.

Given all of the reasons for non-stationarity discussed here, it is imperative that ongoing precipitation, streamflow, soil moisture, groundwater, snow pack, and glacier measurements be given high priority. In addition, the changing character of our globe and our individual watersheds makes it imperative that hydrologic frequency analysis be kept current, and that the analysis be open to considering statistical models in which statistical populations have the potential for abrupt or gradual shifts. In closing, I would like to quote Ralph Keeling on the subject of observation and understanding of the Earth: "A continuing challenge to long-term Earth observation is the prejudice against science that is not directly aimed at hypothesis testing. At a time when the planet is being propelled by human action …*We cannot afford such a rigid view of the scientific enterprise. The only way to figure out what is happening to our planet is to measure it, and this means tracking changes decade after decade and poring over the records.* ("Recording the Earth's Vital Signs," *Science*, 2008)

For more information on the 2010 Workshop on Nonstationarity, Hydrologic Frequency Analysis, and Water Management, visit: www.cwi.colostate.edu/nonstationarityworkshop/index.shtml

The Climatology of Heavy Rains in Colorado

by Nolan Doesken, Colorado Climate Center, Department of Atmospheric Science, Colorado State University

Most people don't ever give it a thought. It's totally taken for granted until something bad happens. But anywhere you go in Colorado and across the nation, the infrastructure we rely on—our streets, highways, communications systems, power transmission lines, railroads, public and commercial buildings, parking lots, sewers, and even the gutters and downspouts on our houses—are designed and built with intense rainfall in mind. In rural areas, ditches, culverts, and bridges are the most visible structures designed for specific rainfall standards. Feedlots, fuel, and fertilizer storage areas and other regulated commercial enterprises are also built to withstand certain rainfall rates, as are farm ponds and dry dams designed by the old "Soil Conservation Service" decades ago. Even our "big box" retail stores have to take heavy rain into account. Have you ever considered how much an inch of rain on the roof of the nearest Wal-Mart store weighs?

Analyzing Rainfall Frequencies

Extensive work was done across the country in the 1940s–1960s processing weather station data back to the late 1800s to estimate the frequency of various rainfall intensities and durations. Engineers need this information to design structures that will safely accommodate heavy rain and the flooding that may result. Some low-risk structures may only be designed to withstand a 10-year or a 25-year storm, while others may be engineered to withstand 50- or 100-year storms without experiencing significant flooding. In many areas, building codes are written to take this sort of information and decision making into account. The engineers who designed the Interstate Highway system in the 1950s and 1960s were major users of rainfall frequency information.

The U.S. Weather Bureau Technical Paper 40 (T.P. 40) by D. M. Hershfield, published in 1961 and titled *Rainfall Frequency Atlas of the United States for Durations from 30 Minutes to 24 Hours and Return Periods from 1 to 100 Years* was a landmark publication when it first appeared. This publication is now nearly 50 years old but has remained a design standard for many parts of the country. Here in Colorado and in other western states T.P. 40 was much too generalized for our mountainous regions. In 1973 the "Precipitation Frequency Atlas of the Western United States" was completed with separate volumes for each of 11 western states. This atlas utilized methodologies to estimate variations in rainfall frequency in complex terrain, and 37 years after its publication, it remains the standard reference for design studies and engineering applications.

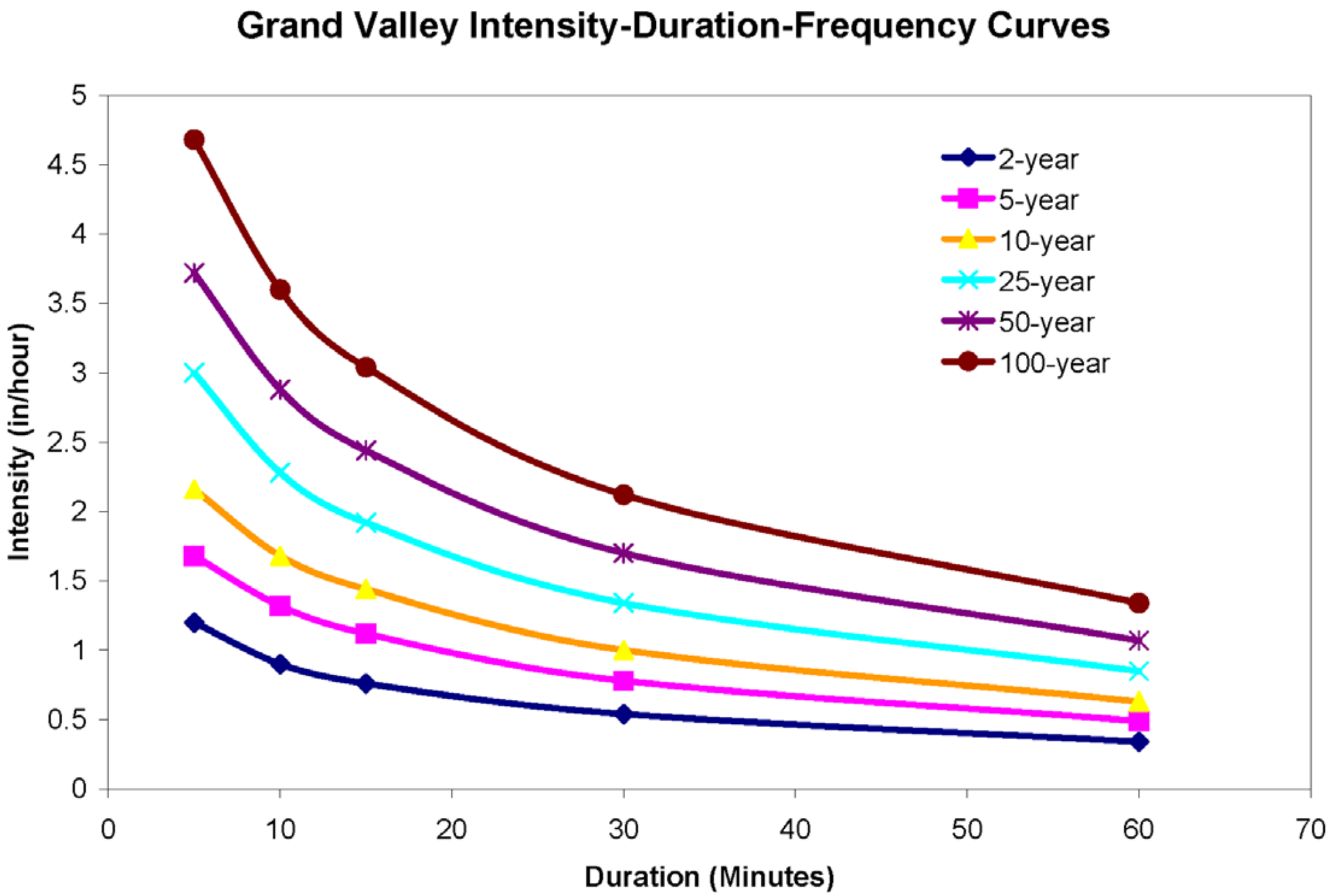
Most of us who refer to the 1973 NOAA Atlas are a little uneasy about still using it today. After all, the most recent data used in that report came from the late 1960s. Back then, there were only a few stations then with 25 or more years of data measured at hourly increments, and few of those were in the mountains. Much more data are available now for assessing both short duration and long duration storms. Still, in hindsight, the 1973 NOAA precipitation frequency atlas was an excellent piece of work and has served our state very well. (www.weather.gov/oh/hdsc/PF_documents/Atlas2_Volume3.pdf)

Are Things Changing?

What we design and build today will need to serve for many decades into the future. Are we using the best information to build for a future with potential climate change? This is a tough question. There is much uncertainty about what Colorado precipitation patterns will be in the future. Will it be wetter? Drier? More extreme? The current generation of computer models probably isn't able to confidently tell us this information. Precipitation is so variable that identifying trends and change will remain extremely difficult. So far, observations of heavy rainfall continue to show large variations with occasional extreme events. An increase in extreme hydrologic events has apparently been observed in some parts of the country, particularly the northern tier of states, but so far nothing stands out here in Colorado.

Precipitation Frequency Update

The Colorado Water Conservation Board is working now to finalize a contract with the National Weather Service to participate in the Precipitation Frequency Project for the Midwestern states. While we wait for this contract to be finalized, Colorado is included in the early phases of this project, and data processing has begun. Within five years we should have comprehensive state and region wide updates and enhancements to all of our precipitation frequency statistics, including the addition of 500-year storm estimates. Hopefully, there will also be an evaluation of the area-reduction methodology and assumptions that are needed to extrapolate point rainfall frequency data to larger basins and regions. To get a glimpse of what these future products will look like, visit: http://www.weather.gov/oh/hdsc/.



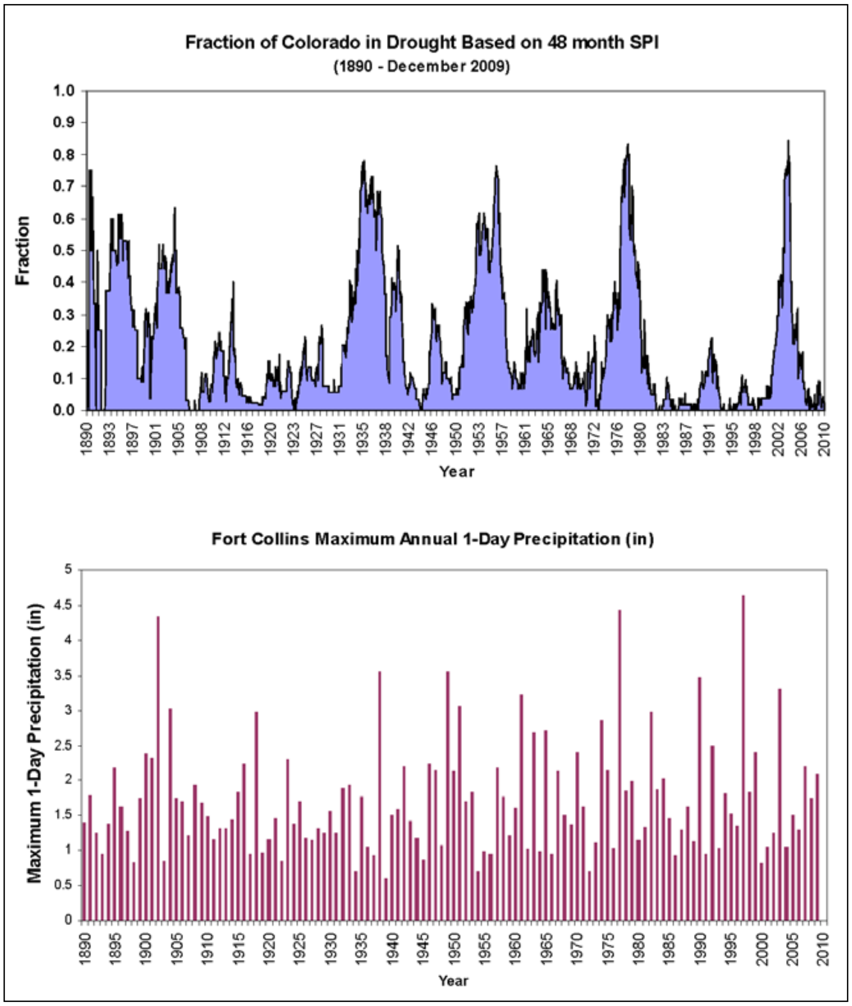
Intensity-Duration-Frequency Curves for the Grand Valley, Colorado. (Courtesy of Colorado Climate Center)

The Really Big Storms

Storms of the 25-year, 50-year, and even 100-year magnitude are a routine part of life. But as we learned here in Fort Collins in July 1997, things can and do get much worse. In the 1990s, we had the opportunity to assist on a project for the Dam Safety branch of the Colorado State Engineers Office. It was an eye opening experience. We were asked to identify and document all the largest storms that have ever occurred in or near Colorado. These are the real monsters—double, triple, or quadruple the 100-year rainfall amounts from the NOAA precipitation frequency atlas.

We started with the infamous flood of 1864, which forced the relocation of Fort Collins and parts of Denver, and we worked our way into the 1990s. Here are a few storm events that may catch your attention:

- July 1885, Templeton Gap (near Colorado Springs): 16 inches estimated
- May 1904, northern Larimer County: 10 inches possible; huge flood on Cache la Poudre River
- June 1921, Penrose-Pueblo: Up to 12 inches of rain and devastating flooding in Pueblo
- May 1935, Portions of Kit Carson and Yuma Counties: Up to 24 inches of rain; one of the worst floods in Colorado history ensued
- September 1938, Colorado Front Range: Up to 10 inches; possibly remnants of a tropical storm
- May 1955, Wet mountains above Pueblo: Up to 13 inches of rain
- June 1965, eastern Colorado: A week-long episode of extreme rain events; over 14 inches may have fallen in several areas. Catastrophic flooding, including Plum Creek and the South Platte River through Denver and many other areas.
- July 1976, Big Thompson Canyon: Up to 12 inches of rain in the foothills of Larimer County triggered the most infamous of all Colorado flash floods, with about 140 fatalities.
- July 1981, Frijole Creek near Trinidad: Up to 16 inches



Hydrometeorological variability is a natural part of the climate system. Even during times of drought, heavy rains and flooding are possible. (Courtesy of Colorado Climate Center)

The final report on this storm study was submitted to the State Engineers Office in 1997, and within a few weeks we experienced first-hand the type of extreme rainfall we had described for other times and places. The Fort Collins flash flood occurred with over 14 inches of rain locally, followed the next evening by an even larger storm in terms of area and total runoff; in a few hours, up to 13 inches of rain fell over the Pawnee Creek watershed of northeastern Colorado. Less than two years later in April 1999, the Colorado Springs area was splashed by up to 10 inches of spring rainfall, causing erosive flooding on Fountain Creek and extensive flooding downstream on the Arkansas River.

The July 1997 flash floods in Fort Collins and on Pawnee Creek in northeastern Colorado stirred several special hydrologic studies and a year-long controversial reassessment of the Fort Collins rainfall design criteria for stormwater projects.

Fortunately for Colorado, it has now been over 10 years without another extreme precipitation event. But our history tells us that it's only a matter of time before the next extreme storm hits, and it will most likely be somewhere along the Front Range—where the intersection of mountains and plains tends to focus and exacerbate flood-producing storms. Will we be ready?

What Comes Next?

That, of course, is the big question. A clear finding from past rain gauge and streamflow data is that Colorado's largest storms and most extreme flash floods occur at elevations below about 7,500–8,000 feet, primarily east of the Continental Divide. This is because the bulk of the moisture in our atmosphere is transported in the warmest layers in the nearest few thousand feet above the ground, and the greatest sources of moisture come in summer air masses that originate near the Gulf of Mexico or across the humid Midwestern states. But if the atmosphere continues to warm, there could periodically be more water vapor available to fuel extreme storms at higher elevations, both east and west of the Continental Divide. If this were to happen, we might see more extreme rain events at higher elevations that would lead to dramatic flash floods. Climate scientists and hydrologists are not sure this will happen, but it could. Are we ready?

The 100-Year Storm Happens Often

Ever since engineers and statisticians first coined the phrase "100-year storm," widespread confusion and misunderstanding have ensued. Rainfall frequency data are based on individual weather stations with data from specific points. A 100-year storm refers to the amount of rainfall that occurs during a specified period of time (1, 2, 3, 6, 12, or 24 hours or more than one day) at a point that has a 1% likelihood of occurrence in any given year. For example, for one 6-hour duration, the 100-year storm ranges from just over five inches over extreme southeastern Colorado to less than two inches over some of Colorado's dry western valleys. Yet, almost every year, you will hear of downpours that exceed those amounts. In fact, there can be dozens of these events.

How can this be? Remember, the values are estimates for individual points, and each point may be assumed to represent an area of 10 square miles or less. Colorado covers more than 100,000 square miles, and in any given year there can be many storms that locally exceed the estimate for the 100-year storm. A 100-year storm can also happen two straight years, or even twice in the same year at a given point. That happens with statistics.

Nonstationarity: Another 'Inconvenient Truth'

by Margaret A. Matter, recent Colorado State University graduate, Ph.D. in Civil and Environmental Engineering

Engineering and management of water and related resources are changing from a paradigm of assumed stationarity in the climate/hydrologic system to actual nonstationarity in the system. Until recently, available data indicated that the hydroclimate varied such that mean values essentially did not change over time, or were stationary. This convenient assumption formed the foundation of many methods and tools used to plan, design, and manage water resources projects. But by the mid-1990s, longer data records and other data sets, including paleo data, suggested that natural variability in the hydroclimate was greater than expected and was exacerbated by climate change, modifications to land use, land cover, water use, and other factors. Thus, methods based on the assumption of stationarity are no longer valid.

Subsequent challenges for water resources engineering and management are considerable, especially in semi-arid or arid regions where water demands are increasing to meet growing populations and environmental requirements. It is therefore critical to understand the underpinnings of hydroclimatic variability in order to develop new methods to accurately anticipate, mitigate for, and adapt to effects of changes in climate on water and related resources.

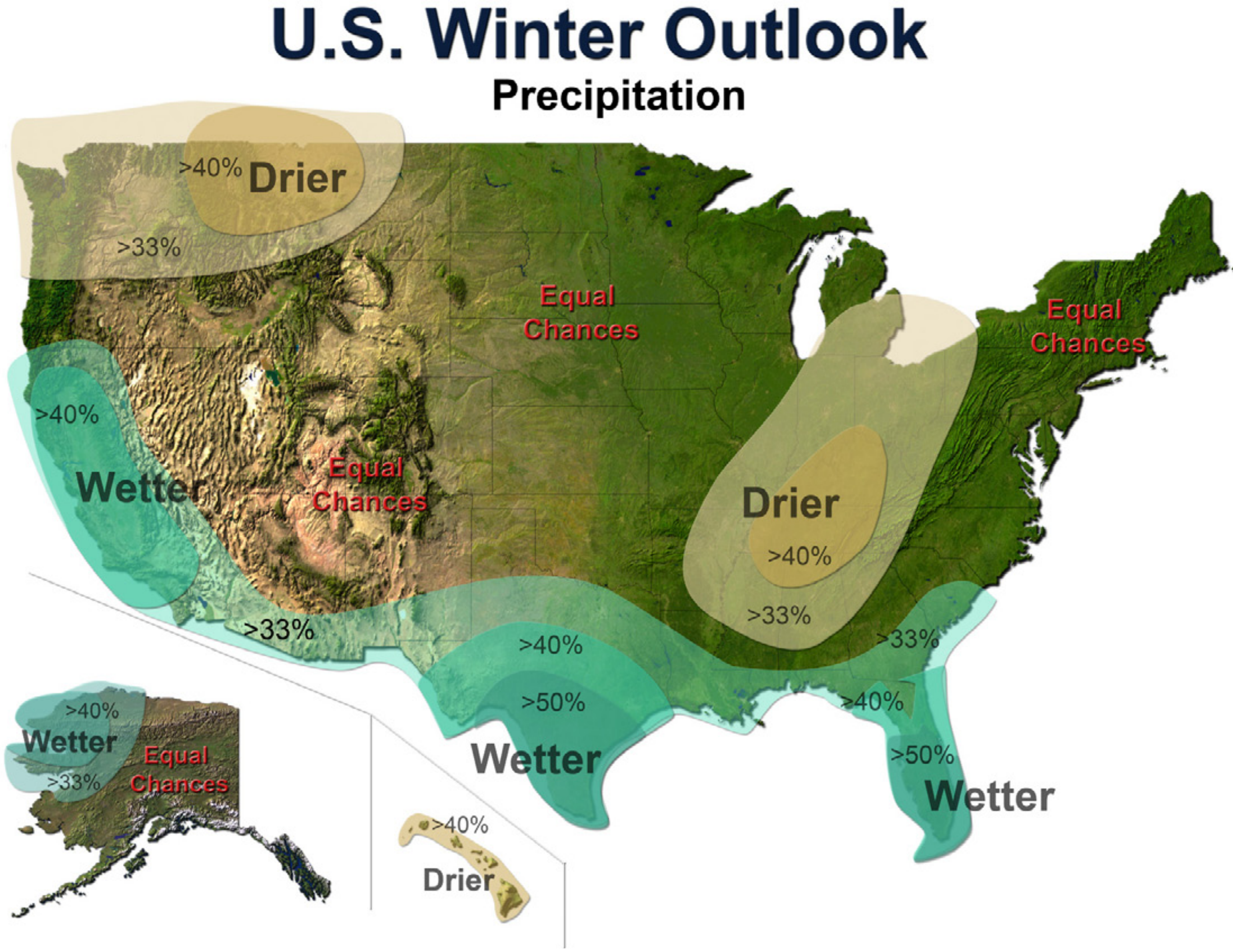
Fluctuations in hydroclimate originate from (1) variations that are part of (i.e., internal to) Earth's climate system, and (2) factors that are not part of (i.e., external to) Earth's climate system. Variations in climate that are internal to the climate system occur over time periods ranging from seconds to thousands of years, and include formation and dissipation of clouds and the large-scale ocean/atmosphere interactions involving changes in sea surface temperatures in ocean regions; for example, El Niño-Southern Oscillation (ENSO), Atlantic Multidecadal Oscillation (AMO), and Pacific Decadal Oscillation (PDO). The ocean/atmosphere interactions are cyclic or oscillatory because of energy checks-and-balances in the climate system. They evolve over time spans of years (e.g., ENSO) to decades (e.g., AMO), causing changes in ocean and atmospheric circulation that affect temperature and precipitation during seasons or over years in different regions of the world.

Combined effects of some ocean/atmosphere interactions shape climate cycles, another form of climate variation. Climate cycles involve prevailing temperature and precipitation conditions (e.g., cool/wet or warm/dry) that persist approximately 25-30 years and change with variations in the ocean/atmosphere interactions. Three climate cycles, shaped by AMO, PDO, and ENSO, occurred in the Colorado River Basin over the 20th Century: a cool/wet, followed by a warm/dry, then a second cool/wet cycle. The two cool/wet climate cycles are similar, but not identical, for reasons including the effects of factors external to the climate system.

Factors that influence hydroclimate but are external to Earth's climate system are external forcings. They may be natural or human-caused, and they affect hydroclimate by influencing internal climate variations (e.g., ENSO, AMO, and climate cycles). Natural external forcings originate from natural phenomena—for example, volcanic eruptions and variations in energy output during solar cycles. Natural external forcings are often episodic (e.g., volcanic eruptions) or periodic (e.g., variations in solar energy output), and consequently affect climate for limited periods of time while the effects dissipate. Human-caused external forcings are due to human activities and are often ongoing, rather than episodic or periodic. Human-caused external forcings include (1) increasing greenhouse gas concentrations in the atmosphere, such as from burning fossil fuels for vehicles, power plants, industry, and heating; (2) modifications to land cover, land use, and water use; and (3) sulfate aerosols, industrial soot, and wind-derived dust, which influence temperature, precipitation, and snowmelt timing.

Geenhouse gases trap heat in the atmosphere, and when concentrations of greenhouse gases are in balance with other elements of the climate system, they contribute to suitable temperatures for life on Earth. However, since the beginning of the Industrial Revolution, greenhouse gas concentrations have been increasing, which traps more heat and changes temperature and precipitation conditions across the globe, affecting the checks-and-balances of the Earth's internal climate system.

The effect of increasing greenhouse gas concentrations on climate is typically called "climate change." Greenhouse gases persist in the atmosphere a long time, allowing concentrations to build up. The rate of build-up increases with population growth and subsequent increases in use of fossil fuels and emission of other greenhouse gases. The effects of climate change, modifications to land use and land cover, and other external forcings interact with one



The NOAA Climate Prediction Center's 2009 Winter Outlook showed that the El Niño in the central and eastern equatorial Pacific Ocean was expected to be a dominant climate factor influencing precipitation in the United States in December through February. (Courtesy of NOAA)

another, and they influence internal climate variations, such as ENSO, AMO, and related climate cycles.

Modifying land use and land cover for food production, recreation, housing, businesses, and other purposes affects regional climate and influences how climate change affects regional climate. Thus, projecting impacts of changes in climate on precipitation and streamflow is complicated by effects of land use, land cover, and water use changes in river basins. Results of recent studies conducted on rivers in the eastern U.S. and on tributaries of the Upper Colorado River suggest that changes in streamflow during the 20th Century are related more to effects of changes in land use, land cover, and water use than to climate change alone. However, results for the Upper Colorado River also suggest that changes in climate, including climate change and climate cycles, exacerbate effects of modifications in land use, land cover, and water use on water resources. Thus, it is critical to understand the interactions among sources of hydroclimatic variability and subsequent effects on water resources. In particular, it is important to determine the physical mechanisms underlying (1) how modifications to land use, land cover, and water use affect surface and ground water resources; and in turn, (2) how changes in climate exacerbate the effects of modifications of land use, land cover, and water use on water resources.

Although nonstationarity in the hydroclimatic system may be "inconvenient" in the near-term, in the long-term, accuracy of projections of effects of changes in climate will improve, and planning, design, and management strategies for water resources projects will be more flexible, adaptable, and robust to accommodate projected variability in hydroclimate.

Questions or comments about this article may be directed to the author at margaret.matter@colostate.edu or (970) 491-7620.

A History of Colorado Water by the Decades

by Neil S. Grigg, Department of Civil and Environmental Engineering, Colorado State University

The evolution of Colorado's water management system makes a fascinating story that involves miners, farmers, cowboys, bankers, and other characters of the Old and New West. Beginning before the 1850s, each decade featured signature events that shaped today's water scene in Colorado. This article traces a few of the most important events that shaped how water is managed today in Colorado and frame our challenges for the future.

> "As it looks to the future, the state sees the need for more water storage, flexible options for water management, water for the environment, and cooperation and coordination."

Prologue: The Early Explorers

While Native Americans had used water in Colorado for centuries, the opening scene for today's management system occurs after the Lewis and Clark expedition of 1804–1806. Lt. Zebulon Pike and Major Stephen Long explored eastern Colorado soon afterwards, and both considered Colorado too dry for settlement. Major Long thought it was part of the "Great American Desert." Soon, trappers and settlers began to arrive over the Oregon and Santa Fe trails. Typical migrants were portrayed in James Michener's book *Centennial*, which includes characters Levi and Elly Zendt, who set out for Oregon but decided instead to travel down the South Platte Valley to settle near today's Greeley, Colorado. By about 1850, scattered groups of settlers were farming and scratching out a living along the Front Range. At the same time, settlers were already in the San Luis Valley, where the People's Ditch was constructed in 1852 as the oldest adjudicated water right in the state. The early settlers along the Front Range had no idea of the disruption about to begin when gold was discovered.

By the 1960s, an era of water infrastructure development had led to the construction of several tunnels and reservoirs in Colorado, including Dillon Reservoir in Summit County. (Courtesy of Laurie J. Schmidt)

1850s: The Colorado Gold Rush

In 1848, Mexico ceded vast areas of land to the United States, including southern Colorado and California, where the gold rush began that same year. On their way to California, a band of Cherokee Indian travelers from Georgia noticed gold at the confluence of Cherry Creek and the South Platte River, and they returned with William Green Russell in 1858 to prospect. Many miners came in 1859 after the California gold fields petered out, and this led to an explosion of mine development and placer mine operations in Colorado valleys. The mining operations had tremendous effects on Colorado streams, such as such as Clear Creek and the Blue River.

1860s: Farm Expansion with Irrigation

Miners and other new arrivals needed housing, food, and supplies, which led to urban expansion and the need for farms and ranches. This stimulated an expansion in irrigation and resulted in new ditches wherever water could be diverted onto productive farmland. Many of Colorado's oldest water rights date back to the 1860s when this agricultural expansion began. As soon as the water ran out, conflicts developed over who would get it.

1870s: Colorado Constitution and the Appropriation Doctrine

One of the conflicts was between upstream and downstream farmers on the Cache la Poudre River, causing serious discussions among Greeley and Fort Collins-area farmers about how to deal with the situation. In 1874, two farming groups met in a schoolhouse in Eaton to figure out how to proceed. Settling this conflict was one of the events that led to the Appropriation Doctrine's inclusion in the Colorado Constitution.

No. 6227

United States of America

DEPARTMENT OF STATE

To all to whom these presents shall come, Greeting:

I Certify That the document annexed is a true copy of the "Colorado River Compact," signed 24th November, 1922, at the City of Santa Fe, New Mexico, the original of which is on file in this Department.

In testimony whereof I, Charles E. Hughes Secretary of State, have hereunto caused the Seal of the Department of State to be affixed and my name subscribed by the Chief Clerk of the said Department, at the City of Washington, this twenty-second day of December, 1922.

Charles E Hughes
Secretary of State.

By
Chief Clerk.

A "true copy" of the Colorado River Compact, signed in 1922. (From the Delph Carpenter Papers Collection; Courtesy of Water Resources Archive, Colorado State University Libraries)

Denver continued to grow in the 1870s, and in 1872, the Denver City Water Company began to deliver water. It constructed a large well with a steam pump that delivered water through about four miles of mains in a city that was nearing 5,000 in population.

1880s: Mining Boom and Bust

The 1880s saw a continuation of Colorado's growth and development of agriculture and cities. Mining expanded with new metals being extracted, but the area soon learned that demand for metals such as silver did not grow. Thus, there were busts as well as booms in the area's growth. Meanwhile, Colorado was clarifying its approach to water management with the appointment of Division Engineers and the organization of the State Engineer's Office.

1890s: Depression and Expansion of Railroading

The Depression of 1893 and William Jenning Bryan's "Cross of Gold" speech during the 1896 presidential campaign framed the economic turmoil of the decade. Colorado continued to grow sporadically with mining, railroading, and urban development. The Denver Union Water Company, headed by Walter Cheesman and David Moffat, became the first city-wide water provider after it was incorporated in 1894. It assumed the assets of the other water companies and obtained a 20-year monopoly franchise to serve Denver.

1900s: Denver System and Cheesman Dam

As the Denver Union Water Company began to serve the full area, it saw the need to expand the system and built Cheesman Dam, which was the world's highest dam when it was constructed. In the decade of the 1900s, Denver's population grew from about 130,000 to nearly 215,000, or an annual rate of about 5%.

1910s: Denver Water Goes Public

The Denver Water Board was created by a vote of the people in 1918 and proceeded to buy out the Denver Union Water Company's system. This set the stage for West Slope water development and launched an era of infrastructure construction that included (by the 1960s) Moffat Tunnel, Roberts Tunnel, Eleven Mile Canyon Reservoir, and Gross, Dillon, and Williams Fork Reservoirs.

1920s: The Colorado River Compact

In 1921–1923, filings were made on West Slope waters on the Blue, Frazer, and Williams Fork, all tributaries of the Colorado River. Even earlier, the West had come to understand the limits of the Colorado River, and a Compact Commission under the leadership of Herbert Hoover was convened to negotiate its use. The Compact was signed in 1922, with Colorado represented by its Compact Commissioner, Delph Carpenter of Greeley. This model for interstate river compacts is studied all over the world.

1930s: Depression and the Conservancy Act

As the 1920s came to an end, the nation entered the deep freeze of the Great Depression, and Franklin Delano Roosevelt's New Deal focused on infrastructure investments as a way to create jobs and stimulate the economy. One of the projects that emerged was the Colorado-Big Thompson project, which had been identified much earlier by northern Colorado water interests as a way to provide much-needed supplemental irrigation water. To make it happen, state leaders agreed to organize the Northern Colorado Water Conservancy District, the Colorado River Water Conservation District, and the Colorado Water Conservation Board. They also agreed to provide compensatory storage to the West Slope in the form of Green Mountain Reservoir.

This 1964 image shows construction of the Blue Mesa Dam on the Gunnison River. (From the Ival Goslin Collection; Courtesy of Water Resources Archive, Colorado State University Libraries)

1940s: War and Postwar

World War II brought the Depression to a halt, and although the nation focused on its defense industry, federal government water planning continued. In 1948, a landmark case in Colorado occurred when Denver Water raised rates on its customers; Englewood sued Denver and, after losing, decided to build its own water system. Other communities followed suit, including Aurora, Boulder, Golden, Morrison, Northglenn, Westminster, and Thornton. This set the stage for the simultaneous occurrence of post-war demand and a 1950s drought that refocused Colorado's attention on its water needs.

1950s: Drought

The drought of the 1950s stimulated large increases in well construction, which would lead to new rules and management approaches to coordinate stream-aquifer interactions. The drought also caused cities, such as Fort Collins, to look for better ways to manage their water needs through planning and acquisition of water rights. Farther west, California began its gigantic State Water Project during the 1950s.

1960s: Dillon Reservoir and Groundwater Regulation

The 1960s were an active decade for water management activities and saw the 254,000 acre-foot Dillon Reservoir come on line to complete Denver Water's development of major West Slope infrastructure. The decade also saw the completion of the Colorado River Storage Project, which featured Glen Canyon Dam in Utah/Arizona and three dams in Colorado: Blue Mesa, Morrow Point, and Crystal Dam. Blue Mesa is Colorado's largest reservoir, with a capacity of 940,000 acre-feet. The passage of the Water Rights Determination Act was a major development in water management rule-making. It required augmentation plans to pump wells that are tributary to surface waters and is still being implemented today.

1970s: The Environmental Decade

The 1970s brought environmental awareness, which seemed to signal the end of the dam–building era, and opposition to water development increased greatly. New federal environmental legislation, such as the Clean Water Act and the Endangered Species Act, added obstacles to new construction approval. Colorado's instream flow act was passed in 1973, marking the first time that water rights could be claimed for environmental uses. In 1973, Denver proposed to add treatment capacity with the Foothills Treatment Plant, which unleashed environmental opposition. The issue was settled in a compromise in which Denver agreed to a strict conservation program and to release instream flows.

1980s: The Two Forks Experiment

In the 1980s, the Two Forks Project became a landmark case study of conflicts between water utilities and environmentalists. It was being studied by Denver as early as the 1890s, and water rights were filed in 1931. After a long and expensive planning process, the project was vetoed by the Environmental Protection Agency. The negotiation process had included a Governor's water roundtable and extensive hearings for the federal permit.

1990s: The Aftermath of Two Forks

The consortium of Metropolitan Water Providers that had proposed Two Forks disbanded after the veto. Denver Water announced that it could no longer serve as the main water supplier for all the suburbs and refused to join a suit to overturn the Two Forks veto. New Front Range water authorities were organized, and Thornton announced a "City-Farm Program" to buy farms and water supplies from Northern Colorado.

2000s: Drought Returns and the IBCC Begins

Drought returned in the early 2000s, and 2002 was one of the driest years on record. The Colorado General Assembly passed the Colorado Water for the 21st Century Act, which established a framework and forum for water discussions with a statewide Interbasin Compact Committee and Basin Roundtables.

2010s: What Will the Future Bring?

As Colorado entered the current decade, it faced a financial crisis rather than frenetic growth. Still, as it looks to the future, the state sees the need for more water storage, flexible options for water management, water for the environment, and cooperation and coordination, such as that envisioned by the Colorado Water for the 21st Century Act. To achieve these will require good ideas from government, universities, and the private sector; working groups to develop consensus to carry ideas through the political process; and perseverance and willingness to work tirelessly on complex issues.

Integrated Decision Support Consumptive Use (IDSCU) Training Course

On April 9, 2010, the Integrated Decision Support Group at Colorado State University will conduct a one day hands-on training course on the use of the IDS Consumptive Use model (IDSCU) and the IDS Alluvial Water Accounting System model (IDS AWAS). These models were developed as part of the South Platte Mapping and Analysis Program (SPMAP), a collaborative effort between IDS and water users in the South Platte Basin. The models are data driven and are being used around Colorado. The course will instruct users on how to create and use templates to develop data sets and access weather data from COAGMET and NCWCD. Features of the IDSCU model that will be discussed include:

- Generating inputs for the model (weather, crop coefficients, water supply, crop data, modeling area information)
- Computing a complete water budget
- Using the model to compare CU values computed with different ET methods
- Modeling crop stress due to water shortages
- Use of user supplied ET values
- Evaluating the application efficiencies of wells by comparing depletions of groundwater computed using a water budget with pumping records multiplied by a presumptive depletion factor

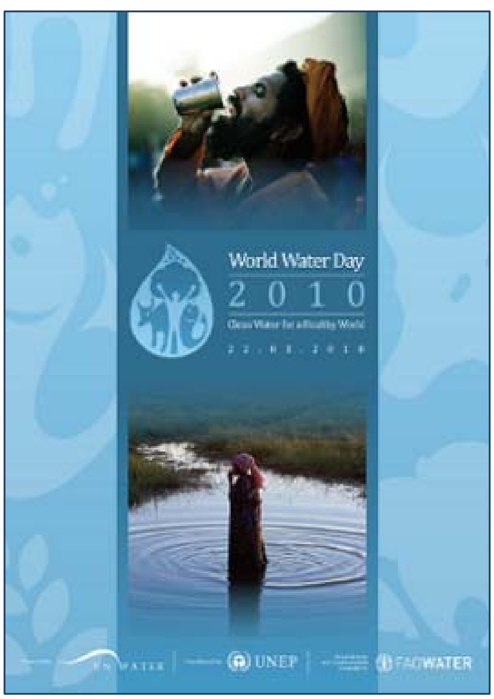
The course will include an introduction to exporting depletion of groundwater information to the IDS AWAS model or generating input files for the IDS AWAS model. Participants will be shown the major features of the IDS AWAS model.

The cost of the course is $250; registration will be limited due to the availability of computers for hands-on training. For more information and to register, visit www.ids.colostate.edu.

World Water Day 2010
22 March 2010
Clean Water for a Healthy World

Colorado State University

COLORADO STATE UNIVERSITY PRESENTS WORLD WATER DAY
in conjunction with Hydrology Days



WHAT: **World Water Day**
WHEN: **Monday, March 22, 2010**
WHERE: **Lory Student Center, Fort Collins, CO**

KEYNOTE: **Dr. John Matthews**
Senior Program Officer of Freshwater Program,
World Wildlife Fund

CSU is hosting its first World Water Day event at the Lory Student Center on March 22, 2010. Activities include a World Water Day Fair, dignitary and keynote speakers, workshops, demonstrations, and community service projects. World Water Day at CSU will highlight local, regional, and global educational and outreach programs.

For more information about CSU World Water Day and Hydrology Days please visit the CSU World Water Day web site at www.globalwater.colostate.edu. To participate, please contact faith.sternlieb@colostate.edu.

Upper South Platte Watershed Assessment Test Case

by Brad Piehl, *JW Associates Inc.*
and GayLene Rossiter, *Colorado State Forest Service*

Severe wildfires pose an immediate threat to water infrastructure and a greater post-fire threat to watershed function and infrastructure through floods, sediment, and debris flows. And, many reservoirs, pipelines, and ditches lie in high to extreme wildfire hazard zones.

Impacts of the 1996 Buffalo Creek and 2002 Hayman fires on the Upper South Platte Watershed have long illustrated the threat of severe wildfires to Colorado Front Range communities and water supplies. Although extensive restoration work has occurred, storms still carry sediment and debris into Strontia Springs and Cheesman Reservoirs. The annual cost to maintain and rehabilitate these reservoirs has been enormous.

During 2006-07, the Pinchot Institute for Conservation assessed wildfire hazards on the Front Range and developed a report on the risk to watershed values and water collection, storage, and transport infrastructures in 10 counties. The report revealed that more than two million acres were classified as high hazard for wildfire in these counties and associated major watersheds. The full report, *Protecting Front Range Forest Watersheds from High-Severity Wildfires*, is available online at www.frftp.org/docs/FINAL_Protecting_Front_Range_Forest_Watersheds_081407.pdf.

In September 2007, the Front Range Watershed Wildfire Protection Working Group was established to evaluate ways to reduce the risks outlined in the Pinchot report and protect source watersheds from severe wildfire damage. Three sub-workgroups now serve under the guidance of this oversight group. In 2008 to early 2009, the Data Refinement Workgroup (Workgroup), one of the sub-groups, built on the Pinchot report results. In addition, they reviewed additional data and refined their technical approach for assessing critical sub-watersheds (sixth-level) with the larger source watersheds (fourth-level). Their goal is to prioritize the watersheds for future potential forest treatments that could reduce the severity of wildfires.

Upper South Platte Watershed Assessment: A Test Case

After the Workgroup developed the technical approach, they used a test case before applying it to other Colorado watersheds. The Workgroup chose the Upper South Platte Watershed because it is well known and studied, a previous prioritization exists to which results can be compared, and some data challenges were present.

Sediment is removed from Turkey Creek in the Upper South Platte Watershed. (Courtesy of Colorado State Forest Service)

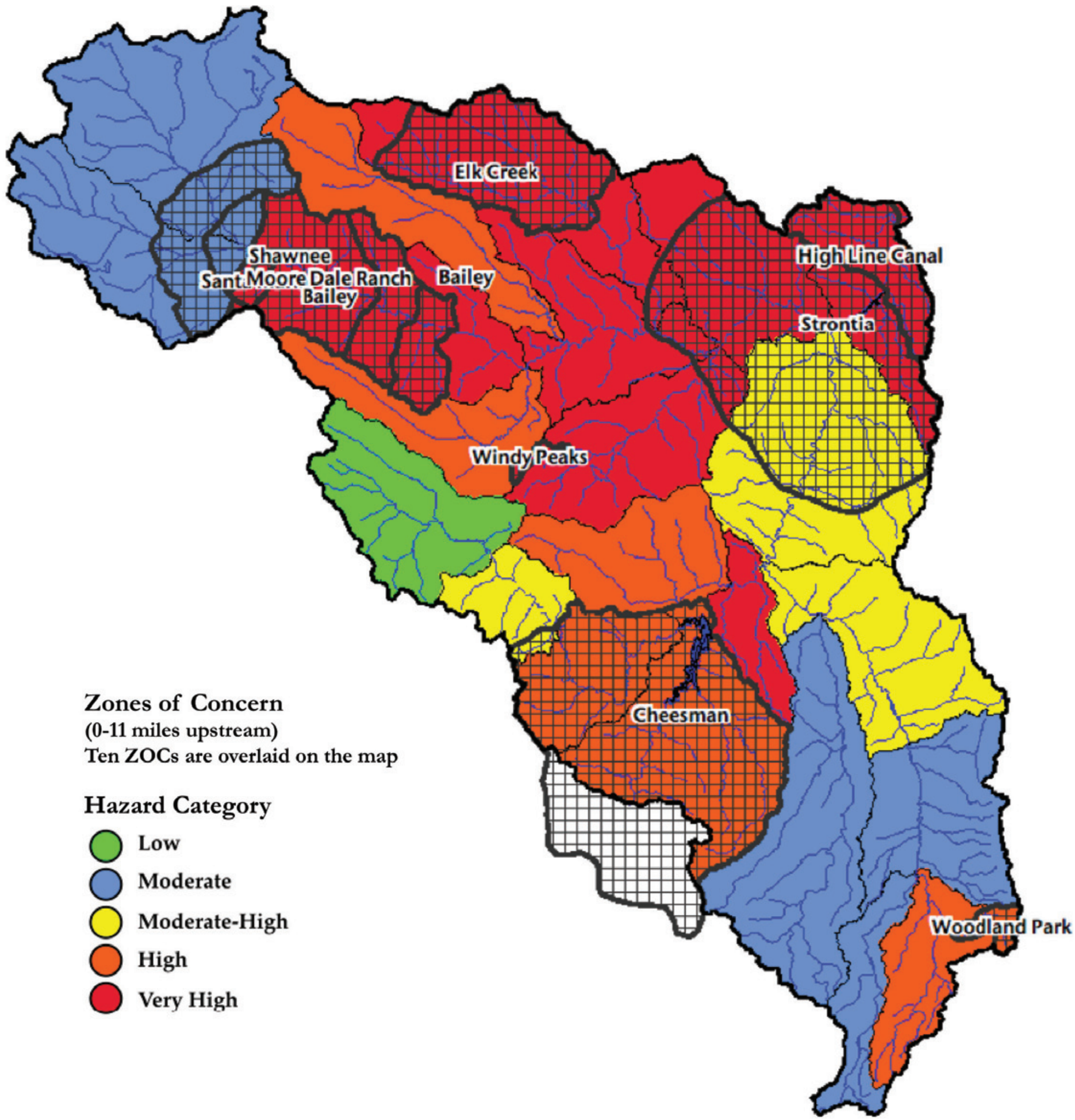
Watershed Characterization

The Upper South Platte Watershed is a fourth-level watershed that is approximately 649,694 acres in area, contains 22 sixth-level watersheds, and provides the City of Denver with 75 percent of its drinking water supply. Because of its close proximity to Denver, the Upper South Platte Watershed provides easy accessibility to fishing, hiking, and other outdoor experiences. The watershed is also home to portions of the Lost Creek and Mount Evans Wilderness Areas. In addition, portions of the South Platte River are designated as a gold medal trout fishery.

Watershed Assessment Components

The potential of a watershed to deliver sediments following severe wildfire depends on forest and soil conditions, and the physical configuration of those watersheds. High-severity wildfires can cause changes in watershed components that may dramatically alter runoff and erosion processes in watersheds. Water and sediment yields may increase as fire affects more of the forest floor.

The Workgroup's watershed assessment consists of four components that are essential to the evaluation of hazardous watershed conditions: wildfire hazard, flooding or debris flow hazard, soil erodibility, and water uses ranking. In addition, the Workgroup uses Zones of Concern to identify upstream areas that may affect downstream water supply facilities. Each sixth-level watershed is assessed and assigned a hazard ranking based on the four components. The hazard rankings



Upper South Platte Watershed Prioritization with Zones of Concern. (Courtesy of JW Associates Inc.)

and Zones of Concern are then used to identify high-priority sixth-level watersheds, where forest treatments are most needed to reduce potential wildfire damage to watershed infrastructure and water supply.

Final Watershed Prioritization

The three watershed assessment components (wildfire hazard, flooding/debris flow hazard, and soils erodibility) were combined into a Composite Hazard Ranking for each sixth-level watershed in the Upper South Platte Watershed. The sixth-level watersheds that contained water supply features were then identified. The Final Watershed Prioritization for each sixth-level watershed involved increasing the Composite Hazard Ranking if a water supply feature was present. The result of this process for the Upper South Platte Watershed is shown in the five hazard categories (category 1-low to category 5-very high) displayed on the Final Watershed Prioritization map.

ZONES OF CONCERN
Bailey
Elk Creek
Cheesman
High Line Canal
Moore Dale Ranch
Santa Maria
Shawnee
Strontia
Windy Peaks
Woodland Park

Source water areas upstream of important water supply reservoirs or diversions that have a higher potential for carrying considerable sediment or debris downstream are called Zones of Concern.

The Upper South Platte Watershed Assessment applied Zones of Concern to an 11-mile stream distance upstream. These zones were based on historical affects of wildfire on downstream water supply facilities. Following the Buffalo Creek Fire in 1996, sediment and debris from the burned area were transported an 11-mile distance along the stream course downstream to Strontia Springs Reservoir—a critical water supply reservoir. Ten Zones of Concern were identified, the boundaries were determined by GIS analysis, and then the Zones of Concern were overlaid on the Final Watershed Prioritization map.

Stakeholders can use these Zones of Concern to focus watershed protection actions in areas that would provide the greatest benefit.

Test Case Results Presented to Water Providers

In March 2009, the Front Range Watershed Wildfire Protection Working Group presented the results of the Upper South Platte Watershed assessment test case to key water providers and land management agency leadership. Water providers and agency leadership identified next steps for the workgroup, and the group used these recommendations to develop additional strategies and actions.

Current Watershed Assessment Efforts

Later in 2009, Denver Water, Colorado Springs Utilities, City of Aurora, other water providers, JW Associates, Colorado State Forest Service, and the U.S. Forest Service proceeded to assess other Front Range watersheds using the watershed assessment template. (*Front Range Watershed Protection Data Refinement Work Group. 2009. Protecting Critical Watersheds in Colorado from Wildfire: A Technical Approach to Watershed Assessment and Prioritization*, available online at www.frftp.org/docs/Work-Group-Final-Report-V6.pdf).

Four additional watershed assessments have been completed using the process developed by the Front Range Watershed Wildfire Protection Data Refinement Workgroup the Blue River, Upper Colorado Headwaters, Pikes Peak, and Saint Vrain. Watershed assessments are underway for the Arkansas and South Platte headwaters. The results of the assessments can be found at www.jw-associates.org.

Thirteen other watershed assessments (Eagle River, North Platte Headwaters, Upper North Platte, Upper Yampa, Little Snake, Medicine Bow, Upper Laramie, Big Thompson, Cache La Poudre, Lower Colorado Headwaters, Clear Creek and Bear Creek, Upper Lodgepole and Crow, and Upper White) are part of the U.S. Forest Service's bark beetle hazard mitigation efforts and will be completed through the Composite Hazard Ranking without the stakeholder process. The Roaring Fork Watershed may be added to the list.

Stakeholder involvement throughout the development of each watershed assessment has been invaluable to the success of the process. The Workgroup has built collaborative support through ongoing communication among large and diverse groups. This engagement results in a better understanding of the methodology and will allow watershed stakeholders to use the assessment to achieve their common shared goals relative to watershed protection.

Erosion is evident in the Upper South Platte Watershed after the 2002 Hayman Fire. (Courtesy of Colorado State Forest Service)

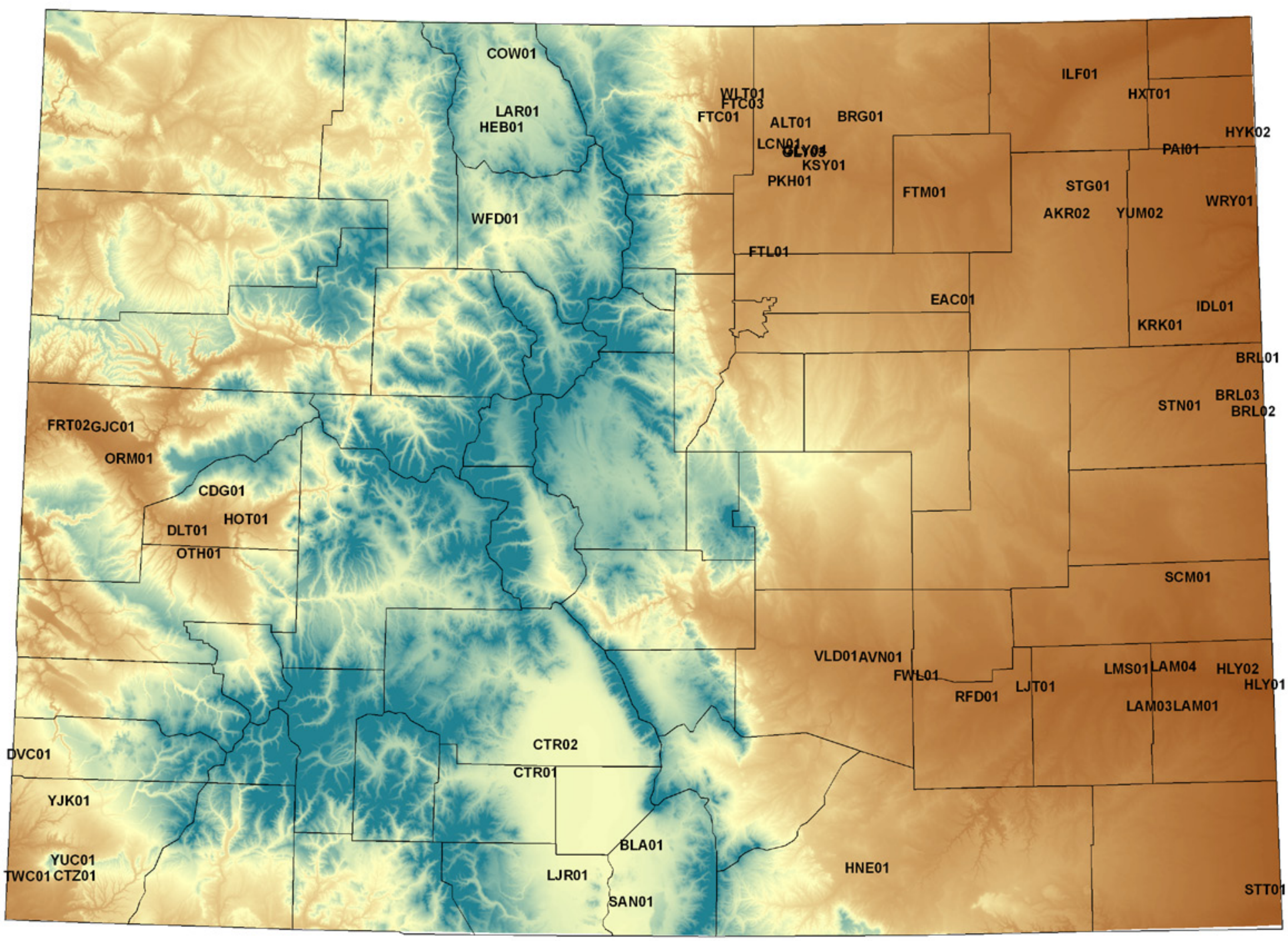
CoAgMet Needs Your Help

by Nolan Doesken, State Climatologist, Colorado Climate Center

Twenty years ago, plant pathologists at Colorado State University studying onion and dry bean diseases and agricultural engineers from the USDA Agricultural Research Service discovered they had something in common—they both needed detailed local weather data from agricultural areas of Colorado to support their research and outreach. At about the same time, automated weather observing equipment was improving in quality and affordability, and cell phone technology was just being introduced. The two groups pooled resources and started a small network of weather stations in Colorado. In time, the network was named the "Colorado Agricultural Meteorological Network," or CoAgMet for short.

Since then, other groups have gotten involved, including Western Slope fruit growers, San Luis Valley potato growers, CSU Research Centers and Extension, the USDA Natural Resources Conservation Service, the National Park Service, and most recently North Park hay growers. Water management issues related to the Arkansas River interstate compact with Kansas brought a need for extensive monitoring of weather conditions affecting crop water use in the Arkansas River Basin east from Pueblo.

Gradually, CoAgMet has grown to a network of over 60 automated weather stations located from one end of the state to the other, primarily in irrigated crop lands. In the late 1990s, the Colorado Climate



This map shows CoAgMet station locations throughout Colorado. (Courtesy of Colorado Climate Center)

> "Gradually, CoAgMet has grown to a network of over 60 automated weather stations located from one end of the state to the other, primarily in irrigated crop lands."

Center at CSU, due to its expertise in weather and climate data management, became the host for the network and the provider of the data via the Internet: http://ccc.atmos.colostate.edu/~coagmet/.

Managing a Large Weather Network in a Very Large State

For nearly 20 years, CoAgMet has been managed and operated using an unusual but effective "scientific cooperative" approach. Several organizations with shared interests have provided "in kind" technical support to check and maintain each weather station and perform annual and emergency maintenance. A variety of groups have helped purchase instrumentation. Local Extension Offices, CSU Research Centers, individual research projects, the State Engineers Office, and the USDA have helped perform weather station maintenance and pay cell phone bills. Individual producers across the state have shared parts of their land to provide open areas for weather stations to be installed and operated. CSU's Agricultural Experiment Station, under the direction of Dr. Lee Sommers, has provided direct assistance through the Colorado Climate Center to help calibrate and upgrade weather sensors, as well as support the database and server costs. In all, the CoAgMet infrastructure is worth close to $1,000,000 today, not counting human resources.

Advantages and Disadvantages

The advantage of this cooperative approach is that an amazingly large and effective weather network focused on the needs of Colorado agriculture and water users has been developed and maintained for nearly two decades and at minimum expense. But the disadvantage is that CoAgMet is totally dependent on in-kind contributions and technical experts who are willing to travel to the far corners of our very large state.

In recent years, the "cooperative" has begun to deteriorate. Budget cuts, loss of key personnel, reduced discretionary spending, and travel limitations have forced several CoAgMet partners to cut back or pull out altogether. It is no longer possible to do routine and emergency station maintenance and much-needed data quality control. CoAgMet is still running, but it is necessary now to begin shutting down stations and skipping annual maintenance and calibration. This is a practical necessity, but an unfortunate loss.

Weather Station Sponsors Needed

Based on a network-wide assessment performed in late 2009, it should be possible to preserve the core functions of CoAgMet and maintain high quality data for many agricultural and natural resources applications if (1) redundant, low quality or low-use stations in the network are discontinued, and (2) approximately $2,000 per remaining station per year is raised to cover basic and essential services, including annual weather station maintenance, site maintenance, instrument calibration, data management, and quality control.

Evapotranspiration Workshop: Fundraiser for CoAgMet

Friends of the Colorado Agricultural Meteorological Network have organized an exceptional workshop on evapotranspiration and crop water use to be held on Friday, March 12, 2010, in Fort Collins. This workshop will highlight the critical value of quality, timely weather data for water management. Proceeds from this event will support CoAgMet operations and maintenance.

To make a contribution to CoAgMet or for more information, please contact:

Nolan Doesken, State Climatologist, or Wendy Ryan
Colorado Climate Center
Department of Atmospheric Science
Colorado State University
Fort Collins, CO 80523-1480
Phone: (970)-491-8545
nolan@atmos.colostate.edu

Checks should be made out to "Colorado State University Foundation" with a note saying "in support of CoAgMet." Contributions may be made using credit card.

Fifth Annual Water Tables Raises Record Funds

by Patricia J. Rettig, Colorado State University Libraries

and Jane Barber, Colorado State University Libraries

On February 20, 170 guests attended Water Tables 2010 to raise money for the Water Resources Archive at Colorado State University. (Courtesy of Colorado State University Libraries)

On February 20, the Colorado water community came together for archival treasures, collegiality, and dinner conversation at Water Tables 2010, an annual fundraiser held by the Colorado State University Libraries. The event, now in its fifth year, was the biggest and most successful yet, hosting 170 guests and raising more than $45,000 for the Water Resources Archive.

The event's theme was *Across State Lines: Sharing the Resource*, and the 19 table hosts included water experts from Colorado, as well as Wyoming, Nevada, Montana, and Mexico. This unprecedented gathering for a reception and dinner enabled collegial discussions about the sharing of Western water.

The evening began with a reception in Morgan Library and tours of the Water Resources Archive. An exhibit, "Finding Buried Treasures: Maps of the Colorado River," was on view, displaying a small portion of the historical maps, publications, and photographs of this highly used western river. Also on display were highlights from new collections donated in 2009. This included transcripts, pleadings, and other materials from the Papers of Arthur L. Littleworth, a recent donation announced at Water Tables. Mr. Littleworth served as the special master for *Kansas vs. Colorado*, a U.S. Supreme Court case involving the Arkansas River that lasted for 25 years. His collection documents the case in its entirety.

During the reception, guests were welcomed by Lou Swanson, CSU vice provost for Outreach and Strategic Partnerships, and Patrick Burns, CSU vice president of IT and interim dean of Libraries. They thanked the guests and sponsors for their support of the Water Resources Archive, especially important during tight budget times. History professor Jared Orsi followed, describing how his history class used the Archive and the lessons they learned from the project. Orsi recognized the privilege that CSU holds this world-class resource.

"This event is a unique forum for educating people on a variety of subjects in a small venue that provides a very personal dialogue with the participants," said Steve Vandiver, general manager of the Rio Grande Water Conservation District. "Many people are unfamiliar with some of the outlying issues from other parts of the state. I appreciated giving the presentation on the Rio Grande Compact to help a very diverse group understand the idiosyncrasies of the administration of that Compact."

Following the reception, guests made their way through the accumulating snow to the Lory Student Center ballroom for dinner and topical conversations. Table topics included The Colorado-Wyoming Coalition: *Developing Colorado River Water across State Lines*, discussed by Frank Jaeger, district manager of the Parker Water and Sanitation District; and "*Why We Have to Share—Limits on Our Right to Consume*, discussed by David Robbins, president and co-founder of Hill & Robbins, P.C. Mario López Pérez of the National Water Commission of Mexico brought an international perspective to the event with his table topic *The Colorado River as an International River: Mexico's Perspective*.

Colorado State University graduate students browse a display of highlights from new collections donated to the Water Resources Archives in 2009. (Courtesy of Colorado State University Libraries)

“I enjoyed pre-dinner activities as much as the roundtable discussion during dinner,” said graduate student Faith Sternlieb. “It is wonderful to engage in conversation with others who share equal enthusiasm about the state of water resources in Colorado and the surrounding region, whether to discuss differences in perspectives or open opportunities for collaboration.”

Thanks to the generosity of many individual and corporate sponsors, 30 graduate students were able to attend the event and interact with current leaders in the water industry. The funds raised will help the archive continue to prepare historical materials for public use, digitize and deliver materials online, and increase outreach to potential donors and researchers.

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2010 Arkansas River Basin Water Forum

April 6-7, 2010
Cañon City, Colorado

The 2010 Arkansas River Basin Water Forum will be held on April 6-7 at the Historic Abbey in Cañon City.

Purpose: The Forum has been a focal point for highlighting current water issues in the Arkansas River Basin and in Colorado since its inception in 1995. Planners, presenters, and attendees represent a wide variety of organizations, agencies, and public citizenry working on water resources issues in the Basin.

Description: As the Basin contends with an array of resource management goals, the Forum theme this year is “The Arkansas River: Our Multifaceted Gem.” Topics will include economic benefits of water use in the Upper Arkansas, planning for future water supply variability, water supply planning for rural and small municipalities, stormwater runoff management, and an overview of major projects in the Lower Arkansas Valley. Our keynote speaker this year will be Doug Kemper, executive director at the Colorado Water Conservation Board.

Scholarships: The Forum sponsors are pleased to offer $2000 in scholarships to outstanding graduate students. More information is available on our web site.

Registration prior to March 26 is $45 for both days and $25 for one day. Please visit the Forum website at http://www.arbwf.org/ or contact Dr. Perry E. Cabot at (719) 549-2045 for more information.

Spring 2010
Interdisciplinary Water Resources Seminar

Sponsored by: CSU Water Center, USDA-ARS, Civil and Environmental Engineering, and Forest, Rangeland, and Watershed Stewardship

Wednesdays from Noon to 1:00 PM

February 3 LSC Room 228	**Tim Scheibe**, Pacific Northwest National Laboratory, Hydrology Group **2010 Darcy Distinguished Lecture--Flow and Reactive Transport: From Pores to Porous Media to Aquifers**
February 10 LSC Room 210	**Faith Sternlieb**, Colorado Water Institute, CSU **Planning for CSU's first World Water Day Celebration**
February 17 LSC Virginia Dale	**Mark Williams**, Institute of Arctic and Alpine Research, CU **Potential Climate Impacts on the Hydrology of High Elevation Catchments, Colorado Front Range**
February 24 LSC Room 210	**Jim Ascough**, Agricultural Systems Research, USDA-ARS **Spatially Distributed Modeling using the Component-Based AgroEcoSystem Model**
March 3 LSC Room 210	**Dennis Harry**, Geosciences, CSU **Opportunities and Adventures in Hydrogeophysics**
March 10 LSC Room 210	**David Theobald**, Human Dimensions of Natural Resources, CSU **Assessing Threats to Colorado Watersheds**
March 17	**No Seminar** **Spring Break**
March 24	**No Seminar** **Hydrology Days (LSC Cherokee Park Room); www.hydrologydays.colostate.edu**
March 31 LSC Room 210	**Tom Sale**, Civil and Environmental Engineering, CSU **Emerging Concepts in Subsurface Contaminant Transport and Remediation**
April 7 LSC Room 210	**Tim Steele**, TDS Consulting **Clear Creek Long Range Planning**
April 14 LSC Room 224	**Thijs Kelleners**, Renewable Resources, University of Wyoming **Measurement and Modeling of Water Flow, Heat Transport, and Gaseous Exchange in Rangeland Soils**
April 21 LSC Room 210	**Domenico Bau**, Civil and Environmental Engineering, CSU **Anthropogenic Uplift of Venice by Seawater Injection into Deep Aquifers**
April 28 LSC Room 210	**Mike Coleman**, Civil and Environmental Engineering, CSU **Soil Moisture Estimation**
May 5 LSC Room 210	**Romano Foti**, Civil and Environmental Engineering, CSU **TBA**

* Room may be changed if needed. Check weekly announcements.

All interested faculty, students, and off-campus water professionals are encouraged to attend.
For more information, contact Reagan Waskom at reagan.waskom@colostate.edu or visit the CWI web site.

Colorado Water Congress 52nd Annual Convention

by Reagan Waskom, Director, Colorado Water Institute

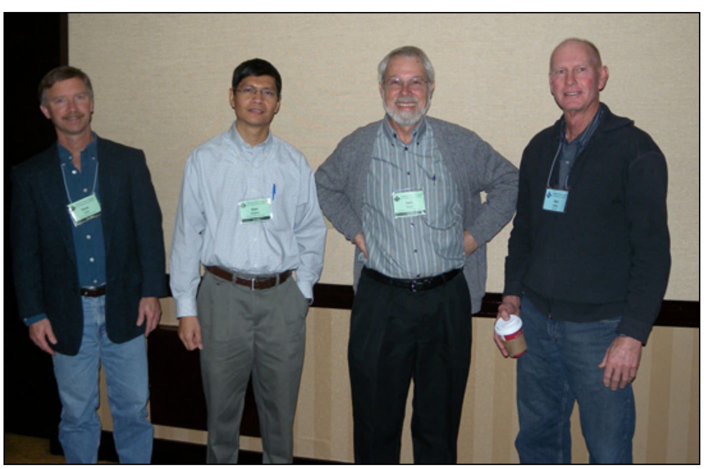
The Colorado Water Congress held its 52nd Annual Convention in Denver on January 27-29, 2010. The conference theme was *Respecting Our Past, Leading in the Present, Building for the Future*. A panel of legislators kicked off the opening Thursday morning breakfast with discussion about the water bills introduced in the 2010 legislative session, but the focus was mostly on the impending budget fights and the jeopardy faced by the Department of Natural Resources (DNR), Colorado Water Conservation Board (CWCB), and other state agencies as we attempt to balance our budget in the midst of recession. Amendments 60 and 61 and Proposition 101 were also discussed, as they would enact further financial limits on taxing entities in Colorado.

John Hall, Hall and Associates; Robert Johnson, Water Consult and HDR Engineering; and Mark Pifher, Aurora Water serve on a panel at the Colorado Water Congress 2010 Annual Convention. (Colorado Water Institute photo)

Governor Bill Ritter provided a special address to the Water Congress on Thursday morning, outlining his three pillars for providing water for Colorado's future. He stated that cooperation, preserving agriculture, and stretching water supplies are the pillars on which our future must be built.

Ritter also called on the Interbasin Compact Committee (IBCC) to speed up its work during his last year in office. He stated that he wanted the group to meet six times this year to develop two portfolios that describe a mix of conservation, new projects, and ag transfers to meet the demands of growing urban areas.

The second general session featured the recently released report commissioned by the Front Range Water Council on "Water and the Colorado Economy." The report, written by Summit Economics and the Adams Group, states that the Front Range uses 19% of the state's water (2.9 million acre-feet) but generates 86% of the state's economic activity and tax revenue. An acre-foot of water used in the urban economy of the Front Range generates an average of $132,000 in sales of goods and services, while agriculture will generate on the order of $1,000 in sales per acre-foot withdrawn.



Dave Clow, USGS; Alan Andales, CSU; Tom Trout, USDA; and Mel Rettig, farmer and Colorado River Basin Roundtable member were among attendees at the Colorado Water Congress 2010 Annual Convention. (Colorado Water Institute photo)

Three water science sessions were hosted at this year's convention, featuring faculty from CSU, Colorado School of Mines (CSM), and the U.S. Geological Survey and covering new research on snow hydrology, evapotranspiration, groundwater quality, drought, and biofuels. Several CSU and CSM graduate students participated in the conference, and the Water Congress is interested in enhancing the activity and visibility of students at future events.

A final highlight of the convention was the announcement of the 2010 Aspinall Award winner, the top water honor given in Colorado. This year, Alan Hamel, executive director of the Pueblo Board of Water Works, was given the honor for his 40 years of exemplary service to Pueblo and the Colorado water community.

The Colorado Water Congress will reconvene in August 2010 for its annual summer convention, to be held on August 25-27, 2010, in Vail. For more information, visit http://www.cowatercongress.org.

Workshop on Nonstationarity, Hydrologic Frequency Analysis, and Water Management: January 13-15, 2010

by Reagan Waskom, Director, Colorado Water Institute

On January 13-15, 2010, the U.S. Army Corps of Engineers (USACE), U.S. Bureau of Reclamation, U.S. Geological Survey (USGS), U.S. Environmental Protection Agency, NOAA, and Colorado State University hosted an interagency workshop in Boulder, Colorado. The purpose of the workshop was to create a venue for a small group of agency and academic scientists and engineers to discuss operational alternatives to the assumption of stationarity in hydrologic frequency analysis that can be used by water managers and planners.

L to R: Jery Stedinger, Cornell University; Beth Faber, U.S. Army Corps of Engineers; Tim Cohn, U.S. Geological Survey; and Richard Vogel, Tufts University were among presenters at the Workshop. (Colorado Water Institute photo)

The Intergovernmental Panel on Climate Change (IPCC) has said, "Climate change challenges the traditional assumption that past hydrological experience provides a good guide to future conditions" (Bates et al, 2008). Stationarity means that the statistical properties of hydrologic variables in future time periods will be similar to past time periods, but anthropogenic climate change and decadal climate variability present a challenge to the validity of this assumption. Although several recent academic articles have criticized the assumption of stationarity, it is not apparent what, if any, alternative methods should be used as a replacement.

The workshop objective was (1) to discuss in detail how water management agencies should plan and manage water resources in the face of nonstationarity, and (2) to form a coordinated action plan to help the agencies move forward.

Robert Hirsch of the USGS asserted that we must consider nonstationarity in planning and management. We already do it in terms of urbanization effects, groundwater declines, and reservoir storage. The question is: do we have a basis for including climate-related nonstationarity? Changes in rain/snow volumes and timing have already been detected, while observed streamflow trends are very mixed across the United States. It is important to note that the length of data record used can greatly affect results and conclusions, and to consider long-term records and paleo-records.

Jerry Webb of the USACE followed up by stating that no applied hydrologist ever believed there was true stationarity. We know our current means of analysis is flawed, and we need a new consistent methodology to use, but for now we must use methodologies that are accepted and consistent across the nation.

According to excerpts from USGS Circular 1331 (*Climate Change and Water Resources Management: A Federal Perspective*, Brekke et al, 2009), "A number of researchers have proposed alternative probabilistic techniques that allow for nonstationarity in flood event distributions. The most common adaptation approach is to allow the parameters of an assumed distribution to vary with time; nonparametric techniques have also been proposed. In general, additional research is required to establish the most suitable methods for treating nonstationarity in flood-risk evaluations for the United States. An alternative is that flood risk be evaluated using a more limited set of recent observations, but extrapolating the probability of infrequent events from a short record is fraught with uncertainty."

The example of the Red River of the North was presented by Pat Foley, USACE; he explained that an upward trend in flood peaks at Fargo has been observed from 1901 to present. However, there is no correlation between precipitation trend and the flood peak trend, and there is clearly more going on than just increased precipitation.

Some discussion focused on Bulletin 17B, which provides the current uniform flood frequency techniques used by U.S. federal agencies. Many attendees observed that the bulletin has not been updated in 20 years, and that we now have better statistical methods.

Decision-making challenges with nonstationarity were addressed, and it was noted that climate uncertainty will affect both economic analysis and engineering design. Water managers may need to

Kuniyoshi Takeuchi of the International Center for Water Hazards and Risk Management in Japan provides international perspectives at the Workshop. (Colorado Water Institute photo)

recognize that their estimates for the likelihood of future hydrologic events are very uncertain, and designs based on the estimate of future probabilities may not be reliable. They may also need to adopt alternatives that perform well for many possible future scenarios.

In summary, a number of conclusions were shared by workshop participants, including that fact that while the climate or hydrology community never believed that stationarity existed, there is a need to move away from stationary risk assessment models in order to design systems for future robustness and resiliency. Much of the discussion on climate models centered on how results from downscaling general circulation models (GCMs) are being used to make hydrologic predictions, and the recognition of uncertainty in current downscaling techniques. It was noted that European countries do a better job than the United States in making the public aware of the possibility of catastrophic events. For example, the Dutch plan for the 10,000-year event.

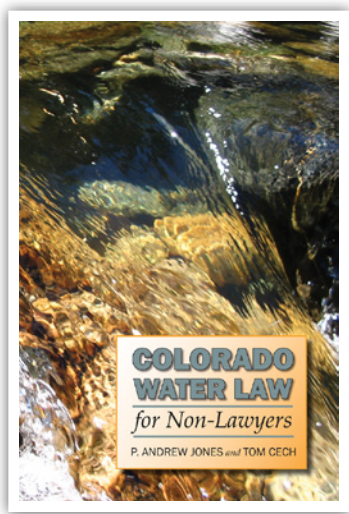
Proceedings, slides, and proposed next steps resulting from the workshop will be available on the workshop web site at http://www.cwi.colostate.edu/NonstationarityWorkshop.

New Book: *Colorado Water Rights for Non-Lawyers*

Why do people fight about water rights? Who decides how much water can be used by a city or irrigator? Does the federal government get involved in state water issues? Why is water in Colorado so controversial? These questions, and others like them, are addressed in *Colorado Water Law for Non-Lawyers*.

Legal issues related to water rights in Colorado first surfaced during the gold mining era of the 1800s and continue to be contentious today with the explosive population growth of the 21st century. Drawing on geography and history, authors P. Andrew Jones and Tom Cech explore the flashpoints and water wars that have shaped Colorado's present system of water allocation and management.They also address how this system, developed in the mid-1800s, is standing up to current tests—including the drought of the past decade and the competing interests for scarce water resources—and they predict how it will stand up to future demands.

This book will appeal to non-lawyers involved in water issues, students, attorneys, and water professionals desiring a succinct and readable summary of Colorado water law, as well as general readers interested in Colorado's complex water rights law.



Colorado Water Law for Non-Lawyers
by P. Andrew Jones & Tom Cech
ISBN: 978-0-87081-950-6
Paperback, 6 x 9
276 pages, $26.95

Faculty Profile

Larissa Bailey, Assistant Professor, Department of Fish, Wildlife and Conservation Biology, Colorado State University

I joined the faculty in the Department of Fish, Wildlife and Conservation Biology at Colorado State University (CSU) in January 2009. I am also a member of the Graduate Degree Program in Ecology (GDPE), the largest interdisciplinary graduate program at CSU. Prior to joining the faculty at CSU, I was a research scientist in the Biology Division of the U.S. Geological Survey (USGS), where my primary responsibility was directing the Amphibian Research and Monitoring Initiative (ARMI) in the northeastern United States. The position involved collaborating with various agencies to conduct amphibian research and monitoring programs on federal lands throughout the northeast region. I have continued to work in some of those ecosystems since arriving at CSU and have been fortunate to get involved, collaboratively, with projects in Colorado.

My research focuses on measuring and monitoring biological systems, where monitoring is considered a vital, active step in furthering understanding from a scientific or management perspective. My research has involved developing and implementing methods to estimate the three most common state variables used to explore changes in plant or animal communities: population size, species richness, and species distribution. I am also interested in exploring the vital rates responsible for changes in these state variables. My research tends to be applied, often motivated by management or conservation needs, and thus involves a number of talented, diverse collaborators from various academic, state, federal, and non-profit institutions.

The majority of my past and current research involves amphibian species and their habitats. The amphibians I've worked with range from completely terrestrial to those that are almost always found in or near aquatic habitat. There are few long-term or large-scale studies on amphibians, but many populations appear to be declining, with the cause of those declines varying regionally. Unbiased estimates of vital rates such as survival, movement, and breeding probabilities are critical to understanding how amphibian populations function. Much of my work aims at answering questions about the relative importance of different life history phases and associated habitats to inform management and conservation decisions. Restoration and recovery efforts are an ideal arena to employ adaptive management methods that promote scientific learning and optimal management decisions.

Currently, I'm involved in projects that range from exploring management of vernal pool habitats on federal lands to maintain obligate amphibian species, to developing a long-term monitoring program that explores potential threats to the federally endangered Shenandoah salamander, to estimating the success of introduced boreal toad tadpoles in Rocky Mountain National Park. I'm also engaged in several fisheries projects involving American eels on the east coast, and several species of plains fish that are of concern in Colorado. It is not surprising that many of the toughest management decisions involve water resources, and designing scientific studies to inform such decisions will likely be a continued theme in my research in the coming decades.

My published work involves applying, and in some cases developing, new quantitative tools to apply to these biological systems. For example, how can we estimate demographic parameters for populations where only a subset of the population (breeders) is available for sampling each year? In other cases, we are interested in exploring factors that influence species distributions, knowing that we often 'miss' our target species even though they may be present at a given location. Failing to account for the proportion of the population(s) that are not sampled can lead to biased estimates. My work aims to correct such errors and provide robust biological inferences. These challenges are common to many vertebrate systems, and I often collaborate with a variety of biologists and statisticians.

I teach many of these quantitative methods in both graduate and undergraduate courses at CSU. In the coming year, I will be developing another undergraduate course that will likely focus on management decision-making, hopefully with several water-related case studies. Given the excellent reputation of water-related research at CSU and the enormous complexity of water management in the West, both the students and I will learn a lot from the network of people facing water-related fisheries and wildlife issues.

Water Research Awards

Colorado State University (December 15, 2009 to February 15, 2010)

Bauerle, William L, Horticulture and Landscape Architecture, University of Maryland, Precision Irrigation and Nutrient Management for Nursery, Greenhouse, and Green Roof Systems: Wireless Sensor Network for Feedback and Feedforward Control, $249,542

Bestgen, Kevin R, Fish, Wildlife and Conservation Biology, Fish & Wildlife Service, Monitoring Non-Native Species & Native Species: Native Species Taxonomy Studies, $37,500

Bledsoe, Brian, Civil and Environmental Engineering, Geosciences, Stream Restoration, Ecological Engineering, and Nutrient Retention of Streams in Urban and Agricultrual Settings, $61,484

Bradley, Thomas Heenan, Mechanical Engineering, University of Colorado Boulder-C2B2, Lifecycle Sustainability Assessments for Microalgal Biofuel Production, $34,817

Cooper, David Jonathan, Forest Rangeland Watershed Stewardship, DOD-ARMY-Corps of Engineers, Watershed to Local Scale Characterization and Functioning of Intermittent and Ephemeral Streams on Military Lands, $540,658

Cotton, William R, Atmospheric Science, University of Miami, Improving Cloud and Precipitation Physics in a Seamless Regional-Global Climate Model, $132,699

Doesken, Nolan J, Atmospheric Science, University of Colorado, Climate Support to The Western Water Assessment (WWA), $25,000

Garcia, Luis, Civil and Environmental Engineering, USDA Agricultural Research Service, Delivery of a Prototype Field-to-Watershed Scale Model for CEAP using an Enhanced OMS, $41,388

Labadie, John W, Civil and Environmental Engineering, Colorado Springs Utilities, Efficiency and Performance Improvement of Colorado Springs Utilities MODSIM Daily Model for Water Supply Yield Analysis, $9,089

Liston, Glen E, Cooperative Institute for Research in the Atmosphere (CIRA), National Science Foundation, Collaborative Research: Norwegian-United States IPY Scientific Traverse: Climate Variability and Glaciology in East Antartica, $50,801

Oad, Ramchand, Civil and Environmental Engineering, New Mexico State University, Afghanistan Water, Agriculture and Technology Transfer Program (AWATT), $40,000

Poff, N LeRoy, Biology, Camp Dresser McKee, Colorado Basin Watershed Flow Evaluation Tool, $27,280

Sanford, William E, Geosciences, Regenesis Management Group, Development of Field-Scale Project to Quantify Change in Irrigation Return Flows due to Limited Irrigation, $29,791

Venayagamoorthy, Subhas K, Civil and Environmental Engineering, Colorado Dept of Public Health and Environment, Baffle Factors of Small System Disinfection Contact Basins, $10,000

Waskom, Reagan M, Colorado Water Institute, Walton Family Foundation, Initiative: Innovative Strategies for Agricultural/Urban/Environmental Water Sharing in the Colorado River Basin, $114,828

Zeidler, James A, CEMML, Army Corps of Engineers, Aquatic and Fisheries Project Management Tasks For Fort Leonard Wood, Missouri, $198,894

Calendar

March

22-24 Hydrology Days, Colorado State University, Fort Collins, Colorado
The 30th Annual Hydrology Days, held on the Colorado State University campus.
http://hydrologydays.colostate.edu

April

6-8 Arkansas River Basin Water Forum; Canon City, Colorado
This year's theme is "The Arkansas River: Our Multifaceted Gem."
http://www.arbwf.org

11-13 Sustainable Water Sources; Albuquerque, New Mexico
Explore the tools critical to managing current and future water supply needs.
http://www.awwa.org

11-15 2010 Ground Water Summit and 2010 Ground Water Protection Council Spring Meeting; Denver, Colorado
This year's theme is "Groundwater for a Thirsty World."
https://info.ngwa.org/servicecenter/Meetings/

11-15 SAGEEP 2010; Keystone, Colorado
Symposium on the Application of Geophysics to Environmental and Engineering Problems.
http://www.eegs.org/sageep/index.html

25-29 Seventh National Monitoring Conference: Monitoring From the Summit to the Sea; Denver, Colorado
This year's theme is "Monitoring from the Summit to the Sea."
http://acwi.gov/monitoring/conference/2010/

27 WaterEC 2010; Nashville, Tennessee
Industry professionals will meet to discuss water resource efficiency and conservation management.
http://www.waterec.net

May

2-4 2010 International Symposium on Waterborne Pathogens; Manhattan Beach, California
Learn about cutting-edge ideas related to the critical public health issue of waterborne pathogens.
http://www.awwa.org/Conferences/

16-21 Tamarisk Coalition 2010 Raft Trip in Cataract Canyon; Moab, Utah
A rafting research trip for those interested in biological control of tamarisk.
http://www.coloradowater.org/documents/TamariskCoalition2010TripFlier.pdf

16-21 ASFPM Annual Conference; Oklahoma City, Oklahoma
This year's theme is "Building Blocks of Floodplain Management."
http://www.floods.org

20-21 Colorado Water Law-Compacts, Cases, Coalbed Methane & Conservation; Denver, Colorado
Noted speakers will present on water law in Colorado.
http://www.cle.com

21-24 National River Rally 2010; Snowbird, Utah
An educational and celebrational event for river conservation.
http://www.rivernetwork.org/events/11th-annual-national-river-rally

24-25 14th Annual Water Reuse & Desalination Research Conference; Tampa, Florida
A showcase of results from cutting-edge research related to water reuse and desalination.
http://www.watereuse.org/foundation/Research_Conf/14

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A hiker enjoys a trail at Horsetooth Reservoir near Fort Collins. (Courtesy of City of Fort Collins)