COLORADO WATER

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Focus Climate and Water:

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Cloud seeding for snow.

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Director: Reagan Waskom
Office Manager: Nancy Grice
Editor: Rebecca Anderson

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Published by the Colorado Water Resources Research Institute * Colorado State University, Fort Collins, CO 80523
Phone 970-491-6308 * FAX: 970-491-1636 * E-mail: nancy.grice@colostate.edu

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Colorado Water Resources Research Institute: http://cwrri.colostate.edu
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EDITORIAL

Weather Modification – Can We Produce More Water?

by Reagan M. Waskom, Colorado Water Resources Research Institute, Director

This issue of the Colorado Water provides some focus on climate related water research. One of the more interesting and controversial aspects of climate and water is the question of our ability to impact climate, both on the global and the local scale. This is certainly not a new concept, or a new controversy. My grandfather, an old west Texas cowboy, told me more than once that, "Timing has a lot to do with the outcome of a rain dance."

CSU Atmospheric Sciences Professor William Cotton provides us with a summary of the state of the scientific knowledge on weather modification, more specifically, cloud seeding, on page 7. It's interesting that a process that has been known for 60 years still generates the uncertainty and debate surrounding cloud seeding and its impact on stream flow. What makes this discussion currently relevant is that two new potentially large weather modification projects may soon impact the Colorado River and other western streams.

A five-year, $8.8 million project to examine whether seeding clouds from ground-based and airborne generators with silver iodide produces a measurable increase in snowfall over Wyoming's Medicine Bow, Sierra Madre, and Wind River mountain ranges was recently funded by the Wyoming Legislature. Scientists from the National Center for Atmospheric Research (NCAR) have received some of the funds to evaluate the project's impact on precipitation processes and snowpack. It is estimated that even a modest 10% increase in snowpack in the project's targeted areas would provide between 130,000 and 260,000 acre-feet of water in additional runoff each spring, according to a Wyoming Water Development Commission (WWDC) report. Conservative estimates put the value of that extra water between $2.4 and $4.9 million. These numbers do not include the value associated with generating more hydroelectric power, enhancing recreation and tourism, improving water quality, and other environmental benefits. At a cost of $6.50 to $13.00 per acre-foot of produced water, the investment would be a bargain if it works.

In a second weather modification project even closer to home, the seven Colorado River Basin states are planning to hire a consultant this spring to evaluate the potential for cloud-seeding to improve Colorado River flows. In three years, the Basin states hope to launch the first phase of a regional cloud-seeding program. Most likely, the seeding would be done in high altitude areas of Utah, Wyoming and Colorado, where it snows more. In a letter to the previous Interior Secretary Gale Norton, representatives of the seven states - Arizona, California, Colorado, Nevada, New Mexico, Utah and Wyoming - identified cloud seeding as a key component for dealing with or averting future water shortages brought on by population growth in the West. Any new water would belong to the whole Colorado River system, meaning that in years when there is above average runoff, all seven states would be able to benefit from the excess.

Cloud seeding is big business and western states spend millions each year seeding clouds to increase snow. Four Western states currently have significant investments in weather modification programs - Utah, Wyoming, Colorado and Nevada. Utah, which runs one of the oldest and largest cloud-seeding projects in the West, estimates it has increased runoff an average of 13 percent a year. This year, Utah will spend more than $400,000 on cloud seeding across four drainage areas.

To what extent cloud seeding produces additional runoff has long been the subject of debate among the scientific community. In 2003, the National Academy of Sciences reported that there was no convincing scientific proof of the efficacy of intentional weather modification programs and called for a national research effort in this area. They did not question the fundamental science behind cloud seeding, rather the failure to demonstrate verifiable and reproducible results. The lack of federal and state funding for research in weather modification has limited this type of scientific research into cloud seeding over the last decade. Previous federally-funded research that ended in the early 1990s produced some evidence that cloud seeding works in the mountains, but the additional snow measured in many cases did not exceed the natural variability. The Weather Modification Association, a national group that promotes research and development of cloud-seeding, has published a report that says that there have been statistically proven seeding success stories. One generally agreed upon fact is that cloud seeding is not a drought busting tool; there must be moist atmospheric conditions for it to be successful.

The challenge for scientists is to document whether observed snowfall levels would have occurred anyway, or clearly resulted from the seeding. Even a 10% increase would fall within the range of natural variability of a single storm or a whole season. Cloud seeding is attractive to water providers because they believe it costs very little to produce the extra water - about $10 to $20 an acre-foot. That's a fraction of what it costs to build a new reservoir and perhaps so little that it is worth the gamble. Droughts always cause people to think differently and develop new water strategies. Perhaps silver iodide is the next silver bullet. It will take rigorously controlled scientific studies to sort out the natural variability in the system and determine the effectiveness of cloud seeding on producing additional water in our streams.

Water Tables Whets Appetites and Nearly Doubles Fundraising for Water Resources Archive in Second Year

For a second year in a row, the archival reading room of Morgan Library was alive with the sounds of laughter, debate, and wonderment as a crowd of 130 gathered for Water Tables 2007. A benefit for the Water Resources Archive, the evening offered guests a chance to explore primary source materials documenting landmark achievements in water resource development while engaging with the foremost water experts tackling some of the state's most pressing resource concerns. Sponsors and participants raised $20,000 to support the Archive and the evening, and proceeds will help the Archive to acquire, preserve, and promote additional and existing collections significant to Colorado's water history.

Water Tables Planning Committee Members (From left to right): Mark Fiege, MaryLou Smith, Robert Ward, Mike Applegate and Dave Stewart.

"Archival collections are what the National Archives terms 'history in the raw,' said Colorado State University Libraries Dean, Catherine Murray-Rust. "They are the collections that define a research library equipped to support a great research university like Colorado State and little else compares with watching someone discover this kind of living history for the first time."

Water Tables Hosts (Back row from left to right): Don Glaser, Russell George, Justice Hobbs, Bart Miller, John Porter, William Wallace, Brit Storey, Tom Iseman. (Front row from left to right): Sharon O'Toole, Pat O'Toole, Melinda Kassen, Evan Vlachos, Felipe Chavez-Ramirez, Melinda Laituri and Steve Mumme.

Guests donned white gloves and literally held history in their hands as they wandered around an array of materials from the Archive's holdings including Delph Carpenter's briefcase, Ival Gosling's hardhat, and lanternslides from the Ralph Parshall Collection. This year's display also featured "Dam Beautiful: Robert Glover and Arch Dams," an exhibit exploring the beauty and controversy of the arch dams that dramatically alter the western landscape - in both positive and negative ways.

"I was elated with the crowds in the Archive," said Patty Rettig, Head Archivist for the Water Resources Archive. "Looking at materials helped inspire people to think about what records should be saved and their role in doing so. I expect great strides in saving Colorado's water history to emerge from Water Tables 2007."

In some respects, those great strides were already made as Water Tables 2007 doubled the amount of funds raised during the first event in 2006.

"As a historian of the environment and the American West, and as a Colorado resident, I have a professional and civic obligation to support and help build the collection," said Mark Fiege, professor of history at Colorado State University and a member of the Water Tables Planning Committee. "The Water Resources Archive distinguishes Colorado State as a top-rank university interested in developing a research collection that reflects the expertise of faculty and alumni and that speaks to the importance of water to all Coloradoans. Our state is the Mother of Waters, but those waters flow through dry landscapes, some of which are filling up with people. Water has never been more important than it is now."

Don Glaser, Patty Rettig, and Justice Gregg Hobbs discuss water during the Water Tables reception.

Archives and Special Collections Staff: Janet Bishop, Shan Watkins, Linda Meyer, Patty Rettig, Nick Kryloff and Kate Legg.

"This kind of fundraising affords us opportunities we won't have otherwise," added Janet Bishop, Coordinator for Archives and Special Collections. "Not only are we able to preserve existing collections and build new ones, we can also digitize more archival materials and create online exhibits for worldwide access. We are one of only three named water archives in the county and it's important that we share our materials in as many ways as possible."

Planning Committee Member MaryLou Smith and Director of Development for CSU Libraries Andrea Lapsley present Dave and Mary Stewart a token of appreciation for Stewart Environmental's silver sponsorship of the event.

While the archival collections mark the foundation from which many water policy decisions have been made, guests were escorted across the plaza to the Lory Student Center for topic conversations with the foremost water experts helping to make those decisions for the future. Hosts expertise ranged from natural resource management to environmental advocacy to extensive knowledge of water law to in-depth historical understanding. Conversations ranged from discussing wildlife, water issues, and conflicts to opportunities and challenges in urban water conservation to current problems in border water management. (For a complete list of hosts and topics, please see page 6.)

William Wallace leads his table in discussion of The Coming Crisis in Western Water Resources: Is it Real &, If So, How Much Time Do We Have to Fix It?

"I greatly enjoy the opportunity to share conversations with outstanding professionals who are working, or have worked, at the cutting edge of Colorado's constant challenge to secure water supplies to meet human demands while protecting our aquatic environment," said Robert Ward, former director of CWRRI and a member of the event planning committee. "I find these evenings enlightening and rewarding in that I never walk away from the evening without learning something new about Colorado's water history."

Both hosts and guests had the opportunity to walk away with expanded perspectives. "The greatest part of the event was that I was learning just as much from the people around my table as I hoped to teach them," said table host William Wallace, who led a discussion on The Coming Crisis in Western Water Resources: Is it Real &, If So, How Much Time Do We have to Fix It? "We had a very well-rounded and lively discussion with many points of view."

A first this year, Water Tables Silver Sponsors donating $1,000 or more - Applegate Group, Inc., Boyle Engineering Corporation, CDM, and Stewart Environmental Consultants, Inc. - made it possible for graduate students to attend the event.

"The opportunity to interact with so many people involved with the past and future of water in Colorado was fantastic," said Dan Gibson-Reinemer, a Masters candidate in the department of fishery and wildlife biology at CSU. "It's events like Water Tables that make me particularly proud to be a CSU student."

Dan Gibson-Reinemer, a Masters candidate in the Department of Fishery and Wildlife Biology at Colorado State University, examines materials in the Archive.

"I hope the event helped the community see that this is their Archive," noted Bishop, "containing a vast array of materials that will inform, enlighten, inspire, educate, and sometimes even surprise."

Russell George offers a director's perspective on Protecting Colorado's Future Through Interbasin Compacts.

Additional sponsors for the event included Aqua Engineering, Inc. Bishop-Brogden Associates, Inc., Black & Veatch, Bureau of Reclamation, Kennedy/Jenk Consultants, Meurer & Associates, Inc., Northern Colorado Water Conservancy District, Norlarco Credit Union, Tetra Tech, Inc., TST, Inc. Consulting Engineers (Bronze Level Sponsors donating $500 or more), Hilton Fort Collins, Odell Brewing Company, and Harrison Resource Corporation.

So what's in store for 2008? "More hosts! More tables! More people!" says planning committee member, MaryLou Smith. "The fact that we have water buffaloes and environmentalists drinking from the same trough - and finding out they have more in common than they might have thought - is what makes Water Tables a success. We look forward to expanding on our accomplishments with next year's event."

2007 Water Tables Hosts

Felipe Chavez-Ramirez, The Platte River Whooping Crane Maintenance Trust, Inc., *Wildlife, Water Issues, & Conflicts*

Russell George, Colorado Department of Natural Resources, *Protecting Colorado's Future Through Interbasin Compacts: A Director's Perspective*

Don Glazer, Colorado Foundation for Water Education, *Colorado's Water in the 21st Century: Meeting the Challenge*

Justice Gregory Hobbs, Jr., Colorado Supreme Court, *The Poetry of Rivers*

Thomas Iseman, The Nature Conservancy in Colorado, *Water for People & Nature in Colorado & Beyond*

Melinda Kassen, Trout Unlimited, *Sustainable Water for All of Colorado's Needs*

Melinda Laituri, Department of Forest, Rangeland, & Watershed Stewardship, Colorado State University, *Environmental Security & Water Resources: Global Perspectives*

Bart Miller, Western Resource Advocates, *Opportunities & Challenges for Urban Water Conservation*

Stephen Mumme, Department of Political Science, Colorado State University, *Current Problems in Border Water Management*

Patrick & Sharon O'Toole, Family Farm Alliance, *Water, Irrigation, & Family Agriculture*

John Porter, Former Manager, Dolores Water Conservancy District, *Can the Grassroots Process Work for Addressing Colorado's Water Challenges?*

Brit Storey, Senior Historian for the Bureau of Reclamation, *Knotty Water Issues: Past, Present, & Future*

Evan Vlachos, Department of Sociology, Colorado State University, *Transboundry Waters: Water for Peace or Water Waters?*

William Wallace, Wallace Futures Group, LLC, *The Coming Crisis in Western Water Resources: Is it Real &, If So, How Much Time Do We Have to Fix It?*

Cloud Seeding as a Component of Water Resource Management in Colorado

by William R. Cotton
Department of Atmospheric Science, CSU


William R. Cotton.

Introduction

Cloud seeding is often considered to be one component in water resource management. In this article I review the status of cloud seeding for winter snowpack enhancement.

Deliberate cloud seeding concepts can be divided into two broad categories: glaciogenic seeding, in which ice-producing materials (e.g., dry ice [solid CO_2], silver iodide, liquid propane, etc.) are injected into a supercooled cloud for the purpose of stimulating precipitation by ice particle growth. The underlying hypothesis for glaciogenic seeding is that there is commonly a deficiency of natural ice nuclei and therefore insufficient ice particles for the cloud to produce precipitation as efficiently as it would in the absence of seeding.

The second category of artificial seeding experiments is referred to as hygroscopic seeding. In the past this type of seeding was usually used for rain enhancement from warm clouds. However, more recently this type of seeding has been applied to mixed-phase clouds as well. The goal of this type of seeding is to increase the concentration of collector drops that can grow efficiently into raindrops by collecting smaller droplets and by enhancing the formation of frozen raindrops and graupel particles. This is done by injecting into a cloud (generally at cloud base) large or giant hygroscopic particles (e.g., salt powders) that can grow rapidly by the condensation of water vapour to produce collector drops.

In this summary I focus on the application of glaciogenic seeding of orographic clouds. This is for several reasons. First of all for Colorado, the principle water resource available to replenishing reservoirs is from melting of snowpack. The major contributor to winter snowback is snowfall for winter orographic clouds. Snowfall at higher elevations in the winter months accumulates, with very little loss by evaporation and runoff owing to the cold temperatures and high humidities with respect to ice. By contrast rainfall from convective clouds during the summer months is largely absorbed locally by surface vegetation and lost by surface evaporation and evapotranspiration thereby contributing little to runoff into reservoirs. An exception is during southwest monsoon periods where rainfall for a number of days can saturate soils and vegetation leading to some runoff. But these are periods when flash flooding is likely thus most seeding operations would be curtailed. The second reason is that the strongest scientific evidence that seeding can increase precipitation comes from seeding winter orographic clouds, whereas there is far more controversy whether seeding can enhance precipitation for convective clouds. For a complete overview of the concepts and evidence suggesting precipitation enhancement by cloud seeding see Cotton and Pielke (2007).

It is not my intent to write-off hygroscopic seeding potential for wintertime orographic clouds, but no one has attempted it as far as I know. Nonetheless, given the evidence that pollution is decreasing wintertime orographic precipitation and that hygroscopic seeding can be very effective in mixed-phase clouds, I hypothesize that modelling studies and experimentation begin testing the application of hygroscopic seeding strategies or a combination of glaciogenic seeding and hygroscopic seeding strategies to winter orographic clouds.

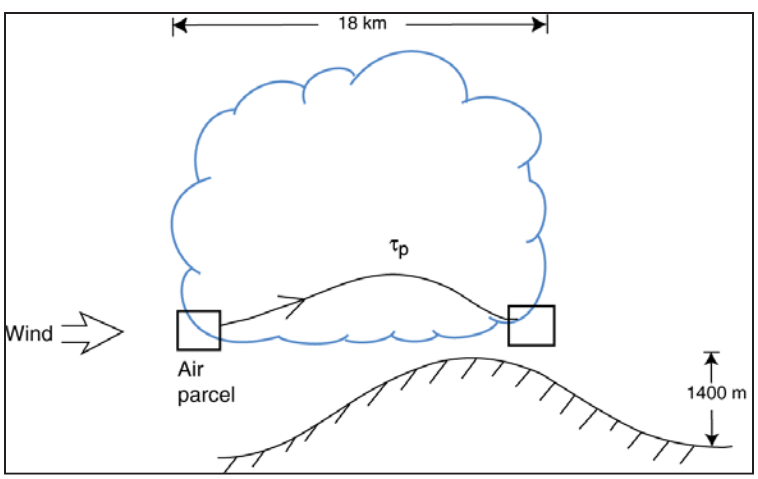

Figure 1. Schematic of a stable orographic cloud indicating the trajectory of an air parcel through the cloud, which determines the Lagrangian time scale (tp) for the development of precipitable particles.

A conceptual view of orographic clouds

Figure 1 illustrates the formation of an orographic cloud as air is forced to lift as it passes over hills or mountains. Updraft velocities depend upon the speed and direction of the wind and the height of the barrier, and they can be several meters per second. Water contents are typically a few tenths of a gram per cubic meter of air, depending upon the altitude at which the air enters the cloud upwind and its maximum altitude above the mountain top. Orographic clouds may be quite transitory, but if winds are steady they may last for many hours. The relevant time scale that determines the time available for precipitation formation is the time that it takes a parcel of air to transect from the upwind lateral boundary to its downwind boundary, as shown in Figure 1. Because the liquid water contents of stable, wintertime orographic clouds are low, usually less than 0.5 grams per kilogram of air, production of precipitation requires efficient conversion of cloud droplets to precipitation. Thus it is the intent of glaciogenic cloud seeding to reduce the timescale of precipitation formation so that precipitation is optimized on the upwind side of the mountain crest.

Concepts of precipitation formation

Precipitation processes can be lumped into two broad categories, warm cloud precipitation processes in which the cloud is above 0C and ice or mixed-phase precipitation processes in which the cloud or a large part of it is below 0C.

Warm cloud precipitation processes are dominated by collision and coalescence processes in which larger-sized droplets settle relative to slower settling smaller droplets and collide and coalesce to former still larger droplets. For the collision and coalescence process to proceed rapidly, a number of droplets must become larger than 40microns in diameter. Once this happens the growth of precipitation proceeds very rapidly especially of the liquid water content made up by all the droplets is large, as a few larger droplets get bigger they sweep out a greater number of smaller droplets.

We know that the efficiency of the collision and coalescence process depends on the time available for droplets to remain in a cloud (see Figure 1), the liquid water content of the cloud, and on the concentration of cloud droplets that form. Cloud droplets form on hygroscopic (or salt) particles in the atmosphere that we call cloud condensation nuclei (CCN). These are produced naturally principally by what are called gas-to-particle chemical reactions in the presence of sunlight, where there is a lot of vegetation decay such as over forests, swamps, and other decaying biological materials. Over the clean oceans, the concentrations of CCN are low, generally less than 100/cc. Whereas over land the concentrations in clean remote areas maybe be a few hundred per cc to a 1000/cc. However, human activity can produce large numbers of CCN. There are a lot of emissions associated human activity such as with industry, automobiles, diesel trucks, and coal-fired power plants that contribute to CCN concentrations. In polluted airmasses, concentrations of CCN of several thousand per cubic centimeter are common.

Returning to the efficiency of warm cloud precipitation formation, the concentrations of cloud droplets that form are related to the concentrations of CCN as well as the vertical velocities at cloud base in clouds, with higher updraft velocities contributing to higher cloud droplet concentrations for a given number of CCN available. The clouds most efficient in producing warm rain by collision and coalescence are clouds with low concentrations of CCN (i.e. a clean airmass) and high liquid water contents. When there are high CCN concentrations, the droplets that form compete for the available liquid water and are as a result smaller and less likely to experience collision and coalescence. Clouds with warm base temperatures are most likely to have high liquid water contents because the saturation mixing ratio at cloud base is much higher if the base temperature is warm. Thus in Colorado, warm rain precipitation is most likely during the warm season and in the wetter convective clouds in particular. For wintertime orographic clouds where cloud base temperatures are quite low, the opportunities for warm cloud precipitation is much less and probably limited to transition seasons like late fall and late spring storms. Nonetheless, the concentrations of CCN can have strong influences on ice-phase precipitation processes.

Ice phase precipitation processes are mainly due to vapor deposition growth of ice crystals, by ice particles collecting cloud droplets or what we call riming, and by collision and coalescence among ice crystals or what we call aggregation.

Vapor deposition growth of ice crystals can be quite efficient owing to the fact that the saturation vapor pressure with respect to ice is less than that with respect to water. Thus an ice crystal that forms on an ice nuclei (IN) in a cloud of droplets that is water saturated, will find itself in a supersaturated environment and grow by vapor-deposition quite efficiently. As the ice crystals grow they deplete the water vapor content of the air and thus the droplets find themselves in a sub-saturated environment. Thus we say that the ice crystals grow at the expense of cloud droplets. We find that pure vapor-grown ice crystals can produce precipitation and appear much like the story book snow flakes we see replicated on Christmas trees. Note that the efficiency of the process of ice crystals growing at the expense of cloud droplets is related to cloud droplet sizes. Because cloud droplets are nearly spherical, the surface to volume ratio of cloud droplets decreases as droplets become larger. Thus for a given liquid water content, if there are high concentrations of small cloud droplets, the droplets evaporate very rapidly depleting all the liquid in the cloud and forming what we call a glaciated cloud. Modeling studies show that a cloud becomes glaciated (free of any liquid water) much more efficiently if the air mass is polluted with high CCN aerosol concentrations.

The second process of ice precipitation formation is ice particle growth by riming. This process involves ice particles settling through a population of cloud droplets colliding with some of them, and when impact occurs the cloud droplets freeze since an ice crystal is the most efficient IN. This process can lead to heavily-rimed ice crystals, graupel particles, and even hail. The greater the liquid water content of a cloud, the longer the time available for particle growth (i.e. the deeper the cloud), and the larger the sizes of cloud droplets the more efficient this process is in producing precipitation. Note from above, for a given liquid water content, the higher the CCN concentration, the smaller are the cloud droplet sizes and the lower is the efficiency of this process. Clouds forming in a polluted air mass will generally produce more numerous smaller droplets which will be less efficient in contributing to precipitation formation by riming.

The final process for precipitation formation is by collision and coalescence or aggregation among ice crystals. This process occurs most readily if the concentrations of ice crystals is high, if air temperatures are relatively warm(near 0C) where ice crystals become sticky, and if the ice crystals are complex branched structures like dendritic crystals where the branches of the dendrites can interlock contributing to higher sticking efficiencies. Air pollution can enhance this process if the polluted air is high in IN concentrations. At this time it is still unresolved whether polluted air contains higher IN concentrations.

I conclude this section by discussing what determines the concentrations of ice crystals. Because the intent of glaciogenic cloud seeding is to increase the concentrations of ice crystals above that which occurs naturally, it is important to understand how ice crystals form naturally. Ice crystals form by nucleating on some form of aerosol particle that contributes to the freezing of a cloud droplet or to vapor deposition to form ice directly on the aerosol particle. These aerosol particles we call IN. Typical concentrations of IN are small being generally less than 1/liter or 100,000 times fewer than CCN. Natural sources of IN are mineral dust, where they are found in high numbers in dust storms, vegetation materials such as phytoplankton in the sea, and some plant pathogenic bacteria, and pollen. Sources associated with human activity include heavy metal industries and mines, leaded automotive fuels (this has nearly disappeared in the U.S.), and human contributions to dust formation through marginal agricultural practices (like over grazing), construction, and mining. Generally we find that for a given air mass, the concentrations of IN increase with decreasing temperature and increase with supersaturation with respect to ice.

Some explanations or hypotheses that have been proposed to account for the high ice particle concentrations observed in some clouds. Of these the one that has been given the most attention and quantified in models is secondary ice particle formation by the rime-splinter process in which ice splinters are produced at high rates over a narrow temperature range(warmer than -8C) and in which there is a mix of large and small cloud droplets. This process is most efficient in clouds containing high liquid water contents and large numbers of large ice particles like graupel particles, frozen raindrops, and hailstones. This process has been parameterized in a number of cloud and mesoscale models which has improved their estimates of ice crystal concentrations considerably but not for all clouds. As far as winter orographic clouds this process is not particularly active except in wet spring/fall storms. It is more likely to take place in the San Juan Mountains in which the snow events are fed by moist southwest flow and less likely in the drier central and northern Colorado mountains during the main winter season.

An implication is that the seedability of clouds is lower in storms in which secondary ice particle formation is the greatest, as seeding would compete with high concentrations of naturally formed ice crystals.

Application of Glaciogenic Seeding Concepts to Wintertime Orographic Clouds

Application of the glaciogenic cloud seeding concept to orographic clouds has several advantages over cumulus clouds. Orographic clouds are persistent features that produce precipitation even in the absence of large-scale meteorological disturbances. Much of the precipitation is spatially confined to high mountainous regions thus making it easier to set up dense ground-based seeding and observational networks.

The basic concept behind glaciogenic seeding of orographic clouds is to introduce seeding material that will produce the optimum concentration of ice crystals for precipitation formation. The question of what is optimum has not been precisely defined nor can it be without considering the particular features of the clouds forming on a given day and location, and the background aerosol concentrations. In recent years physical studies and inferences drawn from statistical seeding experiments suggest that there exists a limited window of opportunity for precipitation enhancement by glaciogenic cloud seeding. The window of opportunity for cloud seeding appears to be limited to:

- clouds which are relatively cold-based and continental;
- clouds having top temperatures in the range of -10 to -25C;
- a time scale defined by the time available for precipitation formation as illustrated in Fig 1.

As explained above, if clouds are not cold-based and continental, then warm cloud precipitation processes can be quite efficient and the clouds are likely to produce high concentrations of ice particles through secondary ice particle processes and thereby produce precipitation at near optimum rates without seeding. Since clouds can be cold-based and maritime, or warm-based and continental, there is a lot of wriggle room where seeding can potentially enhance precipitation.

As to the temperature window, if clouds are colder than -25C, natural ice crystal concentrations can be quite large, thus seeding might produce too many small ice crystals which would result in what we call an "overseeded" cloud. Such small ice crystals would settle through the air slowly and blow over the mountain crest and settle into dry subsiding air on the lee slopes. On the other hand, at temperatures warmer than -10C seeding materials like AgI are less effective in nucleating crystals. Even dry ice pellets which nucleate ice crystals by homogeneous nucleation (nucleation without nuclei) owing to the very cold temperatures moist air is cooled to, produce fewer ice crystals at these warmer temperatures. The same is true of propane which also nucleates ice crystals by homogeneous nucleation due to the cold temperatures as the air is cooled adiabatically as the gas expands from the generator nozzle.

As to a time window, for orographic clouds it is related to the time it takes a parcel of air to condense to form supercooled liquid water and ascend to the mountain crest. If winds are weak, then there may be sufficient time for natural precipitation processes to occur efficiently. Stronger winds may not allow efficient natural precipitation processes but seeding may speed up precipitation formation. Even stronger winds may not provide enough time for seeded ice crystals to grow to precipitation before being blown over the mountain crest and evaporating in the sinking subsaturated air to the lee of the mountain.

Most cloud seeding operations and experiments have used AgI which has a crystalline structure similar to ice. Its ice nucleating ability depends on the mode of generation. Most generators are acetone generators in which AgI is suspended in acetone. The acetone is burned which produces a smoke of IN. The advantage of this method is that the generators can be located on the ground and take advantage of natural turbulent transport and diffusion processes, to get IN into the cloud. The disadvantage of this method is that generators sited in mountain valleys can produce IN that are trapped in the valleys just as smoke from woodstoves is trapped in mountain resort communities.

Seeding with dry ice pellets is not optimum for use in orographic clouds because of the difficulty and expense (if by aircraft) of dispensing the pellets.

Seeding with propane generators cools the air by adiabatic expansion to temperatures cold enough to nucleate crystals homogeneously. It is a relatively inexpensive method of cloud seeding and is suitable for remote computer-controlled generation. However, the generators must be located within the cloud to be effective. For some meteorological conditions supercooled clouds do not reach the surface. Moreover, placement of generators at the tops of mountains may not be possible for political reasons if the areas are designated as Wilderness Areas.

Evidence that cloud seeding increases precipitation

Overall there is compelling evidence from AgI cloud seeding experiments that seeding can increase precipitation. The actual amount of precipitation increase is still under debate. For example, in the original analyses of the Climax experiments in Colorado it was concluded that there was a 100% increase in precipitation on seeded days for Climax I and 24% for Climax II. On the other hand, an independent reanalysis of those experiments suggested that precipitation increased by about 10% in the combined Climax I and II experiments. As a conservative estimate we should use the 10% figure but realize that larger increases are possible under optimum conditions.

In the future it is recommended that cloud seeding operations be optimized to consider the day-by-day variations in the meteorology that controls the conditions suitable for cloud seeding. This should include measurements of variations in background cloud nucleating aerosol concentrations (CCN and IN). Our application of the high-resolution mesoscale model RAMS to cloud seeding decision making and to evaluation of cloud seeding effects (Cotton et al., 2006) is one example of a methodology for optimizing cloud seeding operations. Recent refinements in that model should improve its overall performance and if used with higher resolution it should be a valuable tool for cloud seeding decision making and evaluation of the impacts on orographic precipitation.

Summary

In summary, the application of glaciogenic cloud seeding to orographic clouds has been shown to cause the expected alterations in cloud microstructure including increased concentrations of ice crystals, reductions of supercooled liquid water content, and more rapid production of precipitation elements. The evidence that seeding orographic clouds can produce increases in precipitation on the ground and cause significant increases in snowpack is quite compelling, particularly in the more continental and cold-based orographic clouds. Moreover, as noted above there is strong evidence that air pollution is decreasing orographic precipitation by as much as 30% per year. Cloud seeding therefore may be needed to offset the negative effects of air pollution. However, it still has to be determined if polluted clouds are as seedable as clouds forming in relatively clean continental air masses.

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Colorado State University Agricultural Experiment Station

The Colorado Climate Center

by Nolan Doeskin, Colorado State University Climatologist

The Colorado Climate Center is located within the Department of Atmospheric Science on the Foothills Campus of Colorado State University and is part of CSU's College of Engineering. The primary mission of the Colorado Climate Center is to monitor and track climatic conditions throughout all of Colorado and to serve as an information resource to business, government, industry, education, research and the general public.

Historic Fort Collins weather station on the campus of Colorado State University

A brief history

Throughout the 1950s and 1960s there was a State Climatologist in every state across our nation. This was a federal position that was part of the old "U.S. Weather Bureau." Joseph Berry served Colorado in that capacity for many years. Colorado's State Climate office in those early years was in downtown Denver in the Post Office building. Then, in the early 1970s, the federal program was abolished. Colorado, recognizing the incredible importance of its' varied and extreme climate on the economy of the State, was one of the first states in the country to re-establish this position and office. Professor Lewis Grant (retired), long-time faculty member in CSU's Department of Atmospheric Science and a well-known local farmer and advocate for agriculture, was instrumental in securing state funding for the office and moving the Center to Colorado State University. Initial funding for the Center was authorized through the Colorado Agricultural Experiment Station. That support continues today and is supplemented by other contracts and grants.

Dr. Thomas McKee was hired in 1974 to become the first State Climatologist for Colorado at CSU. He served until his retirement in 2000. Dr. Roger Pielke then served from 2000 until his retirement from CSU in 2006. Nolan Doesken, who has been with the Center since 1977, was appointed State Climatologist in 2006.

Duties and Responsibilities

The main activities of the Colorado Climate Center are climate monitoring, data archival, applied research, public service, state/federal/local coordination, education and outreach.

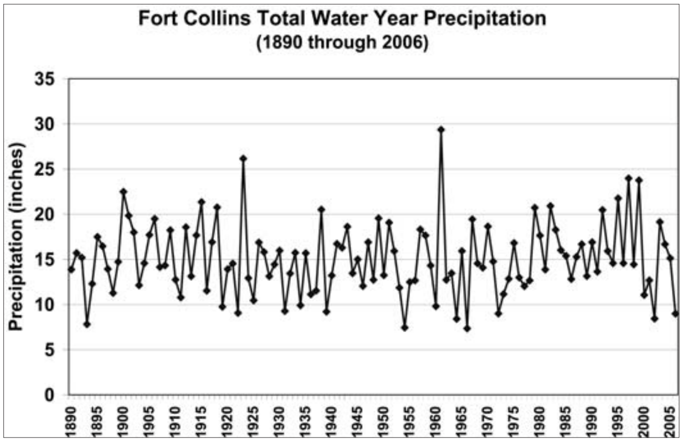
Climate monitoring

The essence of our work is tracking weather conditions day by day, season by season, and year by year and interpreting, explaining and understanding the observed patterns and variations that climate provides. In a mountainous state like Colorado, there are huge local differences in climate. With limited water resources and many competing demands, climate information is essential for anticipating and managing water supplies. The backbone of U.S. Climate monitoring continues to be the National Weather Service's Cooperative Network with over 200 stations in Colorado reporting temperatures and precipitation on a daily basis. Some of these stations date back more than a century, providing the longest continuous data records for tracking climate variations and change. CSU's main campus weather station is operated by the Climate Center and is Colorado's premier historic weather station. Records here data back to the early 1870s and are complete back since the 1880s. The Climate Center also incorporates observations from other organizations. USDA's Natural Resource Conservation Service snow surveys, for example, provide essential data for climate and water supply monitoring.

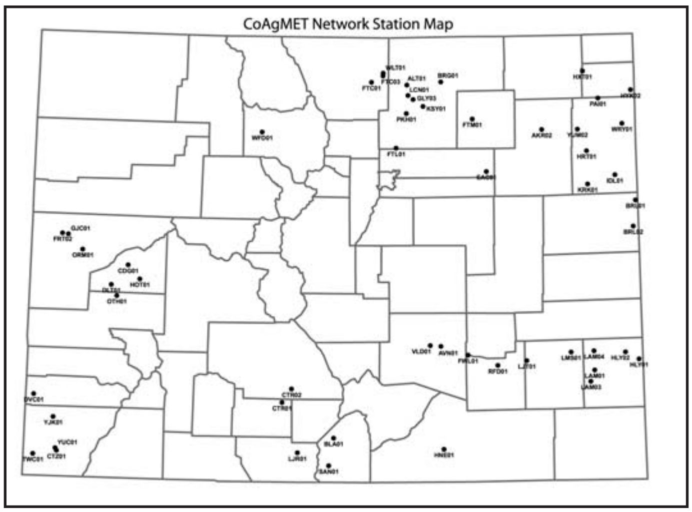
Beginning in the early 1990s, the Colorado Climate Center assisted several other CSU and federal groups in establishing a specialized automated weather observing network to serve Colorado agriculture. The Colorado Agricultural Meteorological Network (CoAgMet) now provides detailed hourly weather data from 60 stations across the state representing most agricultural areas. Observations include temperature, humidity, wind speed and direction, precipitation, solar energy and soil temperatures. Computations of evapotranspiration from CoAgMet have become the primary data source for much of the state for tracking water use by crops. All current and historic data from this network are available online free of charge at:http://ccc.atmos.colostate.edu/%7Ecoagmet/

Data Archival
The Colorado Climate Center serves as an archive of historical climate data collected in Colorado. A small library contains original climate data and published summaries back into the 1800s. Digital databases are also maintained. For efficiency, much of the data management is coordinated nationally by the National Climatic Data Center in Asheville, North Carolina, and by regional climate centers in Nebraska and Nevada.

Climate Research
Since it's beginning, the Colorado Climate Center remains actively involved in research. Tom McKee spearheaded drought research and developed a drought monitoring index, the "Standardized Precipitation Index," that is now used worldwide. Years of research on mountain and valley weather patterns has lead to greater understanding of mountain climatology. Energy, crop production, and engineering applications are just a few other topics of investigation.



Time series of Fort Collins WY precip through 2006.



Map of Current COAGMET Stations.

Snow sensors at the Fort Collins weather station.

The Colorado Climate Center also works closely with the National Weather Service in research to improve weather stations and weather observations. The Center is currently leading a nationwide test and evaluation of automated snow measurement systems.

A list of publications of research results is maintained on the Colorado Climate Center website at: http://ccc.atmos.colostate.edu/publications.php

Climate Services
Providing climate date, information and expertise to benefit the citizens of Colorado is the ultimate goal of the Climate Center. Services are provided on various levels. The web site at http://ccc.atmos.colostate.edu is now the primary means for answering questions and sharing data and information. The Center also welcomes phone calls and walk-in visitors. Over the years, tens of thousands of questions have been addressed on wide ranging topics. Climate information is useful in more ways than most people realize. Potential for introducing new crops, causes for fluctuations in crop and livestock production, recreational opportunities, commercial and residential construction, transportation, verifying insurance claims, human and animal health, where and when to schedule conferences and outdoor events, dam and spillway design and floodplain management, drought and water supply -- the list is nearly endless.

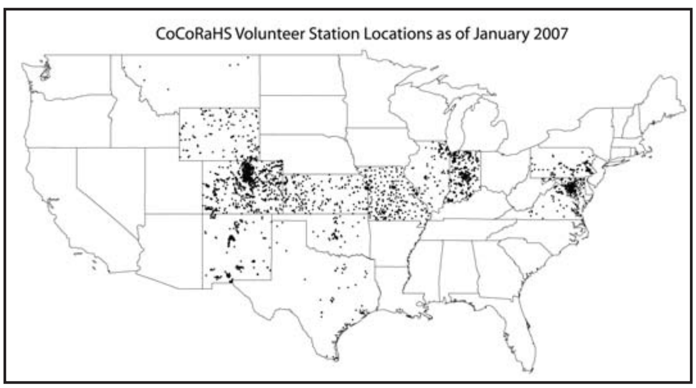
The Center also participates in many statewide meetings and organizations.

The Colorado Climate Center was actively involved in the development of Colorado's Drought Response Plan and have attended nearly every meeting of the Colorado Water Availability Task Force since it was established in 1981.

Education and Outreach
Recent years have seen a huge upswing in education and outreach opportunities. Tours of the historic Fort Collins Weather Station bring hundreds of visitors to campus each year. Many talks and presentations are provided on the topic of Colorado's amazingly variable climate.

The most visible education and outreach activity of the Colorado Climate Center today is CoCoRaHS -- the Community Collaborative Rain, Hail and Snow Network. Thousands of citizens of all ages are helping monitor the weather and water resources in Colorado by setting up backyard rain gauges across the state. This program is providing educational opportunities for a large number of individuals while also contributing an incredibly valuable data resource for studying weather patterns and local rainfall variations in Colorado. The project is so popular that it has spread to many other states and may be a nationwide program by 2010.

If you would like to help monitor and report rainfall from your own neighborhood, or if you know someone who would, please go to www.cocorahs.org and click on "Join CoCoRaHS."



State Climatologist Nolan Doeskin explains a weather station to students

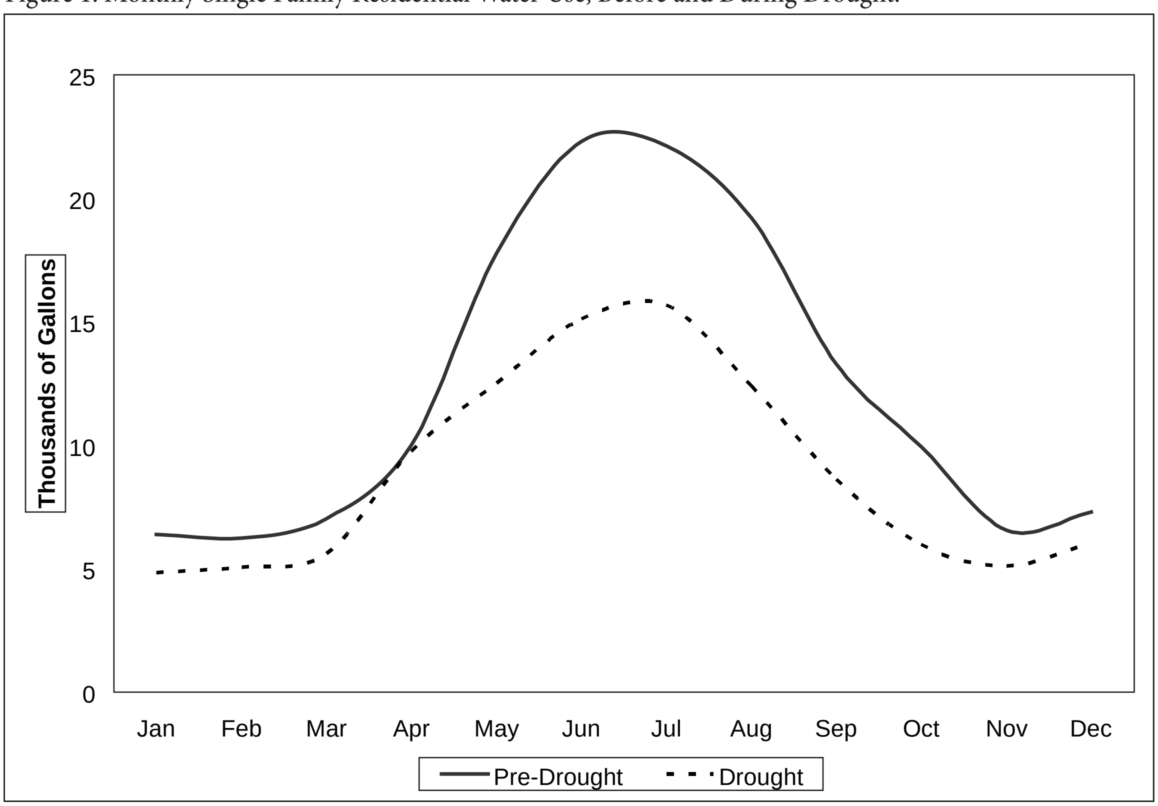
CoCoRaHS Volunteer Observer, photo by Henry Reges.

Residential Water Demand Management in Aurora: Learning from the Drought Crisis

by Doug Kenney, Chris Goemans, Bobbie Klein, and Jess Lowrey, CU-NOAA Western Water Assessment
Kevin Reidy, Water Conservation Supervisor, Aurora Water

Recent drought years in Colorado have brought many unwelcome burdens and challenges to Colorado's water management community, but have also provided a strong incentive for reform and innovation. One example can be found in Aurora, where drought conditions in 2002 prompted an aggressive expansion and acceleration of a variety of residential demand management programs, aimed not only at surviving the drought crisis but also at reducing long-term per capita demand. Programs have included outdoor water-use restrictions, incentive and rebate programs, and a variety of pricing reforms, all nested within an ongoing public education campaign. By almost any measure, this mix of tools was immediately and hugely successful, with demands in 2003 down 26 percent from pre-drought conditions in 2000 and 2001. Average pre-drought (1/1/2000 to 4/30/2002) and drought (5/1/2002 to 4/30/2005) residential consumption levels in Aurora are shown in Figure 1. Several other Colorado cities have reported similar success stories.

Figure 1. Monthly Single Family Residential Water Use, Before and During Drought.



In order to reap the full benefits of its demand management efforts, Aurora Water identified a need to better understand why their efforts have thus far been successful in reducing system wide demands, as this knowledge is central to answering questions about whether the observed reductions are likely to continue, and which of the policy tools already employed should be prominently featured (or discontinued) in future conservation efforts. This not only calls for investigating the relative effectiveness of the various tools employed, but also for considering how the effectiveness of these tools varies among different types of residential customers. Answering these questions in a rigorous way calls for a quantitative, statistical analysis.

To conduct this research, in the fall of 2005 Aurora Water partnered with researchers at the Western Water Assessment (WWA), a NOAA-funded effort based at the University of Colorado's Cooperative Institute for Research in Environmental Sciences. Aurora Water sought information that would help them with future planning and management exercises, while WWA researchers wanted to better understand the opportunities for residential demand management programs as a tool for adapting to climate change and variability in the West. The following paragraphs summarize some of the findings from the initial Phase 1 of research.

Research Methodology

Many academic studies document those factors known to influence residential water consumption. Prominent among these influences are several factors within the control of the water utility (e.g., price, water restrictions, and rebate programs), and several that are not (e.g., weather and climate, and demographic characteristics of customers). In our research, we utilized a model of water demand that includes both types of factors, while focusing our analysis primarily on those factors that are within the utility's sphere of influence. Fortunately, Aurora provides an ideal case study for examining these factors, as the city has recently experimented with several types of price, restrictions, and rebate programs. For example, over the past 5 years, Aurora Water's water rate structure has evolved from a flat to an increasing block rate (IBR) structure, and from an IBR applied uniformly across the customer base to one that features individual (household level) water budgets. Also significant has been the use of mandatory outdoor water-use restrictions throughout most of 2002 to 2004, and the ongoing use of rebate programs for both indoor and outdoor water-saving technologies.

We have been able to take advantage of this wealth of experimentation by virtue of having household-specific consumption (billing) records going back to 1997, prior to the drought crisis and the imposition of the most aggressive demand management measures. Using a statistical technique known as fixed effects, we have evaluated changes in water-use within more than 10,000 individual households in Aurora, tracking how each household has responded to changes in price, restrictions, and for those that participated, rebate programs. Comparing the responsiveness of individual households to the overall responsiveness of the entire study population allows us to identify important relationships between the demand management tools and the types of customers affected. Specifically, we choose to distinguish between customers that, prior to the drought, were high, medium, and low volume water users. Not surprisingly, the vast amount of system wide water savings achieved in Aurora has come from modifying the behavior of the high-volume water users; thus, understanding how this group reacts to conservation programs is of particular importance.

Preliminary Findings

The most common focus of water demand studies is the determination of price elasticity of demand—i.e., the extent to which consumption drops for a given increase in price. In Aurora, the overall price elasticity of demand is calculated to be -0.60 across the full study period and population, meaning that a 10 percent increase in price reduces demand by 6 percent. This figure, well within the range found in other studies, is a useful finding, but the real insights come from delving deeper. For example, our research demonstrates that the price elasticity of demand is considerably higher among the high water users, in the summer months, and during drought conditions.

Of particular salience to managers is the interaction of pricing tools with water-use restrictions, a special point of emphasis in our research. Pricing tools and water restrictions can both reduce water demand, but they do not operate independently, and their levels of savings are not fully additive since, for any given customer, one or the other (not both) will limit water consumption. In Aurora, enacting mandatory water restrictions reduces the overall price elasticity of demand from -0.60 to -0.37, meaning the effectiveness of price in limiting demand is reduced. To understand this change, one needs only look at the high-volume water user category, whose price elasticity of demand averages -0.75 in periods without water restrictions and -0.24 in periods with restrictions, the decline occurring since restrictions limit water use among these users before any personal price threshold is reached. This observation has many policy implications, perhaps suggesting that managers attempting to control demand of high-volume water users would be wise to focus on pricing tools in non-drought periods (when restrictions are not in place) and water restrictions in drought years. Of course, modifying the severity of the pricing or restrictions policies can alter this conclusion, as can a consideration of the equity impacts of demand management tools on the full spectrum of water users.

Other findings with significant management implications involve those programs promoting technology upgrades for indoor water-using fixtures, namely toilets and washing machines. Aurora residents participating in the indoor rebates programs reduced consumption by 10 percent, a finding that is consistent with other studies. This is a water savings that is likely to persist. Less intuitive were findings regarding the use of Water Smart Readers, devices Aurora Water customers can purchase (at a subsidized price) that allow them to track their water-use in real time. Without these devices, individuals only learn of their consumption when their bill arrives, a full month after the water-use decision were made. Individuals with Water Smart Readers tend to increase use (by 16 percent), an initially surprisingly finding that makes sense only when it is observed that these individuals use the knowledge obtained from the Readers to take full use of water allotted to them in the lower priced tiers while avoiding the upper tiers with more punitive pricing policies. Presumably, without a Water Smart Reader, users wishing to avoid the higher priced tiers would err on the side of caution, using water sparingly and thus not using the full allotment of the lower priced water.

Looking Forward

As is typical in research endeavors, our improved knowledge in some areas has only highlighted our need to better understand other factors. For example, demographic statistics regarding our customer base suggest that high-volume water users tend to be wealthier, older, and live in newer and larger homes than other customers (Table 1). These observations have potentially important implications both for conservation programs and for forecasting changes in long-term demand, but there is much more to be learned. Better understanding how customers actually make water-use decisions, for example, is a pressing need, but one that will require obtaining additional data about matters such as the irrigation system and cooling system technologies employed in these households. This is information that utilities rarely collect. Addressing these and related deficiencies in our preliminary analysis of residential water demand is likely to be the subject of a Phase 2 of research.

Additional Information
Please contact Doug Kenney, project manager, at 303-492-1296 or douglas.kenney@colorado.edu.

To access this article in its entirety, please visit: http://wwa.colorado.edu/resources/water_demand_and_conservation/WaterDemandAurora.pdf

Table 1. Summary Statistics by Type of User.

	Household Type		
Variable	Low	Middle	High
	Average		
Average Monthly Consumption	4.90	9.34	14.80
Economic-Demographic (census-block)			
Household Income	50,680	53,967	58,928
Median Age of Homeowner	33.66	34.33	36.35
Persons Per Household	2.81	2.87	2.82
Percentage of Homes Built After 1960	77%	84%	92%
Number of Bedrooms	1.40	1.44	1.46

Demonstration of the Colorado Agricultural Meteorological Network COAGMET for Improved Irrigation and Pest Management

by Troy Bauder, Department of Soil and Crop Sciences
Nolan Doeskin, Department of Atmospheric Sciences
Howard Schwartz, Department of Bioagricultural Sciences and Pest Management
Mike Bartolo, Arkansas Valley Research Center

Agriculturalists have long understood that weather events and patterns greatly influence their chances for establishing, growing, harvesting, and often marketing a successful crop. Thus, farmers and ranchers have always depended upon weather information to aid in making a variety of production decisions. However, the information or data available for these decisions and the methodology used to interpret this data has not always been sound. Fortunately for the present-day crop producer, agricultural scientists have found ways to utilize meteorological data to develop tools that have the potential to improve and enhance the farmer's management decisions. The need for this information has led to the installation of weather station networks to gather and report basic meteorological data.

Colorado producers have had access to decision support information produced from a weather station network called the Colorado Agricultural Meteorological Network or CoAgMet for over a decade. The CoAgMet network was established in the early 1990's by Plant Pathology extension specialists at CSU and USDA's Agricultural Research Service Water Management Unit, after they discovered that they had a mutual interest in collecting localized weather data in irrigated agricultural areas. Plant pathologists used the data for prediction of disease outbreaks in field crops such as dry bean and vegetable crops such as onion and potato, and ARS specialists used almost the same information to provide irrigation scheduling recommendations. Two information products that resulted from this collaboration are daily crop evapotranspiration (ET) rates and disease forecasting. These products are supplied by the web pages of the Colorado Climate Center (www.coagmet.com) and at www.colostate.edu/Orgs/VegNet/Resources at Colorado State University.


AVRC weather station.

The information supplied by this network can be used to help irrigating producers advance their irrigation and pest management in many instances. However, recent survey data suggests that only a small minority of growers are taking advantage of these products to improve their management. The reasons for this low adoption are unknown, but may include a lack of knowledge that the information exists, a need for assistance in adopting the technology, usefulness and reliability of the products supplied, others reasons, or a combination of these explanations. Gathering and reporting meteorological data and associated crop decision reports will not produce the desired impacts unless these products are adopted by crop producers. Direct interaction and assistance with producers is often necessary for them to adopt new technology and change how they make decisions using this technology. This interaction is especially useful because it also affords the producers an opportunity to influence the development of a product designed to help them make farm level decisions.

Thus, this team is conducting a validation and demonstration effort in the Arkansas Valley during the 2007 and 2008 cropping seasons. The Arkansas Valley area was chosen because recent survey results suggest that only a few growers (3 to 7%) use weather station ET as either their primary or secondary irrigation scheduling method in this basin and the same survey showed that only 7% of respondents were using pest forecasting in their pest management program (Bauder et al., 2005). Additionally, the CoAgMet weather station network in the Arkansas Valley has undergone a comprehensive enhancement with new and relocated stations, an improved maintenance schedule and data review to support the Colorado v. Kansas litigation. These improvements to the weather station network will also provide better ET and disease forecasting tools to users in the Arkansas Valley.

This project expects to increase the number of crop producers utilizing CoAgMet weather data to improve irrigation management with ET-based scheduling and integrated pest management using disease forecasting; validate onion disease (Xanthomonas Leaf Blight) forecast models and demonstrate the need for timeliness of pesticide applications when warranted by weather monitoring and crop/pest scouting. We also plan to update and improve the delivery of web-based evapotranspiration (ET) and disease forecasting decision support tools delivered on www.coagmet.com and www.colostate.edu/Orgs/VegNet/Resources. Additionally, we are partnering with the Southeastern Colorado Water Conservancy District (SECO) to promote their water efficiency program described at the SECO Water Wise Website (www.secowaterwise.org), where CoAgMet weather data products are linked.

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Water Resources Archive at Colorado State University Libraries

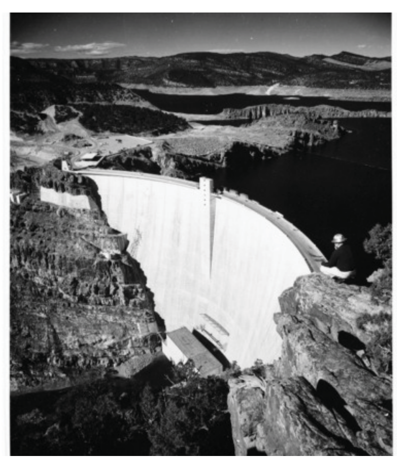
"Dam Beautiful" Exhibit

Now on display in Colorado State University's Morgan Library is a new exhibit created by the Water Resources Archive. Entitled "Dam Beautiful: Robert Glover and Arch Dams," the exhibit features items from the Papers of Robert E. Glover.

A Bureau of Reclamation engineer for more than thirty years, Robert E. Glover made significant contributions to the design of arch dams. His concrete studies influenced the way Hoover Dam was constructed, and a 1956 symposium he organized influenced the future design of arch dams.

Featuring photographs, reports and artifacts from Glover's personal papers, this exhibit examines some of the West's beautiful arch dams and Robert Glover's contributions. As debate over the costs and benefits of dams promises to be ongoing, a look at one aspect of their history can be informative.

"Dam Beautiful" is open from 8:30 to 4:30, Monday through Friday until February 26, 2007, in the Archives and Special Collections reading room in Morgan Library. Call 970-491-1844 for more information.



Flaming Gorge Dam, Utah. From the Glover Papers, CSU Water Resources Archive.

Colorado Water Resources Research Institute Awards Funding for FY07 Research Projects

CWRRI was fortunate to receive additional funds from the State of Colorado in FY07 to expand the research portfolio. Under Section 104(b) of the Water Resources Research Act, CWRRI is to "'plan, conduct, or otherwise arrange for competent research…" that fosters the entry of new scientists into water resources fields, the preliminary exploration of new ideas that address water problems or expand understanding of water and water-related phenomena, and disseminates research results to water managers and the public. The research program is open to faculty in any institution of higher education in Colorado that has "demonstrated capabilities for research, information dissemination, and graduate training … to resolve State and regional water and related land problems."

The general criteria used for proposal evaluation included: (1) scientific merit; (2) responsiveness to RFP; (3) qualifications of investigators; (4) originality of approach; (5) budget; and (6) extent to which Colorado water managers and users are collaborating.

A call for proposals went out last July and was responded to by over 20 high quality requests totaling over $1 million in requested support. A peer review process and ranking by the CWRRI Advisory Committee resulted in funding 10 projects for FY07. Project titles and investigators and listed below. For more information on any of these projects, contact the PI or Reagan Waskom at CWRRI. Special thanks to the many individuals who provided peer reviews of the project proposals.

Effects of Pine Beetle Infestations on Water Yield and Water Quality at the Watershed Scale in Northern Colorado. John D. Stednick, Dept of Forest, Range and Watershed Stewardship, Colorado State University. $49,658

Occurrence and Fate of Steroid Hormones in Sewage Treatment Plant Effluents, Animal Feedlot Wastewater, and the Cache la Poudre River of Colorado. Thomas Borch, Dept. of Soil & Crop Sciences, Colorado State University. $49,944

Detecting Trends in Evapotranspiration in Colorado. Nolan Doesken, Colorado Climate Center. $47,802

Evaluation of Engineered Treatment Units for the Removal of Endocrine Disrupting Compounds and Other Organic Wastewater Contaminants During Onsite Wastewater Treatment. Robert L. Siegrist, Environmental Science and Engineering, Colorado School of Mines. $49,746

Direct Determination of Crop Evapotranspiration in the Arkansas Valley with a Weighing Lysimeter. Abdel Berrada, Arkansas Valley Research Center, Colorado State University. $49,995

Refining Water Accounting Procedures Using the South Platte Mapping and Analysis Program. Luis Garcia, Dept of Civil and Environmental Engineering, Colorado State University. $22,985

Development of Oilseed Crops for Biodiesel Production Under Colorado Limited Irrigation Conditions. Jerry J. Johnson, Dept. of Soil & Crop Sciences, Colorado State University. $47,933

Characterizing Non-Beneficial Evaporative Upflux from Shallow Groundwater Under Uncultivated Land in an Irrigated River Valley. Jeffrey D. Niemann, Luis Garcia, Dept of Civil and Environmental Engineering, Colorado State University. $49,942

Predictability of the Upper Colorado River Streamflows. Jose D. Salas, Colorado State University and Balaji Rajagopalan, University of Colorado. $44,859

Simultaneous Water Quality Monitoring and Fecal Pollution Source Tracking in the Big Thompson Watershed. Lawrence Goodridge, Dept. of Animal Sciences, Colorado State University. $49,995

NON DETECTS AND DATA ANALYSIS: Short Course

March 12, 2007 - Colorado School of Mines

This one-day short course presents statistical methods for interpreting data below detection limits.

For more information, contact: International Groundwater Modeling Center
phone: 303 273-3103
fax: 303 384-2037
email: igwmc@mines.edu

A Web-Based Groundwater Quality Information Tool for Colorado

by Troy Bauder, Deptartment of Soil and Crop Sciences, Colorado State University
Robert Wawrzynski, Colorado Department of Agriculture
Dave Patterson, Integrated Decision Support Group, Colorado State University

The Colorado Agricultural Chemicals and Groundwater Protection Program (Groundwater Program) is charged with "protecting groundwater and the environment from impairment or degradation due to the improper use of agricultural chemicals while allowing for their proper and correct use...". The Groundwater Program uses education and regulation to prevent future contamination, and groundwater monitoring to determine areas where contamination has occurred. These approaches are used in combination to identify those areas where increased efforts are necessary to prevent further degradation of water quality. Groundwater monitoring has been an important component of the Groundwater Program since its inception in 1990 (Austin, et al. 2001). Groundwater systems in the largest agricultural regions of Colorado have been surveyed by the Groundwater Program (Figure 1). From these efforts, over 1,850 samples have been analyzed from over 1,050 wells. The samples are analyzed for 47 pesticides, nitrate-nitrogen and routine inorganic constituents. The results of these monitoring efforts are reported in fact sheets, annual reports, and verbally to various interest groups and the Colorado Water Quality Control Commission. Unfortunately, this information has not yet been made available to the public in one centralized location that can be quickly and easily accessed.

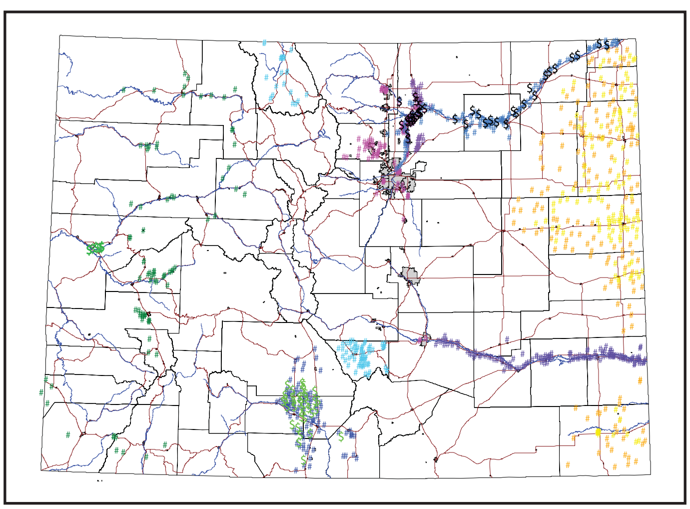


Figure 1. Monitoring locations of the Groundwater Program.

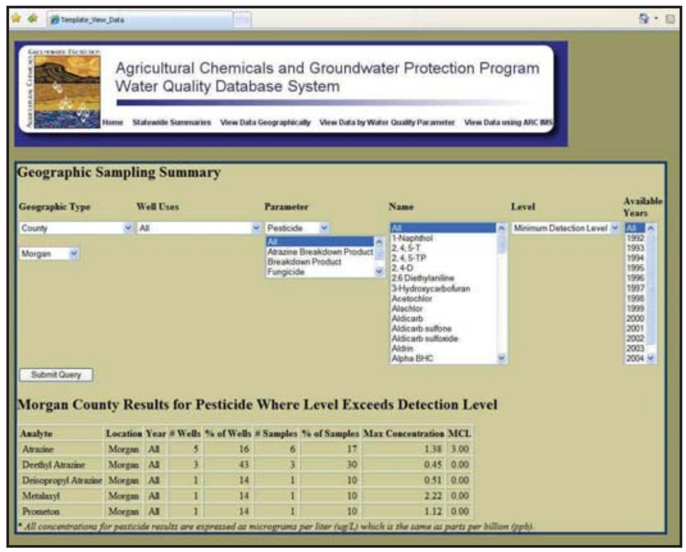


Figure 2. Example query from the Groundwater information tool.

The Groundwater Program has also developed sensitivity/vulnerability/probability maps and products for general pesticides (Hall, 1998; Murry, et al. 2000; and Schlosser, 2000), atrazine (Rupert, 2003) and nitrate (Ceplecha, 2001 and Rupert, 2003). To promote public availability of this groundwater information, as well as the Program's ongoing groundwater protection efforts, we built a web-based groundwater information tool that allows users to quickly access information to help them make better-informed decisions to protect water resources.

The water quality information is searchable by several geographic choices, water quality parameter, well type, analyte concentration and sample year (Figure 2). The flow of the website provides water quality data from general to specific and allows users to obtain summaries and basic water quality statistics. The backend of the web server is an Access database and is connected to the server using ODBC and Webware for Python. Users of the ground water quality web site are also able to view water quality data and vulnerability and sensitivity maps at various scales using ARC-IMS technology. This tool allows general public users to quickly and easily assess ground water quality data to determine if there are real or potential contamination problems in their area. Government and private planners can determine where to best allocate ground water protection resources and allocate more time and resources to the management and protection of highly vulnerable areas, thereby efficiently utilizing limited ground water protection resources.

The Groundwater Program's expected outcomes of this information tool are improved accessibility and knowledge of water quality data; improved use of resources to protect vulnerable ground water; a GIS tool for directing future ground water management efforts at multiple scales; and increased stakeholder awareness and involvement regarding any potential, as well as identified, ground water contamination. The Groundwater Program plans a public release of this information product on March 1, 2007. It will be linked at www.csuwater.info. This project was funded by a grant from the USEPA, Region 8.

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Emerging Issues in Soil and Water:
Gary A. Peterson and Dwayne G. Westfall Annual Lecture Series

Presents

"On the Sustainable Management of Soil and Water Resources: Historical and Contemporary Perspectives"

Dr. Daniel Hillel
April 19, 2007 from 2:00-3:30 p.m.*
North Ballroom, Lory Student Center
Colorado State University Campus

*The lecture is free and open to the public and will be followed by a reception from 3:30-4:30 p.m. in the North Ballroom

For additional information please contact Dr. Neil Hansen
Phone: 970-491-6804
Email: Neil.Hansen@colostate.edu

An interdisciplinary organizing committee at Colorado State University has established an annual lecture series to promote awareness of critical and emerging issues related to soil and water resources. This lecture provides a forum to explore issues, to inspire creative thinking, and to recognize excellence in research and teaching on the topics of soil and water resources. Each year, the event will feature a public lecture by one or more international experts whose insights apply to emerging issues for Colorado citizens. The lecture is named to recognize Dr. Gary Peterson and Dr. Dwayne Westfall and their dedication to the understanding of soil and water resources in Colorado agroecosystems.

Utton Center Develops a Model Insterstate Water Compact

by Marilyn O'Leary, Director, Utton Transboundary Resources Center

Disputes among states sharing interstate waters have increased significantly over the past two decades. These proliferating disputes involve water quantity, water quality and the effects of a variety of federal environmental laws enacted since the early 1970s. Drought has exacerbated these tensions.

As interstate water conflicts have increased, so has the realization that most of the existing compacts appear to be inadequate to resolve such conflicts. Consequently, in 2002 the Utton Center initiated a comprehensive project to develop a model interstate water compact that could be adapted either along the lines of a traditional interstate compact, with only states as signatory parties, or a federal/interstate compact with the United States also a signatory party, which is the approach the four most recent compacts approved by Congress have taken. Either approach would include Native American representation. This project was undertaken with funding the Center received from the Department of Energy with the help of Senator Pete Domenici.

First, a national conference titled 'Interstate Waters: Crossing Boundaries for Sustainable Solutions, a Multidisciplinary Approach,' was held to address the approaches of a variety of disciplines that are key in managing interstate water resources. Seventy lawyers and scientists from across the U.S. with extensive expertise in interstate water issues gathered to share what they believed to be the strengths and the limitations of their particular discipline when it came to addressing complex water issues with a view to identifying ways that they could better work together to support the management goals of stakeholders. A second national conference, 'Crossing Cultural Boundaries for Sustainable Solutions,' brought together a variety of experts who had been successful in crafting Indian water rights settlements. Perspectives on the values related to water were shared by representatives of major water user groups.


Jerome Muys, Jr.

Then, in 2004, the Utton Center began work on the model compact. Jerome C. Muys, Jr. an attorney with considerable experience with interstate compacts was contracted to oversee the project. He was assisted by George W. Sherk, an attorney with an engineering background, also extensive experience and knowledge with interstate water compacts. They were assisted throughout the research stages of the project by UNM law students. Together with Marilyn O'Leary, Director of the Utton Center, Muys and Sherk developed a methodology for carrying out the project as follows:


George Sherk.

- First was a thorough literature review to identify and evaluate the asserted strengths and weaknesses of the use of compacts to resolve interstate water conflicts in both theory and practice.
- Second was to review and catalog the language of all existing interstate water allocation compacts and required Congressional consent legislation by topic to identify how critical issues have been addressed historically. This research was supplemented with information obtained in response to a questionnaire sent to each of the interstate water compact commissions on the practical administration of those compacts.
- Third was selection of an Advisory Committee comprised of thirty individuals representing a wide range of professional areas of expertise and stakeholder interests in interstate water issues.
- Additional research included an analysis of the impact of federal environmental legislation affecting existing interstate water compacts and a review of compact litigation in the Supreme Court.
- Research efforts were complemented by several case studies, including the Great Lakes and the Apalachicola-Chattahoochee-Flint River Basin and the Alabama-Coosa-Tallapoosa River Basin Compacts in the Southeast to identify problem areas and opportunities in the interstate compact approach.
- In March 2005 the Advisory Committee assembled at Bishop's Lodge near Santa Fe, New Mexico. It was no

coincidence that Bishop's Lodge was the site of the negotiations for the first interstate water allocation compact, the Colorado River Compact, in 1922. The 3-day workshop was to evaluate and supplement the principal issues identified by the project study and to receive recommendations regarding specific approaches, methodologies and topics to be addressed in the model compact. A summary of the workshop's principal conclusions and recommendations was prepared for review and comment by the Committee.

- Muys, Sherk and O'Leary prepared a working draft of a model compact which was sent to the Advisory Committee for review and comment. Many of the comments were incorporated in the draft model compact.

- Each compact article is accompanied by a commentary to explain why particular approaches were taken, along with suggestions for alternative approaches to critical issues such as compact commission membership and voting procedures, interstate allocation methodologies, dispute resolution, and adjustments to changing hydrologic data or legal requirements. These commentaries are drawn from the comments received from the Advisory Committee and illustrate how the model compact, which is not intended as a "one size fits all" proposal, can be adapted to different situations in various river basins.

The primary goal of the model compact is to provide a mechanism by which interstate water conflicts may be resolved in an amicable, efficient, equitable and effective manner. The intention is to empower states to take interstate water management into their hands in a collaborative way and avoid the uncertainties and costs of litigation and vagaries of Congressional legislation. It is hoped that this compact will provide a blueprint not only for states and sovereign entities to collaborate for sustainable management of shared water resources but can also serve as the basis for peaceful resolution of international.

The compact and commentaries will be published in the winter Natural Resources Journal and will be available at the Utton Center website at http://uttoncenter.unm.edu.

FACULTY PROFILE

Dr. Stephanie Kampf

Dr. Stephanie Kampf is a Colorado native, born in Denver and raised in Grand Junction. As an avid hiker, Kampf enjoys wandering around the desert and mountains while exploring new terrain.

Kampf has long been interested in western water issues, though she only discovered the interest after leaving Colorado for the wetter climate of western Massachusetts during her undergraduate years. At Williams College, Kampf studied geosciences with a concentration in environmental studies with an idea that she should eventually study water. Starting out the water studies, she then went to Chile on a Fulbright fellowship, and there Kampf researched how climate fluctuations affect groundwater recharge in the Atacama Desert. Kampf's graduate studies took her to the University of Nevada, Reno, where she worked on an M.S. in hydrogeology studying evaporation at a dry lake, the Salar de Atacama, in northern Chile. From Reno, she went on to the University of Washington for her doctoral studies in hydrology in the Department of Civil and Environmental Engineering.

With a background in geology, groundwater, and surface hydrology, Kampf now works on 'integrated hydrology', trying to merge our understanding of the physical processes of water movement between the atmosphere, land surface, and underground. According to Kampf, "whether in the research or the management domain, many of the water issues we confront involve complex interactions between climate, surface and groundwater. My research is about exploring how we can best understand and represent these interactions, so I focus both on hydrologic measurement techniques and on physics-based computer simulation models of surface water, groundwater, and evaporation."

Kampf is excited to be back in Colorado and joining the faculty in the Forest, Rangeland, and Watershed Stewardship department at CSU. During the Spring 2007 semester she will be teaching a graduate course, Modeling Watershed Hydrology, and joining the other faculty in the Watershed Science program in teaching the senior-level capstone course, Watershed Problem Analysis. In future years, she will also teach Watershed Management and additional graduate courses on evaporation and land-atmosphere interactions.

Lower South Platte Water Symposium
Wednesday March 7, 2007

Northeastern Junior College - Sterling, CO
Registration begins at 8:00 a.m.
Today's Actions for Tomorrow's Livelihood

This symposium will enlighten you about the "Big Picture" of the Lower South Platte River. Update your knowledge on current water use and management practices and obtain insight on the issues at hand concerning the future and protection of this most valuable resource.

State Water Supply Initiative Update
Rick Brown, Colorado Water Conservation

Changes in the River and Water Supply Update
Jim Hall, State Engineer's Office

Three State Agreement
Alan Berryman, Northern Colorado WCD

Water Supply with Global Climate Change
Brad Udall, NOAA

Future of Water Legislation
Dianne Hoppe (invited)

Parker Water
Frank Jaeger, Parker Water and Sanitation

Water Conservation Districts and Water Rights
Jay Winner, SE Water Conservancy District

Regional Impact of Irrigation
James Pritchett, Colorado State University

Who should attend? Ag producers, elected officials, city council/managers, electric association boards, SCD boards, ground water management boards, people associated with water use issues and citizens.

Major support for this symposium is being provided by
Lower South Platte Water Conservancy District

Registration Fee: Lunch, Breaks & Handouts

Before February 21st - $20/person

Late Registration Fee - $35/person

Payable to: Golden Plains Area Extension Fund
181 Birch Avenue
Akron, CO 80720

For More Information Contact
Joel Schneekloth
970-345-0508

Hydrology Days 2007

The 2007 Hydrology Days will be held at Colorado State University during March 19 - March 21, 2007.

Abstracts are due by February 9, 2007.

Hydrology Days has been held on the campus of Colorado State University each year since 1981. Hydrology Days is a unique celebration of multi-disciplinary hydrologic science and its closely related disciplines. The Hydrology Days vision is to provide an annual forum for outstanding scientists, professionals and students involved in basic and applied research on all aspects of water to share ideas, problems, analyses and solutions. The focus includes the water cycle and its interactions with land surface, atmospheric, ecosystem, economic and political processes, and all aspects of water resources engineering, management and policy.

The Hydrology Days Award is presented each year to an outstanding individual in recognition of his/her contributions to hydrology and related fields. In recognition of his outstanding contributions to hydrologic science in the areas of infiltration theory, soil water hydrology, and preferential flow and solute transport in soils, the 2007 Hydrology Days Award will be presented to Professor J-Y Parlange. The award will be presented during a special session in which Professor Parlange will present the Hydrology Days Award Lecture titled "Recent Advances in Hydrological Sciences"

In addition to the Annual Hydrology Days Award session, and the sessions associated with the Borland Lecturers in Hydrology and Hydraulics:

- Recent Advances in Hydrological Sciences - Hydrology Days Award Lecture: Prof. J-Y Parlange - Cornell University
- Behavioral Modeling: A New Theoretical Framework for Hydrologic Predictions - Borland Lecture in Hydrology: Prof. M. Sivapalan - U. of Illinois
- Sediment Transport and Storage in the Andes-Amazon Sediment Dispersal System - Borland Lecture in Hydraulics: Prof. T. Dunne - UCSB

Special sessions will address:

- Land Use Changes and Streams
- Nutrient Dynamics in Alluvial Streams
- Biocomplexity Issues Related to Interactions between Humans, Aquatic Ecosystems and Complex Landscapes
- Emerging Contaminants
- Measuring and Modeling the Mountain Snowpack;
- Monitoring and modeling pollution and water quality in irrigated stream-aquifer systems
- Estimating evaporation and evapotranspiration in the field
- Groundwater Remediation - focusing on advancements in groundwater remediation technologies
- Transport in Porous Media - focusing on fate and behavior of contaminants in subsurface environments
- Ground water-Surface water conjunctive management
- Semi-arid region vadose zone hydrology and contaminant transport
- Scaling issues: scale dependence and scale invariance in hydrology
- Morphodynamics
- Detecting and Modeling Climate Variability and Change Using Stochastic Approaches
- Stochastic Techniques in Water Resources Planning and Management

For detailed information about Hydrology Days 2007, including details about special sessions, please go to our web page at:
http://HydrologyDays.ColoState.edu/

The web page also provides information about on-line registration and on-line submission of abstracts and papers.

32nd Colorado Water Workshop: To Look at the Whole Colorado River

"Equalizations, Equity and Environment: A Watershed Wide Look at Colorado River Opportunities"
May 22-24, 2007, at Western State College of Colorado in Gunnison

Can the Seven-State Agreement - and the whole Law of the River - survive the predicted consequences of climate change?

How do the "reserved rights" for Native Americans, National Parks and endangered species fit into the management of an over-appropriated river?

How can the issues with Mexico and the river delta be best resolved?

What are the three best opportunities for improving environmental quality and cultural/international equity in the Colorado River watershed?

These are some of the questions that an exciting array of speakers will explore at the 32nd Colorado Water Workshop in Gunnison, May 22-24, focusing on "Equalizations, Equity and Environment: A Watershed Wide Look at Colorado River Opportunities."

Dan Beard, former Commissioner of the Bureau of Reclamation will be the keynote speaker at the opening night banquet and other invited speakers include former Hopi Tribe Chair Ferrell Secakuku, Richard Ingebretsen of the Grand Canyon Institute, current Bureau of Reclamation Commissioner Bob Johnson, Black Mesa Water Coalition Executive Director Enei Begaye, Jennifer Pitt, Pat Mulroy of the Southern Nevada Water Authority, Tijuana and San Diego professor Carlos de la Parra, former federal water planner Mark Bird, and many returning speakers including Justice Greg Hobbs, Eric Kuhn, and Don Glaser.

Water Workshop Director Pete Lavigne says the Workshop will be a diverse and interesting group this year representing the interests of the Colorado water districts, a variety of Colorado River organizations, ranchers, tribes, Mexico, and the basin states.

"We're expecting a packed audience this year and we have had a lot of early registration interest; a great sign with the move from July to May," says Lavigne.

The Applegate Group will again be sponsoring the H2O Benefit Golf Tournament and college apartments and dorm housing will again be available for the conference. Local hotels will have plenty of space available as well.

For further details as they become available check the Western State college website at www.western.edu/water.

RESEARCH AWARDS

Colorado State University, Fort Collins, Colorado
Awards for December 2006 to February 2007*

Abt, Steven R: USDA-USFS-Rocky Mtn. Rsrch Station - CO: Bedload Transport in Gravel-bed Rivers & Channel Change: $90,174

Austin, Richard T: US Department of Energy: Operational Retrieval of Cloud Microphysical Properties using Combined Measurements by Diverse Instruments: $107,000

Child, R Dennis: DOI-BLM-Bureau of Land Management: Sustainable Rangelands Roundtable : $40,000

Conant, Richard T: NSF-Biological Sciences: Vulnerability of Soil Organic Matter to Temperature Changes: Exploring Constraints Due to Substrate: $180,000

Cotton, William R: National Science Foundation: Aerosol/boundary Layer Cloud Interactions-Simulations and Parameterization Testing: $170,000

Cotton, William R: National Science Foundation: Collaborative Research: Inhibition of Snowfall by Pollution Aerosols: $89,526

Cotton, William R: NorthWest Research Associates, Inc.: Observations and Numerical Modeling of Rotor Dynamics: $20,781

Davis, Jessica G: USDA-NRCS-Natural Resources Consvtn Srv: On-Farm Evaluation and Demonstration of Ammonia Reduction Best Management Practices (BMPs) for Feedlots and Dairies: $286,711

Garcia, Luis: Colorado State Water Conservation Board: Monitoring of Irrigation Amount, Timing, and Crop Yield in the Arkansas River Basin, Colorado: $50,000

Handa, Robert J: Syngenta: Effects of Atrazine on Reproductive Neuroendocrine Function: $215,412

Hansen, Neil: USDA-ARS-Agricultural Research Service: Irrigation, Tillage, and Weed Management to Maintain Agricultural Profitability with Limited Water: $48,456

Harry, Dennis L: American Chemical Society: The Nature of the Crust Beneath the Deep Gulf of Mexico and Development of the Syn-Rift and Early Post-Rift Gulf Basin: $54,128

Holtzer, Thomas O: Parker Water & Sanitation District: Developing a Model to Sustain Irrigated Agriculture While Meeting Increasing Urban Water Demand in Colorado: $858,712

Knapp, Alan Keith: Environmental Protection Agency: Ecosystem Response to Climate Change: Sensitivity of Grassland Ecosystems Across the Great Plains to Variability in ...: $2,669.00

Liston, Glen E: National Science Foundation: Collaborative Research: Norwegian-United States IPY Scientific Traverse: Climate Variability and Glaciology in East...: $53,347

MacDonald, Lee H: USDA-USFS-Forest Research: Upper South Platte Watershed Protection and Restoration Project: Proposal for Summer 2006-$33,000

Ogle, Stephen M: Natl Aeronautics & Space Admin.: Accounting for CO2 Fluxes in Agricultural Lands : $70,268

Rutledge, Steven A: National Science Foundation: The Colorado State University - CHILL Radar Facility: $112,669

Sale, Thomas C: Atlantic Richfield Company: Single Well Tracer Release Studies : $7,000

Sanders, Thomas G: DOI-NPS-National Park Service:

Preservation, Protection, & Management of Water Aquatic Resources of Units of the National Park System: $75,000

Schubert, Wayne H: National Science Foundation: Dynamics of the Tropical Troposphere : $192,468

Stephens, Graeme L: UCAR-NCAR-COMET Atmospheric Tech. Divis.: Inspiring the Next Generation of Explorers: $108,614

Stephens, Graeme L: University of California at Berkeley: Studies of Biosphere-Atmosphere Interactions with a MODIS GCM: $132,100

Theobald, David M: The Nature Conservancy: Freshwater Classification for the Colorado River Basin: $27,977

Thilmany, Dawn D: Colorado Department of Agriculture: Exploring Consumer Preferences and Travel Plans for Agritourism in Colorado: $36,170

Valliant, James C: USDA-NRCS-Natural Resources Consvtn Srv: The Effect of the Use of a Traveling Sprinkler and a Polyacrylamide-Zeolite Blend on Onion Stands, Yields, Quality and...: $74,332

Venkatachalam, Chandrasekaran: UMASS-University of Massachusetts: ERC: The Center for Collaborative Adapative Sensing of the Atmosphere: $197,223

Westra, Philip: Washington State University: Influence of Temperature, Moisture, and Nitrogen Stress During Maternal Plant Growth on Seed Production: $39,090

*Research awards from institutions of higher education in Colorado other than Colorado State University are provided by self-report of the Principal Investigator. If you have water related research awards to report, send them to cwrri.colostate.edu

CALENDAR

Feb. 12-13	13th Annual Whirling Disease Symposium. Denver, CO. For more information or to register please visit http://whirling-disease.org/
Feb 11-14	NIWR 2007 Annual Meeting. Washington, DC. For more information visit http://snr.unl.edu/niwr/
Feb. 22-23	DARCA 5th Annual Conference-"Go With The Flow". Sterling, CO. For more information and/or to register visit http://www.darca.org/
Feb. 22-23	NCES 8236: Introduction to Floodplain Management and Preparation for the Certified Floodplain Manager Exam. For more information about this course and to find additional available courses visit http://www.cudenver.edu/engineer/cont
March 1-2	NCES 8384: Dam Safety and Permitting in Colorado. For more information about this course and to find additional available courses visit http://www.cudenver.edu/engineer/cont
March 19-21	AGU Hydrology Days 2007. Fort Collins, CO. For more information and to register please visit http://HydrologyDays.ColoState.edu/
March 26-28	NWRA Federal Water Seminar. Washington, DC. For more information visit http://www.nwra.org/meetings.cfm
April 12-13	Arkansas River Basin Water Forum. Rocky Ford, CO. For more information and/or to print out a registration form visit www.arbwf.org
May 22-24	Colorado Water Workshop: A Watershed Wide Look at Colorado River Controversies. Gunnison, CO. For more information online visit http://www.western.edu/water/. Information by email please contact Peter Lavigne (Director Colorado Water Workshop) at plavigne@western.edu or pete@igc.org. Contact by phone: 970-641-2579

CALENDAR CONTINUED

June 6-9	USCID Second Conference on SCADA and Related Technologies for Irrigation System Modernization. Denver, CO. For more information visit http://www.uscid.org/
June 24-28	AWWA 125th Annual Conference & Exposition: Explore the Future of Safe Water at World's Water Event. Toronto, Ontario, Canada. For more information and/or to register visit http://www.awwa.org/
June 25-27	SWRA Summer Specialty Conference: Emerging Contaminants of Concern in the Environment: Issues, Investigations, and Solutions, Vail, CO. For more information go to http://www.awra.org/meetings/Vail2007/index.html
July 24-26	2007 UCOWR/NIWR Conference: Hazards in Water Resources. Boise, ID. For more information visit http://www.ucowr.siu.edu.
July 25-27	NWRA Western Water Seminar. Monterey, CA. For more information visit www.nwra.org
Aug 23-24	Colorado Water Congress 2007 Summer Convention. Steamboat Springs, CO. For more information visit www.cowatercongress.org or call 303-837-0812
Sep. 30 to Oct. 5	USCID Fourth International Conference on Irrigation and Drainage: Role of Irrigation and Drainage in a Sustainable Future. Sacramento, CA. For more information about conference and call for papers go to http://www.uscid.org/
Nov. 7-9	NWRA Annual Conference. Albuquerque, NM. For more information visit www.nwra.org

Colorado State University
Colorado Water Resources Research Institute
Campus Delivery 1033
Colorado State University
Fort Collins, CO 80523-1033

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