Colorado Water

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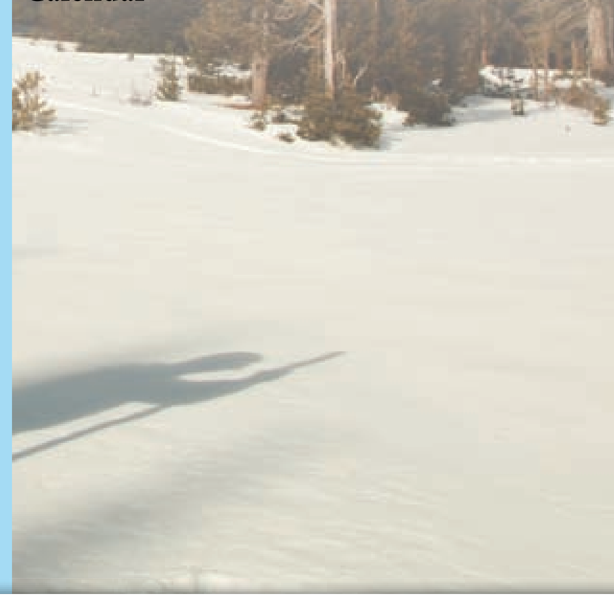
Highlights:

In Every Issue:



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Director: *Reagan Waskom*
Assistant to the Director: *Nancy Grice*
Editor: *Laurie Schmidt*
Graphic Design: *Zach Hittle*
Research Associate: *Faith Sternlieb*
Research Associate: *Julie Kallenberger*

Published by: Colorado Water Institute, Colorado State University, Fort Collins, CO 80523-1033
Phone: (970) 491-6308, FAX: (970) 491-1636, Email: cwi@colostate.edu

Cover Photos (L to R): USDA snowcourse at Cameron Pass; SNOTEL site in northern Colorado; Todd Boldt at Cameron Pass snowcourse.

Editorial

by Reagan Waskom, Director, Colorado Water Institute

If you are like most of us, when you think of water in Colorado, you envision liquid blue water flowing in our streams and reservoirs. However, if you really want to talk about water in Colorado, you've got to think snow.

Snow is our annually renewable water resource and you might say the Rocky Mountains are our water towers. Hydrologists estimate that about 75% of Colorado's streamflow is derived from snowmelt, so it is little wonder that we watch the snowpack accumulate and melt off each water year with so much interest. No one knows exactly how much of Colorado's $235 billion gross domestic product depends on snow, but if you add the value of the ski industry, agriculture, summer water-based recreation, hydroelectric power, municipal and industrial water supplies, and the free water storage that our mountain snow represents, the total value of Colorado's annual snowpack is considerable. As a result of topography and elevation, a majority of the water in Colorado's hydrologic cycle begins as snow, and our natural environment reflects a snow-based hydrograph. For these reasons, snow monitoring, cloud seeding, and snow hydrology are all areas of active research here in Colorado.

This issue of the Colorado Water newsletter brings you some of the latest in snow research, described in articles by Dan Breed, Gabrielle David, Steven Fassnacht, Mike Gillespie, Douglas Hulstrand, and Mark Williams. As pointed out in these reports, one of the most difficult challenges is to accurately characterize the snow water equivalent in a given watershed from a limited number of point measurements, due to the extreme variability in snow cover and depth. Systematic snow measurements have been conducted in Colorado since the 1930s when a network of manual snow courses was first implemented across the state, yet scientists continue to look for ways to better characterize the snowpack and develop runoff forecasts. In addition, the possibility of significantly augmenting snowpack through cloud seeding continues to receive scientific scrutiny, as described by NCAR researcher Dan Breed.

Readers will note that water research at CSU continues to have international impact. This month we report that Dr. Kurt Fausch was awarded the International Fisheries Science Prize, and Dr. Ted Yang received the Prince Sultan Bin Abdulaziz International Water Prize.

Two new features have been added to the Colorado Water newsletter beginning this month: A regular column on water history and a partnership with the Colorado Climate Center. We hope that you will enjoy these new regular features and as always, we appreciate hearing from our readers. Best wishes from the CSU Water Center for the upcoming holiday season and New Year.

The Water Year: Monitoring and Managing Colorado's Most Precious Resource

by Nolan Doesken, *Colorado State Climatologist, Colorado Climate Center*

October 1 marked the beginning of a new year for Colorado—the 2009 Water Year. This will be my 32nd year professionally tracking the fascinating and dynamic climate of our beautiful state here at the Colorado Climate Center. While our seasonal cycles follow a similar path each year, the details are always different and the significance for Colorado water resources is profound.

The "Water Year" is an arbitrary 12-month period used by water and climate professionals to track water supplies and demands. But it is a very practical calendar that is true to our climate and water cycles—at least approximately. This 12-month period corresponds to our water storage and water usage cycle.

The first killing freeze of the autumn typically occurs in early October for much of the state and marks the end of the summer growing season and the main irrigation season. Around the same time, the first major snows of the year begin to accumulate in Colorado's high country. This is the beginning of our annual cycle of winter storage. In the months that follow, snow accumulates episodically and becomes increasingly widespread, adding layer after layer to our precious frozen reservoir that we call "snowpack." The mountain snowpack usually reaches its maximum water content sometime in April.

At Colorado's lower elevations, winter snow cover tends to be intermittent, and precipitation amounts are often very low. The vegetation lies dormant and winter evaporation rates are very low. With the arrival of spring comes hydrometeorological excitement. Mountain snow begins to melt, rivers rise, reservoirs fill, and large storms sometimes soak the Front Range and eastern plains, replenishing soil moisture. Trees leaf out and new crops and perennial vegetation emerge and grow, immediately using the available water.

Colorado's growing season and summer recreation season goes from May through September. Thunderstorms rumble and localized rains may fall intensely, but most of the time water demand exceeds supply. Evapotranspiration (ET) and irrigation water use peak in late June and July in response to sunlight and high temperatures. You can track ET each year for many areas of Colorado using the Colorado Agricultural Meteorological Network (CoAgMet) on the web at: http://ccc.atoms.colostate.edu/~coagmet.

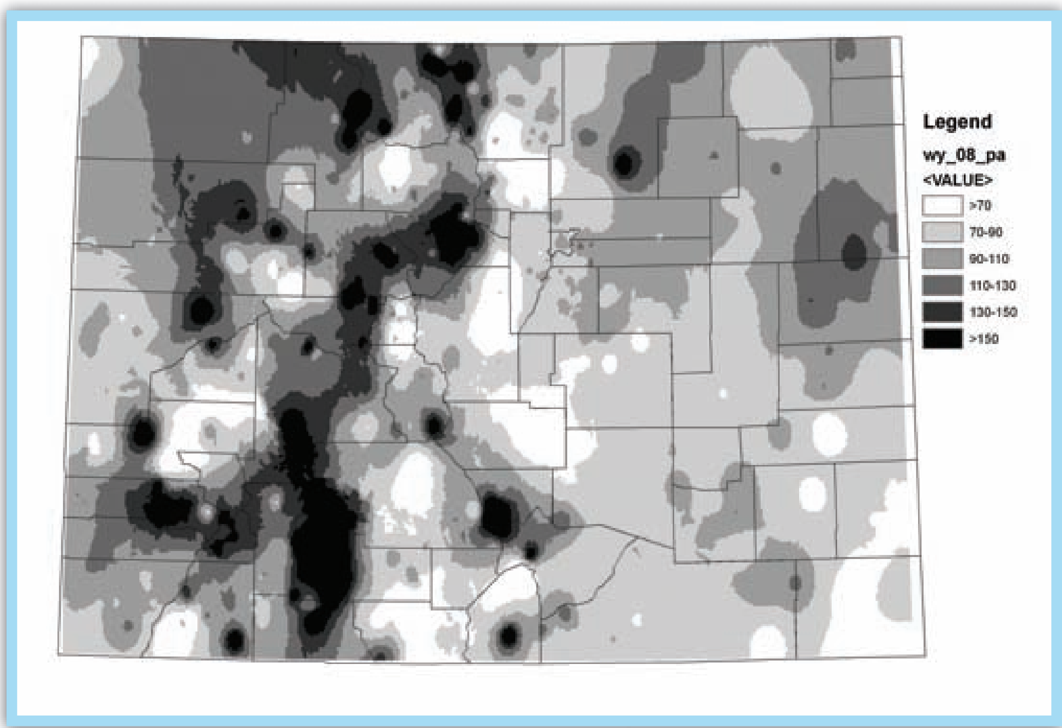

Figure 1. This graph shows Colorado precipitation amounts as percent of average for Water Year 2008.

Colorado's remarkable water infrastructure is active year-round, but it especially comes to life from late spring through September. Diversion canals, pipelines, tunnels, and irrigation ditches move large amounts of water from where it initially falls and flows to where it is put to use.

The 2008 Water Year was fairly good to Colorado. After a dry start in October and November 2007, the skies over the Rocky Mountains opened up and covered the mountains with deep snow throughout the mid-winter months. As we moved towards spring, the heaviest snows shifted from the southern mountains up to areas around Steamboat Springs. Spring flooding in 2008 was anticipated due to the very deep snowpack, but thanks to fairly dry and cool spring weather, the snowmelt was spread over many weeks. There was plenty of high water, but few serious flooding issues.

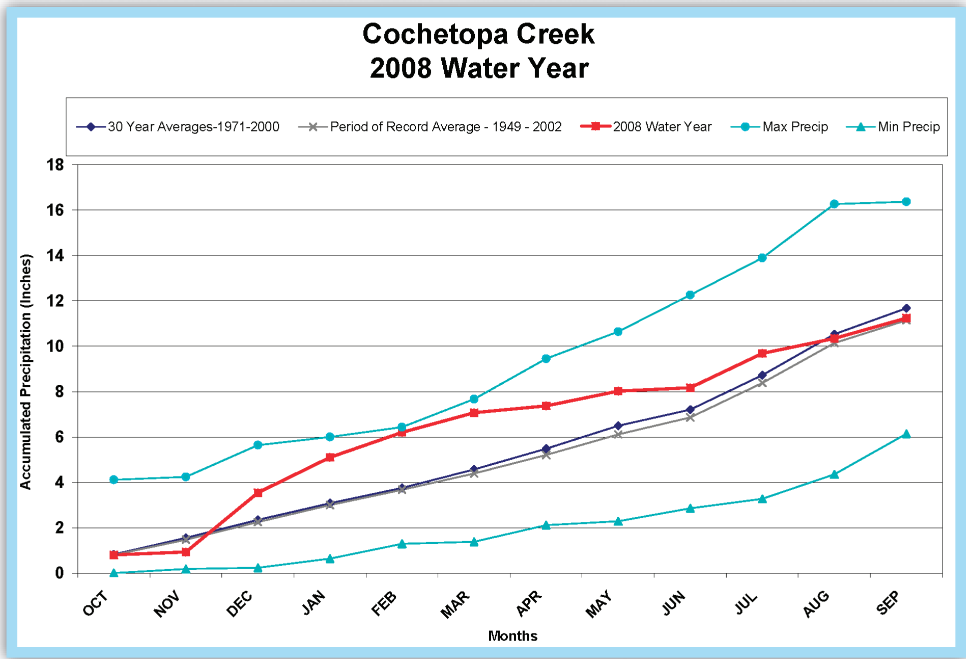

Figure 2. This graph shows Water Year 2008 precipitation at Cochetopa Creek Cooperative Station in Gunnison County, Colorado.

Surface water supplies for the 2008 irrigation season were fairly good. However, slow-moving spring storms that sometimes bring copious rains and snows to the Front Range were few, and the first part of summer was unusually dry. Emerging drought conditions impacted Colorado agriculture, especially in extreme southeastern counties. Fortunately, August precipitation was heavy across the plains and helped alleviate drought problems.

We don't know with confidence what the 2009 Water Year will bring, but I can assure you we will all be paying close attention. For those who want to pay attention along with us, below is a list of resources that can help you track the 2009 snow accumulation, snow melt, and water supplies. So, to you and yours, a safe and happy "New Water Year."

To track the 2009 Water Year precipitation and snowpack accumulations for the Colorado mountains, visit the **USDA Natural Resources Conservation Service** web site:

www.wcc.nrcs.usda.gov/snotel/Colorado/colorado.html

The **Colorado Climate Center** web site provides compilations of precipitation data and graphs from NOAA's National Weather Service Cooperative Weather Observer network. Precipitation data users can view precipitation amounts and departures from our long-term averages:

http://ccc.atmos.colostate.edu/coloradowater.php

The **U.S. Geological Survey** and **Colorado Division of Water Resources** will be tracking streamflow throughout the state:

http://co.water.usgs.gov
http://water.state.co.us

In Fort Collins, the **Poudre School District** is getting in the Water Year spirit. Students have begun producing monthly videos to track local water resources in the Poudre watershed. Video updates can be viewed throughout the 2009 Water Year via the PSD web site:

www.psdschools.org/services/channel10/wtwy.aspx

Lastly, anyone in Colorado with an interest in measuring and tracking our variable precipitation resources can help out. The **Community Collaborative Rain, Hail and Snow** network provides detailed maps of daily precipitation throughout the year, and new volunteers are needed to fill gaps in our observing networks:

www.cocorah.org

It's Cold in Here! Snow and Ice in the Water Archive

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

In modern times, we have fancy, high-tech ways to measure not only snowfall, but also snowpack and water volume therein, thus leading to predictions of runoff for the spring water supply. In the old days, the only way to get such predictive measurements was to go out on skis and snowshoes, hauling equipment to accessible sites and manually sampling the snow. Wouldn't it be fascinating to be able to look back in history and see this work in action? How much more would we appreciate the technology now available, as well as the effort put forth during those early days?

Ralph Parshall (on right) and an unidentified person sample snow at Bear Lake in Rocky Mountain National Park in May 1941 (Groundwater Data Collection, Water Resources Archive).

As it happens, the CSU Water Resources Archive has a film that provides this opportunity. It is one of numerous resources in the Archive that documents snow and ice studies. Recorded on 16mm film probably in 1941, the 30-minute reel shows two men on a mountainside measuring snow. They tromp through the snow, set up their equipment, and take their measurements. One of the men is likely Ralph Parshall, inventor of the famous Parshall flume, so the viewer gets a glimpse of him in action, not at a flume.

Whitney Borland measures snow at Camp Hale, Colorado, in February 1960 (Borland Papers, Water Resources Archive).

This fascinating film in the Parshall Collection is further contextualized by a set of slides in another collection. In the Groundwater Data Collection are more than 20 slides of Ralph Parshall and two other men measuring snow in 1941. More than likely, the images depict the same event, thus complementing the film by providing more information about the same story. The index accompanying the slides reveals the survey locations as Bear Lake in Rocky Mountain National Park and Cameron Pass. With Parshall, as identified in the slide index, are Grant Eddy and Paul Ginter. The Groundwater Data Collection also contains more than 30 other slides of snow surveying activities in 1943 at various Poudre Basin sites.

Other collections, if not quite so visually interesting, are full of important data nonetheless, including the Climate Data Collection recently received from the Climate Center at CSU. This collection contains data as far back as the 1890s from weather stations around Colorado. The information was recorded by hand daily and includes precipitation amounts, along with temperatures. The set of tens of thousands of pages provides a glimpse at how much snow fell at numerous weather stations across the state.

The most concentrated information about snow and ice in the Water Resources Archive is contained in the Papers of Whitney M. Borland. These materials fill more than three boxes in the collection and consist of reports and publications on the subjects of snow and ice, including avalanches. A Bureau of Reclamation engineer, Borland primarily

Snow samples are taken at Cameron Pass in May 1941 (Groundwater Data Collection, Water Resources Archive).

Ice conditions are produced by sprinkling at too low a temperature, Austin Branch Experiment Station, October 1949 (Groundwater Data Collection, Water Resources Archive).

focused his research on sedimentation and hydraulics, but he also studied avalanches. Perhaps most significant in the collection is the set of Borland's own reports that present his data and observations on snow conditions causing avalanches in the ski areas and highways around Denver, issued from 1952 through 1963. Borland also saved numerous articles, reports, and studies on such issues from the 1950s through the 1970s, so the collection is a great resource on the information of the time, nationally and internationally.

Other collections in the Water Resources Archive touch in part on snow and ice issues and can be found by searching the Archive's web site. However, these materials are not voluminous, despite snow being a major source of the state's water supply. Collections on these topics are welcomed as donations to the Archive.

For more information about the Water Resources Archive, visit the web site at http://lib.colostate.edu/archives/water/ or contact the author at (970) 491-1939 or Patricia.Rettig@colostate.edu.

Colorado Snow Survey and Water Supply Forecasting Program

by Mike Gillespie, *Snow Survey Supervisor, Natural Resources Conservation Service*

The Cooperative Snow Survey Program

Since 1935 the Natural Resources Conservation Service's (NRCS) Snow Survey and Water Supply Forecasting Program has monitored mountain snowpack and climate variables in the western United States to forecast spring and summer water supplies. The earliest snow measuring sites in Colorado date back to the 1930s, at which time a network of manual snow courses was implemented across the state. In the late 1970s, NRCS began installing automated SNOTEL (SNOwpack TELemetry) monitoring stations throughout the West. Today, Colorado NRCS coordinates the Federal-State Cooperative Snow Survey Program, which includes 107 manually sampled snow courses and 104 SNOTEL stations in Colorado (throughout the West there are 1,200 manually sampled sites and about 700 SNOTEL stations). This network provides the snowpack and climate data required to forecast spring and summer water supplies at 90 locations affecting Colorado water users. A wide variety of economic decisions, totaling many millions of dollars annually, are dependent on the snowpack data collected and water supply forecasts issued by the NRCS.

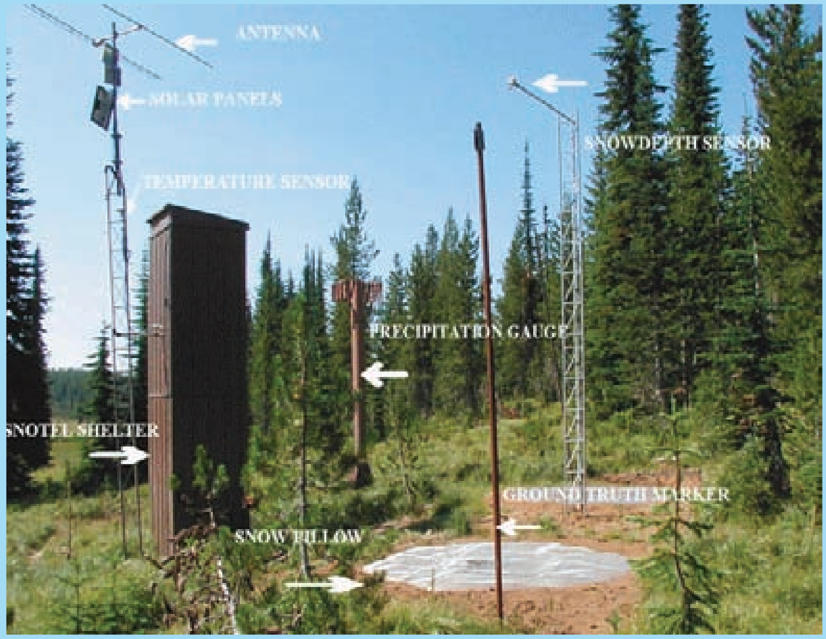

Figure 1. A typical remote SNOTEL site with snow pillow, snow depth sensor, a storage precipitation gauge, and an air temperature sensor.

The SNOTEL Data Collection System

The key to determining spring runoff is the timely and accurate monitoring of remote mountain snowpacks. SNOTEL sites are designed to operate in the harsh winter conditions of the mountainous West. A typical SNOTEL site consists of measuring devices and sensors, an instrument shelter for the radio telemetry equipment, and an antenna that also supports the solar panels used to keep the batteries charged (Figure 1). A standard sensor configuration includes a snow pillow, a snow depth sensor, a storage precipitation gauge, and a temperature sensor.

- The snow pillow consists of a hypalon rubber bladder filled with a non-freezing solution. Snow pillows are 10 feet in diameter and are placed on leveled ground. A plumbing line connects the snow pillow to a manometer tube inside the instrument shelter. As snow accumulates on the pillow, the weight of the snow water content raises the fluid level in the manometer. A pressure transducer converts the fluid height into an electrical reading of the snow's water equivalent.
- The precipitation gauge measures all precipitation in any form that falls during the year. A second pressure transducer converts the accumulation of precipitation into an electrical measurement in a similar fashion as the snow pillow.
- An ultrasonic snow depth sensor is installed on a meteorological tower near the snow pillow and measures the time required for an ultrasonic pulse to travel to and from the snow surface. Also installed on the meteorological tower is the air temperature sensor.
- At midnight, a data logger computes the previous day's maximum, minimum, and average temperatures.

Nearly one-third of Colorado's SNOTEL sites are augmented to collect soil temperature and soil moisture data. Sites equipped with these sensors typically have them placed at 4-, 8- and 20-inch depths. Each sensor uses an electromagnetic signal propagated from the center tine of the probe to measure multiple parameters. Soil moisture data are becoming increasingly important in helping streamflow forecasters estimate how much of the snowpack's water content will merely soak into the soil profile before contributing to runoff from that winter's snowpack.

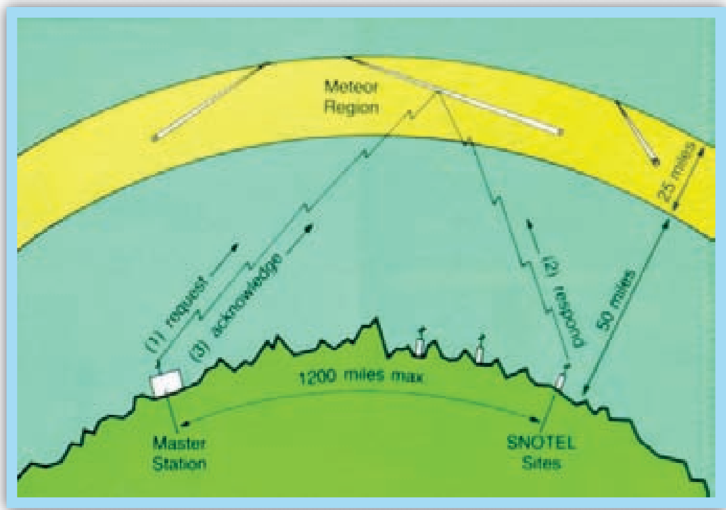

Figure 2. Meteor burst technique.

One of the most unique aspects of the SNOTEL system is the method of data transmission. The network uses the principle of meteor burst to relay data to water users. Meteor burst communication aims radio signals skyward, where the trails of meteorites reflect the signals back to Earth (Figure 2). This technique allows communications between two locations up to 1,200 miles apart. Two master stations, at Boise, Idaho, and Ogden, Utah, cover the 10 western states—an area of about one million square miles.

Via telephone lines, the master stations feed the data to the NRCS central computer in Portland, Oregon. The data are then made available to the public through various products available on the Internet. The Colorado snow survey program's webpage (http://www.co.nrcs.usda.gov/snow) hosts a comprehensive variety of data products, ranging from SNOTEL data reports to maps and graphs of snowpack data, and is updated daily with current conditions.

One of the newest NRCS data products is the daily streamflow forecast. With the accumulation of nearly 30 years of daily snowpack and precipitation data at many SNOTEL sites, these data are now being used to drive an automated forecast system that provides a daily update to the seasonal water supply forecasts. As storms pass across a watershed, water managers can now get an instant assessment of how much their water supply situation has improved or deteriorated. These forecasts are made possible by an automated process that evaluates each day's relevant SNOTEL data and generates a new forecast equation based on the best predictors for each site, with one predictor based on snow (current snowpack, snowpack on a past date, or the peak snowpack to date) and another based on water-year precipitation (to date, or to some date in the past). Three graphics are produced: (1) a cross-plot graphic of historical and observed volume forecasts; (2) daily exceedance forecasts vs. historical bounds; and (3) guidance volume forecasts (percent of normal) vs. skill (Figure 3).

Public Benefits

Since Congress' initial appropriation for the installation of the SNOTEL network in the late 1970s, the number of SNOTEL sites in Colorado has doubled, growing from 52 sites to the current number of 104. Installation costs for all new sites have been paid by cooperators who rely on real-time data in assessing their water supplies.

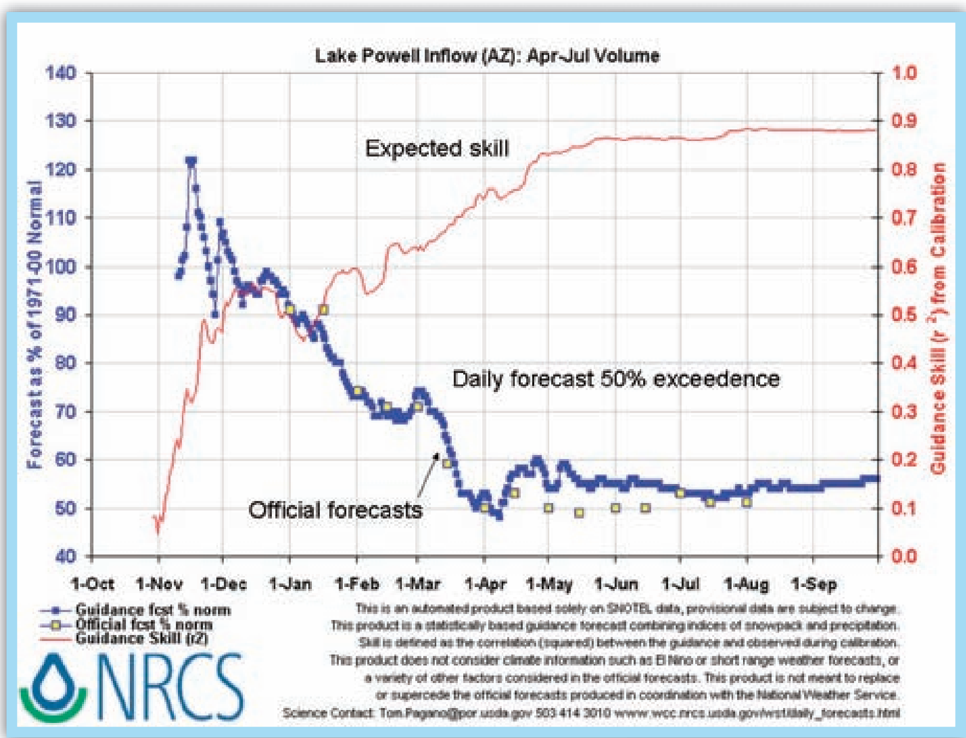

Figure 3. Daily guidance forecasts vs. skill level.

In the past year, three new SNOTEL sites have been installed in Colorado, and additional sites are scheduled for installation in the coming years. Those sites installed in 2008 include Moon Pass and Sargents Mesa in the Rio Grande Basin and Hourglass Lake in the Cache la Poudre Basin (Figure 4).

The information provided by the Snow Survey and Water Supply Forecasting Program is essential to Colorado's economy. The traditional customer of the snow survey program has been irrigation districts and farmers who need to assess water supplies for the coming growing season. Matching crops to forecasted water supply can have a significant impact on net farm returns. Increased income from using water supply forecasts varies from year to year and is dependent on crops grown, crop market, weather conditions, and other variables.

Use of snow survey information is not limited to irrigation planning. Hydroelectric power generation potential is based on water supply forecasting, and the availability of water for power generation strongly influences power pricing and inter-regional power transfers.

Snow survey information is also used in water rights administration, reservoir operation, management of municipal water supplies, flood emergency management, wildfire management, avalanche forecasting, and the tourism and recreation industry.

A 2008 economic assessment of the snow survey program showed that decisions based on program information affect 25.5 million acres of irrigated agriculture in the West, with a market value of $51.1 billion dollars (Census of Agriculture, 2002). The snow survey program's budget for the western U. S. in Fiscal Year 2007 was $10,588,000; yet, economic decisions affecting tens of millions of dollars are made on a daily basis using products generated by the program. The importance of the snow survey and water supply forecasting program can only increase this century as western populations continue to grow and as we experience increased climate variability that will have a profound impact on the economy of the West.

Figure 4. This SNOTEL site was recently installed at Sargents Mesa in the Rio Grande Basin, Colorado.

Recent Publications

Evaluation of the Acoustic Doppler Velocity Meter for Computation of Discharge Records at Three Sites in Colorado, 2004-2005 by M.R. Stevens, P. Diaz, and D.E. Smits http://pubs.usgs.gov/sir/2007/5236/

Field Techniques for Estimating Water Fluxes Between Surface Water and Ground Water Edited by D.O. Rosenberry, and J.W. LaBaugh http://pubs.usgs.gov/tm/04d02/

Increase in Nuisance Blooms and Geographic Expansion of the Freshwater Diatom Didymosphenia geminate by S.A. Spaulding, and L. Elwell http://pubs.er.usgs.gov/usgspubs/ofr/ofr20071425

The National Streamflow Information Program by M.J. Morris http://pubs.usgs.gov/gip/70/

Central Colorado Assessment Project – Application of Integrated Geologic, Geochemical, Biologic, and Mineral Resource Studies by T.L. Klein, S.E. Church, J.S. Caine, T.S. Schmidt, and E.H. DeWitt http://pubs.usgs.gov/fs/2008/3084/

Comparison of Water Years 2004-05 and Historical Water-Quality Data, Upper Gunnison River Basin, Colorado by N.E. Spahr, D.M. Hartle, and P. Diaz http://pubs.usgs.gov/ds/331/

Estimating the Effects of Conversion of Agricultural Land to Urban Land on Deep Percolation of Irrigation Water in the Grand Valley, Western Colorado by J.W. Mayo http://pubs.usgs.gov/sir/2008/5086/

Summary and Evaluation of the Quality of Stormwater in Denver, Colorado, October 2001 to October 2005 by C.R. Bossong, and A.C. Fleming http://pubs.usgs.gov/sir/2008/

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

Estimating Snowmelt Contribution to an Alpine Water Balance

by Douglas M. Hultstrand, Graduate Student, Geosciences, Colorado State University

Introduction

The annual hydrograph in high-elevation areas is driven primarily by the formation and melting of seasonal snowpacks. In the western United States, stream runoff during the snowmelt season (May-July) accounts for approximately 75% of total annual flow. Snow water equivalent (SWE) is an important input into any high-elevation hydrologic model for flood forecasting and water resource estimates. Spatial and temporal estimates of SWE are limited due to the extreme spatial variability of snow. A challenging problem in snow hydrology is understanding and quantifying winter precipitation in mountain catchments. Typical watershed studies measure both solid and liquid precipitation quantity with a standard precipitation gauge. Precipitation gauges, shielded and unshielded, inherently underestimate total precipitation due to local airflow, wind undercatch, wetting, and evaporation loss. As an alternative to using precipitation gauges, previous studies have had significant success using a combination of slope, aspect, elevation, solar radiation, wind redistribution, and northness as independent variables in statistical models for computing SWE distribution across a watershed.

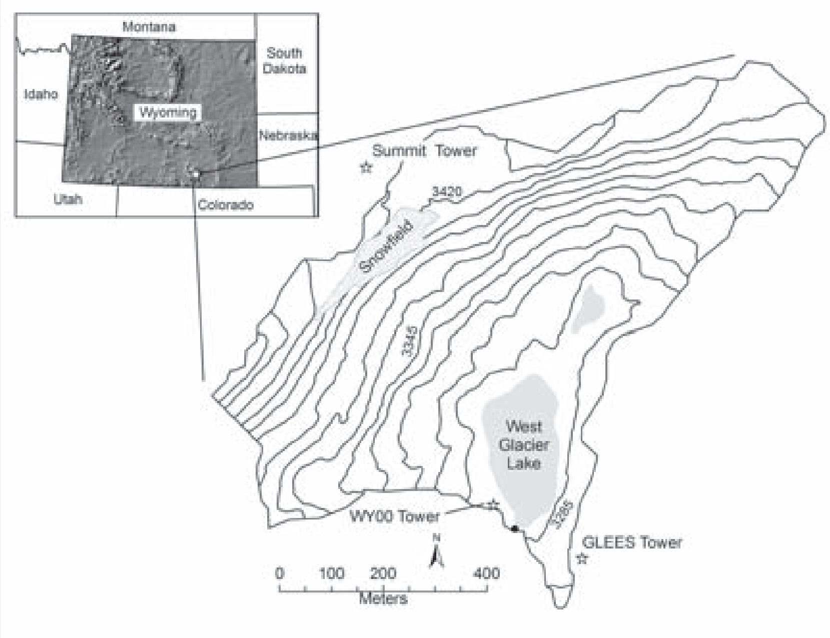

Figure 1. Site map of West Glacier Lake Watershed.

Study Area

West Glacier Lake watershed is located within the U.S. Forest Service's Glacier Lakes Ecosystem Experiments Site (GLEES), an alpine/subalpine research study area located in the Medicine Bow National Forest of Wyoming (Figure 1). West Glacier Lake watershed encompasses 0.61 square kilometers (km), ranges in elevation from 3,200 to 3,500 meters (m), and has a mean annual average temperature of -1°C at the outlet and -2.5°C at the top of the basin. Average annual precipitation is approximately 1.20 m, with 75–85% falling as snow. West Glacier Lake watershed has a unique problem: measured streamflow out of the watershed has been previously estimated at 40% to 130% greater than measured precipitation input. Additional input into the watershed has been attributed to a permanent snowfield in the upper portion of the watershed covering approximately 2.4% of the watershed area. However, the excess output may be a result of inaccurate estimation of water quantities using current precipitation and stream gauging methods.

Methods

Field Methods

An intensive snow survey was conducted on April 20 and 23, 2005, during peak snow accumulation. Snow depths were measured using an aluminum probe pole on an approximate 50-m measurement grid. At each sample location, five depth measurements were collected (one center point plus four points spaced two meters apart in each cardinal direction). The five measurements were recorded to the nearest 0.01 m and averaged to minimize local variation in snow depth at that point. Global positioning systems (GPS) were used to record the location of each center snow depth measurement. A total of 538 snow depth measurements were used for modeling snow depth distribution (Figure 2).

Seven snowpits were excavated and density profiles collected at each site during the intensive snow survey. Snow density was measured with a 1-liter stainless steel cutter and an electronic digital scale with 1-gram resolution. Density profiles were collected at 0.10-m increments and then integrated over total depth to obtain one density value for each snowpit. GPS was used to record the location of each snowpit location (Figure 2).

Independent Variables

Slope, aspect, elevation, solar radiation, and northness were the independent variables used to aid in statistical modeling of snow depth and density. Slope, aspect, and elevation were derived from a 5-m digital elevation model (DEM) using the ArcGIS 9.0®. Northness was calculated as the product of the cosine of the aspect and the sine of the slope. An index of net solar radiation was calculated using methods similar to Elder et al. (1998), using the Solar Analyst extension in the ArcView® software.

Spatial Modelling

Snow Density. The calculated snowpit densities were used to predict density distribution across West Glacier Lake watershed. A multiple linear regression model was applied to point snow densities, along with different combinations of the derived independent variables.

Snow Depth. Using the SPLUS® statistical and mathematical software, snow depths were spatially distributed across the watershed through the following nine spatial interpolation methods: inverse distance weighting, binary regression tree, ordinary kriging, co-kriging with elevation, co-kriging with slope, co-kriging with northness, co-kriging with solar radiation, modified residual kriging, and a combined method using binary regression trees and geostatistical methods. Cross-validation procedures were used to compare the value estimated (without using the observed value) to the observed snow depth value. Residuals from cross-validation procedures were used to evaluate the performance of each model based on the coefficient of determination (R2), the mean absolute error (MAE), and the root mean square error (RMSE).

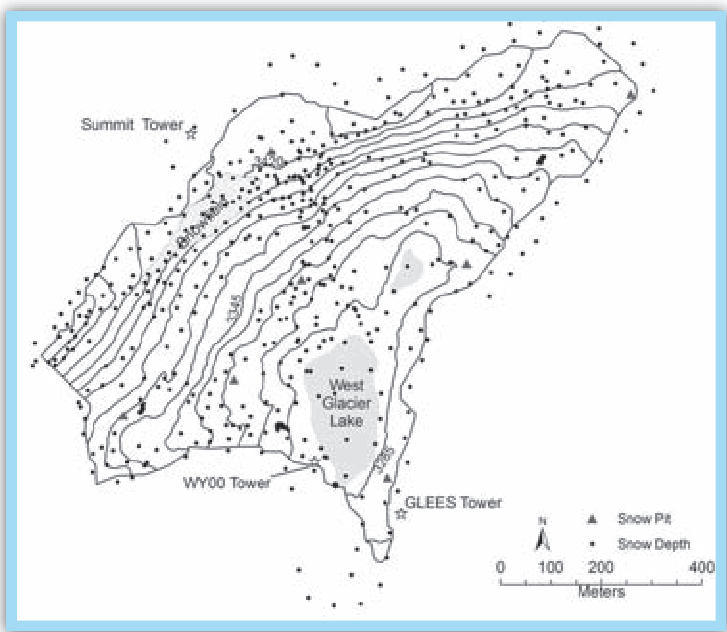

Figure 2. Snow depth and density sample locations for West Glacier Lake watershed.

Snow-Covered Area. Snow-covered area (SCA) was derived from aerial photographs of GLEES taken on April 16, 2005, during peak accumulation. A supervised classification scheme in ArcGIS 9.0 was used to classify aerial photographs into a binary value of zero (0% snow cover) or one (100% snow cover). The SCA for West Glacier Lake watershed was calculated to be 94%.

Snow Water Equivalent

Net winter precipitation was derived by modeling SWE for each 5-m pixel within the West Glacier Lake watershed. The best spatially modeled snow depth layer was used to calculate SWE distribution.

Water Balance

A water balance equation was used to compare annual inputs and outputs for West Glacier Lake watershed:

$$Q = P_s + P_r - E_t - E_s +/- G$$

where Q is stream discharge, P_s is total winter precipitation calculated as estimated SWE plus snowpack sublimation loss, P_r is precipitation as rain, E_t is evapotranspiration, E_s is snowpack sublimation, and G is groundwater. Evapotranspiration was estimated as the difference between precipitation inputs and stream outputs.

Results

Snow Depth Modelling

Cross-validation procedures were used to examine the validity of the snow depth interpolation models. Based on the cross-validation, co-kriging with solar radiation was determined to be the most accurate method for estimating snow depth across West Glacier Lake watershed. Co-kriging with radiation explained 94% of the variance in observed snow depth measurements.

Snow Water Equivalent

Co-kriging with solar radiation model was used along with the snow density and SCA layers to calculate SWE distribution (Figure 3). The modeled SWE distribution resulted in a maximum SWE estimate of 240 centimeters (cm), a mean of 113 cm, and a minimum of 0 cm. Total winter inputs in West Glacier Lake watershed were calculated as peak SWE (1,060 millimeters [mm]) plus snowpack sublimation loss (251 mm), which yielded a total 1,311 mm of winter precipitation.

Water Balance

Calculated inputs and outputs were applied to the simple water balance. Total net input from precipitation as snow (1,311 mm) and rain (170 mm) was 1,481 mm. Annual runoff calculated from the Parshall flume was 1,000 mm.

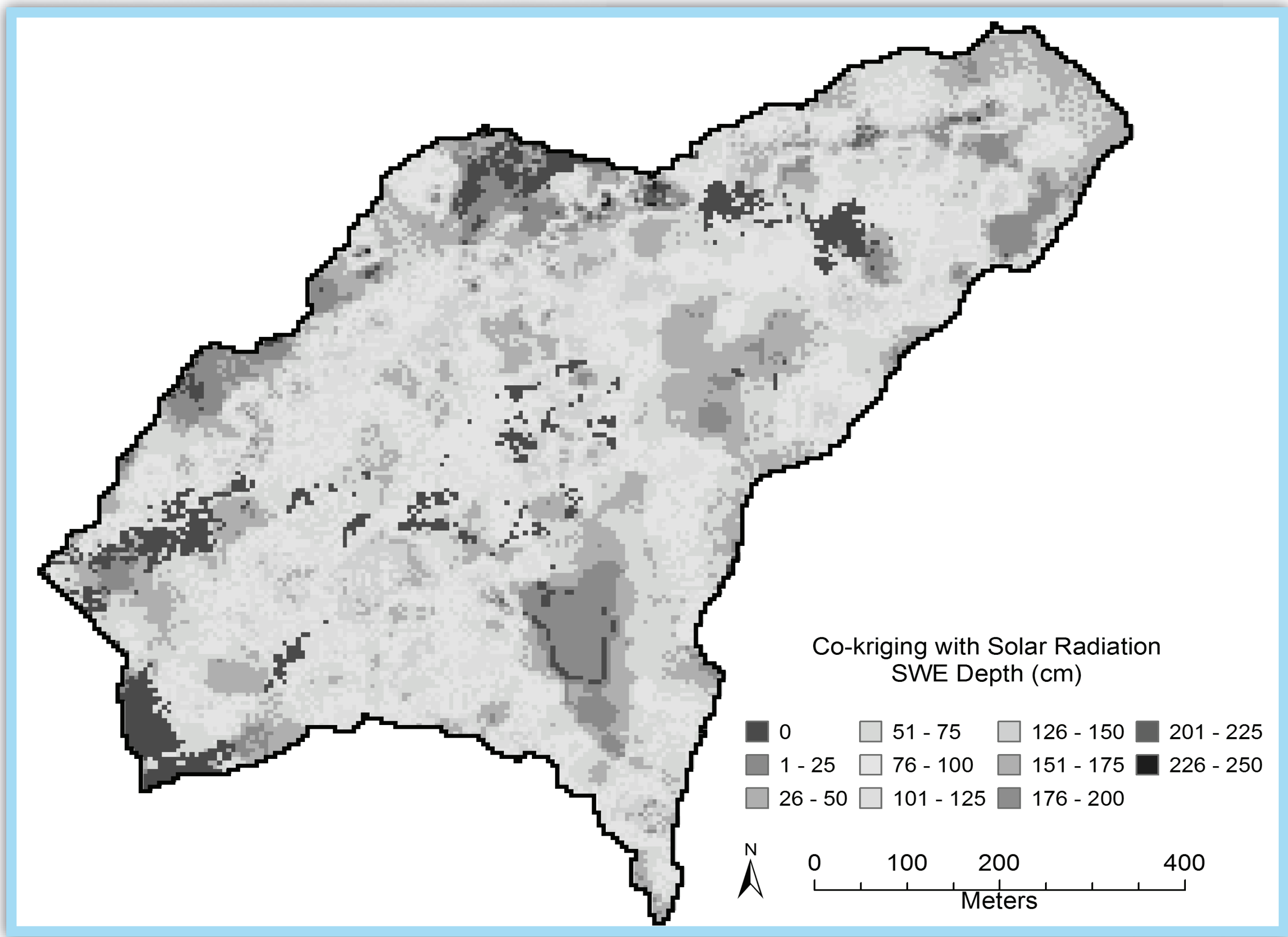

Figure 3. Calculated SWE distribution for West Glacier Lake watershed.

Snowpack sublimation was calculated from mass transfer equations and yielded 251 mm of water lost from the snowpack. The difference between the inputs and outputs yielded an evapotranspiration estimate of 230 mm.

Conclusion

The nine spatial models explained 18% to 94% of the observed snow depth variance, but SWE estimates were within +/- 2% of the best snow depth model. Co-kriging with solar radiation yielded the most accurate estimates of snow depth. The intensive snow survey was able to capture the large-scale and small-scale snow depth variability. The estimated SWE inputs were 67% greater than precipitation gauge estimates, and snowmelt accounted for 85% of the annual streamflow. Summer precipitation was less than snowpack sublimation. These results suggest that snow survey and spatial interpolation methods provide a more accurate representation of precipitation inputs into West Glacier Lake watershed than precipitation gauge estimates. West Glacier Lake water balance was closed without consideration of snowmelt contributions from the permanent snowfield.

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Variability at Colorado Snowcourse Stations

by Steven R. Fassnacht and Magdalena Skordahl, Watershed Science Program, Warner College of Natural Resources, Colorado State University

Introduction

The United States Department of Agriculture (USDA) has been collecting snow data since the mid-1930s. Originally, these data represented biweekly or monthly snowcourse measurements of snow depth and snow water equivalent (SWE) taken at 10 to 15 stations over a 100- to 300-meter transect. The data were reported as average snow depth, SWE, and density for a particular date. In the 1970s, numerous automated snow telemetry (SNOTEL) sites were established to report daily SWE, and during the past five years automated snow depth measurements have been added to many of the SNOTEL sites.

Snowcourse data collected on or about April 1 are used to represent peak accumulation across most of the western U.S and have been used to understand annual trends related to climate and climate change. However, few studies have used the 10 to 15 individual snowcourse station measurements to understand the variability associated with these data. Wells and Doyle (2004) examined long-term measurements at specific snowcourse stations relative to forest growth and found no significant trend in peak SWE.

Recent research into the spatial distribution of snow data has used variograms, power spectra, and related analyses to understand the correlation structure of the data and the fractal characteristics. Analyses used in soil science to understand surface characteristics, in particular related to tillage practices, have been applied to understanding snow surface roughness. Some of the metrics used to define roughness can also estimate spatial and temporal variability; the simplest of these is the coefficient of variation (COV), which disregards the relative location.

Study Area and Methodology

Focusing on the individual snowcourse measurements, this paper examines the variability at the transect scale for five snowcourses in Colorado (Table 1 and Figure 1). These stations are or were all co-located with SNOTEL stations. Different years of snow accumulation patterns were investigated for April 1 SWE at the snowcourses to determine the inter-annual variability for different snow years. The intra-annual variability in snowcourse data was determined using weekly measurements for four winters at one snowcourse: 23 dates during the winter of 1965, 27 dates during the winter of 1965-1966, 17 dates during the winter of 1966-1967, and 17 dates during the winter of 1968-1969.

These snowcourses represent different snow accumulation stations, with the Tower site receiving the most snow

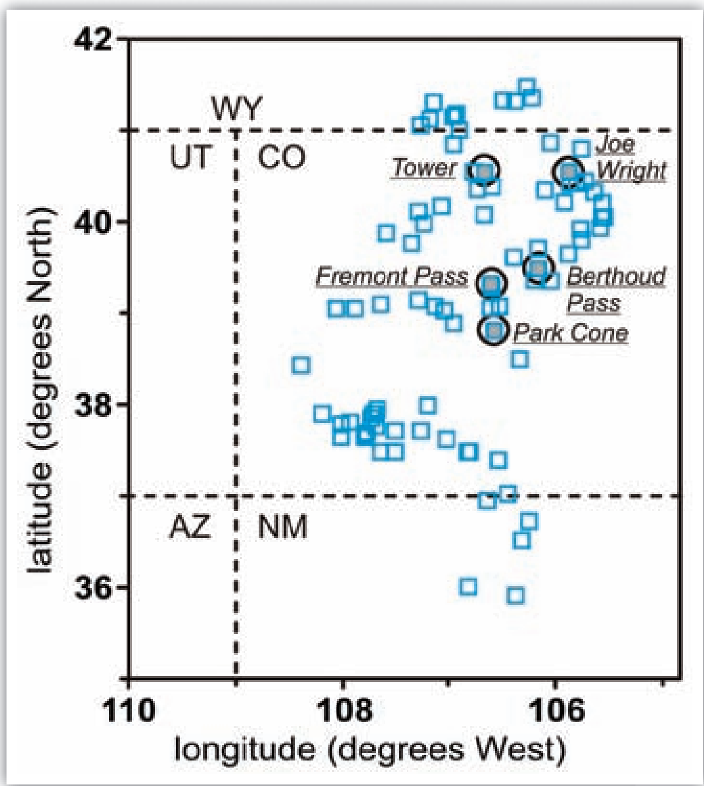


Figure 1. Location map for the five study snowcourse stations within the state of Colorado.

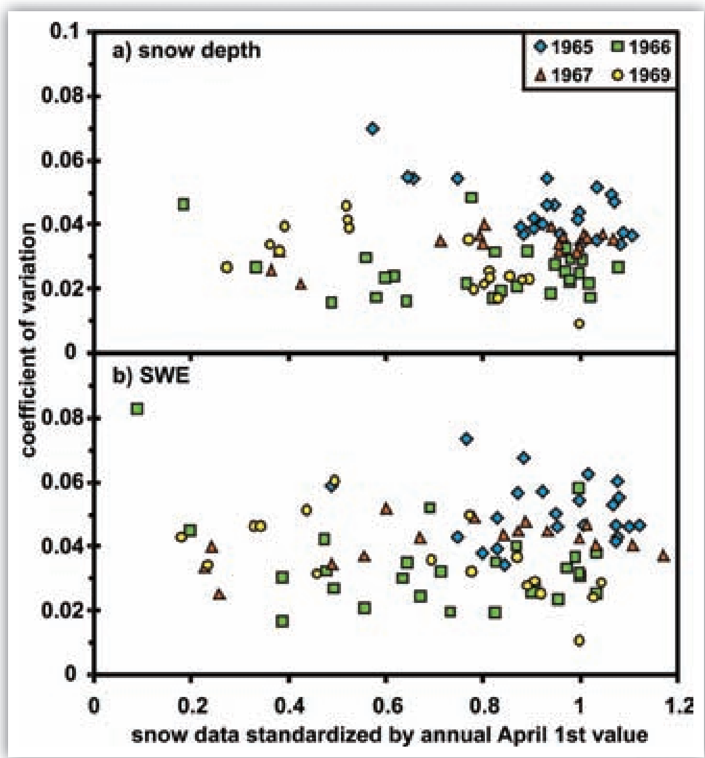


Figure 2. Plot of coefficient of variation versus annually standardized (a) snow depth, and (b) SWE for four years of weekly data for the intra-annual evaluation from the Tower station.

recorded across the entire Colorado River Basin. The other stations are Berthoud Pass, Fremont Pass, Joe Wright, and Park Cone (Table 1 and Figure 1), which represent different accumulation patterns.

Results and Discussion

The intra-annual variability is presented by the coefficient of variability versus the standardized data to remove units associated with the data (Figure 2). Trends among the annual snow depth data (Figure 2a) were more evident than in the SWE data (Figure 2b). Overall, the COV was consistent after enough snow had accumulated but prior to substantial snowmelt.

Using the one annual set of measurements that is used for many analyses (i.e., April 1), the variability was inversely and non-linearly related for both snow depth and SWE, except at the Tower station that was consistent as with the intra-annual data. Data from the other stations should be examined to determine any systematic variability. It is likely that other metrics would better explain the variability.

Individual snow depth and SWE measurements are reported to the nearest 1.27 centimeters (cm) (0.5 inches), and for deeper snow (depth > 254 cm, SWE > 1270 mm) this is often rounded to the nearest 2.54 cm (1 inch). This yields precision of at least 1 to 2% (depth and SWE) for deeper snow, but only 5% for many measurements. Early in the snow season depths are shallow, and accumulation of SWE in relative terms is lower, so precision is less and could increase the estimated variability. Few measurements are made late in the melt season. Fortunately, the variability estimates discussed herein will mostly be used in temporal proximity to peak accumulation.

Due to the strong consistency in snow density, the variability between SWE and snow depth is strongly related. However, this could change for snow season times other than April 1, which is approaching peak accumulation at the five study stations.

Numerous snowcourse stations have been replaced by co-located USDA SNOTEL stations. The SNOTEL stations report daily (or shorter time) SWE, based on automated measurements representing approximately 10 square meters. Snowcourse replacement by SNOTEL stations will remove the potential to assess snow variability at snowcourse stations. For snowcourses that have not been replaced, the data can be supplemented with the co-located SNOTEL SWE (and now snow depth) measurements, since location does not change.

Conclusions

Four years of weekly data at the Tower site, the highest measured snow accumulation in the state, illustrated that the intra-annual variability was consistent for most of the winter. The exception was during early accumulation and after melt had initiated. The individual data for April 1 snow depth and SWE illustrated an inverse relationship between variability and quantity of snow.

Figure 3. Todd Boldt of the USDA Natural Resources Conservation Service (NRCS) takes snow measurements at the Cameron Pass snowcourse.

station		latitude	longitude	elevation	average April 1st SWE		average April 1st depth	
number	name	[N]	[W]	[m]	[mm]	rank	[m]	rank
05K03	Berthoud Pass	39°50’	105°15’	2957	414	40	1.372	34
06K08	Fremont Pass	39°23’	106°48’	3475	414	40	1.422	31
05J37	Joe Wright	40°32’	105°7’	3085	645	11	1.905	10
06L02	Park Cone	38°49’	106°25’	2926	269	82	0.965	81
06J29	Tower	40°32’	106°19’	3200	1278	1	3.353	1

Table 1: Snowcourse stations used in this study with location and average April 1 SWE and depth. Rank is compared to all 147 snowcourse stations within the state of Colorado that have at least 20 years of April 1 measurements.

Snow Hydrology at the Niwot Ridge LTER

by Mark W. Williams, Institute of Arctic and Alpine Research and Department of Geography, University of Colorado

Figure 1. Maintenance work is done on a high-elevation meteorological station at the NWT LTER site in the mid-1950s (NWT LTER archive).

Snow hydrology is one of the primary monitoring and research efforts of the NSF-funded Niwot Ridge (NWT) Long-Term Ecological Research (LTER) program. Research began at the NWT LTER site in the 1940s when World War II veterans returned with extensive experience in cold-region logistics. By the early 1950s a series of climate stations and ecological index sites had been established along an elevational transect. The NWT LTER has continued to operate these climate stations, such as the D1 site shown in Figure 1, which is located at an elevation of 3,739 meters (m) and has operated continuously since 1952—the highest-elevation meteorological station in the United States.

The NWT LTER program is based at the University of Colorado at Boulder and is administered through the Institute of Arctic and Alpine Research (INSTAAR) in cooperation with the Mountain Research Station, with special use permits from the U.S. Forest Service. The NWT LTER site extends up to the Continental Divide at elevations greater than 4,000 m, with snowfall accounting for more than 80% of annual precipitation (Figure 2). It is surrounded by designated Wilderness Areas and by public closures, which allows research into one of the most pristine areas in the United States. The NWT LTER program welcomes visitors and researchers who wish to develop independent or collaborative work at the field site, located about 40 kilometers (km) west of Boulder, Colorado, at the headwaters of North Boulder Creek.

The timing, amount, and duration of snowfall and snowmelt is the strongest climate driver in alpine ecosystems. In much of western North America, snow provides the primary means for storage of winter precipitation, effectively transferring water from the relatively wet winter season to the typically dry summers. Snowpack is the lifeblood of the West and provides about 75% of the region's water supply. Much of our research at NWT LTER is related to how changes in climate may affect snow properties and, in turn, how changes in snow properties may drive changes in ecosystem function.

Logistical constraints have caused data collection in seasonally snow covered areas to generally be on a campaign basis with limited instrumentation. The problems of winter access, cold air temperatures, and blowing snow cause both equipment malfunctions and problems with consistent and timely maintenance. We have been operating a meteorological station and subnivean (below snow) laboratory at 3,517 m since the spring of 1994 to collect information that will allow us to better understand snow-surface energy exchanges and the mass flux of water during snowmelt. This unique and high-quality data set was designed to measure the meteorologic and hydrologic parameters necessary to compute the surface energy and snowpack mass balances at a point for development, calibration, and verification of snow models.

All meteorological parameters are directly measured, including both incoming and outgoing short-wave and long-wave radiation. The timing, magnitude, and chemistry of snowmelt are measured before contact with the ground in snow lysimeters that drain into the subnivean laboratory. Meteorologic parameters and energy fluxes are available at 10-minute, hourly, and daily time steps. Complementary information includes a high-resolution digital elevation model (DEM), snowpits at three locations, and stream discharge.

One of the main challenges in snow hydrology is characterizing the spatial distribution of snow depth and snow water equivalent over an area of interest. In particular, understanding the spatial distribution of snow in alpine areas has been considered an almost insurmountable problem because snow depths can vary from 0 to 1,500 centimeters (cm) over distances of less than 100 m. To evaluate this problem, we have conducted surveys of snow depth at maximum accumulation since 1997, with about 500 measurements over the 2.3-square-kilometer Green Lakes Valley watershed. We used these data to model the

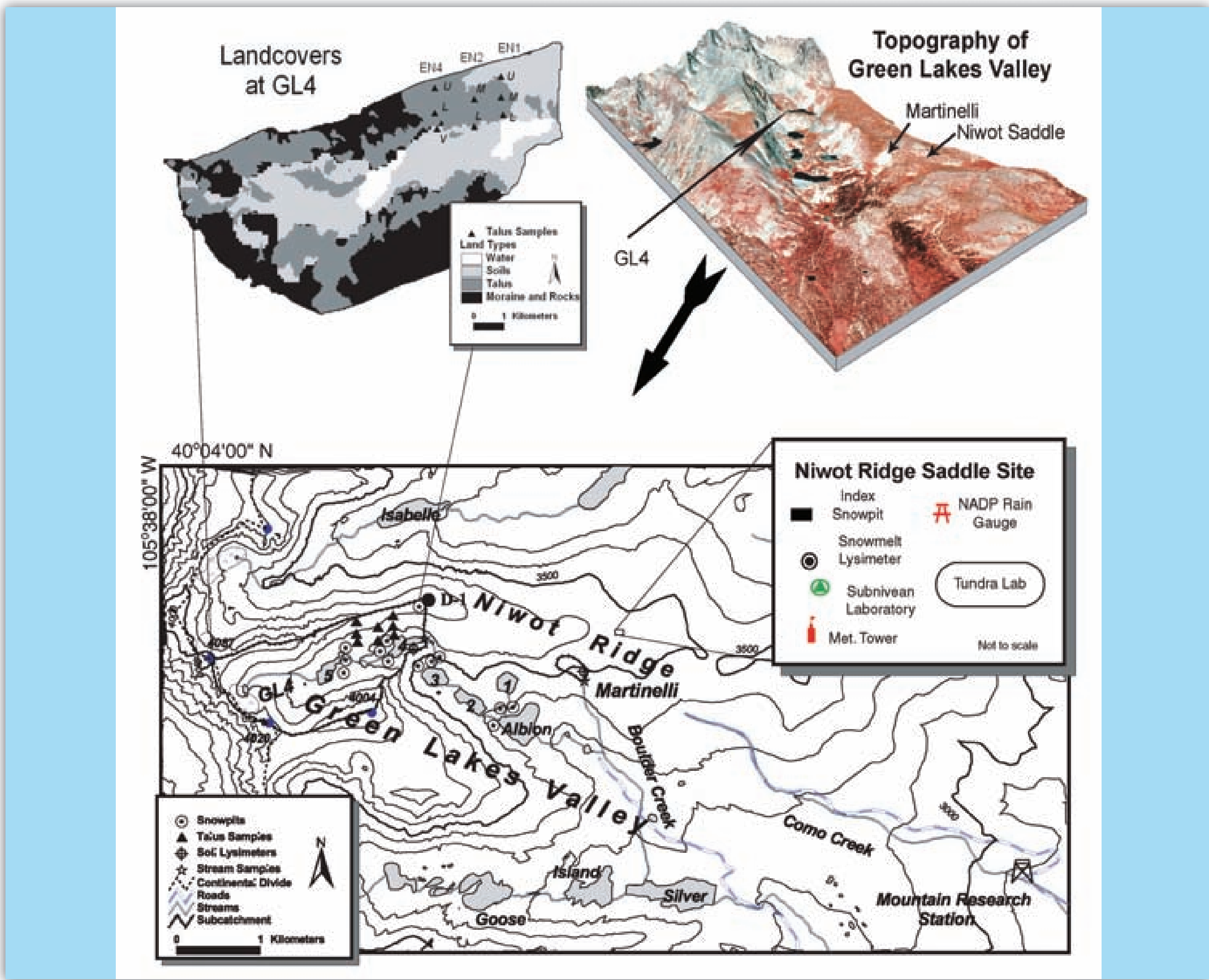


Figure 2. Map of Niwot Ridge and the Green Lakes (Liu et al., 2004).

spatial distribution of snow depth using a geostatistical approach with a complex variable mean. Terrain variables that were important in modeling the spatial distribution of snow included elevation, slope, potential radiation, an index of wind sheltering, and an index of wind drifting. Lag distances were on the order of 200 m, varying with annual climate conditions. Somewhat counter-intuitively, our results showed that snow distribution in alpine areas is predictable, with some areas always receiving higher amounts of snow and some areas always receiving low amounts of snow, as a result of topographic steering of snow accumulation, redistribution, and ablation patterns.

A major research emphasis of the snow hydrology program at NWT LTER site is to improve our understanding of the fate of snowmelt runoff. Water stored in the seasonal snowpack acts as a "water bank" that releases water over a short period during snowmelt. This water then rushes immediately into streams and rivers to downstream farmers, cities, and industry. The common perception is that snowmelt runoff in streams and lakes is new water because mountain catchments act as "Teflon basins" with little contact between snowmelt runoff and the subsurface. We have used isotopic and geochemical measurements to provide unique fingerprints of different water sources in an attempt to understand the fate of snowmelt runoff. These results show that there is much more infiltration of snowmelt into subsurface reservoirs in high-altitude areas of the Colorado Rockies than previously thought. Surface-groundwater interactions during snowmelt runoff influence the availability of fresh water, the quality of that water, and the movement of nutrients through mountain catchments. The common perception that water stored in mountain snow packs melts and then runs immediately into streams and rivers is probably wrong, and the Teflon basin myth is incorrect.

Based on the research activities above, we are now using remotely sensed snow cover data and a physically based snowmelt model to estimate the spatial distribution of energy fluxes, snowmelt, snow water equivalent, and snow cover extent over the different land cover types within the NWT LTER. The spatially explicit snowpack model has been coupled to the Alpine Hydrochemical Model (AHM), and estimates of hydrochemical fluxes at the basin outflow have been successfully modeled when compared to measured values.

Figure 3. Snow properties are sampled at Niwot Ridge. Measured properties generally include depth, density every 10 cm, temperature every 10 cm, grain size, grain type, and stratigraphy (NW LTER archive).

Figure 4. A researcher does a snow survey in the upper Green Lakes Valley of the NWT LTER program (NWT LTER archive).

Life in Extreme Environments

We have found that microbes are churning away under the snow in the dead of winter, breaking down organic and inorganic material and recycling carbon and nitrogen at a higher-than-expected rate. This finding that microbial communities are active under snow has changed the estimated global rates of biogeochemical processes beneath seasonal snow packs. Unexpectedly, our results show that the microbial biomass of tundra soil reaches its annual peak under snow and not during the snow-free, warmer summer months, and that fungi account for most of the biomass. Similar research has shown active microbial populations in unexpected locations, such as talus piles and rock glaciers.

Broader Impacts of NWT LTER Program in Snow Hydrology

LTER science is increasingly being used to address pressing environmental problems, the management of ecosystems for the sustainable production of essential goods and services, and the education of future generations of scientists by applying theoretical understanding to real-world issues. One example is the Aspen Canary Initiative, which involved forecasting future snow and ski conditions on Aspen Mountain for the years 2030 and 2100. Using the snow hydrology techniques developed as part of the NWT LTER, application to future climate conditions at Aspen showed that the snow line will move up in elevation, ski seasons will get shorter, and in-bound and in-season wet snow avalanches will be more frequent.

The research on surface-groundwater interactions during snowmelt runoff at NWT are being used to guide the use of innovative procedures to efficiently eliminate or control acid mine drainage on a site-by-site basis. These tools were used to guide the development of a science plan for decommissioning the Leadville Mine Drainage Tunnel, which may undergo catastrophic failure at any time. The $4 million engineering plan calls for stuffing a concrete plug in the tunnel, diverting a major source of clean water from one nearby mine shaft to another drainage, and placing pumps in additional shafts in case the water pools up. In a similar fashion, these techniques have been used to address a mining conflict in a high-elevation area of the Peruvian Andes. Two farmers were killed during protests against the proposed mining activity when different national and international actors became involved. Based on NWT LTER results from the snow hydrology program, a proposed water monitoring scheme could contribute to more productive relationships between local communities in Peru and mining development.

Most data from the projects mentioned above are available at our web site at http://culter.colorado.edu/NWT/. The NWT LTER site has been selected as one of three Critical Zone Observatories funded by NSF (http://instaar.colorado.edu/czo/), and it is also a candidate core site for the Southern Rockies/Colorado Plateau domain of the new National Ecological Observatory Program (NEON) (www.neoninc.org). Snow hydrology at NWT LTER is a dominant theme in these new programs.

For additional information about data availability and data management, contact Todd Ackerman at todda@colorado.edu or Hope Humphries at Hope.Humphries@colorado.edu. Mark Williams can be reached at mark@snobear.colorado.edu.

Cloud Seeding to Enhance Snowfall

by Daniel Breed, *Project Scientist, Research Applications Laboratory, National Center for Atmospheric Research*

Introduction

Most of the water supply in the American West begins as mountain snowpack. Recent studies have documented systematic changes in snowpack and alpine glaciers due to warmer temperatures—a possible impact of climate change. In addition, increased pressures for fresh water from the population shift and growth in the desert Southwest have triggered multiple responses aimed at better managing water resources, particularly in the Colorado River Basin. So, the importance of mountain snowpack and its characteristics—annual amounts, short-term and long-term trends, variability—cannot be overemphasized, particularly for the headwater states of Colorado and Wyoming.

One of the more attractive responses to managing water resources is increasing the snowpack via cloud seeding. It potentially provides an additional source of water, versus shifting or storing current supplies and runoff, and is relatively inexpensive compared to building and managing infrastructure such as dams and reservoirs. Attempts to increase snowpack by seeding clouds have been carried out for over 50 years. Average increases of 10-20% have been reported in some experiments, but the topic remains controversial and many operational programs and scientific experiments have ended without conclusive results. Regardless, the majority of those results have 'suggested' positive impacts from seeding, and the proof of efficacy may be viewed differently depending on whether you are a scientist or a water manager. The topic is scientifically complex, due to our limited understanding of precipitation processes, and remains controversial because of its past.

Precipitation Development in Winter Orographic Clouds

Snowfall in the Rocky Mountains comes primarily from precipitation development in winter orographic clouds. Moist air is forced upwards by the terrain and condenses to form a cloud, which initially consists of small liquid droplets of negligible fallspeed. These cloud droplets remain liquid even at temperatures well below 0°C. The conversion of these liquid cloud droplets (supercooled liquid water or SLW) into ice crystals and snowflakes is highly variable and depends on a number of factors such as temperature, dust or aerosol particles that act as seeds for ice crystals (ice nuclei), and the supply of cloud moisture. Some quantity of SLW often exists throughout the life of a cloud. Figure 1 conceptually illustrates the flow that forms an orographic cloud and, by way of stipled shading, the initial cloud area where SLW might exist.

Figure 1. This simple schematic illustrates airflow (arrows) and cloud liquid water (stipled shading) in an orographic cloud.

Precipitation in winter storms develops and falls out when clouds: (1) have an excess of SLW, (2) exist in a temperature range for efficient ice nuclei activation and crystal growth, (3) form in conditions conducive to further cloud particle growth via collection or 'aggregation' of cloud droplets and ice crystals, and (4) have sufficient time/distance for ice particles to develop, grow, and fall onto the barrier. Ice crystal development can occur either due to ice nuclei activation or the advection of ice crystals, such as from horizontally extensive cloud, fallout from higher clouds (such as in Figure 1), and lofting from the ground. Therefore, an inefficient storm typically lacks a sufficient number of ice nuclei, which can be supplied by seeding. Cloud seeding is then aimed at increasing snowfall from clouds that are likely to be naturally inefficient at converting SLW to snow.

The ice nuclei provided by seeding consist of tiny crystals of silver iodide or silver iodide complexes. These were discovered to be very effective ice nuclei in 1947 by the renowned atmospheric scientist Bernard Vonnegut, who is also notable as the brother of novelist Kurt Vonnegut. The formation of silver iodide nuclei involves a burning process that generates the small sizes of silver iodide particles for transport by the wind. Over 1014 nuclei are generated per gram of silver iodide at -10° C, although this number is dependent on temperature (fewer nuclei are effective at warmer temperatures). The release of silver iodide into the air often raises environmental concerns since elevated concentrations of ionic silver have been shown to be toxic at the lower end of the food chain. However, silver iodide is relatively inert and rarely dissociates appreciably under normal conditions. Also, the miniscule amounts of silver iodide that are released during cloud seeding are well within background levels of what occurs naturally. Several studies on the potential effects of silver from cloud seeding have concluded that there would be no detectable environmental consequences in the concentrations that are nominally used.

Scientific Issues

Our knowledge of precipitation processes has developed rapidly over the past couple of decades, thanks to increasingly sophisticated technologies for detecting atmospheric constituents, clouds and precipitation, airflows, and a host of other parameters important in understanding how precipitation forms. Yet, while cloud seeding seems conceptually straightforward, relevant research has increasingly demonstrated the complexity of the problem. Most of the questions and knowledge gaps that preclude evaluating and quantifying seeding effects are the same ones that hinder progress in accurately forecasting the small-scale distribution and amounts of precipitation. Similarly, research seeking to establish the role of aerosols and clouds in climate change is relevant to cloud seeding applications.

The timely identification of regions of SLW and the efficient targeting and dispersing of seeding material remain difficult problems. Experiments that have seeded wintertime orographic clouds have highlighted the complex interaction between the terrain and the wind-flow structure in targeting seeding material. Major uncertainties include the identification of the right cloud at the right time, the response time for delivering seeding material, the coverage on release, and the potential for volume filling. Evidence from plume tracking and trace chemistry measurements of silver in snow show that plumes of seeding material often do not fill and catalyze the intended cloud volume.

Understanding precipitation processes and their complex interactions with wind-flow structures in winter storms in mountainous regions can be substantially increased using sophisticated numerical models, especially when supported by comprehensive field measurements. Collecting data, both as input into numerical models and to verify the model results, is a key component in evaluating cloud seeding effects. Yet even the fundamental measurement of snow, particularly at high resolution, can be quite difficult. Deployment of special equipment to detect important parameters, such as SLW, precipitation, temperature profiles, or winds, can assist both evaluation and operational efforts. For example, Figure 2 shows the deployment of instruments to measure fine-scale precipitation events and remotely-sensed SLW in collaboration with the U.S. Forest Service Rocky Mountain Research Station at their southern Wyoming mountain site.

Because of the large natural variability of precipitation and the relatively small seeding effect expected, it is generally believed that no single analysis can be convincing regarding the effect of seeding. Rather, it is necessary to build multiple layers of evidence, both from statistical experiments and from physical observations, to provide a consistent picture of the effect of cloud seeding.

Cloud Seeding in Colorado and Wyoming

Cloud seeding projects for snowpack enhancement, some of which have been running continuously for more than 50 years, are being carried out in seven western states. In Colorado, weather modification operations and research has occurred since the 1950s. Currently, seven wintertime programs are permitted by the state, including those in the Vail and Upper Arkansas region, the Grand Mesa, the San Juan/Delores River Basins, and the Gunnison Basin. Outside of the occasional grant (e.g., a 2005 report by CSU on numerical simulations of snowpack augmentation), research funding for the scientific evaluation of cloud seeding has been limited over the past decade or more.

In 2005, the State of Wyoming funded and implemented a five-year weather modification pilot project to investigate the possibility of cloud seeding as a way to enhance water resources (snowfall and stream flow). This project is unique among state-sponsored programs in that it includes a substantial evaluation component, following recommendations of a 2003 National Research Council report on weather modification research. The evaluation efforts are concentrated in the two southern ranges of interest (the Sierra Madres and the Medicine Bows), but also include the Wind River Range of west-central Wyoming.

An experimental design for randomized seeding has been developed and is currently being carried out for the Medicine Bow/Sierra Madre target areas. It is estimated that roughly 250 storm periods (seeding events) will be needed to detect a 15% change in precipitation, which will take at least 4–5 years to accumulate. The project also provides a unique opportunity for "piggy-back" research. For example, researchers at the University of Wyoming are utilizing their King Air aircraft, cloud radar, and airborne lidar to detect possible signatures of cloud seeding in storms over the Medicine Bow range.

For more information about the Wyoming cloud seeding experiment, contact Dan Breed, NCAR Research Applications Laboratory, at (303) 497-8933 or breed@ucar.edu.

Figure 2. Instruments are deployed at the Rocky Mountain Research Station's mountain site in southern Wyoming.

Effects of Ski Slope Development on Stream Channel Morphology in Colorado

by Gabrielle David, Department of Geosciences, Colorado State University

Development of ski slopes from tree-clearing, road construction, machine-grading and snow-making changes the hydrology of a basin affecting the channel morphology and stability. The morphology of a channel is the channel structure or form described by degree of bank stability, bank undercutting, gradient, in-channel wood, grain size of the channel bed, and pool depth. The effects of ski slope development on morphology and stability of stream channels is poorly understood. Although each of these types of development has been studied individually, particularly the effects of tree-clearing and road construction, the combined effect of all four on channel morphology has not been investigated thoroughly. Changes in land-use affect the hydrology of a basin by either causing an increase in the water yield or peak flow, or a change in the size and amount of sediment that the stream transports. The U.S. Forest Service (USFS) funded this project because of their concern about the potential impacts of development on stream channels in national forest land, where the majority of ski resorts are located. Changes in the channel morphology can result in a decrease in habitat diversity and water quality as the stream moves toward a new equilibrium. The USFS can use information on the combined effects of tree-clearing, road construction, machine-grading, and snow-making on stream channels to develop better management practices.

Channels may respond to an increase in discharge from tree-clearing and snow-making by bed coarsening, bank erosion, pool scour, and in extreme cases, channel incision. Many of the project streams had a significantly larger amount of fine sediment and pool filling from roads and graded slopes, which cause a decrease in habitat diversity for macroinvertebrates and fish. Stream channels are complex systems and one change can often trigger another, causing multiple responses to one event. Specific channel response to increased flows associated with ski resort activities partly depends on the type of vegetation growing along stream banks, the type and extent of development, timing of development and underlying basin lithology.

In this study, I investigated the observed and measured changes in channel morphology to better quantify how channels change with ski slope development. We surveyed 48 stream reaches in Colorado's White River National

Figure 1. Parsenn Creek enters a culvert under a ski run at Winter Park, Colorado.

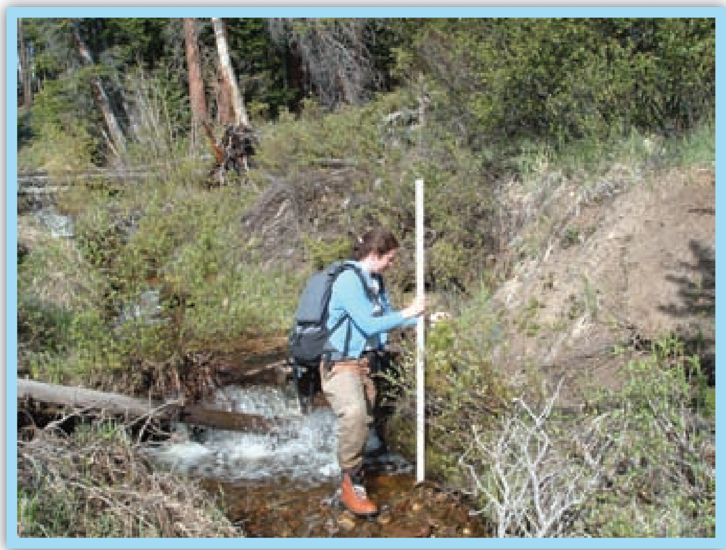


Figure 2. Gabrielle David measures unstable banks along Jones Gulch (incised channel) at Breckenridge, Colorado.

Forest. A reach was defined as a length of stream 200 to 300 meters long that was representative of the rest of the channel. Of the 48 reaches, 24 were 'project' streams located on or below ski slopes in Vail, Copper, Keystone, Breckenridge, Snowmass, and Winter Park; and 24 were 'reference' streams in basins with little or no development. These reference streams were similar in aspect, basin lithology, and size to the project streams. To reduce variability when analyzing the differences between project and reference streams, we chose steep and confined reaches.

We surveyed bank stability, bank undercutting, sediment size, pool depth, amount of wood, and vegetative structure in each stream. These variables were then used in statistical analyses to determine if there were any systematic differences between project and reference streams. The results can be divided into two subsets: (1) differences in channel morphology between project and reference streams and (2) changes related to ski development in the basin.

Figure 3. Dense willow understory cover lines Wheeler Creek at Copper Mountain, Colorado.

Project vs. Reference Streams

The project streams differed significantly from reference streams. Streams are complex systems and all project streams did not alter in the same way or even in the same expected direction. Differences in project streams were mitigated by basin lithology, vegetation, timing of development, and extent of development. The timing of development determines how long a basin has had to respond to a change in water yield or sediment yield, and the extent of development determines how drastic the change in water or sediment is in the stream. Streams in a granitic material and low vegetative understory were found to have the most significant differences from reference streams, with a larger percentage of unstable banks, undercut banks, and fine sediment. Wood, on the other hand, was more significantly related to the surrounding vegetation type than to any changes in the basin hydrology. All the response variables (bank stability, bank undercut, fine sediment, wood, and pool depth) were found to be significantly different in project versus reference streams. I attempted to connect each of these changes to a specific type of development in the basin, but the complexity of the streams, along with the complexity and interaction of each type of development, made it difficult to identify specific cause-and-effect relationships. Below, I describe our current understanding of the relationship between each type of ski slope development and basin hydrology. Next, I describe the development types that most significantly affected changes in the project streams.

Tree-Clearing

Harvesting of trees leads to a decrease in interception and transpiration, increasing the soil water content. The increase in soil water content allows more water to drain into the stream. Also, tree-clearing opens up large swaths of land to sunlight, which affects the rate of sublimation and snowmelt. The rate of change in sublimation and snowmelt on ski slopes is further complicated by the aspect of the slope. A north-facing slope may have a greater increase in water yield from tree-clearing than a south-facing slope, due to greater snowpack Tree-clearing can also increase sediment production in a basin during the initial phase of tree removal; as a slope is re-vegetated, the contribution from this source may be reduced.

Forest Roads

Forest roads tend to increase overland flow and increase the drainage density of stream networks, leading to an earlier and larger peak flow. Drainage density is increased because the roads route the flow directly from water bars and ditches straight into the stream channel. Roads can also intercept subsurface flow, changing the path the water takes to the stream and how quickly the water gets there.

Figure 4. Sediment is shed from a road in Breckenridge, Colorado.

Machine-Grading

Machine-grading is the process of smoothing out the slopes by removal of the topsoil, boulders, and vegetation. In some places, soil is added to the slopes in a similar manner as road-cuts. Machine-grading significantly affects the vegetation by removing the top-soil, thereby changing the infiltration capacity of ski slopes. Slopes that have been machine-graded often are not able to re-vegetate for long periods of time, causing an increase of overland flow and sediment flux into the stream. Therefore, machine-graded slopes and roads potentially have the longest lasting influence on the increase in sediment yield in a stream.

Snow-Making

Snow-making is the process of mixing air and water in a snow gun under pressure and releasing it through a nozzle into the atmosphere. The production of artificial snow can cause a variety of changes to the hydrology of the basin. Most artificial snow is found on cleared ski runs and is exposed to a greater amount of solar radiation than snow underneath a tree canopy, thereby allowing snowmelt to begin earlier and cause an earlier and larger peak flow in a stream. Conversely, artificial snow has a higher density than natural snow, leading to a later snowmelt. Also, ski slopes are heavily groomed, which compacts the snow and increases the density.

Development and Channel Morphology

The development variables that were most significantly related to changes in the stream channel were an increase in graded density, drainage density, and water yield. Water yield combines the effects from both tree-clearing and snow-making. Channels with an increase in water yield and an increase in drainage density are expected to have a coarser bed and scoured pools as more sediment is moved out of the channel. In this case, the project streams were found to have finer sediment, indicating that the input of sediment from roads and graded areas overcame the higher transport capacity from the higher peak flow and water yield. Further work should analyze the connectedness of each of these areas with stream channels. Some roads and graded areas were directly connected to the stream, while other channels had large vegetation buffers between the channels and ski slopes. One variable that I did not consider in the analysis was extent of channel incision. I observed that in basins with large amounts of snow-making, the channels were incised; therefore, channel incision should be considered in any further analysis.

This project is an initial look at changes in stream channels from ski slope development. More work should be done to further connect specific changes in each basin with the changes observed in the stream channels. The reaches in granitic lithology with low understory cover and high gradients were more likely to respond to development in a basin than other reaches. These reaches should be given special consideration when developing a management plan. So, next time you go skiing, think about the streams and how the channel form is affected by the development around you.

Figure 5. Snow-guns along a ski slope in Steamboat Springs, Colorado.

Using Only What We Need: Denver Water's Plan to Cut Water Waste and Boost Efficiency

by Melissa Elliott, *Water Conservation Manager, Denver Water*

The responsibility of serving water to 1.2 million people in the semi-arid Front Range region has always weighed heavily on Denver Water. To that end, the water utility has been sending out the call for its customers to conserve for decades. A recent expedition into Denver Water's archives turned up photos of signs on streetcar trolleys on Denver's 32nd Street in 1936 asking Denverites to "Help Save Water."

The history of the utility's conservation efforts continues to more modern times when Denver Water coined the term 'Xeriscape' in an effort to get Denver-metro residents to plant more sustainable landscaping after a drought in the early 1980s.

More recently, the Denver Board of Water Commissioners has upped the ante. After seeing its customers come together as a community and cut their water use by a third during the 2002-2003 drought, Denver Water adopted its current conservation plan aimed at cutting water consumption by 22% from pre-drought days. Denver Water plans to reduce water use across its entire system by 39,400 acre-feet—enough to serve about 80,000 suburban households for a year—by 2016.

Cutting waste and increasing water efficiency will make it much easier to withstand future droughts, and it helps delay some future water supply projects, which spreads the utility's costs out. Denver Water's future water supply demands that efficiency be a major factor in planning. The utility is fortunate to have a large, productive water supply, but those resources are finite. Denver Water knows that conservation can help stretch today's resources, but conservation alone cannot replace future supplies. Instead, implementing conservation programs is a significant part of Denver Water's future water supply planning, along with expanding the use of recycled water and adding additional supply and storage.

Another major factor in this conservation plan is the fact that Denver Water customers rely in part on a water supply that originates outside the river basin in which they live. When residents of the Colorado River Basin are presented with plans by Front Range utilities to develop water supplies, they provide a very compelling message: that Front Range utilities should use their current supplies more efficiently before seeking more. It is a message Denver Water embraces with its conservation plan.

Since Denver Water has stepped up its water savings goal, it has also adopted new methods of achieving it. Although Denver Water has long promoted the traditional methods of education and outreach, such as distributing publications, inserting literature into bills, and educating school children, the utility's new goal is to make wasting water socially unacceptable. To do that, we have adopted an outreach model called community-based social marketing. This may be a new concept, but most people are familiar with many campaigns that adopt this communication method of behavior change. Essentially, the model identifies the barriers to behavior change and removes them. It is frequently used in health campaigns and is often the key to turning the tide in behavior that is unhealthy or socially unacceptable.

The first step in changing behavior is getting people to understand the problem. Denver Water's "Use Only What You Need" marketing campaign—now in its third year—is

Figure 1. This billboard was designed with a wrapped pole that looks like a broken sprinkler head gushing water to illustrate that "Broken Sprinklers Waste Water."

Figure 2. This billboard was designed with a wrapped pole that looks like a giant hose with a knot in the end to illustrate the utility's restriction on watering from 10am to 6pm, when the heat of the day causes more evaporation.

designed to do just that. It involves bright orange signs bearing a variety of visuals, but all containing the message: "Use Only What You Need." The slogan was derived from research indicating that customers agreed people shouldn't waste water, but that they didn't like the idea of being asked to conserve. Conservation can mean self-deprivation to some people, but the idea of eliminating water waste was one that everyone could support. The campaign includes television advertising that features "drunken" flowers with a message urging people to not let them drink too much (water). It also uses a car that is driven around Denver during events with every extra part removed except what it needs to be street legal, displaying a sign on top that says: "Use Only What You Need." Other elements that have been introduced include a person dressed in a giant toilet costume who ran across the field during a CU-CSU football game with "Stop Running Toilets" flashing on the score board. In 2008, the campaign built huge sculptures of orange barrels to demonstrate how much water is wasted by leaky toilets or inefficient sprinkler systems.

The campaign has been incredibly successful. More than 80% of Denver Water's customers say they recognize the campaign is about reducing water waste and they agree with the message. But just because a customer agrees that people should eliminate water waste and become more efficient doesn't mean they practice what Denver Water preaches. Often it takes Denver Water arriving on the front porch with a new high-efficiency toilet or flagging down a customer who is watering at the wrong time of day to call a halt to water waste. To get Denver Water customers to become more efficient and change their behavior, the utility has to call it to their attention in a way that makes it easy, or at least important, for them to do so.

Denver Water audits large irrigation properties and commercial businesses and provides a list of ways they can use water more efficiently. Employees visit the homes of customers who have unexpected high-water bills to find leaks, and to evaluate the effectiveness of conservation programs, customers are tracked to see how they are doing with their water use.

Last year, Denver Water gave out more than $1 million in rebates on washing machines that use less than 10 gallons of water per load, compared with 45 gallons used by traditional washing machines. More than 100 commercial properties have taken advantage of Denver Water's incentive payments to save water. The utility recently presented Frito Lay with a check for $120,000 because they changed the way they washed and processed the potatoes used to make chips. They saved 83 acre-feet of water—roughly the amount of water needed to supply 160 suburban households for one year. Large commercial and irrigation customers can receive $14 per 1,000 gallons of water saved to put into new efficient products, such as upgrading their cooling towers or investing in new hospital sterilizers.

While Denver Water has carrots for its customers, the utility also has sticks. Denver Water's rules say people can't waste water, and the utility has a cadre of water monitors on the street enforcing rules by handing out warnings and fines. This year, Denver Water added a requirement that all new developments must amend the soil with compost before it is landscaped and before the utility will set the tap.

Landscaping planted on properly prepared soil requires up to one-third less water.

Denver's Board of Water Commissioners has embraced conservation and is funding it to a level that makes these programs successful. Few other utilities in the United States are doing conservation at Denver Water's level, making it a statewide leader. This elite status means Denver Water has a responsibility to lead in this arena, and the utility does that regularly. The Colorado Water Conservation Board conducted a survey of water utilities in Colorado and found that they collectively spend $11.3 million on water conservation and efficiency efforts each year. Denver Water is responsible for 70% of that total, even though it serves only 25% of the state's population.

Denver Water's programs are sought after by utilities across the country and around the world. Several southern and eastern states contacted Denver Water recently for assistance, including Georgia, Florida, and the Carolinas. Representatives from Southeast Water in Melbourne, Australia, recently sat down with Denver Water conservation and planning staff to discuss how they are working through their drought and to exchange ideas on how to become even more efficient.

While our customers have responded well to the call for efficiency, there are still challenges ahead. The farther we get from the drought years of 2002 and 2003, the fainter the memory of water shortages is to our customers. When wet winters with excellent snowpack arrive, members of the media don't really want to talk about planning for a future water supply by using water wisely. But it is critical to keep the momentum going.

There are economic factors at work as well. The recent downturn in the economy means Denver Water customers are less likely to buy a new high-efficiency toilet, even if the utility gives them a hefty rebate. And while everyone wants to be eco-friendly, the mainstream movement is primarily about energy efficiency, not water efficiency. Denver Water is now developing programs that combine the two into resource efficiency.

As we see the eventual end of waste in our service area, the next challenge is to become more efficient. Denver Water may need to be more active in persuading customers to use water wisely, and its employees may be in customers' homes replacing their toilets. The utility will have to be at their doorsteps, asking them to cut their irrigation use with a smart irrigation controller. And Denver Water may need to employ more persuasive strategies to accomplish its goals and demonstrate how to use water efficiently.

Figure 3. Giant sculptures using bright orange barrels were placed throughout Denver last summer to show how much water is wasted by broken sprinkler systems or leaky faucets. This sculpture placed near Coors Field showed how much water a leaky toilet wastes in one month.

Finding Our Way

by Justice Gregory Hobbs, Colorado Supreme Court

I am pleased to write this first column in a series devoted to water history topics; I start with the climate and the vistas, Colorado's enduring heritage of strength and limitation. I'd like to join John. C. Fremont along the route of his 1842 Platte and North Platte expedition to South Pass and the Green River, with a side hike into the heights of the Wind River Range. As a U.S. Army officer assigned to the Topographical Corps of Engineers, Fremont's mission, like ours, pivots on ascertaining the character of the Rocky Mountain West.

This image is a proof for a banner or poster for John C. Fremont when he was a Republican presidential contender in 1856. Fremont is shown on a mountain peak planting an American flag. The scene was likely intended to evoke heroic memories of Fremont's famous exploring expeditions to the Rocky Mountains in 1842 and 1843. (circa 1856, author: Baker & Godwin)

Scary Dry

July 23, 1842, West of Fort Laramie. "The present year has been one of unparalleled drought." Fur trappers and traders report that "both forks of the Platte have entirely failed." In prior years, the expedition had ridden the snowmelt rise out of the mountains to the Missouri and to market. Not this year. "Everywhere the soil looked parched and burnt; the scanty yellow grass crisped under the foot." Arapahoe, Cheyenne, and Sioux all gave "a discouraging picture of the country." Scarce a blade of grass, impending starvation, "no buffalo to be found in the whole region."

Fremont determines to press on, but leaves to his men who of them might choose to turn back. "We'll eat the mules," says Basil Lajeunesse. Crossing over from the North Platte to the Sweetwater, they find buffalo and stop to eat and dry meat.

The Snow Line

August 7, 1842, South Pass on the Divide. "The *snow* line of the mountains stretched grandly before us, the white peaks glittering in the sun" (Fremont's own emphasis). Here, they cross the Divide at about 7,000 feet in elevation "by a gradual and regular ascent to the summit" and the traveler "suddenly finds himself on the waters which flow to the Pacific Ocean." On the Green River side, Fremont finds "bold broad streams," their waters swift, cold, and crystalline. He longs to explore the headwaters of the Colorado, Columbia, Missouri, and Platte Rivers arising in or near the Wind River Range. He settles for an altitude-sick ordeal to the top of the Wyoming peak that now bears his name.

His hike up the mountain starts on August 13; he thinks it's going to be easy, but he encounters a series of precipices. Breaking out at timberline—at about 10,000 feet in elevation—Fremont reports: "I was taken ill shortly after we had encamped and continued so until late in the night, with violent headache and vomiting. This was probably caused by the excessive fatigue I had undergone, and want of food, and perhaps also, in some measure, by the rarity of the air."

The next day he suffers "headache and giddiness, accompanied by vomiting, as on the day before…unable to proceed further." He has provisions and blankets brought from a lower camp and continues to be "ill all afternoon." After the blankets and provisions arrive, "We enjoyed well our dried meat and a cup of good coffee." On August 15, 1842, he achieves the summit at 13,570 feet, thinking it to be "the highest peak of the Rocky Mountains." Exalted, he looks "down upon the snow a thousand feet below" and proceeds to St. Louis.

The Soil of This Country

July 10-11, 1843, Between the Platte and the Arkansas Rivers. The very next year Fremont returns west, coming up the Smoky Hill and the Republican into the Platte and Arkansas Valleys. He marvels at snow falling heavily on the mountains during the night, saying, "Pike's Peak this morning is luminous and grand, covered from the summit, as low down as we can see, glittering white." He finds the soil of this front range country "excellent, admirably adapted to agricultural purposes," and "capable of supporting a large agricultural and pastoral population. The plain is watered by many streams."

From here, Fremont continued to California crossing and mapping the Great Basin. Returning in the summer of 1844, he tracked into New Park (North Park), Old Park (Middle Park), and South Park, exploring along the Continental Divide the demarcations of the North Platte, South Platte, Colorado, Rio Grande, and Arkansas watersheds, going back to Missouri via Bent's Fort.

Home in St. Louis, Fremont dictated from his journals to his wife Jesse, daughter of Senator Thomas Hart Benton of Missouri. Her writing of his reports and memoirs, from which I quote, led to his greater fame as "The Pathfinder." Immigrants into the Oregon and California country, and the Mormons into Utah, followed his paths.

Except for the Hispano settlers into the San Luis Valley from New Mexico in 1852, Colorado lay in waiting until the gold discoveries of 1858. In came the farmers to feed the miners. Fremont's descriptions of Colorado's fertile soil and mountain water—rediscovered.

Snow Worries

Today. We worry about the snowpack. We know of cyclical flood and drought from 150 years of recorded history. We see the tree-ring evidence of prolonged and much more severe droughts. We grapple with the warming of the Southwest, a shift from snow to rain, longer growing days, fewer skiing days, and who knows what else? Maybe a long-term reduction in the water supply we've built our enterprising Colorado agricultural, municipal, and recreational economy around. It's enough to give one headaches and dizziness—a form of altitude sickness that water managers may now be suffering.

Lori Ozzello's article in *The Citizen's Guide to Colorado Climate Change* (Colorado Foundation for Water Education, 2008) starts with "It all begins with snow." Fremont—or should I say Jesse—would agree: whatever our future it'll test our mettle, it'll be worth the risk, and we'll always look to the mountains.

FY09 Student Water Research Grant Program Request for Proposals

The Colorado Water Institute is pleased to announce a request for proposals for the FY09 Student Water Research Program.

All proposals must be submitted online by February 27, 2009. Please visit http://www.cwi.colostate.edu for submission site.

Program Description

This program is intended to encourage and support graduate and undergraduate student research in disciplines relevant to water resources issues and to assist Colorado institutions of higher education in developing student research expertise and capabilities. It is intended to help students initiate research projects or to supplement existing student projects in water resources research. Proposals must have a faculty sponsor and students must be enrolled fulltime in a degree program at one of Colorado's nine public universities (ASC, CSM, CSU, CU, FLC, MSC, MSCD, UNC, or WSC).

Funding

Budgets may include, but are not limited to, expenditures for student salaries, supplies, and travel. Funds will not be approved for faculty salaries. Each award is limited to a maximum of $5,000. Awards may be effective as early as April 1, 2009 and research projects should be completed by March 31, 2010. For these research grants, only direct costs are allowed. Facilities & Administrative (F&A) costs may be shown as institutional cost share. Institutions are encouraged to participate in project costs although cost sharing is not required.

Eligibility

Students must be enrolled full-time in a degree program at one of the nine Colorado public universities. Proposals must have a faculty sponsor from the applicant's institution. The faculty sponsor is responsible for ensuring that the proposal has been processed according to their university's proposal submission policies and procedures.

U.S. Bureau of Reclamation in Colorado until World War II

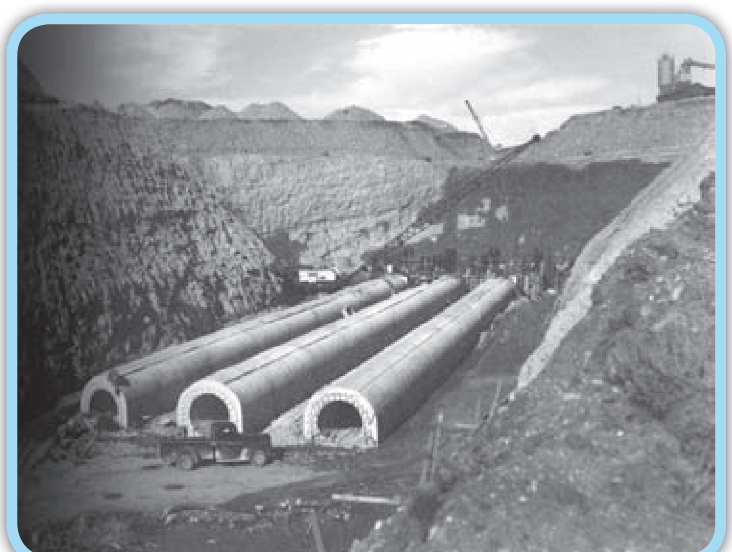
by Brit Storey, Senior Historian, Bureau of Reclamation

The Congress established the U.S. Reclamation Service (USRS) (renamed the U.S. Bureau of Reclamation in 1923) and the Reclamation Fund in an act of June 17, 1902, which directed development of water and irrigation projects in the West. The Secretary of the Interior placed the new bureau within the U.S. Geological Survey (USGS) where, for a time, it was essentially the Division of Hydrography. This was a logical choice since the USGS, for years, had studied several topics central to the success of the USRS: irrigable lands, topography, and water supplies in the West. However, the director of the USGS was also the director of the USRS, and in 1907 he separated the two bureaus completely.

By the end of 1940, Reclamation had authorized the following eight projects in Colorado—out of 66 projects scattered among 17 states in the West:

Gunnison Tunnel

In 1901 Colorado allotted $25,000 for a tunnel to carry water from the Black Canyon of the Gunnison River to irrigable lands around the Uncompahgre River. Within a year the state exhausted its funds and abandoned the tunnel. Because the USGS helped plan and locate the project, the federal government decided to take on the project. In 1903 the Secretary of the Interior authorized the Gunnison Tunnel, now known as the Uncompahgre Project, as one of the first five USRS projects.



This photo, taken on March 13, 1942, shows the east end of the Alva B. Adams Tunnel during construction.

Reclamation relocated the tunnel some five miles upstream and completed a 30,650-foot-long tunnel in 1909 at a cost of $2,905,307, despite difficulties posed by geology and water infiltration. The Gunnison Tunnel was the longest irrigation tunnel in the world at the time, and Reclamation delivered water by acquiring private canals and constructing new diversion dams and canals until 1925, at which time the original project was essentially complete and Reclamation had spent $6,800,000.

The project now irrigates over 60,000 acres of crops, including grains, forage crops, dry beans, seed, and various fruits and vegetables (including the area's signature crop "Olathe sweet corn"). The project also delivers a relatively small amount of local municipal and industrial water.

Grand Valley Project

Soon after the area opened to settlement in 1881, the Grand Valley boomed as an irrigated agricultural area centered around Fruita and Grand Junction. Private canal companies had some 45,000 acres under cultivation by the end of 1886. The balance of irrigable land in the valley along the Grand River (renamed the Colorado in 1921) was above the ditches and could only be irrigated by relatively expensive, and often unreliable, projects that pumped water to higher elevations.

Reclamation withdrew lands from the public domain for this project in 1903 but delayed authorization until 1907 because of expressed local interest in private construction of the project. When those private plans did not materialize, the Reclamation project proceeded. Construction began in 1910 and continued until the mid-1920s when the project's diversion dam, four main canals, and laterals were essentially complete. A 3,000-kilowatt power plant was added near Palisade in the mid-1930s.

Today, the Grand Valley Project serves about 33,000 irrigable acres and produces a variety of crops, valued at over $19,000,000 in 1992, including various grains, forage, dry beans, various vegetables, and fruits—most notably peaches and apples.

Colorado-Big Thompson Project

The area north of Lafayette to and beyond Fort Collins by way of Loveland and Longmont and out to the northeast along the South Platte River was heavily farmed by the mid-1910s. Coloradoans began looking westward across the mountains to the basin of the North Platte River for supplementary water to stabilize irrigation supply in the area. Frustrated by the Colorado v. Wyoming decision in their attempts to tap that supply, they turned to the Colorado River Basin as a source of water.

Approval of the project they visualized required heavy lobbying in Congress and a great deal of negotiation with Edward T. Taylor of Glenwood Springs. Taylor was the powerful head of the Committee on Appropriations in the U.S. Congress, and he feared the project would injure his West Slope constituents since it would export large quantities of Colorado River water to the East Slope. Colorado finally obtained authorization for the Colorado-Big Thompson Project in 1937.

Construction began on the West Slope at Green Mountain Reservoir in late 1938, and various phases of the project continued until the 1950s. The project captures upper Colorado River drainage water at Willow Creek and Granby Dams, pumps up to the level of Grand Lake and Shadow Mountain Reservoir, and diverts to the East Slope of Colorado through the Alva B. Adams Tunnel. Over 13 miles in length, tunnel construction took seven years. Major features on the East Slope include Olympus, Horsetooth, and Carter Lake Dams, as well as numerous other smaller dams, major canal and lateral systems, and several power plants.

Today the project is one of the Reclamation's most successful, providing supplemental water to some 625,000 acres of irrigable land. The value of crops produced in 1992 was over $307,000,000. About 92,000 acres of the project have evolved into urban and suburban uses, and about 40% of the project's water goes to municipal and industrial supply.

This Walter J. Lubken photo, taken on September 29, 1909, on the Uncompahgre Project, shows apples being packed on the Ashenfelter ranch near Montrose, Colorado.

Pine River Project

Located in southwestern Colorado in the area of Bayfield east of Durango, the Pine River Project serves about 50,000 acres of project lands, about 17% of which are Indian lands on the Pine River Indian Irrigation Project. President Franklin D. Roosevelt authorized the project in 1937 based on investigations of the Indian Irrigation Service and Reclamation. Construction of Vallecito Dam began in 1937 and was completed in 1941. Privately owned ditches and canals, all constructed prior to the dam, deliver water from Pine River and a few of its tributaries.

The vast majority of production on the project is attributable to various forage crops, though some grains are also grown.

Fruitgrowers Dam Project

The Fruitgrowers Dam Project is located a few miles east of Delta on the north side of the Gunnison River and north and west of the small town of Austin. Project water services a little over 2,000 acres. President Franklin D. Roosevelt authorized the project in early 1938 after a small private dam failed, flooding Austin and destroying some crops. Reclamation replaced the dam during 1938. Rehabilitation of the Dry Creek Irrigation Ditch occurred in 1940, and water delivery on the Reclamation project used existing private ditches.

In 1992 the project produced crops valued at a little over $1.2 million with the primary crops being apples, peaches, and pears followed distantly by various forage crops, corn, wheat, and cauliflower.

Paonia Project

The State of Colorado began several investigations in the Paonia area in 1934, and Reclamation took up this study in 1936. A private irrigation project already had a canal in place. Three years later in 1939, President Roosevelt authorized the Paonia Project, and after World War II Reclamation expanded plans for the project. In 1950 Reclamation built the Fire Mountain Diversion Dam to serve the private Fire Mountain Canal, and in 1959-1962 it built the Paonia Dam to improve reliability of the water supply. Today the project services a little over 10,000 acres along the North Fork of the Gunnison River between the small coal-mining town of Somerset on the east and Hotchkiss and the Fruitgrowers Dam on the west. Water is delivered to the project by the Fire Mountain Canal out of the North Fork and by the Overland Canal out of Leroux Creek. In 1992 the project produced a little over $6.8 million in crops, including assorted grains, various forage, and fruits, including apples, peaches, and cherries.

This Walter J. Lubken image taken on August 5, 1910, shows orchards, truck gardens, and hay fields near Montrose, Colorado.

Mancos Project

In 1937 Reclamation initiated studies of the Mancos area between Cortez and Durango. Farmers had irrigated in the area for some 50 years, but need had outstripped the water supply and the efforts of local irrigation organizations to store water for the dry period in late summer. Reclamation located an off-stream storage basin of sufficient size, and the President authorized the Mancos Project in 1940. Work began on Jackson Gulch Dam in that year and continued until 1950. The canal into the reservoir from the Mancos River and the main delivery canal were built in the mid- to late-1940s. Today, the Mancos Project irrigates around 8,000 acres, and in 1992 it produced various grain and forage crops valued at a little over $500,000.

San Luis Valley Project

The irrigation ditches of the Conejos River in the San Luis Valley enjoyed very early priorities, and by the 1930s available natural flow was diverted for irrigation. Reclamation's studies of the area showed a viable storage option on the Conejos. In 1940 the Secretary of the Interior authorized a supplemental water project, but like the Paonia Project, construction did not begin until after World War II. Platoro Reservoir, built between 1949 and 1951, stores water that is delivered through private ditches. The much later Closed Basin Unit of the project is intended to provide water for compliance with the Rio Grande River Compact among Colorado, New Mexico, and Texas and with treaties with Mexico. The project services about 72,000 acres and produced about $10,000,000 in crops in 1992—about half in various forage crops and one-quarter each in various grains and potatoes.

Summary

Each one of the above projects provided supplemental water and Reclamation's engineering expertise to existing agricultural areas. Reclamation projects brought various benefits to local economies, including work in a number of construction, Reclamation, and service jobs; enhanced property values; and increased crop production. At the same time, various environmental effects occurred that were often not recognized until years later. As a sea change occurred in American public opinion and environmental laws of the Nixon era took hold, Reclamation and its water users found themselves dealing with many direct and indirect issues of environmental damage caused by the projects. Examples include endangered fish in the Colorado River drainage and water clarity in Grand Lake.

Early Reclamation projects almost invariably overestimated the acreage an irrigation project could serve. However, today these Colorado Reclamation projects have irrigable acreage of about 845,000 acres—about 76% of all Reclamation project land in Colorado. In addition, as some projects urbanize, the water has migrated toward municipal and industrial uses. The Colorado-Big Thompson Project, the most extreme example, has seen agricultural use move from about 98% to about 60% of project water.

All these early projects use water from Colorado's West Slope, including the water supplementing East Slope supplies on the Colorado-Big Thompson Project. The value of crops from these projects, in 1992, totaled over $387,600,000—79% from the Colorado-Big Thompson Project, over 9% from the Uncompahgre project, and almost 3% from the San Luis Valley Project. Before World War II, when natural resources exploitation in the form of agriculture and mining were the leading economic activities in the state, these Reclamation projects were hailed by residents as significant to Colorado's development.

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n.b. Crops have been tied to 1992 because that is the last comprehensive published information available. Additional information is available at http://www.usbr.gov/dataweb/.

CSU Professors Receive Prestigious Awards

Kurt Fausch Honored with International Fisheries Science Prize

Kurt Fausch, professor in the Department of Fish, Wildlife, and Conservation Biology at Colorado State University, has been named the first recipient of the International Fisheries Science Prize. The prestigious award, given by the World Council of Fisheries Societies for outstanding contributions to global fisheries and conservation, will be awarded every four years. Fausch received the prize at the fifth World Fisheries Congress in Yokohama, Japan, where he was also invited as a keynote speaker. "Kurt Fausch's global contributions to fisheries science and conservation have been substantial, and his legacy continues to grow," said Bruce Rieman of the USDA Forest Service Research.

Fausch's research has earned international significance since the 1981 publication of his doctoral work on salmon and trout habitat use and competition, which informed and inspired work on similar problems in North America, Europe, Japan, Australia, and New Zealand. Since that time, Fausch's efforts have included influential papers and international collaborations in landscape ecology, invasion biology, conservation biology, and trophic linkages between terrestrial and aquatic ecosystems. He has produced more than 90 refereed papers, book chapters, and edited volumes, with more than 20 of those including authors from outside the United States.

Fausch has received significant National Science Foundation funding for at least four projects based on his international partnerships, and since 1990 he has given nearly 100 invited presentations, more than one-third of which have taken place internationally. Fausch is a member of the Ichthyological Society of Japan and the Fisheries Society of the British Isles. He has served on graduate student committees or reviews in the United Kingdom, France, Switzerland, Germany, Canada, and Australia.

Ted Yang Receives International Water Award

Chih Ted Yang, a civil engineering professor at Colorado State University, has been selected as the recipient of the Prince Sultan Bin Abdulaziz International Prize for Water, Surface Water Branch—one of most prestigious awards for water-related subjects in the world. The prize aims to give recognition to the efforts that scientists, inventors, and organizations around the globe are making in water-related fields. The honor comes with a personal award of 500,000 Saudi Riyals, or about $133,000. Yang accepted his award and presented the keynote address on November 16, 2008, at the Third International Conference on Water Resources and Arid Environments in Riyadh, Saudi Arabia.

Yang is the Borland Professor of Water Resources and director of the Hydroscience and Training Center in the Department of Civil and Environmental Engineering at Colorado State University. As a world-renowned expert in sediment transport and river morphology, he developed and published two fundamental laws governing the formation and evolution processes of river systems due to erosion and sedimentation.

Prior to joining the university in 2004, Yang served as manager of the Sedimentation and River Hydraulics Group, Technical Service Center, U.S. Bureau of Reclamation, from 1994-2003. He has also served as the International and Technical Assistance Program manager for the Bureau and as a hydraulic engineer for the U.S. Army Corps of Engineers North Central Division.

Yang teaches graduate courses in fluvial hydraulics, computer modeling, river morphology, and river restoration. He has also developed and conducted technology transfer courses in the United States and other countries.

Faculty Profile

Jay Ham, Professor, Department of Soil and Crop Sciences

I joined the Department of Soil and Crop Sciences in August of 2008 with an appointment that includes research, teaching, and extension responsibilities. Prior to joining the faculty at CSU, I led a program in micrometeorology and environmental physics for 18 years at Kansas State University (KSU). My interest in water issues originated early in life while growing up near Garden City, Kansas. Irrigated agriculture, fed by the Ogallala aquifer, remains the economic lifeblood of the region. Corn production under center pivot irrigation dominates the farm landscape, and irrigation scheduling is of vital importance. While working on farms during the summer, I was very interested in water management and how meteorological models like the Penman equation could be used to estimate evapotranspiration (ET). I also watched the flow in the Arkansas River near my home dwindle and then cease completely, mostly due to heavy pumping from the aquifer along the river. I learned at a young age that water management, or the lack thereof, was something of real consequence.

My interest in water, soils, and meteorology was a theme throughout my training. I received my undergraduate degree in agronomy at KSU and my Master's degree at Oklahoma State University with an emphasis in soil physics. For my doctoral work, I attended Texas A&M University and focused on the surface energy balance and ET from sparse cotton canopies in the Texas High Plains. My current research falls into the basic categories of (1) micrometeorological studies of water, carbon, and energy transport between the surface and atmosphere; (2) the effects of animal feeding operations on water, air, and soil quality; and (3) instrumentation development.

Water, Carbon, and Global Climate Change

Research on carbon and water balances of ecosystems has been a main research area throughout my career. The carbon work was driven by concerns over global climate change and how changes in land management/use might affect the carbon storage in fields and rangelands. Since 1997, I have operated a network of long-term eddy covariance sites as part of the Department of Energy's Ameriflux program. These towers, which provided year-round hourly measurements of carbon flux and ET, have been deployed on prairies, a cedar forest, and at livestock operations. New research is aimed at characterizing spatial variations in ET and net carbon exchange so that research done at tower sites can be scaled up to make watershed and regional scale estimates of water and carbon cycles. Water balance studies have focused on ET from sparse crops, rangeland hydrology, and the water balance of ponds and lagoons. Given the importance of water resources in Colorado, continued work on crop water use and ET is needed. Initial efforts may focus on water issues in the Lower Arkansas River Basin. I believe I can make contributions in several areas, including: improved measurement and modeling of ET using eddy covariance, increasing production in saline and water logged soils, optimizing irrigation to address soil salinity and lower the water table, reducing evaporation losses from upflux above shallow water tables, reducing seepage losses from canals and ditches, and reducing water losses from riparian phreatophytes.

Research on Animal Feeding Operations

My research group has developed instrumentation to measure ammonia/ammonium (NH_x) fluxes from feedlots using a micrometeorological technique called relaxed eddy accumulation (REA). The importance of cattle feeding in Colorado and the potential for new regulations regarding NH_x emissions and particulate matter (PM) justify continued work in this area. Ultimately, research could lead to improved practices for reducing NH_x losses by allowing us to measure directly how a change in diet or waste management affects emissions. The concern over nitrogen deposition in Rocky Mountain National Park highlights the importance of more research on NH_x emission inventories. Preliminary modeling studies have shown that understanding the water balance of feedlot pens is one of the most import components of modeling NH_3 losses and fugitive dust. Thus, interdisciplinary research that includes soil water movement and surface hydrology is crucial when addressing air quality issues, as air and water issues must be addressed concurrently.

Anaerobic lagoons are widely used at AFOs (animal feeding operations) to store and treat waste. My research team has been a leader in developing methods for measuring seepage losses and predicting the effects on groundwater quality. Most recently, we developed a water balance technique to measure lagoon seepage with a single overnight test.

Instrumentation Development

I am always looking to improve measurement capabilities. During my career I have developed several new sensor technologies, including sap flow gauges, soil moisture probes, various chamber designs for measuring whole canopy gas exchange, techniques for measuring seepage and gas fluxes from animal waste lagoons, new micrometeorological techniques for measuring fluxes of NH_3 and other trace gases from cattle feedlots, and, more recently, low-cost unmanned aerial vehicles (UAVs) for remote sensing of vegetation. Each year I try to improve my skills in electronics, computer science, and the mathematics so I can bring the latest technology to my research and teaching programs. Other sensor technologies I am interested in developing include: (1) testing a portable rapid-deployment system for measuring hourly ET using eddy covariance, (2) using a large aperture scintilometer to measure ET over large scales (> 1 km) that are consistent with remote sensing products and models, (3) designing a new type of heat pulse sap flow gauge that is monitored via a wireless sensor network, (3) employing wireless technology to improve sensor-based control of automated irrigation systems, and (4) developing low-cost UAVs and other forms of machine "intelligence" for research.

Teaching

I believe that science education should be based on first principles. That is, students must learn the key physical, chemical, and biological factors governing the process or system under study. The hot topics in any field inevitably change over time, but students who have a solid grasp of first principles are equipped to handle almost any situation. I like a quote from Randy Pausch's *The Last Lecture*: "You've got to get the fundamentals down because otherwise the fancy stuff isn't going to work." A course in environmental instrumentation was a favorite of mine at KSU. The course concentrated on measuring environmental parameters (temperature, humidity, radiation, and wind) and interfacing data-acquisition equipment with off-the-shelf sensors and analyzers. I also taught courses in micrometeorology and biometeorology that specifically addressed the needs of students in agriculture, ecology, and engineering. Because hydrology affects many transport processes in the environment, theses courses focused on the physical and biological factors governing ET and transport in the surface boundary layer. I look forward to learning more about the instructional programs at CSU and customizing the content of my new courses in micrometeorology and instrumentation to meet the needs of the students.

Avocations

I think water and air issues in Colorado make CSU one of the best places in the country to develop a new program in micrometeorology and environmental physics. My family and I love Fort Collins and the surrounding community. If not at work or taking care of family matters, I am likely to be "Standing in a River Waving a Stick," as aptly described by noted fly fishing author John Gierach. I'm an avid fly fisher, so if you have a water research project that might take me near a trout stream, please give me a call.

We have a finite amount of time. Whether short or long, it doesn't matter. Life is to be lived. -Randy Pausch

Contact Information:
Jay M. Ham, Ph.D.
Professor
Department of Soil and Crop Sciences
C107 Plant Sciences
Colorado State University
Fort Collins, CO 80523-1170
Phone: (970) 491-4112
Email: Jay.Ham@colostate.edu
Web: http://soilcrop.colostate.edu/ham/

19th Annual South Platte River Forum

by Laurie Schmidt, Colorado Water Institute

"News, Weather and Water" was the theme of the 19th Annual South Platte Forum, held on October 22-23, 2008, in Longmont, Colorado. More than 200 attendees participated in 10 themed sessions during the two-day meeting.

The meeting opened on Wednesday, October 22, with a session titled Weather at the Top of the Hour, in which David Yates, National Center for Atmospheric Research, provided an overview of what we know about local global warming trends and climate models. He discussed the complexities of climate models, particularly with regard to the precipitation variable. Addressing recent news that climate change will lead to much more arid conditions in the Colorado Plateau region, he said, "The assertion that the southwest U.S. will definitely get drier is not a robust finding, and the water vapor variable is very difficult to model."

Tom Perkins, Natural Resource Conservation Service, discussed the dramatic impact that spring weather can have on Colorado snowmelt and runoff. "Extreme spring precipitation —wet or dry—is the biggest source of April 1 forecast errors," he said. Colorado State Climatologist Nolan Doesken talked about the challenges faced by Colorado water resources professionals due to the state's highly variable climate. The final morning session focused on the South Platte Decision Support System and a Judicial Review Forum.

During the lunch break, the Platte River Greenway Foundation was honored with the Friends of the South Platte Award in recognition of its contributions to the South Platte River Basin. Jeff Shoemaker, who accepted the award on behalf of the Platte River Greenway Foundation, was presented with a framed "South Platte Sunset" photo donated by Colorado photographer John Fielder. After the award presentation, former CSU football coach Sonny Lubick gave the keynote presentation, entertaining attendees with colorful anecdotes from his years of coaching.

In an afternoon session titled Letters to the Editor, CSU professor Neil Grigg discussed economic activity in the South Platte Basin and the management measures that will make a difference in economic value, including a more reliable water supply, redistribution, and improved water quality. Next, using South Platte River Segment 15 as an example, Jim Dorsch of Metro Wastewater Reclamation District addressed the importance of water to habitats and biology. The session concluded with a talk by Bruce Bosley, Colorado State University Extension, on the impacts of irrigation dry-ups on land and people.

The final session on Wednesday focused on water quality issues and included presentations by Karl Mauch, Colorado Department of Agriculture; Larry Barber, U.S. Geological Survey; and Laurie Rink, Mile High Wetlands Group, LLC. Barber discussed the fate of consumer product chemicals in surface waters impacted by wastewater treatment plant effluents and presented evidence that a number of these chemicals impact the endocrine systems of fish and other aquatic organisms.

On Thursday, the Forum reconvened with an update from Jerry Kenny on the progress and prospects for the Platte River recovery implementation program. A report on Quagga and Zebra mussels from Mary Fabsiak of the City of Westminster detailed the threat of these invasive species to water systems in the state and the efforts underway to manage and track their transmission from one waterbody to another. CSU professor John Stednick outlined the results of his two-year study on the impact of the pine beetle infestation on forested watersheds. While measurable impact on water yield appears to be variable between catchments, some of the water quality impacts observed across watersheds are cause for some concern.

Nolan Doesken discusses climate at the South Platte Forum.

Highlights of the Thursday sessions included Colorado State Representative Randy Fischer and Department of Natural Resources Executive Director Harris Sherman providing views on the political landscape of water in Colorado and how it might affect South Platte management. The Forum wrapped up with perspectives from members of the South Platte and Metro Roundtables and new state agency directors. The 2008 South Platte Forum, like the previous 18 events, provided participants with an opportunity to network with colleagues and catch up on events and issues related to the Basin.

The 2009 South Platte Forum will be held on October 21-22, 2009. Stay tuned to www.southplatteforum.org for details.

Water Research Awards

Colorado State University (August 15, 2008 to October 14, 2008)

Bauerle, William L, USDA-ARS-Agricultural Research Service, Measurement and Modeling Plant Water Use to Quantify Nursery Water Requirements, $48,750

Bestgen, Kevin R, DOI-BLM-Bureau of Land Management, Hornyhead Chub Distribution, Abundance, & Habitat Use in the Lower Laramie River Drainage, $77,000

Brummer, Joe E, Utah State University, Integrating Perennial Living Mulches into Irrigated Cropping Systems, $146,684

Doesken, Nolan J, DOI-Bureau of Reclamation, Walking Through The Water Year, $40,000

Fassnacht, Steven, University of California, Los Angeles, Scaling Snow Observations From the Point to the Grid Element: Supporting NOHRSC's National Snow Analysis System, $32,110

Fausch, Kurt D, Colorado Division of Wildlife, E. Plains Fish Habitat Survey, $33,000

Gao, Wei, USDA-CSREES-Coop State Rsrch Edu & Ext, Integrated Bioclimatic-Dynamic Modeling of Climate Change Impacts on Agricultural & Invasive Plant Distributions in the United States, $530,000

Garcia, Luis, DOI-Bureau of Reclamation, Modification of the Integrated Decision Support Consumptive Use Model, $24,343

Garcia, Luis, USDA-ARS-Agricultural Research Service, Application of System Models to Evaluate and Extend Cropping Systems Studies at Different Great Plains/Northwest Sites, $72,000

Garcia, Luis, USDA-NRCS-Natural Resources Consvtn Srv, Support Implementation and Development of the Object Modeling System, $100,000

Gates, Timothy K, Lower AR Valley Water Conservancy Dist., Monitoring and Modeling Toward Optimal Management of the Lower Arkansas River, $40,000

Goodridge, Lawrence, NGWA-Natl Ground Water Res & Ed Found., Database Independent Microbial Source Tracking to Determine the Source of Fecal Pollution in Groundwater, $4,000

Hansen, Neil, USDA-ARS-Agricultural Research Service, Develop Knowledge Base and Quantitative Tools for Optimal Crops and Management Practices for Variable Limited Water Conditions in the Great Plains, $30,000

Hansen, Neil, USDA-ARS-Agricultural Research Service, Irrigation, Tillage, and Weed Management to Maintain Agricultural Profitability with Limited Water, $5,854

Hobbs, Nicholas Thompson, DOI-USGS-Geological Survey, Forecasting the Effects of Agricultural Practices on Prairie Wetlands: Implications for the Observation of Migratory Shore Birds, $10,033

Jacobi, William R, Denver Water Department, Continued Investigation of the Impact of Canal Water Flow on the Health of Cottonwood Trees, $12,889

Jacobi, William R, Larimer County, Effects of Chloride Salts on Roadside Vegetation & Water, $47,345

Julien, Pierre Y, Korea Institute of Construction Technolo, Restoration of Abandoned Channels, $64,000

Kampf, Stephanie K, DOE-US Department of Energy, Climate Change Impacts to Hydropower Generation in Pacific Northwest River Basins, $121,910

Kelly, Eugene F, USDA-USFS-Rocky Mtn. Rsrch Station - CO, Monitoring Forest Recovery and Watershed Protection in Beetle-Killed and Salvage-Logged Rocky Mountain Forests, $27,538

Kummerow, Christian D, NASA - Natl Aeronautics & Space Admin., The Next Generation Rainfall Retrieval Algorithm for Use by TRMM and GPM, $100,000

Loftis, Jim C, DOI-NPS-National Park Service, Status and Trends of Impaired, Threatened, and Outstanding National/State Resource Waters, $164,600

Loomis, John B, DOI-USFWS-Fish & Wildlife Service, Improving Estimates of the Contribution of USFWS National Fish Hatcheries in Colorado, $59,962

MacDonald, Lee H, Vietnam Education Foundation, Hydrologic Processes & Effects of Land Use & Field Measurements in Hydrology, $59,765

Myrick, Christopher A, Colorado Division of Wildlife, Evaluation & Development of Fish Passage Designs, $150,000

Norton, Andrew P, DOI-NPS-National Park Service, Monitoring Saltcedar (Tamarix) Biological Control (Diorhabda elongata) Insectary Establishment in Echo Park, Dinosaur National Monument, Moffat County, $14,100

Paschke, Mark W, DOI-NPS-National Park Service, Restoration Native Plant Communities Following Saltcedar & Russian Olive Removal, $49,448

Paschke, Mark W, Shell Oil Company, Revegetation Research on Oil Shale Lands in the Piceance Basin, $1,000,000

Poff, N LeRoy, EPA-Office of Research and Development, Predicting Relative Risk of Establishment and Persistence of Riparian and Aquatic Invasive Species in River Networks under Different Scenarios of Climate Change, $599,748

Sanders, Thomas G, DOI-NPS-National Park Service, Preservaton, Protection, & Management of Water Aquatic Resources of Units of the National Park System, $317,773

Schubert, Wayne H, DOC-NOAA-Natl Oceanic & Atmospheric Admn, Advanced Verification Techniques for the Hurricane Weather Research and Forecast (HWRF) Model, $20,000

Seidl, Andrew F, Upper Gunnison River Water Conservancy D, Upper Gunnison Basin Water Economics Study, $22,050

Snyder, Darrel E, DOI-Bureau of Reclamation, Middle Rio Grande Larval Fish Identification Guide, $208,091

Steltzer, Heidi, DOI-USGS-Geological Survey, Effects of Water Management & Climate Change on the Dynamics of Native & Invasive Wetland & Riparian Plants in the Western USA, $64,573

Stephens, Graeme L, NASA-Goddard, CloudSat, $234,000

Thornton, Christopher I, DOI-Bureau of Reclamation, Investigation of Alphabet Wiers, $30,000

Waskom, Reagan M, DOI-USGS-Geological Survey, OMS Internship - USGS - WRRI Student Internship, $10,000

Waskom, Reagan M, USDA-CSREES-Coop State Rsrch Edu & Ext, Coordinated Regional Water Resources Programming for the Northern Plains and Mountains Region, $590,000

Westra, Philip, Monsanto, Phenotypic Evaluations and Ecological Interactions of Drought Tolerant, $15,120

Colorado School of Mines

Batzle, Mike, U.S. Department of Energy, Geophysical Characterization of a Geothermal System taking Advantage of the Latest Developments in Self-potential Method and Seismic Interferometry, $868,000

Drewes, Jorg, WateReuse Foundation, Predictive Models to Aid in Design of Membrane Systems for Organic Micropollutants Removal, $467,000

McCray, John, DoD Strategic Environmental Research and Development Program, DNAPL Dissolution in Fractured Bedrock Aquifers under Ambient and Remediation Conditions, $450,000

McCray, John, Water Environment Research Foundation, Development of Quantitative Tools to Determine the Expected Performance of Unit Processes in Wastewater Soil Treatment Units, $1,000,000

Revil, Andre, U.S. Department of Energy, Advanced Self-potential Inversion: Development and Use for Investigating Natural Recharge Processes at the ORNL-IFC, $917,000

Siegrist, Robert L, DoD Environmental Security Technology Certification Program, In Situ Chemical Oxidation for Groundwater Remediation – Technology Practices Manual, $372,000

Tzahi, Cath, AWWA Research Foundation, A Novel Hybrid Forward Osmosis Process for Drinking Water Augmentation using Impaired Water and Saline, $155,000

Zhou, Wendy, U.S. Department of Energy, Water Resources Assessment of Rocky Mountain Oil-Shale Basins, $880,000

Calendar

January

25-27 **2009 AWWA Water Conservation Workshop; Portland, Oregon**
Focuses on the challenges facing utilities in meeting diverse demands for water.
http://www.awwa.org/Conferences/

28 **Financial, Decision and Risk Analysis for Ditch Companies; Denver, Colorado**
This workshop will explain traditional methods for analyzing projects.
http://www.darca.org

28-30 **CWC Annual Convention; Denver, Colorado**
The 51st annual conference of the Colorado Water Congress.
http://www.cowatercongress.org

February

8-12 **USDA-CSREES National Water Conference; St. Louis, Missouri**
Provides opportunities for water professionals to share knowledge and ideas.
http://www.awwa.org/index.cfm

12-13 **2009 AWWA Research Symposium; Austin, Texas**
The symposium theme is "Emerging Organic Contaminants."
http://www.awwa.org/Conferences/

17-20 **The Utility Management Conference; New Orleans, Louisiana**
This conference will cover the toughest issues facing the water and wastewater profession.
http://www.awwa.org/Conferences/

18 **Owner's Guide to Dam Safety, Operation, and Maintenance; Pueblo, Colorado**
Pre-convention workshop before the 7th Annual Ditch and Reservoir Alliance Convention.
http://www.darca.org

19-20 **DARCA 2009 Convention; Pueblo, Colorado**
Will cover strategies and alternatives to buy and dry arrangements.
http://www.darca.org/

21 **Water Tables 2009; Fort Collins, Colorado**
Dinner to benefit the Water Resources Archive at Colorado State University.
http://www.cwi.colostate.edu/other_files/teaserpostcard_color_10-15-08.pdf

26-27 **International Water Conservation Conference; Albuquerque, New Mexico**
The theme of the 14th conference is "Watersheds and Foodsheds."
http://waterconservationconference.org/

March

25-27 **Hydrology Days; Fort Collins, Colorado**
The 29th annual celebration of multi-disciplinary hydrologic science.
http://hydrologydays.colostate.edu/

30-1 **NWRA Federal Water Seminar; Washington D.C.**
http://www.nwra.org

30-2 **WaterEC International Water Efficiency Conference; Newport Beach, California**
The first annual International Water Efficiency Conference.
http://www.waterec.net/wec.html

April

21 **Ditch Hazards Awareness and Safety; Canon City, Colorado**
Will focus on hazards and safety related to irrigation ditches.
http://www.darca.org

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The Water Center of Colorado State University
1033 Campus Delivery
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Joe Wright Creek near Highway 14 in Poudre Canyon. (Image courtesy of Laurie J. Schmidt)