

# Colorado Water

July/August 2016



**WATER  
DATA**

Director's LETTER



**B**ig promises are being made for big data. The tsunami of data resulting from new technologies has created some headaches, but also intriguing opportunities. Satellite images, wireless sensor networks, and model output all produce data that must be processed and analyzed to create useful and reliable information. Data does not enhance our understanding or management decisions. Rather, it must be transformed into information that is accurate and reliable to become truly useful.

Data acquisition capacity has grown to the extent that a new branch of information sciences has emerged, known as big data. Big data has been called a “fad” in scientific research, but it is more accurate to call it a “hot topic”, as we know the cascade of data from expanding new technologies will only continue. Numerous scientific conferences and papers on the topic of big data have occurred since the Obama Administration launched the Big Data Research and Development Initiative in 2012 to “greatly improve tools and techniques needed to access, organize, and glean discoveries from huge volumes of digital data.”

Big data has been described as high volume, high velocity, and/or high variety information in excess of one terabyte that is too large for a single machine to handle and that traditional techniques are insufficient to analyze. This definition is fluid and may soon be described in petabytes, but it also includes the velocity at which the data is acquired from multiple independent data sources. Thus, cloud-linked servers are typically needed to adequately store and process the data. Real-time acquisition and processing that enables trend detection and improved decision-making is the goal of businesses and government agencies seeking to exploit big data. In other cases, the goal may be to enable public access to useful, interesting, or important information.

A number of questions must be resolved as we develop new data technologies and capacity. For example, who owns big data when it is crowd-sourced or provided by multiple public and private entities? How does the information remain secure and individual privacy protected? From a scientific perspective, what about data quality and veracity? How do we avoid sampling bias and misinterpretation? Again, data itself is not the goal, but the information gleaned from the data can enhance our understanding of trends, processes, demographics, etc.

Water data collected from multiple public water systems (such as used in past Statewide Water Supply Investigations conducted by the CWCB) is an example of using big data to determine statistical patterns that suggest significant correlations and trends in water use and conservation, forecasting future demands, and to optimize coordination of resources. Water managers with multiple sources of water supply could also benefit from better data-driven forecasting and real-time operations. Sensor technologies have arrived on the market to help water utilities survey underground pipes and detect leaks. Smart meters could help managers and individual users fine-tune their system. In terms of academic research, both the NSF funded NEON and CUASHI networks described in this newsletter have been organized to provide big and open data to researchers. NEON represents the largest single investment in ecological research data ever made. This “research infrastructure” is transforming our ability to advance data visualization and statistical methods to understand patterns, processes, and detect outliers.

The value of big data is the opportunity to answer big questions. What is also exciting about big and open data is the potential for innovations that can improve our decision-making capacity. This issue of the *Colorado Water* newsletter provides examples of how big data for water can be accessed and used. The data tsunami keeps coming at us—the power of that data to help solve big water challenges is ours to capture.

*Reagan Waskom*

Director, Colorado Water Institute

# COLORADO WATER

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**On the cover**  
*NEON tower facilities at the USDA Agricultural Research Service, Central Plains Experimental Range, Nunn, CO.*  
Photo by Forest Banks

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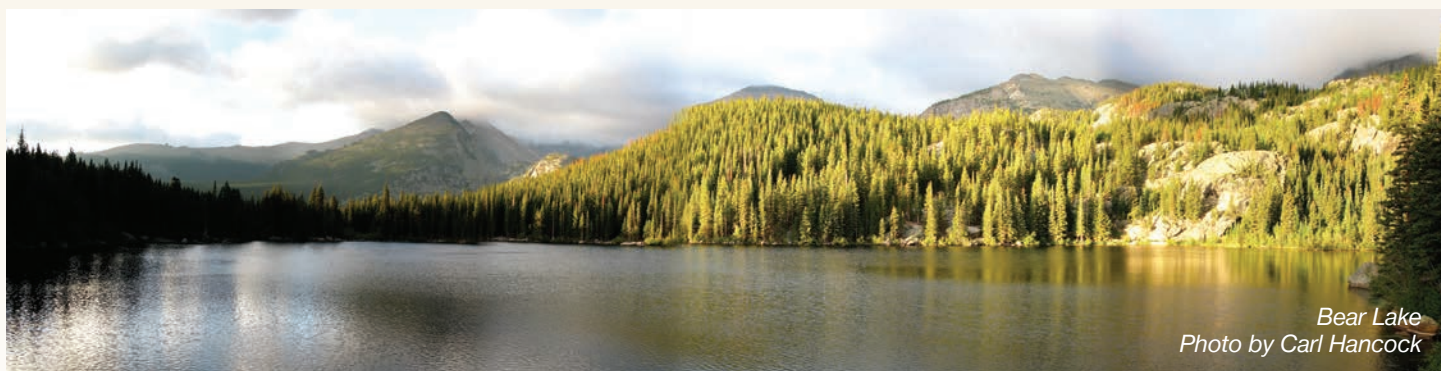


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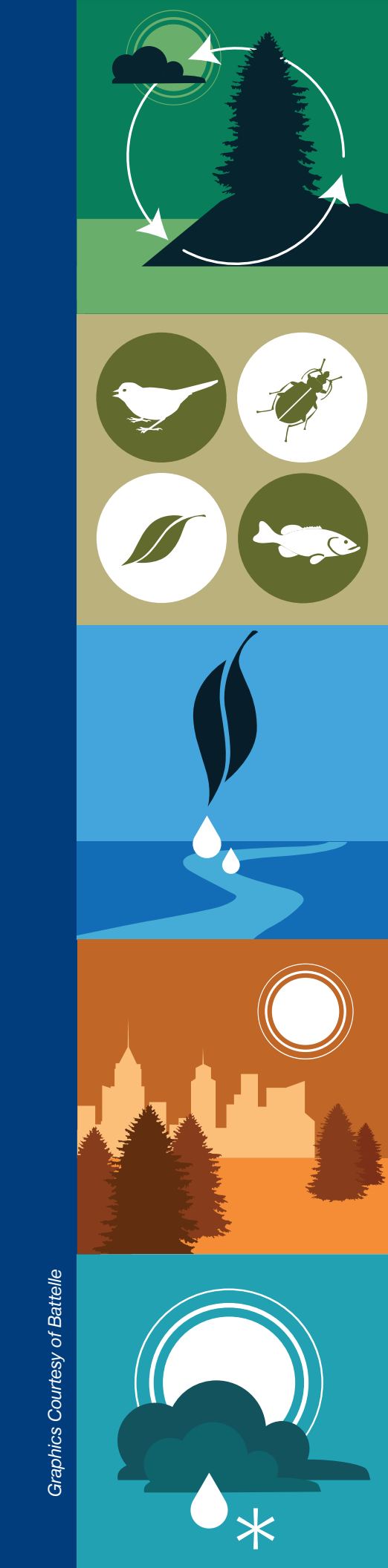
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Cooperators include the Colorado State Forest Service, the Colorado Climate Center, and CSU's Water Resources Archive.

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# Big Data and the Ecological Nexus of Water, Energy, and Food

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## SYNOPSIS

The National Ecological Observatory Network (NEON) is a continental-scale ecological observation facility that provides free data for scholars to address issues related to water, energy, and food.

## Introduction

We have entered the age of ‘big data.’ Ushering in this new era, the White House has recognized and mandated agencies to address the users’ need to access and analyze large multi-scaled datasets with their ‘Big Data Initiative.’ In parallel, the nexus of water, energy, and food is now viewed as having increasing economic importance and as a foci for science discovery. The importance of providing clean water, energy solutions, and food security are intrinsically linked. U.S. federal agencies, state governments, local municipalities, academic institutions, and private industries alike are addressing this imperative.

One such federal effort supported by the National Science Foundation (NSF) is the National Ecological Observatory Network (NEON). NEON is a continental scale ecological observatory that is the largest single investment in ecological research ever made ([www.neonscience.org](http://www.neonscience.org)).

In the U.S. and elsewhere, the development of large-scale scientific research infrastructure such as NEON comes about from the requirements of the scientific community, grand challenges expressed in society, and at high-levels of government planning. NEON does not execute the science itself. Instead, NEON provides freely available data for researchers (public or private) to address the challenges posed at the nexus of water, energy, and food. NE-

ON’s data products, observational design, and the scope of consistently measured, quality controlled multi-scaled datasets were co-developed with the research community to assure their highest utility.

NEON data were designed to also address the seven grand challenges for environmental science identified by the U.S. National Academy of Science including: biodiversity, biogeochemistry, climate change, ecohydrology, infectious disease, invasive species, and land use change ([www.neonscience.org/sites/default/files/basic-page-files/NEON\\_Strategy\\_2011u2\\_0.pdf](http://www.neonscience.org/sites/default/files/basic-page-files/NEON_Strategy_2011u2_0.pdf)). Moreover, NEON employs a novel spatial scaling strategy that takes local, site based information from 81 sites across the U.S. and pairs those data with imagery from an aircraft platform, providing the data to link with other federal datasets (Census data, fertilizer usage, and satellite based products). Sites span the environmental gradients found across North America, from the north slope of Alaska to Puerto Rico, and from Hawaii to New England. Sites also include a variety of land-use types including: forests, grazed lands, agronomic fields, and national parks. NEON also employs a temporal scaling strategy that captures the timescale of the process of interest and does this consistently over decadal timeframes. NEON’s explicit science design allows for site-based information to scale to the landscape (with airborne measurements) and then scale to the region and continent (with ancillary satellite and other federal datasets). In fall 2017, NEON’s construction will be complete and the observatory will begin its 30-year operational lifespan. Some of the datasets are already available ([www.data.neonscience.org/home](http://www.data.neonscience.org/home)). NEON data on water, energy, and food, span many, if not

most, of these grand challenges. NEON aquatic system datasets provide the basis for a long-term consistent baseline understanding that can be used for basic research, water management, and water futures.

### Solutions Require Big Data

Innovative technologies can help catalyze emissions reductions, increase energy efficiency, and provide new monitoring activities. But how might macro technological trends like increasing connectivity among related scientific disciplines, remote sensing, new tools to find and capture otherwise unknown water datasets, and big data analytics have impact on daunting water quantity and quality issues? Moreover, as

food and energy are traded internationally, so is the ‘virtual water’ used in their production. Along with a changing climate comes the increased magnitude and frequency of large disturbance events that directly or indirectly affect water sources, sinks, and flows. Examples of such disturbances include: regional drought, changes in monsoons, increased frequency of storm-induced flooding, amplified runoff, and decreased evapotranspiration from insect outbreaks. Lastly, shifting economics place new pressures on the need for water, which include: increased and more efficient food productivity, shifting crops with different water demands, timber harvests, and the removal of deep water for urban

and agronomic needs that would otherwise recharge aquifers. Understanding the consequences of these events not only requires integrated ‘big data’, but also data products that address the causes (drivers) and the respective effects (processes). Adopting the cause and effect paradigm provides the opportunity to develop a prognostic capability and the tools to plan and manage water resources.

‘Big data’ means different things to different people. It also implies that developers and end-users alike need to evolve with the current paradigms of data usage—which is increasingly complex. Figure 1 suggests areas that facilitate the use of ‘big data’ that individuals all should be aware of. While

<b>Informatics</b>	Informatics is broadly interpreted as: metadata (ISO 19915 compliant) and data formats; persistent identifiers (like DOIs); ontologies, controlled vocabularies and semantic structures; open data policies; data management plans; data sovereignty and associated intellectual property rights.
<b>Epistemology</b>	How do we know what we know? Hence, data quality assurance by knowing how your data trace to international or national recognized standards, best community practices or first principles.
<b>Accessibility</b>	There are many datasets that are well documented and supported by networks, infrastructures, museums and other institutions. There are others, typically from smaller research groups that are posted on the web, but are hard to find. Making all data sets easy to find, searchable and accessible. Examples include web-based tools that can crawl, web services or linked Application Program Interfaces (API) with registries so that data from different sources can be queried and brought together into a single dataset. Accessibility also includes harmonizing data portals from different institutions that have similar data so they can be easily accessed and mined.
<b>Reproducibility</b>	Reproducibility is a core premise of the scientific process, which means having the ability to reproduce the exact datasets that are used in a study. This becomes increasing difficult if (i) data come from multiple, large sources, (ii) a discrete time-series was used from a dataset that data is constantly being added to, and (iii) if the data were then used by models with specific version control. To address this issue, new software manages the data acquisition, analytical workflows, and assures that they are reproducible, e.g., Kepler, Travena, D4science.
<b>Analytics</b>	Analytics include statistics, and modeling frameworks. ‘Big data’ often requires additional data preparation in order to be used by analytical software. New ‘modeling factories’ allow data to be ingested into a number of models for comparison studies. In both cases, virtual machines and supercomputing are used, which take additional time, resources, and planning to achieve success.

Figure 1. ‘Big data’ programmatic areas for end-users that are currently active areas of research. Note that system architectures, novel modular computing structures, and the use of cloud computing, etc., are not included here, because they are a separate (and important) topic but not typically germane to the end-user.



Figure 2. NEON instrument buoy on Barco Lake, Ordway Swisher Biological Station, University of Florida, Melrose, Florida. Photo by Charles Bohall

NEON has adopted programmatic activities in all these areas, it is also important to note that these are also active areas of research and development. Development of these areas is also part of the increased ability to use 'big data' to address the scientific and societal imperatives as mentioned above. The full integration of these areas of 'big data' to foster new analytic applications for science and emergent economies (risk management, water futures, and insurance) is at the frontier of knowledge.

### NEON's Ecohydrologic and Aquatic Infrastructure

NEON is designed to provide ecologically relevant data products to the broadest possible communities. This has been accomplished through formal system engineering approaches. Through large, community oriented scoping activities; NEON has gleaned thousands of questions from end-users, and then moved the field of ecology from hypotheses to a requirements-based approach. This has never been done before in ecology, and it is novel because it defines

1. the scope, budget, risk, and schedule of such a large project, and
2. consistent, multi-dimensional,

multi-scaled data products, and interfaces (reaching the broadest possible user groups).

NEON's design includes terrestrial infrastructure (tower and soil based measurements) coupled with 34 aquatic sites. The philosophy for the aquatic infrastructure is to assess the dominant aquatic systems that have an ecologic connectivity with the surrounding terrestrial ecosystems. This would include low or first-order streams, lakes, or ponds (Figure 2). Both the terrestrial and aquatic sites have a host of human-based observations that comprehensively quantify the biological and chemical environments. The sites are also designed to span the range of hydrogeomorphology (fluvial, braided streams, free-stone systems, channel flow, and constrained watersheds) and hydroperiods (source waters from snowpack, pipe flow, spring-fed, surface water, or groundwater) found across North America.

Taking an ecosystems science approach, NEON's ecohydrologic data adopts the cause and effect paradigm, partitioning the source and sink of water, the mass balance approach, and biotic and abiotic controls on the flows of water (hydrological balance), and evapotranspiration (ET). For example, NEON's research is focused on measuring the following:

1. the stable oxygen isotope composition of water ( $\delta O18$ ) in latitudinal-influenced precipitation, the atmosphere, surface and groundwater to parse the sources of ET and the hydrologic budget;
2. how the entire ecosystem breathes in real-time using sound waves, lasers, and infrared spectroscopy, in particular the exchange of water between the ecosystem and the atmosphere, (i.e. ET), and the component flows of water to develop ecosystem hydrologic budgets, e.g., through flow, and all the abiotic drivers of energy exchange, (i.e. net short- and longwave radiation, humidity, and conductance);
3. the metabolic length scale for streams and estimating rates of stream productivity, along with the drivers of productivity: its chemical environment, above and within stream microclimate, and stream biota; and

4. using LIDAR technologies, a digital elevation map (DEM) encompassing each site and its surroundings enables the model integration of spatial explicit surface hydrology and flows, and the ability to determine changes in stream geomorphology.

Taking the community and population ecology approach, NEON adopts measures of biodiversity: trophic cascade, abundance, fecundity, recruitment, and mortality. Even though the organization has a plot design to measure biodiversity, it is important to note that it is not possible to measure all of the species. To augment the more traditional biodiversity sampling, specific suites of species are also being measured as a function of how quickly they can respond to a changing environment, from trees (long response time) to microbes (fast response). This strategy uses generational turnover time as a proxy for temporal scaling. In addition, many argue that species, species assemblages, and their population dynamics link to ecosystem functions. So where possible, NEON's data products are designed to address the expected changes in species composition, their population dynamics and their feedback to ecosystem functions (e.g., changes in species, and the abundance of top consumers, or benthic microbes that control stream productivity). The data products can be viewed at the following: [www.data.neonscience.org/data-product-catalog](http://www.data.neonscience.org/data-product-catalog).

### NEON, Other Networks, CSU and Water Science

NEON's contribution to big data is not only in the large volume of ecohydrologic and aquatic site monitoring data, but also in its data heterogeneity, and spatial and temporal distribution of these data. In some cases, NEON sites physically overlap with other networks, such as NSF Long Term Ecological Research, United States Department of Agriculture (USDA) Agricultural Research Service (as in the case of Central Plains Experimental Range), Department of Energy (DOE) AmeriFlux, National Oceanic and Atmospheric Administration (NOAA) U.S. Climate Reference Network, Organization of Biological Field Stations (OBFS), NSF Critical Zone Observatories (CZO), and others. In other

cases, protocols and procedures of other networks have been adopted, such as: U.S. Geological Survey (USGS) National Water Quality Assessment, National Atmospheric Deposition Program (NADP), World Meteorological Organization (WMO), National Aeronautics and Space Administration (NASA) Aerosol Robotic Network (AERONET), and others. In all cases, NEON, partner networks, and the respective community of users benefit from the interoperability of our data and the inferences drawn by extending NEON data to join with those of other networks.

Even though NEON is still being constructed, it has benefited from

strong vision and collaboration with CSU's faculty and administration. NEON looks forward to developing and deepening working relationships with the Powell Center, Future Earth, International Drought Experiment, and other CSU sponsored projects and programs. Together, these provide the opportunity not to merely continue with CSU's excellent record of interdisciplinary research, but rather to reach a state of "transdisciplinary research" without walls, and can address questions of scientific and societal importance here in Colorado and globally.

## Acknowledgements

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*NEON Location at 12,000 feet at Niwot ridge. Shows trail, Arapahoe Peaks, and spruce waves. Photo by Hank W. Loescher*

# The Consortium of Universities for the Advancement of Hydrologic Science Inc. (CUAHSI) Water Data Center

## Building a Community Around Water Data for Monitoring, Teaching, and Research

Jon Pollak and Emily Geosling, Consortium of Universities for the Advancement of Hydrologic Science Inc.

### SYNOPSIS

The Consortium of Universities for the Advancement of Hydrologic Science Inc. (CUAHSI) is a 501(c)(3) nonprofit that collaborates with over 100 universities across the US, including CSU, to enhance water resource education and research. The nonprofit provides data sources and tools available for users through the CUAHSI HIS Central Catalog.

For over a decade, the Consortium of Universities for the Advancement of Hydrologic Science Inc. (CUAHSI) community has pioneered and built social and technological infrastructure aimed at enabling the publication and reuse of water data. CUAHSI is an independent 501(c)(3) nonprofit that brings together over 100 universities to support and advance water science education and research. CUAHSI leads activities such as instrumentation training, webinars, fellowship programs, and more, but its largest program is the Water Data Center (WDC) that enables data publication and reuse. Through its flagship technology, the Hydrologic Information System or CUAHSI HIS, the WDC program has built a catalog of over 100 sources of time series data that is still growing.

The dozens of data sources that compose the CUAHSI HIS Central Catalog range from U.S. Federal Agencies like the U.S. Geological Survey (USGS) and National Aeronautics and Space Administration (NASA), watershed associations, local and regional planning agencies, and data from

academic research. The data published by these groups can vary widely; some data are real time or near real time, while many groups publish historical data. The CUAHSI HIS enables data publication for any time series data that falls under the three broad categories of chemical, physical, and biological measurements. To date, over 2,000 different parameters being observed can be found within the HIS Central Catalog from over 1 million locations. In total, this catalog contains over 12 million time series datasets with a combined 400 billion observations.

Together, the data sources registered with HIS Central comprise the largest catalog of its kind in the world. Within each, however, is a story of its own. For instance, the Shale Network ([www.shale-network.org](http://www.shale-network.org)) is a Research Coordination

Network in Pennsylvania funded by the National Science Foundation (NSF) to investigate the impacts of natural gas extraction by collating data from different sources - including academics, citizen scientists, government, and industry - into a single database in the CUAHSI HIS. The group has amassed over 1 million observations at 26,000 locations in and around Pennsylvania, produced four peer-reviewed journal articles, one PhD dissertation, and three Masters Theses. Throughout this multiyear project, the Shale Network team has hosted annual workshops to discuss the environmental and societal impacts of natural gas extraction, observed contamination incidents in the data, and searched for undiscovered incidents that may have left a signature

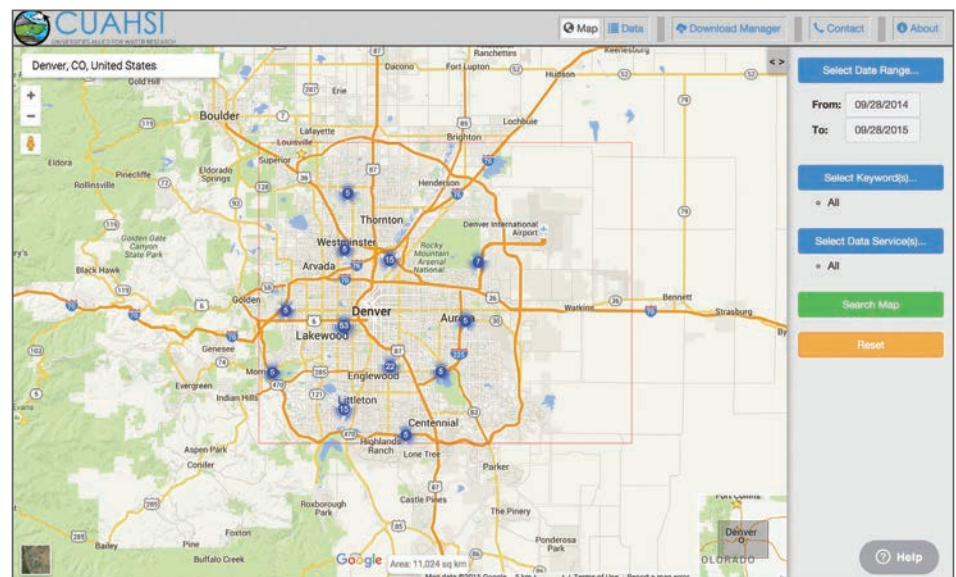


Figure 1. Search results as seen in HydroClient within the Denver Metro area. Each marker contains a number that represents the number of time series for that respective location.



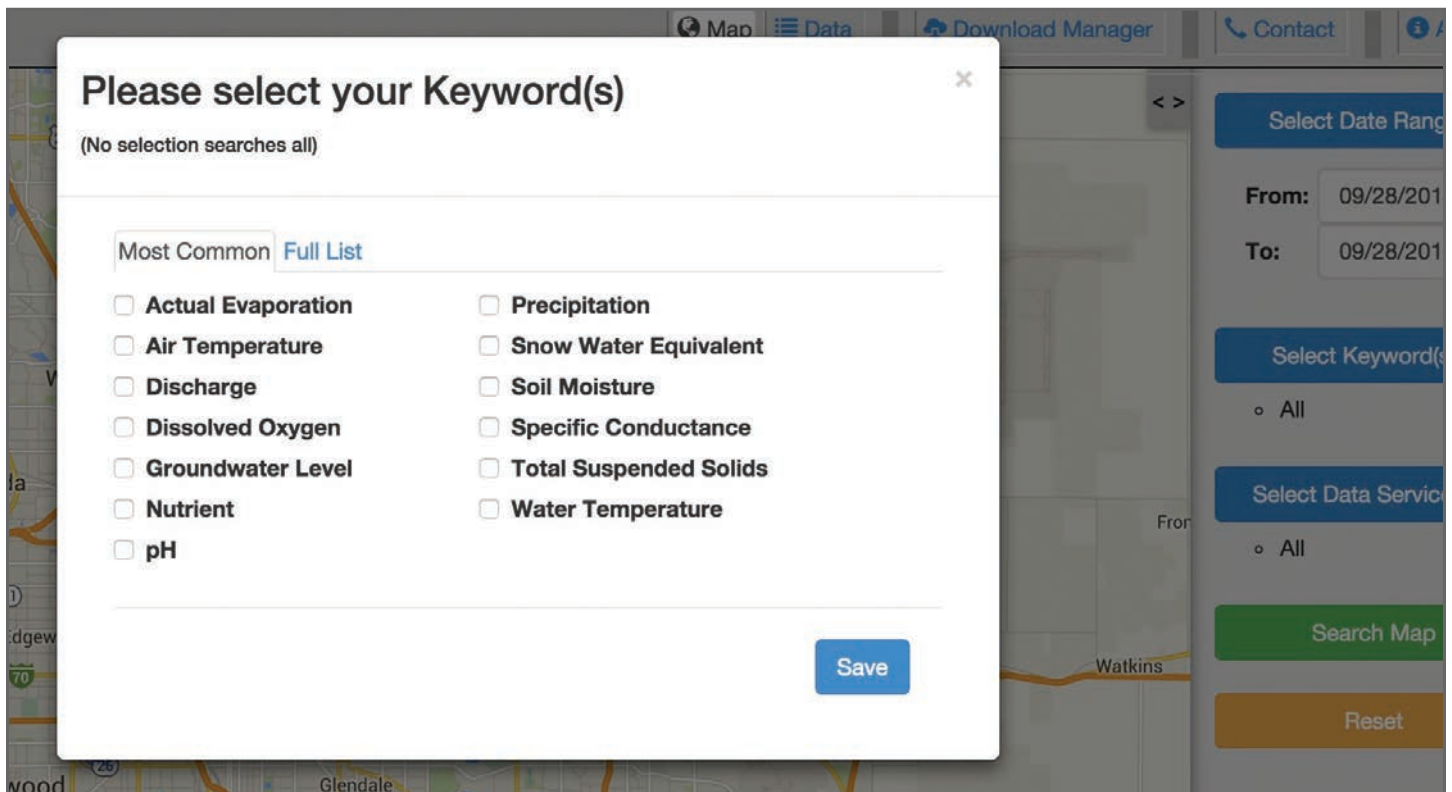






Figure 2. The Keyword Selection window. Common keywords can be selected quickly, while CUAHSI's full list of about 2,500 keywords can be viewed by clicking Full List.

in the data. Although the funding for the Shale Network is scheduled to end in the next year, the data will continue to be available through the CUAHSI WDC for use by researchers and educators interested in water quality issues around resource extraction.

The Innovative Urban Transitions and Aridregion Hydro-Sustainability project, or iUTAH (<http://iutahepscor.org/>), is another group funded by the NSF that is making their data widely available through CUAHSI. Funded by the Experimental Program to Stimulate Competitive Research (EPSCoR), iUTAH is performing interdisciplinary research aimed at securing Utah's water future. By deploying solar powered water and climate monitoring stations, iUTAH researchers are investigating how human activities, climate change, and other factors are affecting the Logan River, Provo River, and Red Butte Creek watersheds in order to determine the current state and future of water supplies in Utah.

The data sources mentioned above, and about 100 more, are accessible using open source tools developed and supported by CUAHSI, in addition to other tools developed by the water science community.

For several years, HydroDesktop has been a tool for accessing and analyzing data that has been developed through CUAHSI and led by Dr. Daniel Ames (Brigham Young University). HydroDesktop is an open source geographic information system (GIS) for the Windows that enables search, download, visualization, and analysis of time series data in the CUAHSI HIS. Three pieces of search criteria are required to execute a search for data in HydroDesktop while a fourth is optional.

-  **TIME** A start date and end date must be specified
-  **SPACE** A geographic extent must be defined
-  **KEYWORD** One or more phenomena being observed, such as temperature or streamflow, must be specified. The Keyword All can be used to search for all data that match the previous two criteria.
-  **DATA SOURCE** (optional) It is possible to limit the search to a subset of the HIS Catalog or connect to a data source directly

Once a search has been completed, data can be viewed in tabular or graphical form and exported in common formats. Data sets can also be analyzed using HydroDesktop's HydroR plugin, which enables the use of R natively inside of the software.

Although a powerful tool, HydroDesktop has also proven to be difficult to integrate into the classroom. As a complete GIS with a suite of tools, it can be intimidating for a novice user because of its complexity. Additionally, HydroDesktop requires installation on a Windows operating system, which is a barrier for two reasons. First, not all educators have the option of installing new software on laboratory computers and second not all educators use the Windows environment. For this reason and others, CUAHSI has developed and released a new web-based application for data access that runs in any major web browser, and thus, is platform independent. This application, HydroClient, is accessible at <http://data.cuahsi.org> and uses the same search criteria as HydroDesktop to discover data.

Both of the tools mentioned above are developed through, and supported by, CUAHSI resources. For users who

List of Timeseries near: 2867-2921 S Platte River Dr, Englewood, CO 80110, USA

To zip one or more data files, please click the associated table row(s) and then click the 'Process Selections' button.

Show 50 entries Select Top 25? Clear Selection(s) Process Selection(s) Search:

Organization	Service Name	Keyword	Variable Name
U.S. Geological Survey	NWISDV	Oxygen, dissolved	Dissolved oxygen, water, unfiltered, milligrams per liter
U.S. Geological Survey	NWISDV	Specific conductance	Specific conductance, water, unfiltered, microsiemens per centimeter at 25 degrees Celsius
U.S. Geological Survey	NWISDV	Temperature, water	Temperature, water, degrees Celsius
U.S. Geological Survey	NWISDV	Temperature, water	Temperature, water, degrees Celsius
U.S. Geological Survey	NWISDV	Discharge, stream	Discharge, cubic feet per second
U.S. Geological Survey	NWISUV	Gage height, stream	Gage height, feet
U.S. Geological Survey	NWISDV	pH	pH, water, unfiltered, field, standard units
U.S. Geological Survey	NWISUV	Discharge, stream	Discharge, cubic feet per second
U.S. Geological Survey	NWISUV	Temperature, water	Temperature, water, degrees Celsius
U.S. Geological Survey	NWISUV	Temperature, water	Temperature, water, degrees Celsius
U.S. Geological Survey	NWISUV	Specific conductance	Specific conductance, water, unfiltered, microsiemens per centimeter at 25 degrees Celsius

Filter by: Organization Service Name Keyword Variable Name

Showing 1 to 33 of 33 entries Previous 1 Next

Figure 3. The Data table is where you can view information about different time series as well as make a selection of up to 25 data sets for download.

The proliferation of new tools and data sets in the CUAHSI WDC ecosystem is creating the opportunity for new initiatives around water informatics.

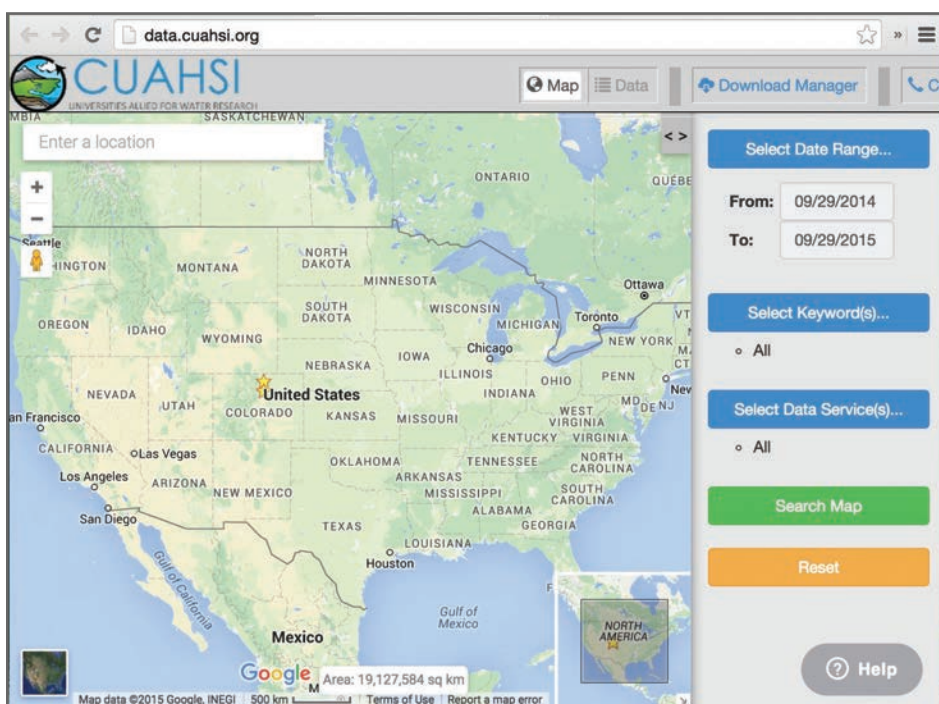


Figure 4. The CUAHSI Website. HydroClient is the newest data access tool from CUAHSI. This web application searches a catalog of over one hundred data sources based the following criteria: time, geography, and keyword. The data sources being searched can also be filtered.

do not wish to use a map interface, but would like to access and analyze data from the CUAHSI HIS, an R Package is available in the Comprehensive R Archive Network (CRAN) library. The WaterML R Package, which was developed and is supported by Jiri Kadlec (Brigham Young University), contains methods for accessing data sources either through the HIS Central Catalog or by connecting directly to a specific data source to enable analysis in any R environment.

The proliferation of new tools and data sets in the CUAHSI WDC ecosystem is creating the opportunity for new initiatives around water informatics. At CUAHSI, one of these is to advance methods of place-based, data driven water science education. Throughout the month of September, 2015, CUAHSI hosted a virtual workshop on hydrology education that allowed educators to share novel, modeling-driven active learning tools. The workshop consisted of three webinars and a virtual poster session that highlighted tools that educators can bring to their classroom. More information, including recordings of the webinars, can be found on CUAHSI's website: <https://www.cuahsi.org/virtual-workshop-on-data-driven-hydrology-education>. Looking ahead, CUAHSI is working towards creating a catalog of reproducible, but modifiable activities, which utilize CUAHSI tools that can aid educators teaching water science.

Through the CUAHSI WDC program, the CUAHSI community is changing the way in which we observe the world, teach concepts, and ask questions about our environment through water data. We want you to join us! As a community-governed organization, CUAHSI has a Board of Directors and a number of committees composed of water researchers and educators from all over the U.S.

To become involved, start by browsing CUAHSI's website ([www.cuahsi.org](http://www.cuahsi.org)) to learn about our programs, sign up for CUAHSI's email list and newsletter, and interact with us on Twitter, Facebook, LinkedIn or Instagram. We hope to hear from you soon!

# U.S. Secretary of Agriculture Tom Vilsack Visits CSU

*Lou Swanson, Vice President for Engagement and Director of Extension, Colorado State University*



**W**ith Climate Smart Agriculture (CSA) practices, farmers and ranchers constantly adjust to weather variability to assure their economic and ecological resilience.

CSA is a major U.S. Department of Agriculture initiative, and U.S. Secretary of Agriculture Tom Vilsack visited the CSU campus on May 20, 2016 to discuss CSA initiatives at CSU, a follow-up to a daylong forum held on campus May 5, 2016.

Vilsack shared his assessment of global climate change and the challenges confronting global food production and distribution. He applauded CSU's engagement with Colorado producers as well as U.S. Department of Agriculture's (USDA) Northern Great Plains Climate Hub, located at the Agricultural Research Service in Fort Collins, Colorado. CSU is a partner in the Climate Hub with land-grant universities located in Montana, Wyoming, North and South Dakota, and Nebraska.

In addition to recognizing the efforts of the Climate Hub and CSU research, teaching and engagement climate programs, Vilsack answered a broad array of questions from Colorado's agricultural leaders who had also attended the May 5<sup>th</sup> forum.

## **CSA initiatives**

CSU leaders emphasized that its CSA initiatives enhance partnerships with Colorado producers, where ideally farmers and ranchers will take the lead in working with their neighbors. CSU Extension, the Colorado Water Institute (CWI) and the College of Agricultural Sciences are actively seeking collaborations with farmers and ranchers and their respective organizations.

"These initiatives are focused on improving Colorado's food systems and food value chains as they adapt to variable weather and climate," said Lou Swanson, Vice President for CSU's Office of Engagement. "The College of Agricultural Sciences and our Office of Community and Economic Development have programs focused on agriculture and food systems innovations that are equally impactful in rural and urban areas of Colorado."

Faculty from a variety of colleges and departments, along with CWI and CSU Extension are providing the primary engagement and outreach programming for these CSA initiatives. A principle program goal, in collaboration with Colorado's farmers and ranchers and their organizations, is to improve their economic and ecological adaptability and resilience as weather patterns change. A guiding engagement principle is emphasis on co-creating programs and developing applied research with Colorado's farming and ranching communities.

Both the USDA and CSU are founding and active members of the United Nations Food and Agriculture Organization's Global Alliance for Climate Smart Agriculture.

More information on CSA and CSU's initiatives, including identifying faculty and staff working in this area is available at <http://engagement.colostate.edu/climate-smart-agriculture/>.

The spring 2016 issue of *Colorado Water* is dedicated to Climate Smart Agriculture. This magazine is available online at <http://www.coopext.colostate.edu/comprtrain/docs/ColoradoWater.pdf>.

*(Above Photo) Provost Rick Miranda (left), Secretary Tom Vilsack (middle) and Vice President Lou Swanson (right). Photo by Joe A. Mendoza*



# Go with the Flow by Way of Interdisciplinary Collaboration

## Sharing, Integrating, and Opening Access to Data from Various Studies in the Cache la Poudre Watershed Following Fire and Flood

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### SYNOPSIS

Interdisciplinary research is fruitful when it comes to understanding the natural world. A team of CSU Water Center funded researchers collaborated to develop a robust and helpful network of data related to the Cache la Poudre Watershed.

### Introduction

Scientists at Colorado State University (CSU) have engaged in interdisciplinary research projects that sought to understand complex processes in the natural world.

These projects generally gave scientists time to cultivate collaborations, communicate their own understanding to one another, and design complementary field sampling campaigns to address interdisciplinary research questions. When a natural disaster happens, such as the High Park Fire in summer of 2012 and floods that followed in fall 2013 in the Cache la Poudre (CLP) watershed, researchers can respond quickly to study these events through Rapid Response Research (RAPID) grants from the U.S. National Science Foundation (NSF). But,

the quick turn-around necessary to meet tight deadlines for proposal submissions precludes researchers in different domains, such as hydrology, ecology, chemistry, and environmental engineering, from coordinating their field campaigns, and data from various disciplines are essential to studying natural and man-made disasters. Individual researchers were funded successfully with RAPID grants in 2012-2013 following the fire and floods, and thereupon collecting data from the watershed, were motivated to share and integrate those

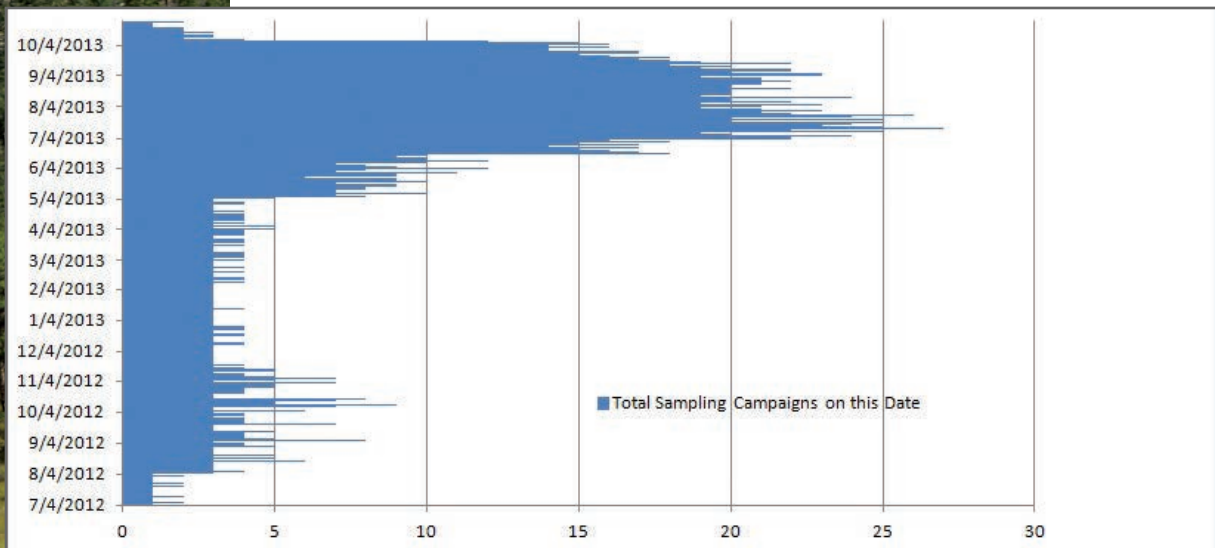
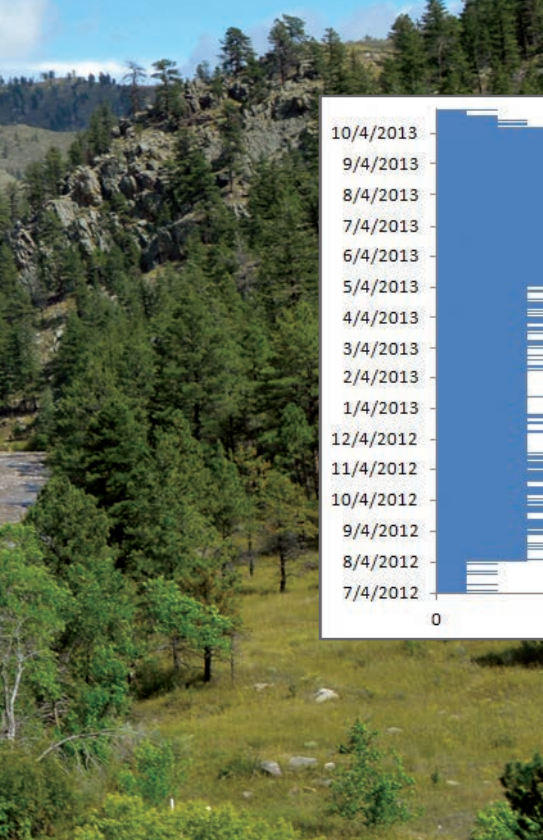


Figure 1. Visualization of sampling within the CLP Watershed over time. Researchers had sampling equipment well positioned in the field to capture the influence of heavy rains in September 2013, which caused major flooding and transport of materials in the CLP watershed.

(Left) The view of the main stem of the Cache la Poudre River looking down into Gateway Park during the September 2013 flood. Photo by Nicole Kaplan

data to address new questions rooted in hydro-bio-geo-chemical processes that were broader in scope. In 2014, the CSU Water Center funded a new team of researchers to do just that. The project entitled, “Developing Scholarly Excellence across the Aquatic-Terrestrial Interface Understanding the Hydro-Bio-Geo-Chemistry of Extreme Events”, formalized the working group consisting of students and faculty from multiple departments and colleges at CSU, and scientists from the U.S. Forest Service (USFS). They used the interdisciplinary study of biogeochemical transformations and physical alterations observed in the CLP watershed following the High Park Fire and flooding as a means to cultivate collaboration, share data, and enhance our understanding of the impacts of extreme events in watersheds around the world. This group established an active and mobile interdisciplinary collaborative working group that could bridge the physical and biological sciences to address water-related research questions and respond rapidly to requests for proposals in the event of extreme disturbances affecting watersheds. They synthesized data and information from two previously funded NSF RAPID awards, with a goal to determine the deposition, transport, and fate of black carbon (burned non bio-available biomass) in the CLP

watershed, enacted a pilot study as a model for conducting collaborative research in the future, and created an integrated database of information from the CLP watershed for open access and future use.

### Identifying Data from the Watershed

Integration of data may sound like a simple task when the information is shared by willing participants who collected data from the same watershed. However, data were sampled on various dates, different locations, and at different scales. Some sampling was performed through automated sensors, such as rain gauges, while other data were collected when a student was scheduled or able to visit specific sampling locations in the watershed. Measurements of processes occur at different scales. Biogeochemical analysis of soils taken from around shrubs or trees, represent processes occurring in plots influenced by vegetation, the soil substrate, and intensity of burn in that location. Many replicates are necessary to represent characteristics of a larger area. Collection of sediments after a precipitation event within a single drainage on a steep slope can represent erosion for an entire hillslope or drainage area.

Our first steps in preparing the group for sharing and synthesizing data and information was to interview students and

researchers about available data, formats which they utilize, and units of measurements (e.g. grams of carbon versus tons of sediment). Important metadata were documented, such as descriptions of methods, equipment used in the field, and calculations for derived values.

In preparation for a workshop that was organized for all the participants, an inventory of available data that visualized the timing and location of sampling was created. Visual props included an extensive timeline, displaying sampling dates of all measurements (Figure 1). A comprehensive map, displaying sampling locations across all watersheds, was developed with geographic information system (GIS) tools, as seen in Figure 2.

Our creation of visual illustrations organized the temporal and spatial coverage of data collection centrally, supported scientists’ decision making in regards to which data could be compared, and were used to identify where more data ought to be collected to fill gaps in coverage. The overlap in time was more straight-forward, and sampling efforts increased for all participants during the weeks of the first run-off and the growing season following the High Park Fire. At the workshop, researchers described their sampling designs and research methods, presented

preliminary results, and articulated at what scale they could make inferences regarding hydro-bio-geo-chemical processes in the CLP watershed. Researchers were able to determine what values could be compared and would contribute to a deeper understanding of carbon transformation and sediment movement within the watershed.

### Integrating Data from the Watershed

A data model within a relational database management system was designed to integrate the information of interest for participating scientists. Sampling location names and date formats were standardized as to ensure co-located data, and data collected within the same timeframe can be queried from the database and accessed together. Metadata documentation was created from interviews with working group participants, the information presented at

the workshop, and source files from data producers. Data contained in the database includes black carbon contents in plant litter, soils, riverbank sediment layers, particulate, and dissolved organic carbon in main stem Poudre River water.

### Opening Access to the Data

Open access to research data can provide valuable information to help answer interdisciplinary research questions, provide field measurements for predictive models, and serve as long-term evidence of trends in the environment. But sharing data is not routine because it is commonly viewed as an unfunded mandate from research sponsors. Thus, scientists are afraid their ideas will be scooped up, and/or they will not be given credit (Smith and Roberts, 2016). As a result, the interdisciplinary working group adopted a data access

policy, which assured participants they would have first shot at publishing their individual findings and would be attributed for their work, while providing data that can be re-used by their collaborators and opened to the public. Data packages will be published within the Digital Collections of Colorado, in the CSU Institutional Repository, with persistent URLs, as Handles, and recommended citations. A landing page, such as, <http://hdl.handle.net/10217/170584>, will serve research data and link to related materials, including theses, dissertations, publications, and online mapping applications that reference the published, integrated research data produced by means of this interdisciplinary collaboration.

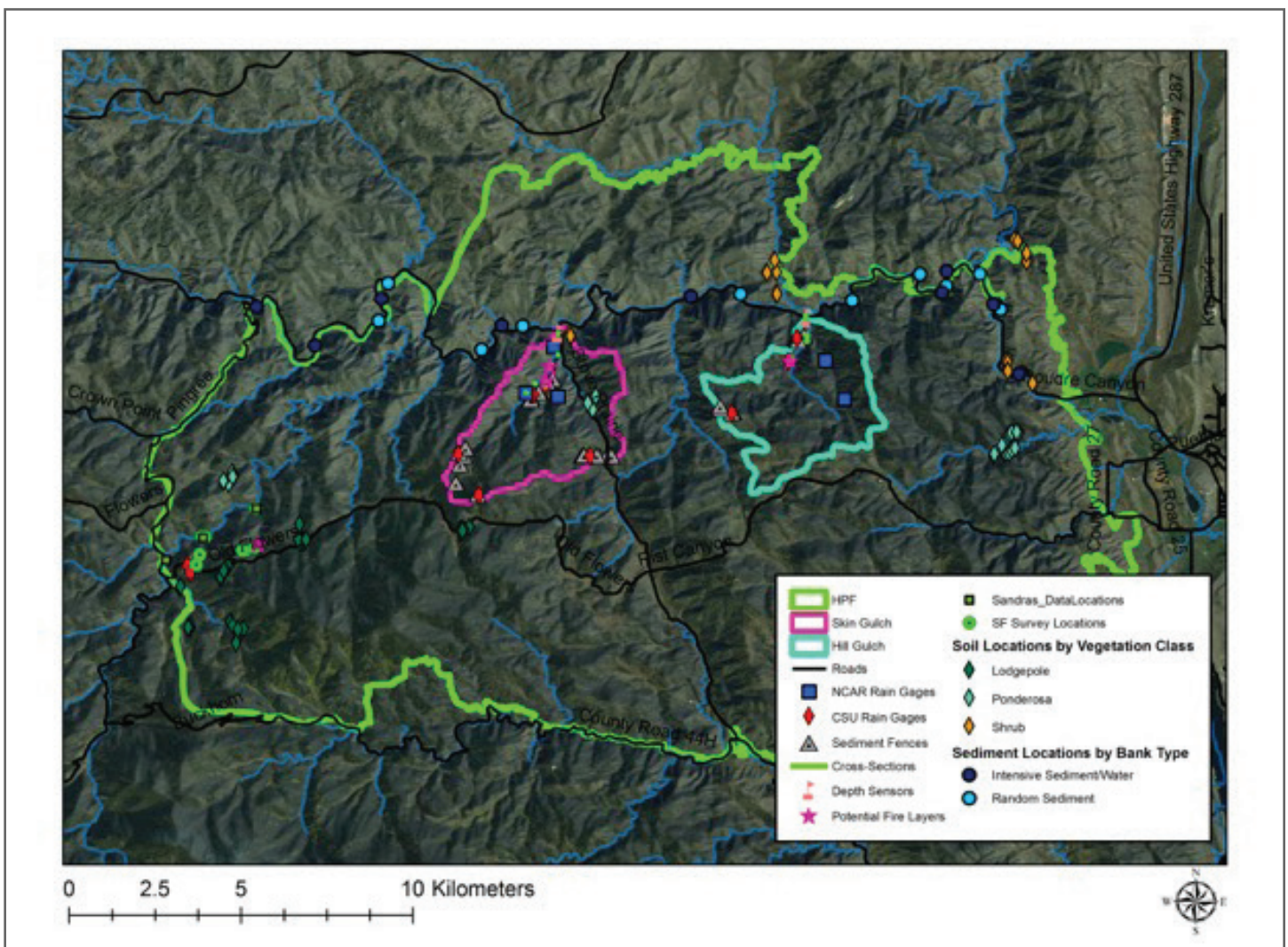


Figure 2. Visualization of sampling within the CLP watershed over space. This map was used to identify the vegetative characteristics, position on the bank and scale associated with the location of sampling. Map created by Daniel Brogan

# Colorado Decision Support System

*Doug Stenzel, Colorado Division of Water Resources and Department of Natural Resources*

## SYNOPSIS

Colorado’s Decision Support System (CDSS) is a water management data system intended to provide user-friendly water related databases, promote interagency collaboration, and offers a plethora of data, tools, and models to assess alternative water administration strategies for a variety of hydrologic conditions.

Colorado’s Decision Support System (CDSS) is a water management system under continual development and improvement by the Colorado Water Conservation Board (CWCB) and the Colorado Division of Water Resources (DWR), both agencies within the Department of Natural Resources (DNR). The CDSS is a data centered system designed for the following:

1. develop accurate, user-friendly water related databases;
2. provide data, tools, and models to evaluate alternative water administration strategies in various hydrologic conditions;
3. maintain a functional system that can be used by decision makers and others and;
4. promote information sharing among government agencies and water users.

The CDSS goal is to provide credible information on which to base informed decisions concerning management of Colorado’s water resources.

### Agency Focus

The CWCB was created in 1937, “for the purpose of aiding in the protection and development of the waters of the state for the benefit of the present and future inhabitants of the state” (House Bill 6, L.

37: p. 1300). In order to accomplish their mission, CWCB must have reliable, robust, readily available data. The CWCB’s mission statement is to conserve, develop, protect, and manage Colorado’s water for present and future generations.

The DWR is the administrative agent for the state, charged with maximizing the beneficial use of water for the citizens of the state in accordance with doctrines set forth in the state constitution, as well as statutes, court decrees, and interstate compacts. Since its establishment by the legislature in 1879, the water commissioner has played a vital role in stabilizing the state’s multi-billion dollar streamflow based economy. Every day, the water commissioner is tasked with balancing the supply of water available for diversion against the demand set by vested water rights, a balance that can often only be

reached by requiring some demands to go unmet. Reliable and timely streamflow and diversion data are a must.

### Collaborative Effort

While CWCB is focused on conservation, water policy, and planning for the future, the DWR is tasked with administrating water rights. The two agencies recognized that both had a need for the same data and began to collect data through a cooperative approach that would come to be known as the CDSS. Millions of dollars have been invested to create a system of publicly available data centered solutions, and tools, that both agencies, water users in Colorado, and others throughout the Intermountain West look to for information. In addition to the investment of public funds by the CWCB and DWR, various consultants have also collaborated to enhance the

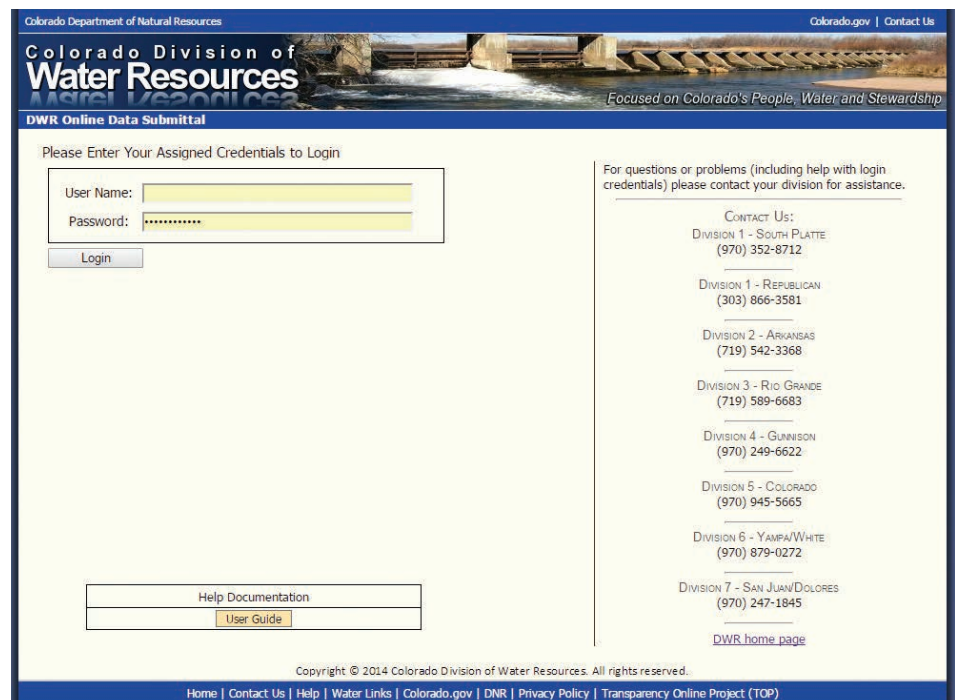
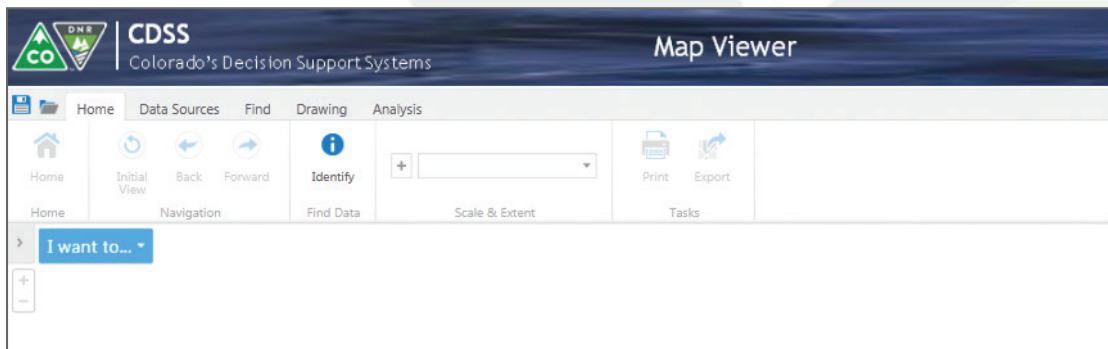
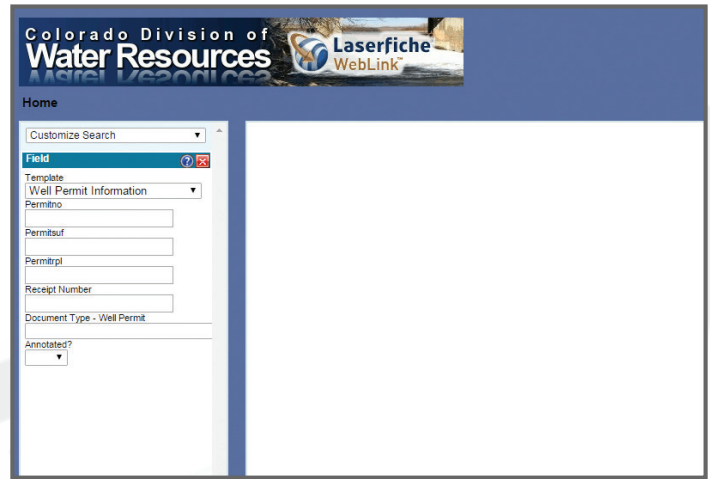


Figure 1. Online Data Submittal.



Clockwise (from top left)  
Figure 2. CDSS Webpage.  
Figure 3. Image Documents.  
Figure 4. CDSS Map Viewer.

publicly available tools as they use them to answer their client's specific questions, providing an additional benefit to other users.

### Publicly Available

For many years, the CDSS data was available to the public for a fee. In the past five years, these data has been available through free downloads and public data sites like the Colorado Information Marketplace, hosted by Governor Hickenlooper's office as a clearinghouse for state data. The state is also pursuing the opportunities afforded by the open data revolution. Instead of continuing to try and host the CDSS software and models internally, the state is looking for an entity that would host the information in an open data environment. The host organization would steward the tools, authenticating improvements to maintain tool integrity.

Much of the data, because it is used to make administrative decisions, will continue to be maintained by the state. But with tools like the Colorado Information Marketplace, the public has

complete access to the data as soon as it is posted to the database.

### Public Can Share Groundwater Data

In order to facilitate ready access to groundwater elevation data, CDSS has developed a web-based portal through which users can share their groundwater elevation data. A Groundwater Level Monitoring Protocol provides guidance regarding the collection of quality groundwater elevation information (<http://water.state.co.us/groundwater/Documents/Groundwater%20Level%20Monitoring%20Protocols.pdf>).

Users can register to submit data at <http://water.state.co.us/groundwater/Levels/Pages/CooperatorProgram.aspx>. Once registered, data can be easily uploaded online, as shown in Figure 1.

### Data Available

As seen in Figure 2, the data available from CDSS includes a broad range of water related data, such as: a tabulation of water rights, administrative call informa-

tion, streamflow data, diversion records, groundwater elevation data, well-metering information, dam safety statistics, irrigated areas, climate data, modeling software, calibrated surface and groundwater models, as well as a host of reports and documents related to Colorado water.

In response to former Governor Ritter's "greening initiative", all DNR agencies use an electronic imaging system (Figure 3) to store the day-to-day information, historically archived in paper format. As a result, information such as a water right decree, well permit, well completion report, etc. can be readily accessed from any internet connection. Many of the DNR agencies have converted to managing information without the need for paper at all, which is the ultimate goal. In addition to imaged documents and tabulated data, the DNR has developed a robust set of geospatial data. A free mapviewer, as shown in Figure 4, can be used to display any information associated with a physical location. All the links to the various tools are on the CDSS webpage at <http://cdss.state.co.us>.



# FTP Please

Kelly Bennett, Managing Partner, Ponderosa Advisors

## SYNOPSIS

Governmental entities are collaborating with the private sector to gather and distribute more data as the demand increases. This is especially prominent in Colorado where firms such as Ponderosa Advisors LLC. and Water Sage have taken the lead to innovate web-based research and data for water rights and land ownership.

**T**oday's world is driven by data: user data, market data, public data, and proprietary data.

Innovators create a plethora of data analytics from a variety of software platforms that were not available a few years ago. Furthermore, 'big data' has become the latest buzzword, and each day, more entrepreneurs strike out to wrangle these datasets into applications that add value to individuals' personal and professional lives. But, at the core of these myriad data-driven innovations is an often contentious and tenuous dynamic—the private use of public data.

Governmental entities, whether local, state, or federal, are under increasing pressure to publish more data in an effort to be more transparent and serve a growing demand for data access. The diverse approaches to using that data require it be accessible in raw format and downloadable *en masse*, as efficiently as possible. Many initiatives, like the Colorado Information Marketplace, exist to aggregate large databases of public information to meet the ever growing demand for access to as much data as possible.

A growing source of this demand comes from the private sector, where firms such as Ponderosa Advisors innovate ways to analyze and add value to data in order to solve real world problems. Making raw data readily available can serve a number

of important purposes such as:

1. it provides opportunities for management, policy, and technological innovation;
2. makes governmental agencies more transparent and accountable for the data they are tasked with managing; and
3. facilitates discussion about important issues based on real data.

Most individuals would agree that better access to data and the quality of analysis that it enables makes for better

decisions. Importantly, as private ventures continue to innovate ways to use data, it alleviates the pressure on state data stewards. Instead of allocating funds for perpetual software development, state agencies may assign resources to improve the quality of the data itself.

Every large public dataset reflects an evolution of regulatory regimes, management and business rules, bureaucratic structures, and the technology available to the manager at the time. This is often accentuated by the fact that in-house,



Graphic Courtesy of Ponderosa Advisors, LLC.

large-scale data management is relatively new for many agencies – many used to (and many still do) hire consultants to set up database solutions and manage them over time. These consultants may have little or no operational knowledge of the data and how it gets used. This shortfall is reflected in the quality and usability of the data structures they create. Even expert consultants are forced to build their work product to a limited scope, which may be incredibly narrow compared to the broad set of uses for the data. The implications of this evolving approach to data management can be vexing for end users. Gaps in data, changes in attributes and nomenclature, and seemingly arbitrary changes in database structures are commonplace and make working with these datasets cumbersome, inefficient, and expensive.

For a would-be innovator using these large databases, the impact can be significant. Before an individual can even start doing analysis or building systems, he or she must ensure that the data is structured to meet the given requirements. When gaps are presented within the data, it is critical to provide a thorough and detailed analysis of the data. Unfortunately, not everyone has the business intelligence skills and mastery of database analytics to do this kind of work especially with a large-scale database, and if you do not have those skills in-house, they are expensive. The gaps may be critical: in water rights, some states simply directed their

database managers to stop entering names of water sources part of the way through creating a database. Most states, Colorado included, do not have an effective way to track the ownership of water rights, which inhibits informed planning, policy decisions, and market transactions. As more and more entities, whether private or public, rely on that data, these issues become increasingly apparent and impact a growing network of users who demand information.

With respect to water data, the Colorado Division of Water Resources does a truly commendable job managing and creating access to its vast databases. The state even goes so far as to create services that allow efficient bulk downloads, and the data structures are constructed and maintained by staff that understand and care about the data.

Colorado data is not without issues, however, some of which, like ownership, will take significant policy changes to address. Fixing issues with public data requires multi-agency coordination, massive planning, and large amounts of funding. The complexity and importance of data has historically led agencies to instead invest in publishing tools and software. This investment is much less controversial than database overhaul, and has served a critical role. Until recently, agency-operated interfaces have been the only real way to access any of the data at all. Technology and the

widespread application of big data-style approaches have changed drastically in recent years.

When states like Colorado open the floodgates to their vast databases, the private sector can take on these development challenges. For example, the National Oceanic and Atmospheric Administration (NOAA) called for private sector engagement with its immense and growing databases in 2014. NOAA focused resources on improving its climate data warehouse and better serving that data to private sector users with the stated goal of spurring innovation, new industries, and jobs growth. Private sector innovators are beholden to their customers, driven by profit motive, and the underlying requirement that products must serve the intended audiences. The embrace of private sector entities creating applications around public data can lead to powerful results. For example, Ponderosa Advisor's Water Sage platform expedited a massive conservation project, at a fraction of the cost it would have otherwise incurred.

Stewards of massive public databases have a unique ability that must not be ignored. While anyone can invest in building applications to use public data, only agencies can effect improvements in the data's quality. Technology has advanced so rapidly that basic data analytics are now mainstream. As a result, more individuals seek data, and lots of it. It could be that we are at an important inflection point when it comes to public data, where agencies can finally invest in its quality rather than the latest and greatest publishing platform. The latter task can be left to us, the growing ranks of private sector innovators. Both government and the private sector stand to gain immeasurable value by embracing this kind of partnership.

*Kelly Bennett is a Managing Partner at Ponderosa Advisors, LLC, and a Denver-based startup responsible for Water Sage. Water Sage is a web-based research and analysis platform for water rights and wells, land, and related administrative and legal concerns. Water Sage is available in a growing number of Western states. Visit [www.watersage.com](http://www.watersage.com) for more info.*



Photo by Ben Earwicker, Garrison Photography

# How Much Data Do We Need? A Fine Scale Precipitation Example

Steven Fassnacht and Amanda Weber, Watershed Science Program, Ecosystem Science and Sustainability, Colorado State University

## SYNOPSIS

Precipitation data was collected for 20 locations within the Lower South Fork of the Cache la Poudre Valley to assess daily precipitation data and compare it to operational data at one central location.

## Introduction

Natural resource managers, state engineers, environmental consultants, and scientists use hydrological and meteorological data for real-time decision making to understand processes and change within systems. These professionals rely on historical data and assume that these data are representative of reality. However, these data are merely indicators of temporal patterns and have been shown to change over time.

Today, more data is being collected than ever before from remote sensing with satellite, aircraft, and drones, to automated sensors in our cars, and mobile devices. Often, individuals rely on the latter for real-time updates, but rarely is the accuracy or representation of this information questioned.

In areas of complex terrain, such as mountainous regions, monitoring tends to be limited due to difficult and harsh conditions, safety considerations, power limitations, and historically the lack of people living in such areas to collect the data manually. This lack of data collection further necessitates the remote collection of data. Yet, remotely sensed information must still be compared to measurements on the ground (ground-truthing).

From an experimental design perspective, one variable can be measured at a single location or multiple locations, with the latter used to understand how this variable changes over space, or its spatial variability. The data collected for the experiment illustrated in this paper is daily precipitation over a small area, compared to operational data collected at the same time scale, i.e., daily, but only at one location. Usually over a small area one would expect daily precipitation values to be virtually the same. However, variables like precipitation can vary across small space scales due to a number of factors including canopy cover and topography.

## Case Study

In this study, daily precipitation data was collected at 20 locations (Figure 1) across a 25 hectare (0.25 km<sup>2</sup> or about 62 acres) area across the Lower South Fork of the Cache la Poudre Valley at the CSU Mountain Campus. This 425 m wide by 585 m long area covers a limited elevation range from 2,740-2,760 m. Twenty number ten cans with a diameter of 15.30 cm were used as the precipitation gauges (Figure 2), with the volume measured using a graduated cylinder with 1.00 ml increments. This yielded a gauge precision of 0.05 mm, which is much finer than most gauges used in an operational setting. The gauges were installed on May 19, 2015 and removed on August 6, 2015. Most of the measurements were made by CSU undergraduate students as part of their NR220 (Natural Resources Ecology and Measurements) class. Measurements were usually made around 18:15 local standard time, and it took about 40 minutes to sample all gauges. Precipitation was observed to occur around mid-day, with no measurements taking place when precipitation was occurring.

Data from the 20 gauges was compared to the daily precipitation measured at the

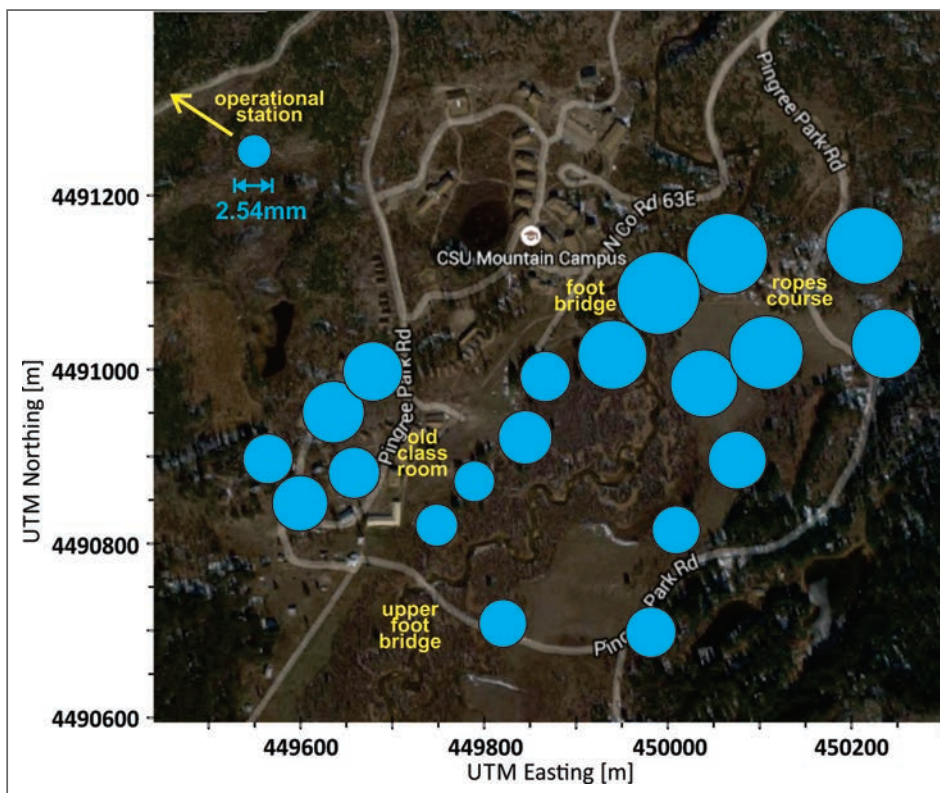


Figure 1. Map of the CSU Mountain Campus study area with the location of the 20 precipitation stations with scale units of Universal Transverse Mercator (zone 13). The operational station is located to the northwest. The size of the circles represents the amount of precipitation measured on June 28, 2015.



Figure 2. Amanda Weber and Steven Fassnacht discussing the collection of the precipitation data.  
Photo by Steven Fassnacht

nearby Hourglass Lake Snow Telemetry (SNOTEL) station (number 1122) that is operated by the Natural Resources Conservation Service, hereinafter called the “operational station.” It should be noted that precipitation is recorded to the nearest 2.54 mm (0.10 in).

## Observations

Snowfall was measured on the first two days of the experiment. However, it is important to note that the snowfall melted by the time the volumetric measurements were made. The remainder of the precipitation was rainfall. Measurements were collected for 68 days with some precipitation being measured on 28 days. However, on five of these 28 days, precipitation was measured as zero for a few of the 20 total gauges. There were a few problems that occurred during the experiment, such as on June 30th at gauge 3 in the south-east corner of the valley when it was noted that a “moose (was) standing over (the) can ... won’t move, (and the students) got chased away.” This resulted in 27 can-days missing (of 1,360 total) or less than 2%. The average daily precipitation was used to fill in the missing amount.

There was significant spatial variability when precipitation was measured across the study area. For example, the rainiest day occurred on July 8<sup>th</sup>. During this period of record, 42.75-49.00 mm of precipitation was observed in the Mountain Campus gauges. Furthermore, 25.40 mm of precipitation was observed at the operational gauge. Conversely, on May 24<sup>th</sup> the least amount of precipitation was observed at the Mountain Campus gauges. At this location, there was a range of 0.03-

0.52 mm of rain reported and 5.08 mm at the operation gauge. The example shown in Figure 1 illustrates variability from 3.20-6.20 mm across the Mountain Campus gauges versus a measurement of 2.54 mm at the operational gauge. There is strong spatial coherency (from a variogram analysis) with larger daily amounts in the north-east and the lowest amounts in the south-central areas of the study domain.

Precipitation was observed at both the operational and the Mountain Campus gauges on 17 days, while on another 11 days precipitation was only observed at the Mountain Campus gauges. Precipitation was never observed at the operational gauge and not at the Mountain Campus gauges. These differences may be due to the resolution of operational gauge (2.54 mm), as the aforementioned 11 days saw a maximum of 1.20 mm rain with an average of only 0.40 mm. For most of these 11 days, there were small amounts of precipitation measured. As such, cumulative precipitation was also used to assess temporal variability. In total, the operational gauge measured only 1% more than the average of the Mountain Campus gauges over the 68 days of measurement (Figure 3). However, using the maximum and minimum daily amounts would yield a +/- 24% difference than the operational gauge. The patterns between the two sets of gauges are similar, with about 20 mm more precipitation for the first three days at the operational gauge, and then the same amount over the first few days of July, yielding almost the same total (Figure 3).

## Implications

It is important to consider the data that were collected by the operational gauges, and the limitations it presents. One consideration is the resolution of measurement for individual events, in particular ones with limited precipitation. Due to the manual measurement of the cans used as the Mountain Campus gauges, their resolution (0.05 mm) was 50 times finer than the operational gauge (2.54 mm). Does a coarse measurement resolution imply that small events or changes are not measured?

There can be much spatial variability, but also spatial coherency among the 20 experimental precipitation gauges. Over more than two months, the average of these cans is almost exactly the same as the nearby operational gauge (Figure 3). However, using one point to represent a diverse area can be problematic, especially for individual precipitation events. The operational stations often have the advantage of having a long time series of data, but such stations are not necessarily representative of the area surrounding them. There is a great need for more data, especially to assess the representativeness of operational stations that are relied upon for making real-time management decisions. This is also crucial as the climate has been changing in the past few decades. It is important to consider the uncertainty associated with point measurements. Studies such as the one shown herein can help us identify this uncertainty, and illustrate these data issues to students.

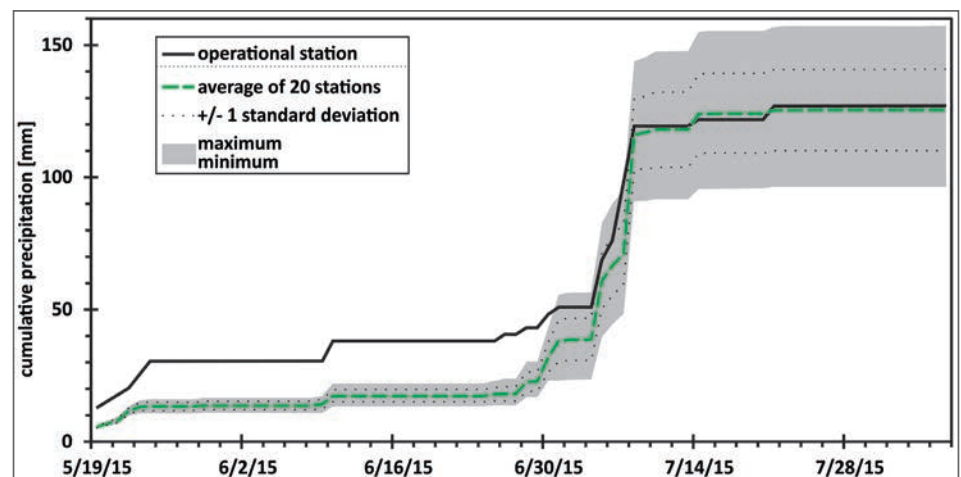
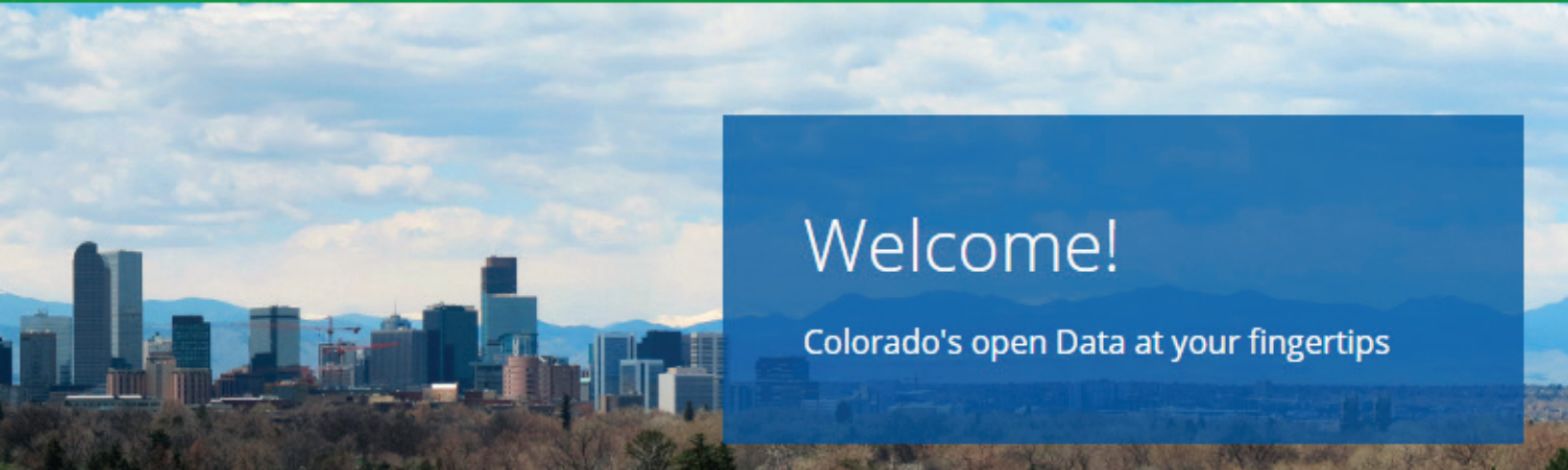
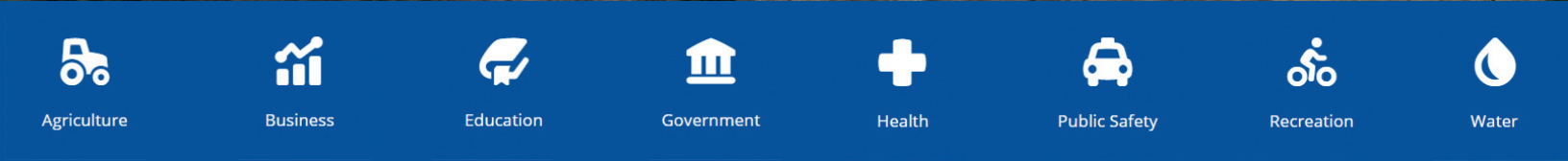


Figure 3. Cumulative precipitation over the 68 days of measurement for the operational gauge, the average of the 20 Mountain Campus gauges, plus the maximum and minimum.



Welcome!  
Colorado's open Data at your fingertips



# Open Data for Water Resources

## How Open Can We Go?

Steve Malers, Founder and Chief Technology Officer, Open Water Foundation

### SYNOPSIS

Water data is critically important to address the benefits and trials users encounter when utilizing open data for research and while on the job.

Technology is continually advancing at a rapid pace with the consumer electronics and communication industries driving change. Recent data indicates that 79% of the cell phone market is now comprised of smartphones. Social media platforms, music, videos, e-mail, and text messaging are the top mobile apps used by consumers on smartphones. Behind each of these apps is an abundance of data. What data do people access? That is more difficult to

determine, but it is likely that sports and entertainment are near the top, followed by financial data, maps for navigation, and weather information. Given the plethora of opportunities to utilize data in everyday life, people have an expectation of being able to access good-quality data.

Access to and use of water data is of interest for personal use, for example to plan recreational outings and to be aware of emergency situations such as floods. Water data are also important for business and research, for example to understand how water availability or quality may impact an organization and its operations.

The term “open data” is being used more frequently. A useful definition of open data is the following:

1. accessible to all – the data becomes

accessible outside of the organization that generated or collected it;

2. machine-readable – data must be usable, which means it must be made available and understandable in formats for third-party applications;
3. free – zero or low costs for data access and openness; and
4. unrestricted rights to use – data that is unencumbered by contractual or other restrictions leads to the maximum potential of innovation and use.

Before the internet and personal computers became mainstream, scientific data were made available through printed media, physical media such as discs, magnetic tapes, and punchcards, or other platforms such as television and radio. It was common to control data access to such

a degree that a search for the right data might take years and lead to incredible frustration. Fast forward to today, and it is quite evident that people are often faced with an overload of data.

Clearly, if I wanted to quickly access water data and perform my own analysis in Microsoft Excel or another type of software, transferring the data from hard to digital copy would be tedious. To improve access to data, federal, state, and local agencies are increasingly providing web services and digitized data.

A well-implemented web service (often called an API, or Application Programming Interface) allows software, including a web browser via the use of a URL, to specify a unique resource identifier for a data resource, and be provided with data in a useful format. Examples of web services include those provided by U.S. Geological Survey (USGS, <http://waterservices.usgs.gov/>), Regional Climate Center (RCC, <http://builder.rcc-acis.org/>), Environmental Protection Agency (EPA, [https://www3.epa.gov/storet/web\\_services.html](https://www3.epa.gov/storet/web_services.html)), and Natural Resources Conservation Service (NRCS, [http://www.wcc.nrcs.usda.gov/web\\_service/awdb\\_web\\_service\\_landing.htm](http://www.wcc.nrcs.usda.gov/web_service/awdb_web_service_landing.htm)). The federal government is investing in the Open Water Data Initiative (OWDI, <http://acwi.gov/spatial/owdi/>) to improve sharing of federal data, with initial focus on floods, water supply, and water quality in response to spills. The state of Colorado also provides web services for some water data (<http://water.state.co.us/DataMaps/WebServices/Pages/WebServices.aspx>). Although the data formats returned from web services are readable, in some instances, the data presented to the user may require software skills that limit the use of the data.

Another approach to providing open data in common usable formats is to use an open data portal. Quite often such portals are designed to be “one stop shops” for data. For example, the state of Colorado’s Information Marketplace ([data.colorado.gov](http://data.colorado.gov)) includes over 200 water-related datasets at the time of this article. Such portals typically cater more to the common citizen and provide data through table and map formats that are easy to use with common software but may not fully represent complex data sets. In addition to

simply proving access to open data sets, a portal can support the government’s goals of transparency in decision-making and help monitor government programs.

But what if the data still contains technical language or provides minimal context? How do I know how to use the data appropriately? This is one of the criticisms against open data. However, if the data provider is a government entity and the data are related to the public service function of that entity, should not the data be published as a way of demonstrating performance and accountability? If the entity is not performing, should not its customers and management be able to evaluate when improvements should be implemented? A recent example in the news that might have benefited from open data is the water quality disaster in Flint Michigan.

The implementation of an open data policy can clarify issues related to open data. A good source of information about open data policies is the Sunlight Foundation (<http://sunlightfoundation.com/opendataguidelines>). A fundamental issue may be whether an organization feels that it should define an open data policy at all, in particular for small organizations. Fundamental to this decision, it is important to determine the list of data and information holdings for an organization, and decide who should have access to the data. In some cases, it may be important to understand the specific uses of the data, but often there may be an obvious primary purpose for sharing the data (e.g., to demonstrate performance, validate a policy, or simplify data sharing on a research project), as well as additional uses of the data that have yet to be determined. For public organizations obligated to be transparent, the organization should expect that data will be used in a variety of ways, some of which are unexpected, innovative, and potentially disruptive.

The federal government releases data according to the Freedom of Information Act (FOIA, <https://www.foia.gov/>) and the state of Colorado, for example, adheres to the Colorado Open Records Act (CORA, [http://www.sos.state.co.us/pubs/info\\_center/cora.html](http://www.sos.state.co.us/pubs/info_center/cora.html)). Whereas in the past a FOIA or CORA request may have been a

last resort for requesting data, implementing an open data approach can increase the efficiency of publishing data and reduce open records requests. An open records request may in the future be a signal to government that they have not yet published a data set on their open data portal. However, progress is slow. For example, proposed SB16-037 legislation in Colorado would have updated the CORA to include language requiring that data be released in the original machine-readable formats (rather than hard-copy or PDF, for example) but the legislation did not advance.

So now that we have an understanding of how to make data available (web services, portals, etc.) and we have more clarity on the policy of open data, it is still not clear how to move beyond the low-hanging fruit of basic open data. Many organizations are publishing open datasets as basic singular datasets, as they should, but there is a dearth of connected datasets that have context and address more complex problems.

An obvious use of water data is to understand flows in rivers for water supply, recreation, environment, etc. Such data can now generally be obtained in basic format through a variety of digital platforms. However, consider something more complex, such as the Colorado Water Plan or an Environmental Impact Statement, a regional response to a drought, or even an annual report to an organization’s stakeholders or the public. Such documents are typically distributed as PDFs with embedded graphs, tables, and maps. But what if I do not trust or understand the message of a graph or a table? What if I want to combine the data from three different datasets in order to explore an idea? Unless the data are openly available, it would be difficult. Often the purpose of a report published in PDF is to provide information at face value, but such reports are a key interface to stakeholders and the public and provide great opportunities for education and understanding.

A different approach for open data use in government might look like the following. First, the original providers of data should publish their data in machine-readable formats, governed by an open data policy. A portal could be as simple as a

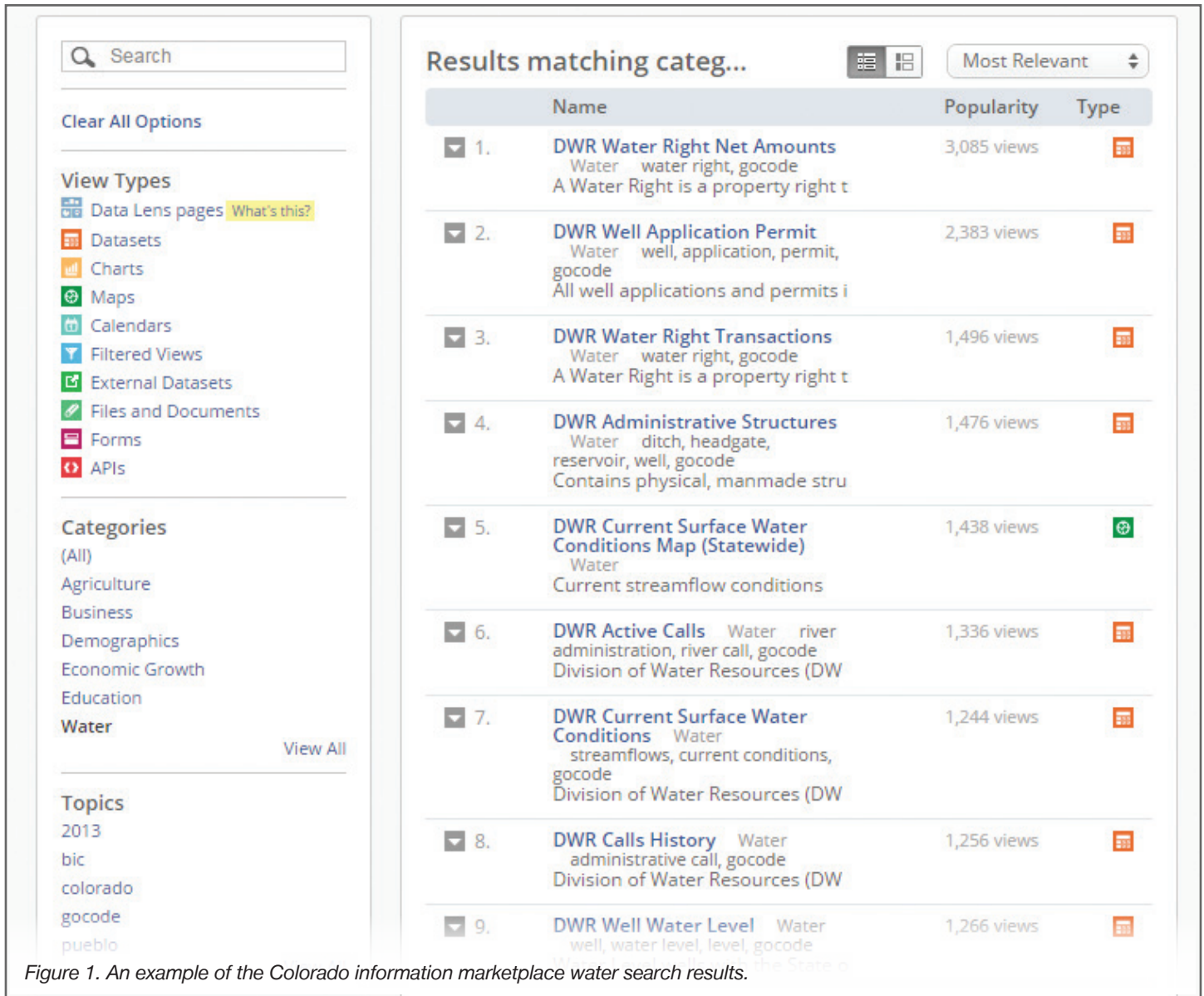


Figure 1. An example of the Colorado information marketplace water search results.

web page with the main data products from an organization, or a web portal platform or web services could be implemented. Any published work that uses third-party data should point to the open data for the original source and/or provide digital content with attribution. The end result would be a transition away from information presented only in PDF documents to documents supported by accessible data sets. At a minimum, a planning document or report could be distributed in PDF format with an accompanying Excel file that contains data for tables and figures in the document.

The return on investment in publishing open data can be large, for example:

1. an organization's efforts to produce data products for their own use and

their constituents means that data are always available, resulting in data-driven decisions;

2. the effectiveness of an organization can be monitored over time, allowing validation of policies and procedures;
3. a better informed public (or stakeholders in a process) leads to greater understanding of issues and more productive dialogue on those issues – full agreement may never be attained because of differences in values, but there can be progress on understanding data and science;
4. open access to data and information increases open market-based decisions; and
5. open access to data allows for innovation and analysis of connect-

ed data, thereby addressing more complex problems.

*The Open Water Foundation (OWF) is a nonprofit social enterprise that is focusing on the development of open source software to help make better decisions about water resources. Water in Colorado is a public resource and OWF believes that the software and data used to manage that resource should also be open. We are working to enable more open data and transparency so that progress can be made on complex water issues. How open can we go? We do not know the answer to that yet, but through technology, policy, collaboration, and innovation are working together to advocate for open data, open government, and open decisions.*

# Drought Monitoring and Early Warning in Colorado

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

*Dust Storm, Manzanillo, Colorado. Photo by Lyric Lucero, 2013*

## SYNOPSIS

Drought has greatly impacted Colorado over the years. It is essential to provide a historic overview of the most prominent droughts within the state and the importance of gathering and monitoring data related to drought.

**D**rought – in the form of weeks, months, or even years of below average precipitation leads to consequences such as: crop and pasture losses, wildlife stresses, wildfire and eventually water shortages, which frequently occur throughout the state of Colorado. If drought is not affecting some portion of Colorado this year, then it probably will be again in the very near future. In fact, drought is present to some degree at least part of the year and in at least part of the state nearly every year. How do we know this? This is known anecdotally, but also because of diligent data collection pursued by several agencies over the years.

Unlike many parts of the country that are closer to major sources of atmospheric water (the Atlantic and Pacific Oceans or the Gulf of Mexico), Colorado is far inland. The state is upwind from the Gulf of Mexico most of the time and downwind in the shadow of many upstream mountain barriers that get first dibs on clouds and water vapor headed east from the Pacific Ocean. That means that the average precipitation in Colorado is quite low. The statewide average is based on 1981-2010, which is 17 in and that was a relatively wet 30-years. But precipitation can easily fall far short of that average whenever weather patterns do not cooperate. In 2012 for example, an extreme drought year for many parts of Colorado, precipitation totals were less than half the average at many weather stations. In southeastern Colorado for example, Rocky Ford, with weather data going back to the late 1880s, expe-

rienced their driest year in recorded history with only 3+ inches of precipitation (rain plus melted snow) for the year.

The Colorado Climate Center (CCC) was established at Colorado State University (CSU) in 1973-1974. From the start, the mission of the new center was climate monitoring, climate data management, and data archival. If there was any doubt about what the new Center should be focusing on, it was quickly determined by the weather. The Big Thompson Canyon flash flood occurred in the summer of 1976 and was followed immediately by the worst snow drought Colorado had ever experienced the next winter (1976-1977). As a result, systematic monthly climate monitoring and reporting promptly began and has existed ever since. This “monitoring” consisted of collecting data from some of the CCC’s own weather stations, but also compiling data from other sources such as the excellent source of long term weather and climate data – the National Weather Service’s “Cooperative Observer Program” and the USDA’s Snow Survey program managed by the Natural Resources Conservation Service ([http://www.wcc.nrcs.usda.gov/partnerships/links\\_wsf.html](http://www.wcc.nrcs.usda.gov/partnerships/links_wsf.html)).

The drought of 1976-1977 was extreme but short lived. Big snow years followed in 1978, 1979, and 1980 followed by another intense winter drought in 1981. The roller coaster continued, as it likely always has, leaving the impression that drought comes in cycles. A huge mountain snow accumulation occurred in back to back years—1982-1983 and again 1983-1984 with subsequent river flooding, landslides, and reservoirs full and overflowing. There has been a lot discussion about climate becoming more extreme, but I assure you it has been plenty extreme already for a long time.

The winter of 1980-1981, with bare ground showing in the mountains well into January, was the second major winter drought in a five year period. This occurred during the years of rapid expansion of Colorado’s ski industry and under the terms of former Colorado Governor Richard Lamm. This helped motivate



Colorado to draft and implement the initial Colorado Drought Response Plan, one of the first in the country. It also instigated the creation of the Water Availability Task Force (WATF) along with several impact task forces to identify and prepare for drought in areas such as: agriculture, municipal water, fish and wildlife as well as wildfire. 35-years later, the WATF, led by Colorado’s Department of Natural Resources Division of Water Resources continues to gather the expertise of multiple federal, state, and local entities. The WATF routinely assembles appropriate water data and meets regularly (monthly most of the year), closely tracking precipitation, snowpack, reservoir levels and all the other components of the hydrologic cycle (<http://cwcb.state.co.us/public-information/flood-water-availability-task-forces/Pages/main.aspx>).

It seems hard to believe in this data-driven technological era, but until fairly recently, climate data were only available and updated several days to weeks after the end of each month. It then took several more days to obtain, assemble, and compile precipitation, snowpack, streamflow, and reservoir data. As recently as 2002, a major drought seemingly snuck up on Colorado as it emerged quickly between monthly reports and scheduled task force meetings. April storms failed to materialize as dry, and exceptionally warm, windy weather set in early. Conditions deteriorated into a dire drought situation in a matter of weeks. By June massive wildfires were burning and cities were scrambling to implement stringent water conservation programs. After more than 20-years without extreme drought at a time when Colorado’s population was soaring, this was a painful wake-up call. In response to that and other major and costly droughts across the country, the National Integrated Drought Information System (NIDIS) was established by Congress in 2006 (<https://www.drought.gov/drought/what-nidis>). Colorado, along with parts of the adjacent states of Utah and Wyoming, were selected in 2008 to be the first “drought early warning” pilot projects of this national program.

This pilot project began with more than a year of background work with a wide range of water users, resource managers, and key users of climate information such as recreation industry leaders from mountain communities. Research was conducted examining how organizations responded to drought and what information, triggers, and indexes were used. Beginning in early 2010, the CCC at CSU launched an aggressive coordinated drought monitoring and early warning activity that continues today. Weekly climate,

water, and drought assessments are now completed on Tuesday of each week to make sure no drought ever “sneaks up” again. Surface observations of climate indicators and water supply measurements are blended with remote sensing products obtained from satellites. New tools including the tracking of soil moisture levels, evapotranspiration rates, and evaporative demand, give a more complete picture of the status of the water balance to show when critical drought thresholds may be reached (<http://climate.colostate.edu/~drought/>). Updates are then provided each Tuesday afternoon to the U.S. Drought Monitor to provide a detailed up-to-the minute status report on current drought conditions. Later that evening, these updates go out as an email to hundreds of interested stakeholders in Colorado, Wyoming, and Utah. From this information, the evolution in drought conditions can be tracked.

At least once a month, this information is communicated in the form of a webinar where local input can be gathered in live discussions and where current conditions and forecasts can be discussed. Is this information sufficient? We certainly have a much better and timelier handle on local, regional, and national drought, climate, and water supply information than during other time periods. Yet, water managers and planners may need more. Will next year bring water shortages, or the year after? Progress in improving seasonal and multi-year precipitation forecasts have been painfully slow. Even with the growing knowledge and improved global monitoring systems to track phenomenon such as the El Niño Southern Oscillation, the accuracy of long-lead seasonal forecasts remain surprisingly low. Another area of weakness is local precipitation and soil moisture monitoring. Precipitation is so highly variable that even existing networks and observing systems are still unable to reliably resolve sub-county scale variations in moisture.

The Upper Colorado River Basin Drought Early Warning System is currently in the process of updating and reinvigoration. Arizona and parts of New Mexico were recently added to the region. Stay tuned for updates. If you would like to be a part of this process, please let us know. Also, do not forget that anyone can contribute to better drought monitoring simply by helping measure and report your local precipitation. Join the Community Collaborative Rain, Hail and Snow (CoCoRaHS) network today ([www.cocorahs.org](http://www.cocorahs.org)).

Contact [Nolan.Doesken@Colostate.edu](mailto:Nolan.Doesken@Colostate.edu) to receive weekly updates as well as webinar invitations.

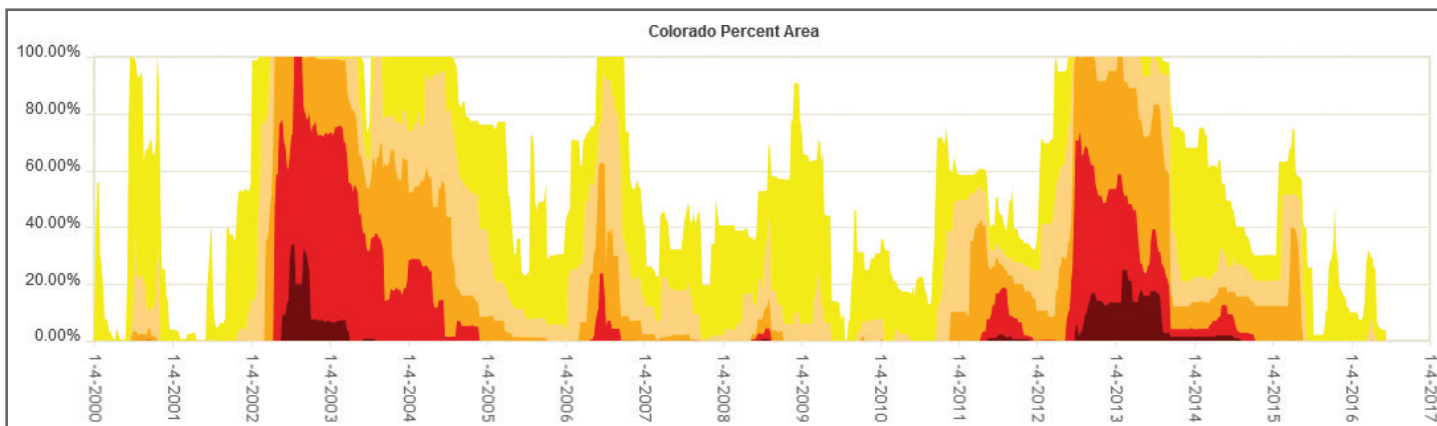


Figure 1. Percent area of Colorado in drought by category from D0 (abnormally dry) to D4 (exceptional drought) based on U.S. Drought Monitor weekly depictions, 1999 - 2016.

# Interview Data Documents Flood and Humanities History

Patricia Rettig, Water Resources Archive, Colorado State University Libraries



“So, Mr. [Ed] Citron who owns the Canyon Inn called the Sheriff’s Department, and they confirmed the fact that there was heavy rain [up the canyon]. ... Mr. Citron came in and said, ‘Everybody has to leave. I just called the Sheriff’s Department. They want us to evacuate the place.’ It hadn’t rained. We went out and looked at the river, and it was just barely up, you know. It was very hard to take seriously.”

– Mary Wells <http://hdl.handle.net/10217/76237>

**M**s. Wells' recollections of the 1976 Big Thompson flood convey her experience that July night, her thoughts about it, and her emotions afterwards. She shared all of this just weeks later with David McComb, a historian collecting data for his study of the event, which was already being called Colorado's worst natural disaster.

Dr. McComb, a Colorado State University (CSU) history professor, conducted this interview and forty other oral history interviews as part of his data gathering in the wake of the flood. To examine "[q]uestions about cause, warning, rescue, prevention, and recovery," McComb embarked on "comprehensive research" regarding the flood and ultimately wrote the book *Big Thompson: Profile of a Natural Disaster*.

Oral historians such as McComb focus not on numerical or scientific data but rather factual and contextual data through recorded interviews. They identify people with firsthand knowledge or experience of their research topic and ask a series of questions to elicit the information. They work to determine the story across the entire event timeline from various perspectives.

Mary Wells, visiting the Canyon Inn for an evening of entertainment, expressed surprise at the need to evacuate. This reaction provides some explanation for the large number of deaths resulting from the flood—ultimately counted as 143—if others like her were unprepared and did not take seriously any warnings they might have received.

*"Really, at that point, there were, in the morgue, only two or three policemen, a couple of the coroners, and the rest of the people were essentially the Mental Health people. On observing the battered and unrecognizable condition of most of the remains, it became pretty darned apparent that identification was going to be a most important process in this"* –James Dooney (<http://hdl.handle.net/10217/76258>).

Mr. Dooney, Director of the Larimer County Mental Health Clinic, witnessed the results of those caught by the raging floodwaters. In his interview, he explained what the scene at the morgue was like. Chaos reigned for a time with not enough workers and too many bodies, too many survivors seeking relatives and not enough paper on which to take notes. From Dooney, McComb heard a firsthand experience of the logistical and emotional difficulties in attempting to reconcile so many remains with a list of hundreds of missing. Dooney described the smells emanating in the absence of body bags and the sensitivity of the media in covering the disaster.

Transcriptions of the tape recordings served as the foundation of McComb's work, but the voices captured convey emotion in a way that words on paper cannot. Because McComb saw the research value in his data for others, the tapes and transcripts have been preserved and are fully accessible to any interested person. McComb donated his data to both the Colorado Historical Society and CSU, where they can now be found in the Water Resources Archive, which has digitized and posted them online.

McComb also collected newspapers, photographs, and radio broadcast recordings as part of his data gathering. Particularly

unique, a set of twelve reel-to-reel audiotapes contains newscasts and interviews from KIIIX Radio, a Fort Collins station. Radio was the main method for conveying immediate information about rescue operations, survivor names, and emergency services. Listening to the recordings now, in the age of social media, hearing name after name of those who made it out of the canyon, letting friends and family know who was living, is arresting. The absence of the names of the many victims, not broadcast for the sake of family privacy, is saddening.

To gather those names of the dead, James Dooney and others identified remains from dental records, photographs, and descriptions. It was a difficult process even to obtain that information, as telephone communications were very limited at first. In another interview, the experience of improving that situation was described.

*"You know, we've pioneered the telephone, now we're pioneering how to use it. But as for, you know, saying that we'd be able to do something like we could have done twenty-five years ago, I kind of doubt it. You know, I doubt if we'll ever be able to get back to that type of a system in which somebody would have access to, you know, the capability to ring all those lines."* –Rick Hays (<http://hdl.handle.net/10217/76220>).

Mr. Hays, an employee of the Mountain Bell telephone company gave a glimpse into emergency response technology of the past, present, and future. He explained that earlier telephone systems operated on a party line, where the operator could ring everyone on that line at once and convey a message. It proved quite efficient for emergency situations. However, by the 1970s, those party lines had been replaced by individual lines, so every household telephone was separate from every other one—great for privacy, but a setback for emergency communications. Hays expressed doubt that a future system would ever regain the lost efficiency of the past.

After historians aggregate it into their final book or report, raw data gathered in oral history interviews rarely gets donated to archival repositories. However, just as it is a valuable resource for the creator, such data sets prove useful for future research as well. Oral history interviews such as these examples serve as historical artifacts, taking us back to a very specific person reflecting on a very specific event, giving us lessons and perspectives for our own times. The recordings humanize history, giving a voice to the past.

Mary Wells did evacuate that night and was mainly impacted by the worry about others. Ed Citron, who had stayed behind, was later evacuated by helicopter. James Dooney continued to process his experience and possibly had his own mental health concerns to cope with. Rick Hays would hopefully be pleased with today's emergency alert systems such as reverse 911. Now, forty years after the flood and on into the future, as we remember that devastating and destructive night of July 31, the eve of Colorado's centennial as a state, we can hear directly from witnesses, thanks to historian David McComb's foresight.

*For more information about the David McComb Big Thompson Flood Collection in the Water Resources Archive, see the website (<http://lib.colostate.edu/water/>) or contact the author (970-491-1939; [Patricia.Rettig@ColoState.edu](mailto:Patricia.Rettig@ColoState.edu)) at any time.*

## We are pleased to announce the recipients of our 2016-2017 CSU Water Center Competitive Grants

The CSU Water Center has selected five Multi-Disciplinary Research/Proposal Teams, one Water Faculty Fellow, and one Symposium Planning Group as recipients of Water Center funding for 2016-2017. Our request for proposals called for projects that would catalyze transformative water research, teaching, and engagement through interdisciplinary collaboration and creative scholarship among CSU faculty and students. We received many excellent proposals that encouraged innovative research and collaboration among colleges across campus. The funded proposals are listed below.

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### Multi-Disciplinary Research/Proposal Teams:

- ❖ *New Frontiers in the Nexus of Food, Energy, and Water Systems: Exploring Food Crop Uptake of Contaminants from Oil & Gas Wastewater* – **Jens Blotevogel, Thomas Borch, Allan Andales, Steven Fonte, Tara O'Connor Shelley, Tara Opsal, Seth Shonkoff and Benny Chefetz**
- ❖ *Evaluating alternative water and nutrient management strategies as climate-smart agricultural options for Colorado and beyond* – **Steven Fonte, Louise Comas, Catherine Stewart, Dale Manning, Jose Chavez, Meagan Schipanski, Troy Bauder and Erik Wardle**
- ❖ *Evaluating the Energy Cost of Groundwater Production in the Denver Basin Sandstone Aquifers* – **Michael Ronayne, Tom Sale and Jordan Suter**
- ❖ *One Health Surveillance of Antimicrobial-Resistant Bacteria in Fort Collins, CO* – **Elizabeth Ryan, Richard Bowen, Susan De Long and Charles Henry**
- ❖ *Investigation of the Effects of Whitewater Parks on Native Fishes in Colorado: A Novel Two-Dimensional Modeling Approach* – **Christopher Myrick and Brian Bledsoe**

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### Faculty Fellow:

- ❖ *Toward a Quantitative Estimate of Organic Carbon Storage in River Corridors of the United States* – **Ellen Wohl**

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### Fall 2016 Campus Symposium:

- ❖ *CSU Subsurface Water Storage* – **Tom Sale, Michael Ronayne, Ryan Bailey and Sally Sutton**

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The CSU Water Center would like to thank everyone who submitted a proposal in response to this year's RFP. The selection process was competitive and the breadth of topics covered by the submitted proposals is indicative of the successful water research community at CSU. Congratulations to these faculty members!

# Whisky is for Drinking; Water is for Values-Based Negotiating

## Tradeoffs and Tensions in the Colorado Water Plan A Study in Values

*Richard Alper, Environmental and Sustainability Studies, University of Northern Colorado*

*This article is the first in a two part series.*

### SYNOPSIS

It is essential to understand and provide examples of tame and wicked problems related to the Colorado Water Plan (CWP) to appreciate the importance of values-based negotiating.

### Does the Colorado Water Plan Address a “Wicked Problem”?

Consider whether the Colorado Water Plan (CWP), delivered to the Governor on November 19, 2015, addresses a “tame” problem or a “wicked” problem. What are these and what do they have to do with values? Getting to the moon is an example of a tame problem because it can be solved by experts armed with good data, can be split in to component parts, which when brought together, may engineer a solution which is based upon efficiency and technology.

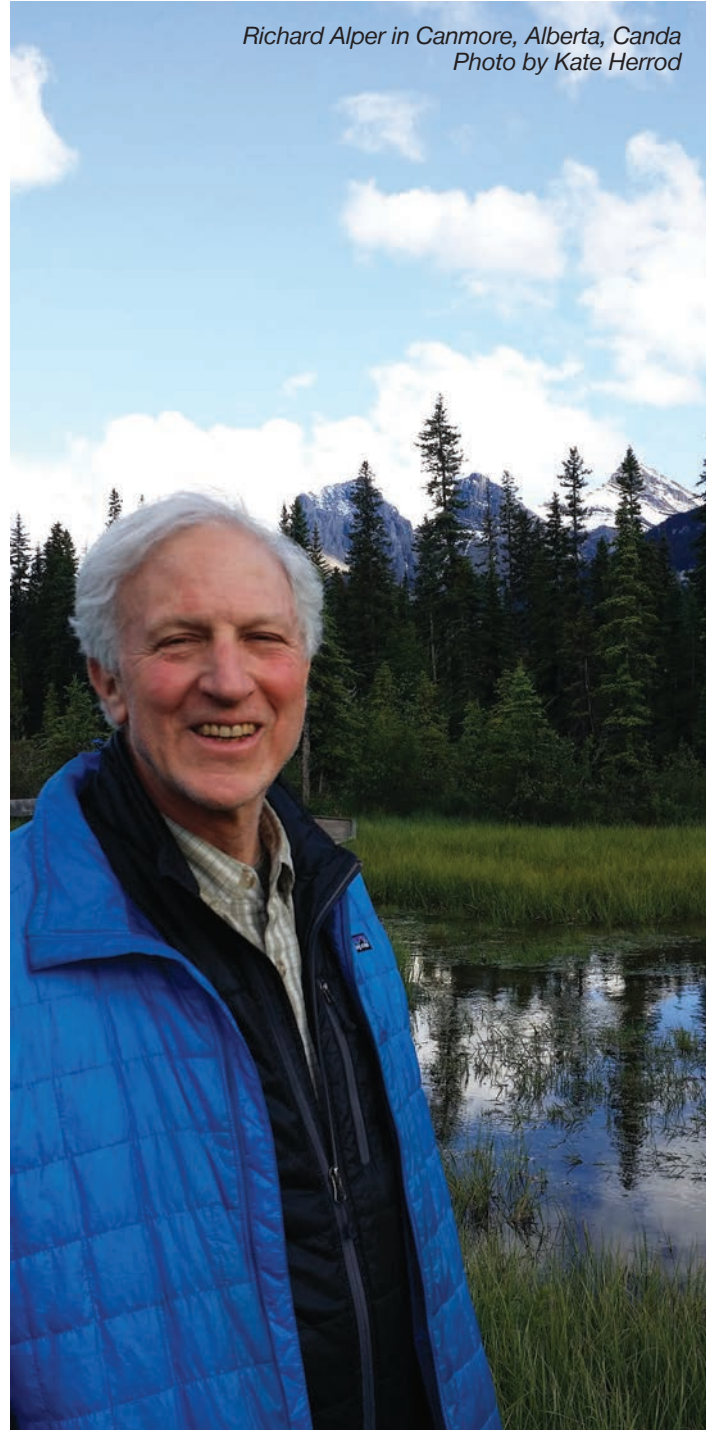
What is a wicked problem and how does it differ from a tame problem? Wicked problems:

- a. call for systems level thinking where everything is interconnected,
- b. will in many ways always be with us,
- c. cannot be split into component parts because pursuit of a technical solution to one aspect of the problem may worsen other aspects (and the more different people study wicked problems the more divergent their opinions on solutions typically become),
- d. have multiple ends and goals in tension with each other, and
- e. have a “solution” that tends to create new problems.

Wicked problems can be compounded when stakeholders suffer from cognitive bias. This is a type of blind spot in our perceptual and decisional processes, which can limit our ability to reason clearly and to capitalize on resources and opportunities controlled by other parties. An explanation and two examples of cognitive bias are discussed below in this article.

Given the complexity of wicked problems, they involve competing underlying values, tensions, and tradeoffs that can be informed by, but not resolved by, science and data. They also often require adaptive changes rather than technical ones. Much in the way that cultural change cannot be legislated, or handed down, adaptive change calls for a broad range of stakeholders to

*Richard Alper in Canmore, Alberta, Canada  
Photo by Kate Herrod*

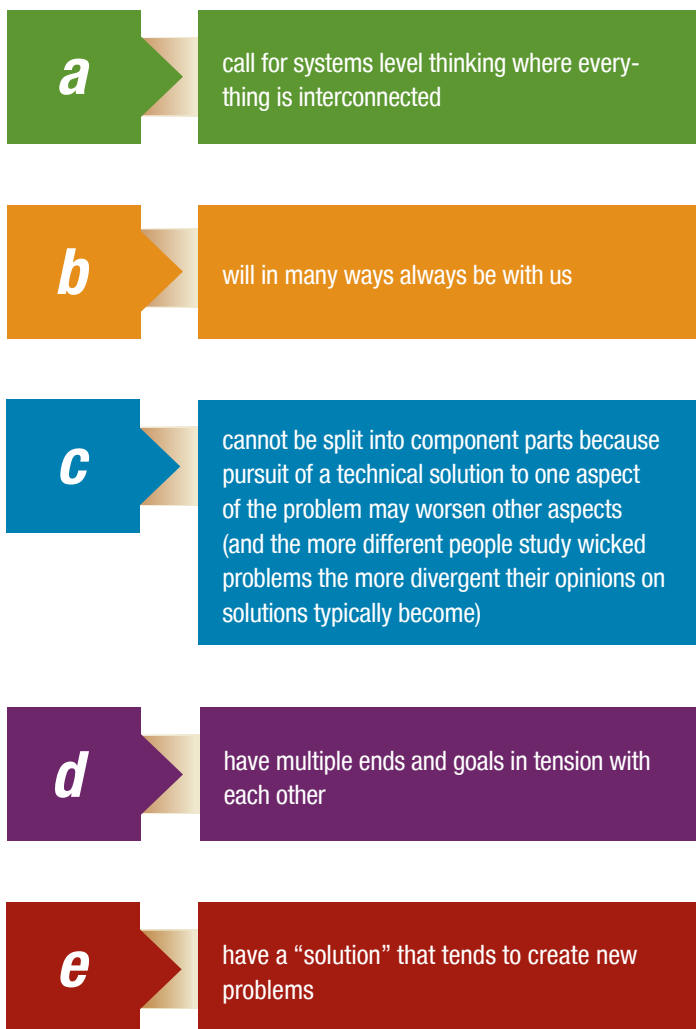


be a part of making and owning the solution, and to continue to refine it as the problem itself changes. This is a form of adaptive management, which is mentioned in the CWP.

Given the complexity of wicked problems and the requirement for involvement of a broad range of stakeholders, what does it take to wrestle with a wicked problem? First, it takes some right brained qualities like creativity, innovation, and imagination, because the accumulation and application of research is necessary but not sufficient. Second, it takes effective and respectful communication and collaboration across multiple perspectives. Because wicked problems call for tradeoffs in values and ends, poor communication—such as “good person” vs. “bad person” or “right” vs. “wrong” values—that narrows thinking to a singular value (for example, freedom, security, equity, control, or wellbeing) is particularly damaging to the critical thinking, shared understanding, and deliberation which wicked problems require.

Now that we have taken a look at wicked and tame problems, does the CWP present wicked ones or tame ones? Or some of both? The CWP proposes that by 2050, there will be a municipal/industrial (M&I) “gap” of as much as 560,000 acre-feet of water. Assuming the projected gap is based on realistic assumptions, is

## Wicked Problems:



the gap strictly solvable by an engineering solution? Is it a tame problem? Or is it a wicked problem?

Let us take a quick look at the Colorado values stated in the CWP and then the famous Inter-Basin Compact Committee (IBCC) 2010 letter to then Governor Ritter and Governor-elect Hickenlooper. The CWP says that we value:

“A productive economy that supports vibrant, sustainable cities, viable and productive [agriculture], and robust skiing, recreation, and tourism industry”

“Efficient and effective water infrastructure promoting smart land uses”

“A strong environment including healthy watersheds, rivers, streams, and wildlife.”

These sound more like goals but thanks to the drafters of the CWP, these goals clearly respond to the concerns raised in the 2010 IBCC letter. Here is a summary from it (CWP Chapter 8): “Colorado may not have enough water to meet its future needs if current usage and management trends continue; Colorado’s water management status quo would lead to massive buy and dry of [agricultural] land and more environmental harm to rivers and streams, inefficient land use decisions, and continued paralysis in permitting and building new water supply projects.”

With respect to buy and dry mentioned above, would it be feasible to separately study and “solve” alternative transfer methods (ATMs) without also addressing environmental harm to rivers and streams? Would it make sense to separately study and “solve” current water usage and management trends, such as urban conservation and reuse, without also addressing inefficient land use decisions? Can any one strand of these interdependent issues listed in the IBCC letter be teased out from the others for separate study and resolution? If that were doable, would it be desirable? While a tame problem may be an incidental aspect of the water gap issue, for the most part, we are faced with a wicked problem.

Wicked problems, such as the complex of Colorado water issues described in the IBCC letter, present Colorado water producers and users with choices that are based not just on facts, but also on values. A value represents something that our citizens think is worth having or protecting. Public problems arise when water producers (conservation districts, irrigation districts, water utilities) and water users (agriculture, M&I, and environment/recreational groups) pursue different values. Public choices arise when producers and users must decide which values they want more of and how to avoid giving up one value in order to get more of another.

The following example illustrates this values dilemma: cattle ranchers and environmentalists in the West argue about the appropriate level of grazing fees on public land. A common debate is about the social value of restricting riparian zone grazing for native fish protection versus allowing grazing on this more productive land for beef production. After all the facts are reviewed, at least two values are in conflict here: protecting native fish and increasing beef production. Ranchers and environmentalists usually agree about the desirability of preserving large blocks of open space. As in this example, finding a larger (superordinate) order value is one way to avoid giving up on one value in order to get more of another.

Closer to home, we see an energetic search for ATMs to avoid or minimize agricultural buy and dry. Why is there a search for viable ATMs? We have a value of preserving agricultural land because it produces food, protects open space, preserves wildlife habitat, supports one in ten Colorado jobs, and preserves our farming and ranching heritage. We also have a value of preparing to provide water for a projected population increase of five million people by 2050 who will predominantly live or work in urban/ industrial areas in our State. Finding and adopting some effective ATMs may be seen as a concerted effort to identify a larger order value to meet the needs of both the agricultural and M&I sectors, without giving up one value in order to get another.

Notice that wicked problems can be framed in a way that each side on a particular issue has positive values and that taken one at a time or taken separately, each single value sounds pretty good. In the grazing case, the environmentalists/ recreationalists want to protect native fish and habitat, while the ranchers want to increase the local food supply. In the buy and dry case, the M&I groups want to be able to provide water to new Coloradoans, while the agricultural groups want local farms, food production and open space. In the grazing case, taken separately, no one is against protecting fish habitat or increasing the local food supply. In the buy and dry case, taken separately, no one is against protecting agriculture or taking action to provide water to new Coloradoans. The rub comes when a positive value of one group is placed against a positive value of another group. As one of the commenters on the CWP said, “There is no free lunch; tradeoffs are involved. Someone’s world is always being played in when you are meeting water needs”.

The problem is not bad people or people with the “wrong” values. The wicked problem is that competing and positive values inherently exist in this situation, and that barring an unlikely breakthrough innovation, or finding a superordinate value (as noted above), the parties in these two situations (Western grazing and ag buy and dry) cannot have more of one value without sacrificing another.

In sum, tackling wicked problems requires a much different process of problem solving and decision-making than working on tame problems. What does it take? Here are some general points about what it takes which will be discussed in more detail as they apply to the Trans-Mountain Diversion (TMD) issue and the Conceptual Framework for it in Chapter 8 of the CWP:

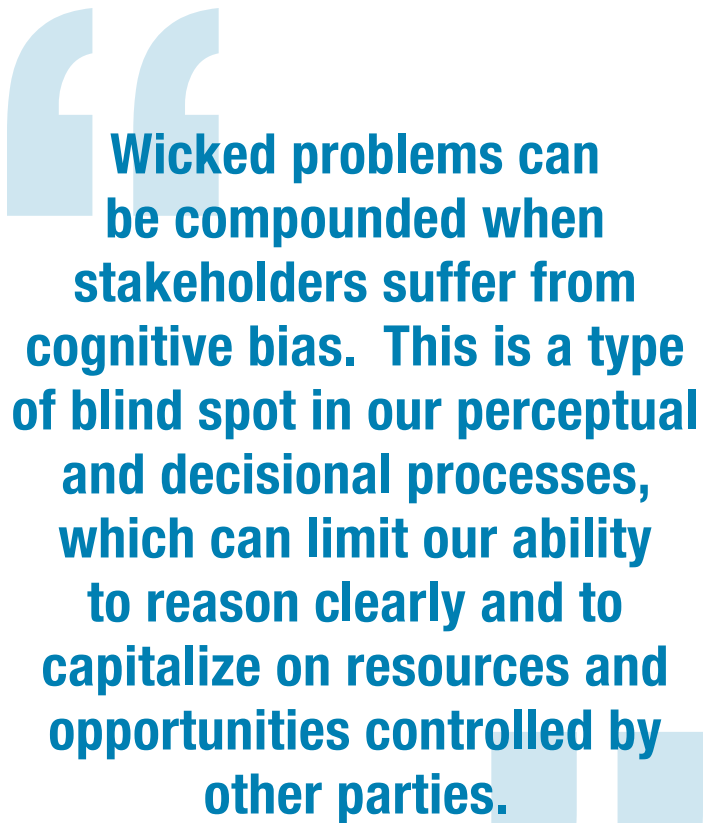
Recognition that there are rarely issues in which only one positive value is relevant (consider the grazing case above);

Recognition that when considered in the abstract and one at a time, any one specific value would receive widespread, if not universal support (for example, consider these values separately, freedom, local control, productive economy, control over one’s destiny, open space, healthy environment);

Recognizing that there are tensions between competing values;

Accepting that the status quo will not get us to our goal and that the State may be facing serious tradeoffs between competing (though cherished) values and policy objectives;

Acknowledging that the other guy at the table has legitimate concerns too;



**Wicked problems can be compounded when stakeholders suffer from cognitive bias. This is a type of blind spot in our perceptual and decisional processes, which can limit our ability to reason clearly and to capitalize on resources and opportunities controlled by other parties.**

Willingness to roll up one’s sleeves to work through the tradeoffs between, and consequences of, each available option to meet some or all of the goals of the CWP.

Assessing where we have come from a generation ago, the Colorado Water Conservation Board (the CWCB), the IBCC and the Basin Round Tables, as drafters of the CWP, appear to have followed these six concepts in important ways. According to one commenter from the Getches-Wilkinson Center at the University of Colorado, “There is a significant change in the landscape from the traditional doctrine of prior appropriation (the DPA). The old view of Denver Water, following the DPA, was that it could go anywhere in the State to appropriate the water [it needed] as long as it was a diversion for a beneficial use. There is a remarkable shift by tough water representatives who are [now] prepared to talk and to acknowledge legitimate concerns other than their own.” Indeed, the CWP may be seen as a strong indicator of a paradigm shift under way from an era of competition for seemingly abundant water resources to an era of more cooperation and dialogue based on a realization of a finite supply of water resources to allocate. It is fair to say there is a growing, though not universal sense, of the interdependence of the basins and the value of collaboration.

*The second part of this series will be featured in an upcoming volume of Colorado Water. Stay tuned!*



## Strengthening Collaborative Capacity for Better Water Decisions

Sylvan Dale Ranch, Loveland Colorado  
November 9-11, 2016



Collaborative decision-making on complex water issues requires acknowledging diverse values and competing interests. It requires thoughtful, inclusive, well-defined processes that build relationships and long-term capacity for problem-solving. The need for collaborative processes and practices to address water challenges in the West is more critical than ever. This is certainly true for Coloradans facing the challenge of crafting definitive actions to address issues laid out in the Colorado Water Plan. Leaders and participants in the water community can benefit immensely from learning best practices to design, facilitate and participate in meaningful collaboration and consensus-building.

### What:

A 16-hour, highly interactive, hands-on training to help water professionals, leaders, and stakeholders deepen and strengthen their skills, tools and capacity for collaboration and consensus around complex water challenges.

### Who Should Attend:

Water professionals, leaders, and stakeholders from Colorado's public, private and non-profit sectors.

### Workshop Framework:

This interactive training workshop will employ basic and advanced principles and best practices and their application through skills-building exercises, case studies, and discussions that explore challenging situations faced by participants. Highlights include:

- Principles, best practices, and skills in collaborative problem-solving
- Interest-based negotiation skills and practice
- Design and facilitation of effective collaborative processes

### When and Where:

- Begins Wednesday, November 9 at 3pm and ends Friday, November 11 at 3pm
- Sylvan Dale Ranch, Loveland CO – <http://www.sylvandale.com>
- This is the second in a series of workshops held at locations throughout Colorado.

### Information and Registration:

- To register, visit <http://cdrassociates.org/training-courses>
- For more information, email MaryLou Smith at [MaryLou.Smith@colostate.edu](mailto:MaryLou.Smith@colostate.edu) or Ryan Golten at [rgolten@mediate.org](mailto:rgolten@mediate.org).



# Hans Albert Einstein

## Albert's Son and Pioneering River Engineer

Robert Ettema, Civil and Environmental Engineering, Colorado State University

### SYNOPSIS

Hans Albert Einstein, a prominent engineer devoted his research to understanding fluvial sediment transportation. The seminar was co-sponsored by the CSU Water Center and the School of Global Environmental Sustainability. Dr. Ettema's book, *Hans Albert Einstein: His life as a Pioneering Engineer*, recently highlighted the engineer's life and accomplishments.

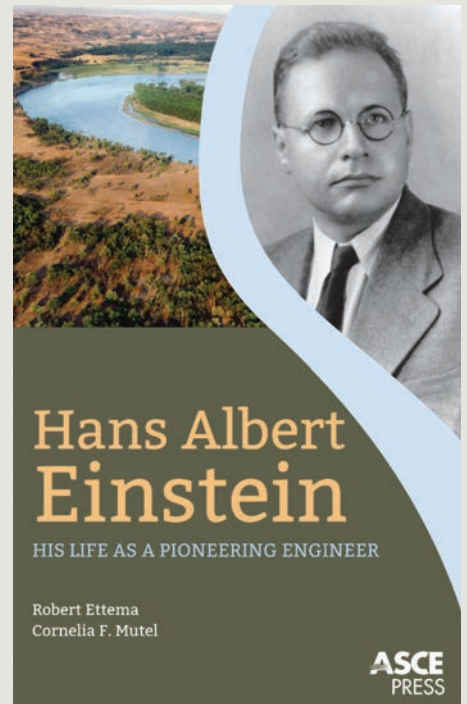
Though working in different fields of science, Hans Albert Einstein and his father Albert Einstein each stood at a scientific frontier. This shared circumstance was a prominent aspect of their complicated father-son relationship. As the early 1900s progressed, a popular quip linked relativity and turbulence as the two toughest topics in science. The quip suggests that only when scientists got to heaven would they finally understand both topics. Albert, whose theory of general relativity was published in 1916, worked on one topic. Hans Albert worked on the other topic, doing pioneering work in the 1930s-1950s, regarding turbulence in the context of alluvial sediment movement in rivers.

The life of Hans Albert Einstein and the importance of his work to understanding rivers form the topic of a recent seminar co-sponsored by the CSU Water Center and the school of Global Environmental Sustainability (SoGES). They also serve as the topic of a book, *Hans Albert Einstein: His Life as a Pioneering Engineer*. The book, written by Robert Ettema and Cornelia Mutel, was published in 2013 by the American Society of Civil Engineers. The book interweaves the elements of Hans Albert's life story, strongly influenced by his father, with technical aspects

of his chosen research field—transport of alluvial sediment by flowing water—and discusses how that transport affects rivers and the interaction of people and rivers. In doing so, they also offer a unique view of Albert Einstein, arguably the most prominent scientist of the twentieth century.

The details of Hans Albert's family life interflow with examinations of his determined search for a formulation to define sediment transport by water. He shared his father's tenacity for pursuing viewpoints intuitively. The seminar and book position Hans Albert's search within the broader history of river engineering, though they can only give a taste of the centuries-old efforts to define order in river behavior. These efforts continue to the present day.

Rivers shape the earth's surface and human society. Mountains and highlands erode, producing rocky debris. Gravity pulls debris and water downslope, concentrating them along swelling watercourses that flow as sinuous ribbons of water and streams of sediment. Water transports much of the debris, breaking it down into particles of various sizes. Fine sediments, clays and silts, mix throughout flowing water, often coloring it a muddy or tawny brown. Coarser sediments, sands and gravels, move more slowly and deeper within a river, rumpling its bed with bars and dunes. Still coarser particles, cobbles and boulders, sit motionless in the upper reaches of watercourses, waiting for the occasional flood to tumble them downstream. As flows of both water and sediment, rivers nurture the lives of plants, fish and other animals, and humans, who rely on them for food production, transportation, industrial use, and



*This book is a chronological walk through Hans Albert's life and his contributions to our understanding of river behavior. It includes first-published discussion of his interactions with his parents*

power. Yet their flow extremes, which can cause flood and drought, erosion and sedimentation, at times bring untold misery and widespread damage. Since ancient times, people have known that river flows are sediment-laden, but only since about the start of the 1900s have people begun understanding how flowing water and sediment interact in ways that animate and complicate rivers.

By virtue of the period in which Hans Albert lived (1904–1973), his formal education in Switzerland, the trans-Atlantic span of his life, and his name, the story of Hans Albert's life forms a convenient narrative for describing how people came

to better understand rivers. His life was shaped by the disruption that splintered his family when he was ten. Despite his father's physical absence, Hans Albert's education and development continued to be directed by his father, who later obtained positions for his son that pulled the younger Einstein into a productive career as a researcher and educator. The father-son relationship was played out against a backdrop of family quarrels and illness, world war tensions, U.S. concerns about soil conservation and erosion, and the development of hydraulic engineering, the branch of civil engineering dealing with how water flows.

Hans Albert's work can be characterized as an intellectual quest to develop a practical, mechanics-based method for accurately predicting magnitudes of sediment transport in river and stream flows. He quickly found that beyond gravity com-

puting water downslope, few things are clear-cut about rivers and how they move water and sediment. In the first place, all boundaries of an alluvial river channel are potentially free to move; water surfaces rise and fall, channel beds can erode down or build upward, and channels may shift sideways or alter in sinuosity. Moreover, the shape and roughness of a channel intimately relate to flow depth, flow velocity, and the rates at which water and sediment move along a channel, and vary with changing flow and sediment conditions.

The mechanics-based view, at the heart of contemporary scientific and engineering thinking, guided Hans Albert Einstein's approach to understanding and formulating sediment transport by flowing water in rivers. It enabled him to make substantial technical contributions and become recognized as the world's foremost expert on sediment problems

in rivers, extensively advising engineers coping with river-sediment problems in the United States and abroad.

In particular, Hans Albert and a handful of engineers drew attention to the importance of fluid mechanics principles and statistics, especially involving flow turbulence, when describing and formulating sediment movement by flowing water and determining the behavior of channels conveying water and sediment. His work helped chart the extent to which these principles could be used for practical prediction of river behavior. In this effort, he embodied the mix of challenges and successes experienced by many engineers who have attempted to use mechanics-based equations to formulate the complicated behavior of water and sediment movement in alluvial channels.

The Einstein name promised new breakthroughs. Hans Albert delivered



*Dr. Robert Ettema, professor in the Department of Civil and Environmental Engineering at CSU, presenting on his book of Hans Albert Einstein His Life as an Engineer. Photo by Beth Plombon, CSU Water Center*



Albert expressed interest in Hans Albert's education. In his letters to Hans Albert, Albert often included mathematics problems, tried to guide his studies, and in later years explained his own research to him. Thus Albert laid the groundwork for a shared intellectual life with Hans Albert.

several, yet his work reveals how often the almost overwhelming abundance of detail and variability in the physical characteristics of rivers forces engineers and scientists to make simplifying assumptions and to resort to empiricism and other less scientifically satisfying concessions in order to make their formulations work for practical purposes. His work also highlights the controversies that arise among engineers and scientists attempting to address difficult problems via different approaches. Accordingly, recurring themes running through this book's description of Hans Albert's work are innovation and compromise. Promising new approaches based on mechanical principles yielded fresh insights but run aground on sandbanks of complexity during attempts to arrive at reliable engineering methods. Make-shift approximations in formulation are commonly needed, and partially work, but inevitably need more study.

Hans Albert's contributions were important because rivers, large and small, play vital roles in the economy of many regions. Moreover, his contributions were made during an especially active period of major engineering projects that altered the water flow and bed-sediment transport behavior of several large rivers, when engineers were rapidly awakening to the potential problems that sediment transport posed for their projects. The problems commonly revolved around two central questions: *How much bed sediment can a river flow transport? And how does flow depth vary with flow rate?* Answering these questions is complicated by the ability of flowing water to erode, transport, and deposit sediment, actions that enable river channels to move up, down, and sideways and to adjust their roughness.

In 1933, when Hans Albert began as a graduate student in Switzerland, engineers could not reliably answer these questions.

However, by capitalizing on momentous advances in fluid mechanics and laboratories, Hans Albert achieved remarkable progress toward addressing them. The detailed insight into bed-particle movement gained while a student in Switzerland, then as an engineer working for the U.S. Soil Conservation Service, and subsequently as a Berkeley professor led to his major work, the now-classic U.S. Department of Agriculture Bulletin 1026, "The Bed-Load Function for Sediment Transportation in Open Channel Flows." When Bulletin 1026 appeared in 1950, it was the most comprehensive method, the "Einstein method," for estimating how much bed sediment a river flow may transport as bed load and suspended load; their sum yields an estimate of total load of bed sediment transported. Moreover, Bulletin 1026 introduced a new method for estimating flow depth in channels subject to changing bed roughness (caused by changing alluvial dune or bar size) as sediment load varied.

The Einstein name was charged with promise of major fresh insights and thus drew attention, but it was Hans Albert's evident grasp of sediment-transport mechanics, together with his direct, plain demeanor that established his reputation. His consulting services became widely sought by a number of agencies facing a wide variety of sediment-related concerns – including along the Missouri, Arkansas, Mississippi and Rio Grande Rivers. In due course, the growing recognition for Hans Albert's expertise would lead him to be hailed as "Mr. Sediment Movement" during the 1963 Federal Interagency Sedimentation Conference, a meeting of leading U.S. professionals concerned with sediment-transport problems in rivers.

# Jordan Suter

*Jordan Suter, Agricultural and Resource Economics, Colorado State University*



I joined the Department of Agricultural and Resource Economics (DARE) at CSU in the summer of 2013 after serving as an Assistant Professor of Economics and Environmental Studies at Oberlin College in Ohio. Specifically, my scholarship focuses on issues at the intersection of land use and water resources. In a semi-arid climate, such as Colorado, nearly all land use changes have implications on water resources and vice versa. As an economist, I seek to understand the individual and group incentives that drive land and water use. These incentives are influenced in important ways by resource management policies that are in place and the physical characteristics of the resources themselves. My work incorporates interdisciplinary thinking from the fields of engineering and the physical sciences whenever possible. My academic training began at Vanderbilt University, where I was exposed to the study of environmental economics as an undergraduate through a senior honors thesis that focused on the economics of programs aimed at promoting biodiversity. That experience propelled me towards graduate school at Cornell University, where I received my MS and PhD in Resource Economics. The tools

and methods of inquiry that I developed in my coursework and dissertation at Cornell have provided a strong platform to address a range of challenging resource management issues, but I have also embraced the necessity for constant learning and personal development to incorporate new methods into my work.

My research program addresses land use and water resource economics using methods of experimental economics as well as analysis of spatially derived data. The economics experiments that I conduct assess how the imposition of resource management policies influences behavior in situations where we do not have adequate naturally occurring data to carry out such an assessment. As an example, I have conducted experiments on policies to reduce non-point source water pollution, which is a challenging economic problem due to the fact that individual pollution contributions cannot be observed. To overcome this challenge, I have tested policies in a laboratory setting that provide incentives to individuals based on outcomes that can be observed at the group (watershed) level. We have found that such policies can be effective and that allowing groups the opportunity to communicate can dramatically improve behavior, even when individual decisions are not directly observable. The experiments are conducted using real financial rewards, which are determined by the actual decisions of the individual and other group members. Although the experiments are typically conducted with subject pools composed of students, I have also replicated the policy experiments using agricultural professionals.

In addition, I have evaluated the performance of water quality trading markets as well as behavior related to the management of groundwater and other shared resources. The distinct advantage of conducting the economic experiments is that the experimenter is able to change

one element of the decision environment at a time, to understand the causal impact of these changes on behavior. Such causal identification is often not possible using naturally occurring data.

A second leg of my research program uses spatially derived data to understand policy impacts on conservation outcomes. This line of research evaluates participation in land and groundwater conservation programs that compensate agricultural landowners for taking sensitive and water-intensive land out of production. I am also working with colleagues at CSU to predict the economic and hydrologic impacts of groundwater conservation policies. This research is designed to provide feedback to groundwater users on both the short and long-run effects of policies that reduce groundwater use from the perspective of farm profits and sustainability. To make these assessments, we are constructing linked hydro-economic models that allow us to predict policy impacts over many years.

My current teaching responsibilities at CSU involve three courses: a senior-level capstone course for DARE's new major in Environmental and Natural Resource Economics, a masters-level course that covers economic welfare and public policy analysis, and a graduate level class focused on land use economics and spatial modeling.



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## 2015 Norman Medal Recipient

*Jose D. Salas, Civil and Environmental Engineering Professor Emeritus, Colorado State University*

The American Society of Civil Engineers (ASCE) selected Dr. Jose D. Salas, Civil and Environmental Engineering Professor Emeritus, Colorado State University (CSU), and Dr. Jayantha Obeysekera, CSU Ph.D. 1981, Chief Modeler of the South Florida Water Management District, for the prestigious 2015 Norman Medal. They co-authored the paper, “Revisiting the Concepts of Return Period and Risk for Nonstationary Hydrologic Extreme Events”, which was published in the Journal of Hydrologic Engineering of ASCE and its specialty organization, the Environmental and Water Resources Institute (EWRI). The Norman Medal is the highest honor granted by ASCE for a technical paper to recognize achievements in research related to Civil Engineering. The announcement of the award commended that the selection committee particularly noted “the presentation of a convincing concept and needed statistical techniques that advance knowledge of nonstationarity in hydrologic observations due to anthropogenic causes and natural processes.” The award was presented during the ASCE Annual Convention in New York City on October 13, 2015. The referred paper was also selected as the 2015 Best Paper published in the journal and the award was presented at the EWRI/ASCE World Environmental & Water Resources Congress in Austin, Texas on May 19, 2015.

Over almost four decades, Professor Salas and his graduate students and collaborators have made significant contributions in diverse areas of Hydrology and Water Resources. He developed stochastic analysis techniques and models of hydroclimatic processes such as precipitation and streamflow, analysis and modeling of multisite complex river systems, aggregation and disaggregation of hydrologic data, non-parametric methods for streamflow simulation, spatial analysis for regionalizing precipitation and infiltration, neural networks for drought identification and agricultural crop yield assessment, methods for modeling and simulating intermittent hydrological processes in arid basins, and analysis and modeling of extreme events such as floods and droughts in non-stationary environments. Of note is the use of these techniques for better understanding the flow variability in the Colorado River, the Nile River, and the Great Lakes Basins. His early work in the 1970s suggested that the sudden shifts observed in some hydrological processes may be forced by large scale atmospheric and oceanic processes, and that stochastic models commonly used for streamflow time series

generation can be conceptually (physically) justified. In the process, he has been a dedicated educator and mentor as evidenced by his books and articles, and the excellent graduate students he has guided at CSU.

A native of Lima, Perú, Salas obtained his Bachelor of Science and Civil Engineering degrees from the National University of Engineering (UNI) in Lima. He came to the United States with a Ford Foundation Scholarship and obtained his Master of Science degree in Civil Engineering (Hydraulics) from CSU and the Ph.D. degree in Civil Engineering (Hydrology and Water Resources) also from CSU. Salas has been a member of the CSU College of Engineering faculty since 1976. Previously he worked for the National Hydraulics Laboratory of Lima, Peru, the University of Pittsburgh, the Ministry of Agriculture of the Peruvian government, and the Interamerican Institute for Water and Land Development in Venezuela. Salas teaching and research activities at CSU have been in the area of hydrology and water resources. While at CSU he has been major professor of 42 M.S. and 37 Ph.D. students. He has written over 250 scientific and technical papers and reports, he is the main author of the book, “Applied Modeling of Hydrologic Time Series”, Water Resources Publications, 484 p., wrote Chap.19, McGraw Hill Handbook of Hydrology, 1993, co-authored 4 Proceedings Books, and authored and co-authored 12 other chapters in books & handbooks. Furthermore, Professor Salas has been involved in consulting activities for national and international organizations and presented keynote conferences and invited lectures and seminars in many countries worldwide.

Professor Salas has received numerous awards in the past and says the Norman Medal is undoubtedly the one that makes him the most proud. At the award ceremony, Salas expressed his gratitude to the colleagues who made the nomination and wrote supporting letters, to the Editor of the ASCE Journal of Hydrologic Engineering, to the Awards Committee of ASCE/EWRI, and especially to his former graduate students and collaborators for the excellent work they made throughout their stage at CSU. Salas indicated that the honor received is an honor for all his students and collaborators as well.

*Shown in the picture are Dr. J.D. Salas (middle right) holding the Norman Medal, Dr. J. Obeysekera (middle left) holding a Diploma Award, and Dr. R.D. Stevens, ASCE President (left) and T.W. Smith, Executive Director (right). Photo by David Hathcox Photography*

# Water Research Awards May 13, 2016 - July 13, 2016

**Bailey, Ryan**, Colorado Water Conservation Board, Quantifying Pumping-Induced Streamflow Depletion in the South Platter River Corridor, \$45,310

**Bailey, Ryan**, Colorado Water Conservation Board, Developing a Refined Groundwater Flow Model for the LaSalle/Gilcrest Area, \$49,234

**Bauder, Troy A.**, Soil and Crop Sciences, Colorado Department of Agriculture, Training and Education for Agricultural Chemicals and Groundwater Protection, \$235,000

**Cabot, Perry**, Colorado Water Conservation Board, Agronomic Responses to Partial and Full Season Following of Alfalfa and Grass Hayfields, \$4,994

**Chavez, Jose L.**, Civil and Environmental Engineering, Colorado Water Conservation Board, Colorado Irrigation Center Design and Concept Development, \$49,876

**Covino, Timothy P.**, Natural Resource Ecology Laboratory, United States Department of Agriculture, United States Forest Service, Rocky Mountain Research Station Colorado, Post Wildfire Watershed Nitrogen Retention Processes, \$84,000

**Covino, Timothy P.**, Ecosystem Science and Sustainability, National Science Foundation, Geosciences, Quantifying and Predicting the Attenuation of Downstream Fluxes Associated with Beaver Meadows, \$279,066

**Ebel, Gregory David**, Microbiology, Immunology, and Pathology, City of Fort Collins, Testing of Mosquito Pools for West Nile Virus, City of Fort Collins 2016, \$45,539

**Gates, Timothy**, Colorado Water Conservation Board, Data Collection and Analysis in Support of Improved Water Management in the Arkansas River Basin, Phase 3, \$50,000

**Loftis, Jim C.**, Civil and Environmental Engineering, Department of the Interior, National Park Service, Water Resources Tools and Database Development, \$184,280

**Malers, Steve**, Colorado Water Conservation Board, Enhanced Open Data for Colorado's Water Resources, \$50,000

**Nelson, Peter August**, Civil and Environmental Engineering, Colorado Division of Parks and Wildlife, Multidimensional Hydraulic Modeling of Whitewater Parks, \$51,621

**Rathburn, Sara L.**, Geosciences, Department of the Interior, National Park Service, Wood Loading and Jam Characteristics Following Disturbances on the Upper Colorado River, Rocky Mountain National Park, \$15,203

**Ruzycki, Thomas S.**, Center for the Environmental Management of Military Lands, United States Department of Agriculture, United States Forest Service, Rocky Mountain Research Station, Colorado, Unit Stream Power Erosion and Deposition (USPED) Model Validation, \$25,000

**Sale, Thomas C.**, Civil and Environmental Engineering, Town of Castle Rock, Colorado, 2016 Studies Supporting Sustainable Use of the Denver Basin Aquifers in the Vicinity of Castle Rock, \$25,000

**Sale, Thomas**, Colorado Water Conservation Board, Aquifer Storage and Recovery: Fountain Formation in Northern Colorado, \$50,000



Telluride Gorge  
Photo by Flickr User lukexmartin

# Water Calendar

## September

- 11-14 2016 RMSAWWA/RMWEA Joint Annual Conference; Keystone, CO**  
Join annual conference of the Rocky Mountain Section of the American Water Works Association and the Rocky Mountain Water Environment Association  
[rmsawwa.org/](http://rmsawwa.org/)
- 11-14 31st Annual WaterReuse Symposium; Tampa, FL**  
Water professionals attend to learn about the latest innovations in water reuse, to network with colleagues, and to find solutions to critical water supply issues.  
[wateruse.org/news-events/conferences/annual-waterreuse-symposium/](http://wateruse.org/news-events/conferences/annual-waterreuse-symposium/)
- 15 Imagine a Day Without Water; CSU Campus**  
Join us on September 15, 2016, as we raise awareness and educate about the value of water.  
[imagineadaywithoutwater.org/](http://imagineadaywithoutwater.org/)
- 16 Colorado River District Annual Seminar; Grand Junction, CO**  
Every Autumn, the Colorado District hosts a seminar on current and sometimes historical Colorado River Basin issues.  
[coloradoriverdistrict.org/events/annual-water-seminar/](http://coloradoriverdistrict.org/events/annual-water-seminar/)
- 28-29 Annual 21st Century Energy Transition Symposium; Fort Collins, CO**  
Formally known as the Natural Gas Symposium. The Energy Institute at Colorado State University is hosting the sixth annual Natural Gas Symposium and the symposium is open to everyone.  
[energy.colostate.edu/p/natural-natural-gas-symposium-2015gas-symposium-2015](http://energy.colostate.edu/p/natural-natural-gas-symposium-2015gas-symposium-2015)

## October

- 2-6 International Trout Congress; Bozeman, MT**  
[troutcongress.org/](http://troutcongress.org/)
- 11-13 2016 Sustaining Colorado Watershed Conference; Avon, CO**  
*A River Runs Out of It, Building Strong Upstream Communities*  
[coloradowater.org/scw-conference-2016](http://coloradowater.org/scw-conference-2016)
- 11-14 Ninth International Conference on Irrigation and Drainage; Fort Collins, CO**  
The theme of the Conference is Improving Irrigation Water Management — Latest Methods in Evapotranspiration and Supporting Technologies.  
[uscid.org/16coconf.html](http://uscid.org/16coconf.html)
- 26-27 South Platte Forum; Loveland, CO**  
[southplatteforum.org/](http://southplatteforum.org/)

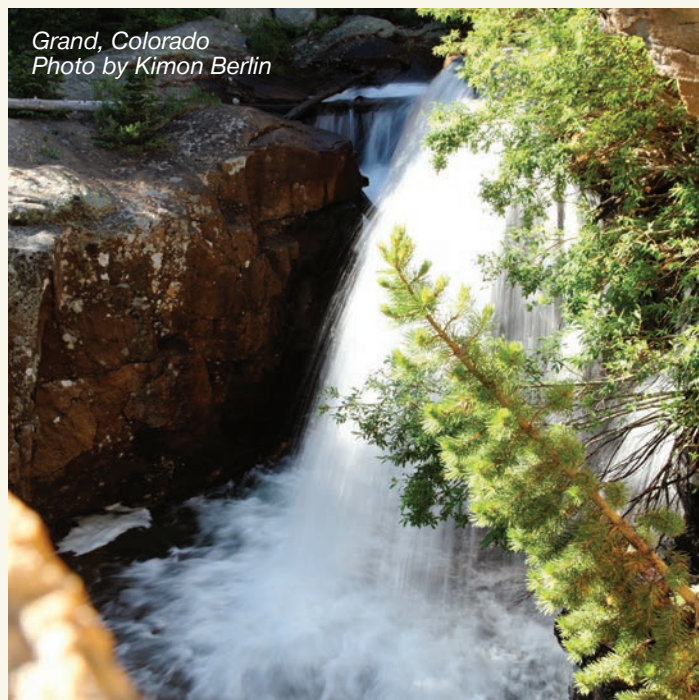
- 30- Nov. 2 Water Infrastructure Conference and Exposition; Phoenix, AZ**  
[awwa.org/conferences-education/onferences/water-infrastructure.aspx](http://awwa.org/conferences-education/onferences/water-infrastructure.aspx)

## November

- 2-3 2016 Upper Colorado River Basin Water Forum; Grand Junction, CO**  
Complex Systems in Flux: Changing Relationships between Water, People, and the Environment  
[coloradomesa.edu/water-center/forum/](http://coloradomesa.edu/water-center/forum/)
- 13-17 AWRA 2016 Annual Water Resources Conference; Orlando, FL**  
[awra.org/meetings/Orlando2016/](http://awra.org/meetings/Orlando2016/)
- 13-17 Water Quality Technology Conference and Exposition; Indianapolis, IN**  
[awwa.org/conferences-education/conferences/water-quality-technology.aspx](http://awwa.org/conferences-education/conferences/water-quality-technology.aspx)
- 14-16 NWRA Annual Conference; San Diego, CA**  
[nwra.org/2016-annual-conference.html](http://nwra.org/2016-annual-conference.html)

## December

- 2 Colorado WaterWise 8th Annual Water Conservation Summit; Denver, CO**  
[coloradowaterwise.org/event-2182580](http://coloradowaterwise.org/event-2182580)



Grand, Colorado  
Photo by Kimon Berlin



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*Dead Horse Creek  
Photo by John B. Kalla*