# Colorado Water

July/August 2018

## RECREATION AND TOURISM

Colorado State University

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*A hiker on the Beaver Creek Wilderness Study Area. Photo by the Bureau of Land Management.*

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References can be found in the online version of this newsletter at http://cwi.colostate.edu/newsletters.asp

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




# COLORADO **WATER**

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# *Director's* LETTER

Colorado is viewed nationally and internationally as a recreational playground for year-round outdoor activities. Recreation and tourism are one of the top industry sectors in the state, accounting for about 5% of the state's GDP and 11.3% of jobs. And the recreational sector is still growing. According to the Colorado Tourism Office, for the eighth consecutive year, Colorado continued its record-setting growth in visitors, traveler spending, and tax generation in 2017.

Recent studies show that Colorado attracted 84.7 million U.S.-based travelers, plus one million international visitors to the state last year. Collectively, they spent $20.9 billion and generated $1.28 billion in state and local tax revenue. The Colorado travel industry supported 171,000 jobs and earnings of more than $6.3 billion.

The recreation and tourism industry in Colorado is an integral part of the state's economy, and it can greatly be impacted by changing weather and climate conditions. Whether the recreation is snow, river, lake, forest or beer-based, water supply conditions are foundational to the experience.

This year will be particularly important to follow given the current drought in southern Colorado, snowpack that melted quickly in a majority of the state, as well as the upcoming monsoon season. It will be interesting to see if the current drought will impact the upcoming ski season bookings for next winter and tourism for the remaining portion of this year. During the recent 416 Fire, the Durango and Silverton Narrow Gauge Railroad reported they canceled about 31,000 tickets, and furloughed about 150 seasonal workers, resulting in about a $33 million impact to the local community.

Recreation and tourism in Colorado is largely dependent upon our water resources, and there are aspects of recreation and tourism in Colorado that include both the rural and urban areas of the state including: rafting, boating, fishing, skiing, snowmobiling, and snowshoeing. Yet from a water manager's perspective, tourists and local recreationalists do not pay to use that water; they are essentially playing on someone else's water (usually agriculture's) as it moves downstream to the water right owners. Competition for scarce water supplies between municipal, industrial, and agricultural sectors directly impacts water availability for recreation, as clearly recognized in Colorado's Water Plan. A changing snowpack in particular will likely be disruptive to the skiing industry's business model.

This issue of *Colorado Water* newsletter focuses on Colorado's water- and snow-based recreation and tourism, with an eye towards understanding how weather and climate may impact this important sector of our economy and our quality of life. Increasing our understanding of what drives and enhances water-based recreation, coupled with an improved ability to forecast and communicate hydrologic data, can help us continue to improve and sustain Colorado's recreation and tourism.

*Reagan Waskom*
Director, Colorado Water Institute

*Contestants in the 2017 Mount Evans Bicycle Hill Climb, Mount Evans, Colorado. Photo by Reid Neureiter.*

*A kayaker braves turbulent waters. Photo by Visit Fort Collins.*

# Tourism and Recreation at the Water Resources Table

Joseph T. O'Leary, Human Dimensions of Natural Resources, Colorado State University;
Christina Minihan, Human Dimensions of Natural Resources, Colorado State University

SYNOPSIS

Water resources are an integral part of the recreation and tourism experience. More than half of Coloradans report involvement in water-based activities, and these opportunities contribute to tourism being ranked as the second largest economic activity in the state. Population growth, an aging population, the growth of immigrant groups, and commitment to stewardship all have powerful impacts on water resources, recreation, and tourism in the next ten years.

From a historical perspective, Colorado has been an exceptional place for outdoor recreation opportunities and a major destination for both U.S. and international travelers. As a focus for public and private organizations, water resources in every form—rivers, streams, reservoirs, lakes, snow—have been key elements in promoting visitation and facilitating participation. At the same time, these resources are under continuing pressure to serve many competing demands. How might we consider how outdoor recreation and tourism might be served at the water resources table? First, let us provide a little background.

## Tourism

Tourism is identified by the Colorado Tourism Office (CTO) as the second largest economic activity in the state. Overnight and day trips in Colorado reached about 82 million trips in 2016 and spending grew for domestic, overnight and day visitors an average of 5-8% to almost $38 billion (Longwoods International, 2017). Outdoor and tourism trips that include outdoor recreation activities are important and have grown faster than other trip types. The highest per capita expenditures in 2016 were for people doing ski trips, an average of $1,306 per person. Water-related activities reported by vacationers as part of their experience included swimming, skiing, and fishing.

Visitation to Colorado has tended to exceed the national norms, an accomplishment certainly tied to the attractiveness of the state and the efforts of the public and private sectors to grow economic activity. But this growth also comes with challenges that must be addressed with forward thinking. These are evident in a recent strategic report that identified four key "pillars" for moving the state agendas forward—compete, create, steward, and advocate. Although one could make a case for examining each of these areas with respect to water resources, the two we might choose are compete and steward (CTO, 2017). Competing suggests that the view to the future will be to maintain and grow domestic and international visitors to the state, thereby also increasing the impacts on

*Table 1. Outdoor activity participation in Colorado by percent of population (Source: CPW 2014:40).*

| Activity | % Population | Rank |
|---|---|---|
| Walking | 66.3% | 1 |
| Hiking/Backpacking | 51.9% | 2 |
| Picnicking | 37.1% | 3 |
| Fishing | 36.4% | 4 |
| Tent camping | 35.6% | 5 |
| Skiing or snowboarding at a ski area | 33.5% | 6 |
| Swimming (outdoors) | 30.2% | 8 |
| Snowshoeing or cross country skiing | 17.7% | 14 |
| Sledding/tubing | 15.7% | 16 |
| Power boating | 13.3% | 20 |
| Whitewater rafting | 9.3% | 23 |
| Backcountry skiing | 7.5% | 25 |
| Water skiing | 7.0% | 27 |
| Ice skating (outdoors) | 5.3% | 29 |
| Kayaking | 5.1% | 30 |
| Snowmobiling | 5.0% | 31 |
| Ice fishing | 4.9% | 32 |
| Canoeing | 3.6% | 34 |
| Waterfowl hunting | 3.4% | 35 |
| **All trail activities (including walking/jogging** | **82.9%** | |
| **All water activities** | **57.3%** | |
| **All wildlife activities** | **29.4%** | |

resources. But complementing this view is a clear realization that stewardship much be considered if there is to be a sustainable future.

## Outdoor Recreation

There are a number of key participants in the outdoor recreation arena in Colorado, attempting to understand what is taking place and issues and direction looking into the future. Colorado Parks and Wildlife (2014) developed a comprehensive outdoor recreation plan for the state that looked at a number of issues including participation in activities and future direction and opportunities. Perhaps one of the most interesting results was that 90% of the residents of Colorado reported participation in some form of outdoor recreation. This is much higher than the average reported for the U.S. in the American Time Use Survey done by the Bureau of Labor Statistics (2016), that suggested about 47% of the population reported outdoor recreation activity involvement.

In Colorado, walking, hiking, and picnicking are identified as the top three activities that people do. Fishing is ranked fourth, while skiing/snowboarding, and swimming are ranked sixth and eighth respectively. Of all activities Coloradans report doing, 57% report water activity participation. Water resources are clearly an important setting for recreation involvement.

Colorado Parks and Wildlife (CPW) also integrated a perspective on the relationship of outdoor recreation and tourism. Their focus was on outdoor, touring, and skiing trips, accounting for over 25% of all overnight visitors and 51% of all marketable trips. These accounted for over $3 billion in visitor spending in Colorado in 2011 or about 35% of all visitor spending.

Visitor spending is a key theme in the various examinations of recreation in the state since it drives economic and social development. At the state level, outdoor recreation helps create about $35 billion in economic activity and helps in the creation of almost 315,000 jobs (CPW, 2014). The importance of these impacts has also been underscored by the Boulder-based Outdoor Industry Association (OIA, 2017) who outlined the importance of outdoor recreation to the U.S. economy and received support from the two U.S. Senators from Colorado (not an accident given the importance of recreation in the state) to have the U.S. Bureau of Economic Analysis report through their ongoing accounts system on the economic role that outdoor recreation plays in GDP for the nation.

Similarly, Colorado established in 2015 the Outdoor Recreation Industry Office (ORIO), which is one of only seven state ORIOS in the county. The goal of the office is to help "…industry and communities thrive in Colorado's great outdoors" (ORIO, 2018). The major areas of emphasis for the organization are economic development, conservation and stewardship, workforce training, and health and wellness. Colorado Parks and Wildlife also echoes this focus in their identification of their outdoor recreation priority areas-education, funding, cooperation between recreation interests, healthy lifestyles, and communities and stewardship (CPW, 2014:7).

*Tubers reveling in Colorado's natural water resources. Photo by Christina Minihan.*

*A couple enjoying Colorado's great fishing areas. Photo by Minturn Anglers.*

## Future Impacts

According to institutions that are quite involved with strategic planning, the real problem is not in selecting a favorite future but in identifying trends, events, factors, forces, and other elements that will define alternative futures and impact the activities we are interested in. Based on patterns that have been identified in examining tourism and recreation above, the following trends and major changes in lifestyles and basic demographics will substantially impact the demand for (it will be growing) and effective supply of recreation and tourism opportunities.

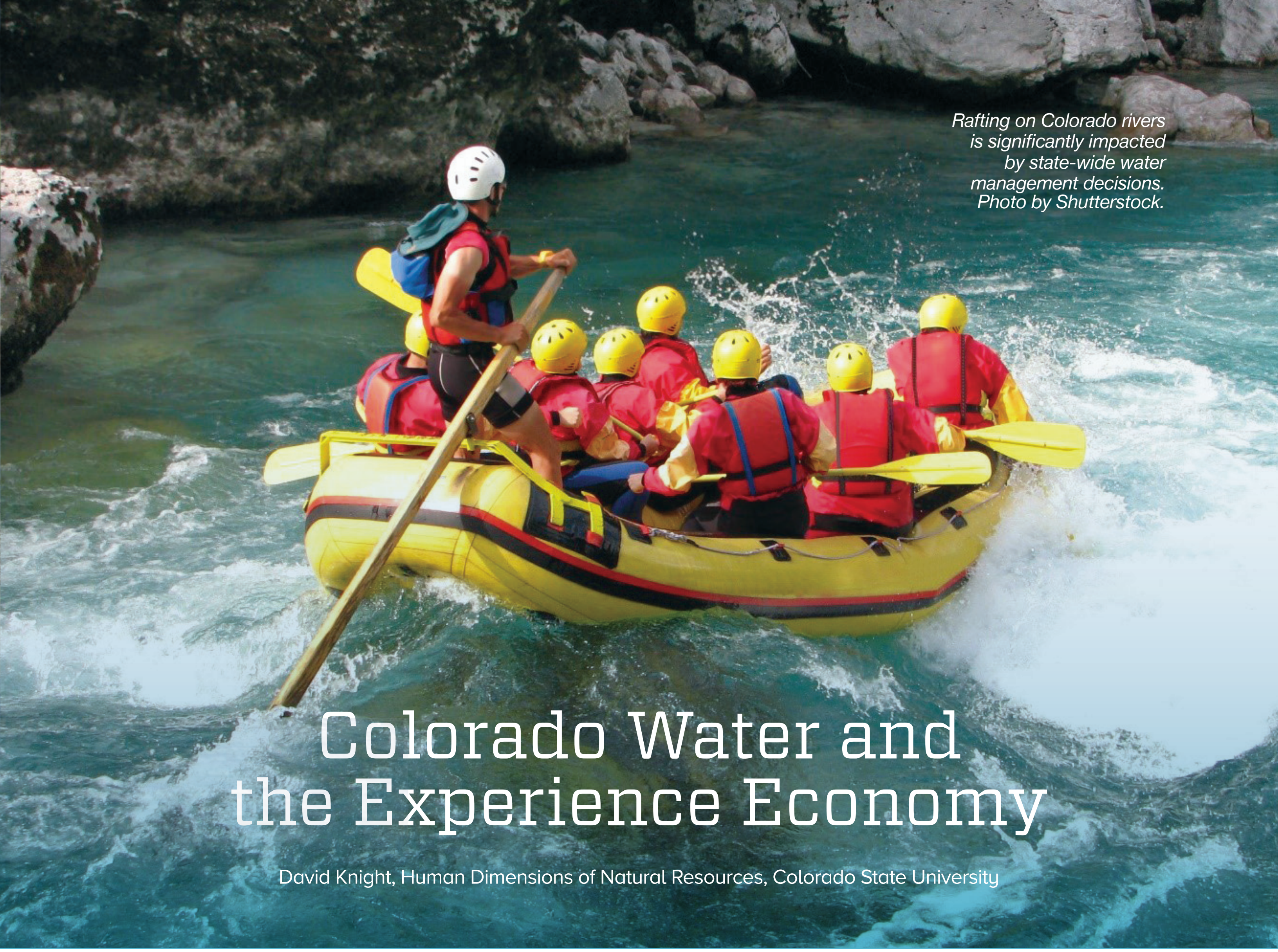
1. Stewardship is consistently identified as critical by all public and private organizations. And because of the demands on water resources in the state, this will be a key issue to accommodate the visitor and sustainability of quality and quantity of the resource.

2. In Colorado, the population is expected to have grown by almost 20% between 2010 and 2020 (5 million to almost 6 million people) and another 20% from 2020 to 2030. Largest growth areas are projected to be in the Northern Front Range and the Denver-Boulder areas (Colorado State Demography Office, 2017). The Colorado Water Plan identifies this issue as a powerful influence on demand and supply and is specific about having to address it with recreation in mind.

3. Age has a powerful impact on recreation and travel experience choices and must be considered in terms of how these impact water use. Colorado is growing in population but is also aging. Garner (2017) reports that by 2030, Colorado's population over the age of 65 will grow to be 77% larger than it was in 2015, from 719,000 to 1,270,000 (Colorado State Demography Office, 2017; Garner, 2017).

4. The role of ethnic groups, immigration, and immigrants in Colorado will continue to be important in how recreational activities are pursued and what the mix of activities chosen will be. The immigrant population is growing faster and is younger than the general population.

The implications of interest and commitment to recreation and travel, plus these major social and demographic changes for recreation and tourism in Colorado are substantial. Additional scenarios could be added to those that have been outlined. However, what we do know is that the future will be exciting, providing more challenges and opportunities than we have ever seen. As the Colorado Water Plan points out, failure to anticipate and take action is not a choice. They represent a critical component of the Colorado economic framework.



Rafting on Colorado rivers is significantly impacted by state-wide water management decisions. Photo by Shutterstock.

# Colorado Water and the Experience Economy

David Knight, Human Dimensions of Natural Resources, Colorado State University


## SYNOPSIS

This article introduces readers to trends in the Colorado experience economy, linking recreation and tourism in the state to concerns over freshwater resources. It focuses on the growing popularity of adventure tourism and health and wellness tourism, highlighting the importance of increased activism for addressing these concerns among anyone who not only depends on, but enjoys one of Earth's most precious natural resources.


## Colorado Water, Recreation, and Tourism

The rise of the so-called "experience economy" since the late 1990s appears little related to global concerns over water quality and supply (Pine & Gilmore, 1999). However, growing demand for quality experiences in recreation and tourism is creating challenges for more and more communities around the world struggling to determine not only how water can be sustainably distributed and *consumed*, but also how it can be *enjoyed*.

In the state of Colorado, as in many destinations with an international reputation for natural resource tourism, water and tourism managers face increasing pressure from both significant population growth and increased demand for recreation and tourism. Studies suggest that Colorado's current population of 5.7 million is set to double by 2050, generating a water shortage equivalent to the yearly supply needed for some 2.5 million residents unless climatic and water consumption trends are sufficiently addressed (Colorado Water General Fact Sheet, 2017).

The possible water shortage linked to Colorado's population growth is substantial, but it fails to account for additional water demand due to increased visitation. From 2009 to 2016, Colorado saw a 37% increase in annual arrivals (the national average was 17%), and recent tourist surveys have placed Colorado at the top of the "state wish list" for so-called adventure travelers, who often engage in water-dependent activities such as skiing, fishing, and rafting (Beckmann, 2015; Sealover, 2017).

To address Colorado's water challenges, collaborative

working groups representing each of the state's major river basins (e.g., the Rio Grande Basin or the Arkansas Basin) have helped design and implement a holistic state-wide water strategy known as Colorado's Water Plan (2015). The Plan emphasizes institutional flexibility, collaboration and "…a robust planning process to facilitate local solutions" to Colorado water concerns (Waskom, 2012, p. 1). By touching on water's recreational and ecological value as well, the Plan highlights the importance of non-consumptive water use in a state where 86% of water supports agriculture and another 11% is allocated to meet urban and large industry demand (Colorado Water General Fact Sheet, 2017).

In the years ahead, sustainably managing Colorado water will require more than improved infrastructure and ongoing collaboration between decision-makers and residents. It will require both activism and engagement from individuals enjoying any aspect of Colorado's outdoor recreation and tourism industries, which collectively generated some 49 billion USD in 2016 (Worthington, 2017). The remainder of this article briefly outlines several considerations in this regard focusing on two areas that continue to grow in popularity: 1) adventure tourism and 2) health and wellness tourism.

## Adventure Tourism

So-called adventure tourism (AT) overlaps with other kinds of tourism to varying degrees (e.g., ecotourism), as well as with many aspects of outdoor recreation in general. While the boundaries of AT are fuzzy, Hall (1992) provides one of the more common descriptions of AT as being comprised of "a broad spectrum of outdoor touristic activities, often commercialized and involving an interaction with the natural environment away from the participants' home range and containing elements of risk" (p. 143). The Adventure Travel Trade Association (ATTA) more loosely describes AT as any recreational or tourism activity involving at least two of these three elements: physical activity, the natural environment, and cultural immersion (UNWTO, 2014).

The 28 billion USD outdoor recreation industry in Col-

*Adventure tourism enthusiasts, and the gear they use, have major implications for Colorado's water and economy. Photo by Shutterstock.*

> "...The rise in demand for luxury travel in Colorado's Front Range suggests that water consumption within this sector may be on the rise."

orado holds significant ramifications for water consumption (OIA, 2017a). With up to 2,700 liters of water needed to grow the cotton to make a single t-shirt, for example, an increasing number of outdoor recreation retailers such as Patagonia (see http://www.patagonia.com/environmental-campaigns.html) recognize the need for more sustainable practices in producing adventurist clothing and related accessories. The world's largest outdoor industry tradeshow now takes place in Denver three times per year (see https://www.outdoorretailer.com/), uniquely positioning Colorado to become a leader in promoting and pursuing such practices among adventurists and outdoor retailers on a global scale, even if the products are not being made in Colorado.

Unpredictable precipitation in Colorado obviously presents additional challenges for appeasing increased numbers of water sport enthusiasts and operators in the state. A state-wide drought in 2002, for example, not only resulted in the closing of numerous Colorado State Park lakes and reservoirs (to the tune of a 140 million USD loss), but it also forced ski areas to make their own snow during much of the season and resulted in a 39% drop in rafting days (Hutchins-Cabibi, 2010). Dry versus wet years influence an array of water management decisions that concomitantly affect adventure tourism. Reservoir decisions to adopt "fill-and-spill" versus "spill-and-fill" practices, for example, consistently impact a host of recreational activities like fishing, SUPing (stand-up paddle-boarding), and rafting, generating conflict with users and operators alike. With numerous water agreements and interstate compacts between Colorado, surrounding states, and the country of Mexico, ongoing and active engagement by users and operators in statewide discussions over water allocation is necessary to balance consumption needs with adventure tourism interests.

## Health and Wellness Tourism

Globally, direct water consumption for tourism represents significantly less than 1% of overall consumption, and studies suggest this will not change much even with expected annual increases of 3-4% in international travel in the years ahead (Gossling et al., 2012). However, there are regions where the extent and impact of water consumption for tourism appear more significant, depending on factors such as climate, hotel type (e.g., luxury versus economy), and the kinds of activities or amenities available to visitors, such as golf courses, on-site laundry, and swimming pools. Gossling et al. (2012), for example, highlight several studies suggesting that, on a per tourist basis, upscale to luxury hotels consume more water on average than economy or low-budget accommodations.

Understanding hotel water use can guide land development decisions affecting water allocation for health and wellness tourism. Like AT, health and wellness tourism (HWT) is difficult to define and overlaps to varying degrees with other kinds of travel. Generally speaking, HWT encompasses a range of usually commercialized touristic activity taking place away from participants' places of residence and focusing primarily on the enhancement of participants' well-being (physical, spiritual, etc.). Spiritual retreats, yoga centers, spa getaways, pilgrimages, and many forms of both culinary (e.g., nutrition-focused, food-to-table) and luxury travel would fall into the HWT category.

Tourism studies have yet to compare the water consumption patterns of health and wellness enthusiasts against other kinds of visitors. However, the rise in demand for luxury travel in Colorado's Front Range suggests that water consumption within this sector may be on the rise. Reports generated by Smith Travel Research (STR), for example, suggest that the demand for luxury accommodations (based on number of rooms purchased) in Denver alone has increased an average of 5.3% per year in the last five years. Given the semi-arid climate in Colorado, which experienced near-record lows in snowfall last winter, resort managers operating in the health and wellness industry should consider and encourage an array of cost-saving, water conservation strategies (low-flow showerheads, xeriscaping, etc.) on their properties. Such actions are particularly feasible for properties in the process of being built or recently completed, and hold significant implications for encouraging visitors to actively engage in water-conserving practices as well.

## Activating Water and Tourism Leaders

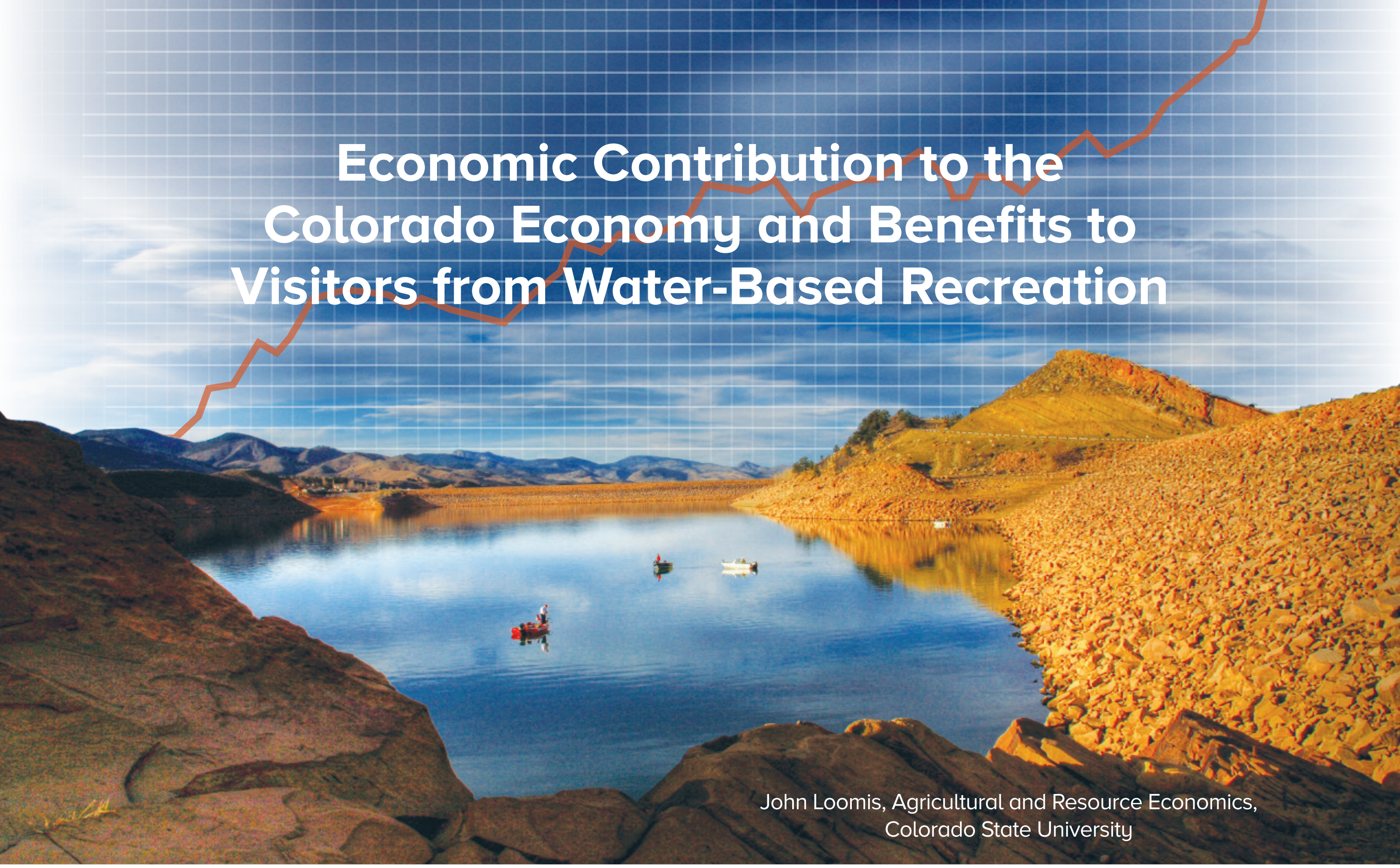
Well-being has been linked to the quality and accessibility of natural environments in which we live and play. This link sits at the crux of a host of water-related concerns surrounding the so-called "experience economy" in Colorado, particularly in the realms of recreation and tourism that depend so heavily on the state's freshwater resources.

Effectively addressing these concerns will require ongoing institutional support for stakeholder engagement and educational programming. Colorado's Water Plan (2015) already recognizes the value of collaboration and institutional flexibility as basin stakeholders engage in conversations to address "drought, interstate compacts and agreements, growing populations, important environmental and recreational values, and sustainable agriculture" (Chp. 3, p. 24). On the educational side, programs like Colorado State University (CSU)'s Master of Tourism Management, which also offers graduate certificates in Adventure Tourism or Ski Area Management (see https://warnercnr.colostate.edu/hdnr/master-tourism-management/), are preparing leaders to address significant water concerns through more sustainable recreation and tourism practices not only in Colorado, but around the world.

With some 71% of Colorado residents engaging in outdoor recreational activity, (OIA, 2017b), and with rising numbers of visitors to the state, these kinds of programs are foundational for achieving what Weaver (2006) refers to as "enhancement sustainability". Enhancement sustainability recognizes the need to move beyond the status quo and toward more regenerative environmental and tourism management practices. Emphasizing such practices in Colorado is essential for encouraging adventure seekers, health and wellness tourists, and others linked to the burgeoning recreation and tourism industries to become active in not only preserving but enhancing the natural world-including freshwater resources-on which we depend.

*A skier making his way down the mountain, another one of Colorado's adventure tourism opportunities. Photo by Flickr user Fredrick Blanker.*

# Economic Contribution to the Colorado Economy and Benefits to Visitors from Water-Based Recreation



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*Fishermen on Horsetooth Reservoir. Photo by AJ Schroetlin.*

## SYNOPSIS

Despite only some types of Colorado water-based recreation being measured in available data, this partial data indicates that water-based visitors spend at least $3.9 billion, supporting at least 33,690 jobs in Colorado. These positive economic effects and the benefits provided by water-based recreation could be increased if water-based recreation was given more consideration in water management decisions. This article discusses improvements such as managing instream flows and reservoir levels to maintain and improve upon water-based recreation, as well as explicitly identifies the gaps in water-based recreation data that need to be filled to provide a complete estimate.

Water resources within Colorado provide economically valuable recreation benefits to residents and non-resident visitors, while also generating a substantial amount of economic activity. This paper utilizes the existing literature to provide a partial estimate of the economic benefits to visitors and the economic contribution to the Colorado economy. We also specify the water management issues that must be addressed to fully realize the potential economic contribution of water-based recreation not only to the economy of Colorado but to the quality of life of people who live here. In the process, we point out the significant knowledge gaps.

## Overview of Economic Activity from Water-Based Recreation

About 2.1 million people participate in water-based recreation in Colorado, which includes boating (both motorized and non-motorized), fishing, and other water contact sports. Table 1 provides an overview of the results. The detailed data for fishing indicates that anglers spend nearly $2 billion annually, supporting 16,400 jobs (Southwick, 2014).

## How are Economic Benefits and Economic Contributions to the Colorado Economy Measured?

In many ways, measuring the economic contribution of recreation to the economy is similar to other industries—it starts with total spending. When data is available, the total economic contribution of this spending includes multiplier effects. While visitor spending makes an economic contribution to local towns (e.g., Buena Vista, related to commercial rafting), the actual visitor expenditures are a cost not a benefit to visitors. The benefit to visitors is measured by economists as the additional amount they would pay beyond their expenditures. For example, private kayakers on the Poudre River have travel costs per day trip of $83 and receive a benefit of $107 per day trip beyond their travel costs. This economic benefit to resident recreationists is a partial economic measure of the quality life in Colorado. The remainder of this short paper will provide existing estimates of both economic contributions to the Colorado economy and benefits to visitors themselves of water-based recreation in Colorado.

## All Boating

Motorized Boating: Trip expenditures by motorized boaters on lakes and reservoirs in Colorado amount to $657 million annually (Southwick, 2014).

Non-Motorized Boating: Non-motorized boating includes sailing, canoeing, kayaking, whitewater rafting, and stand up paddle boarding. These non-motorized boaters spend $1.3 billion annually (Southwick, 2014).

Water Management Issues Associated with Reservoir Recreation: Many of the boating activities take place at reservoirs that are managed for multiple purposes, with recreation being just one. Nonetheless, economically optimum water management needs to account for the benefits of different water use, including recreation. Often times, holding water in the reservoirs just a few days before and during a major holiday (e.g., Fourth of July) can increase recreation benefits by more than the cost to other uses, such as delaying irrigation releases by a few days. Keeping reservoirs fuller increases the economic benefits of reservoir recreation, in part because higher reservoir levels often increase reservoir surface area, thus reducing congestion of boats on the reservoir (Walsh et al., 1980).

Commercial Rafting: The 550,000 commercial rafters in Colorado in 2016 spent $70 million in direct expenditures, which translated into about $179.8 million in total economic contribution within Colorado (Greiner et al., 2016). What is not known is the additional magnitude of private rafting expenditures, as this is rarely measured.

Example of Expenditures Associated with Private Boating on the Poudre River: We do know private recreational use on the Poudre River where there is also commercial rafting. Our estimates of private use by kayakers and other users (e.g. private rafters, tubers) is 21,543 days based on calculations from 2010 data of McTernan (2011). Given there are 41,200 commercial rafting days, private recreational use represents an additional 50% of visitor use that is rarely accounted for when estimates of whitewater recreation on rivers is discussed. Using private visitors average spending of $83 per day (data based on (McTernan, 2011; Loomis and McTernan, 2014; updated to 2016), this private use generates $178,800 of additional spending each year in Colorado.

Economic Benefits of Private Boating on the Poudre River: While expenditures by private boaters is about 5% of total commercial recreation spending on the Poudre River, this difference nicely illustrates the difference between economic contribution of spending and economic benefits to the visitor. While commercial users spent an average of $128, private river uses spent $83 and received an economic benefit of an additional $107 per day trip in 2016 dollars (see Loomis and McTernan, 2014). Unfortunately, data has not been collected on what the economic benefits are to commercial rafters so it is difficult to know how commercial rafters' benefits compare to private boaters.

Information Gaps: Filling the data gaps on total private river use and the economic benefits at all rivers for commercial and private whitewater boaters is very important. Without this data it is not possible to have an accurate assessment of the


*A kayaker at Golden Whitewater Park. Photo by John Loomis.*

*An angler at Blue Mesa Reservoir.*

| Activity | Annual Trip Related Spending |
|---|---|
| Fishing | $1.9 billion |
| Non-Motorized Boating | $1.3 billion |
| Commercial Rafting | $180 million |
| Motorized Boating | $657 million |

*Table 1. Visitor spending on water-based recreation.*

total economic contribution and economic benefit of maintaining adequate instream flows on rivers to be compared with competing water demands.

Water Management Issues Related to Whitewater Boating: The impacts to whitewater boating become particularly apparent on over-appropriated rivers in Colorado that are sometimes dewatered for short periods of time (e.g., this has happened on the Poudre River, despite its recreational significance). Currently, recreation is not a legislative purpose of the Colorado Water Conservation Board (CWCB) instream flow reservations program. Rather, the CWCB's current mission is maintaining flows for a "natural environment," which has often been interpreted as flows for maintaining aquatic life such as fish. The level of flows necessary to maintain aquatic life is often substantially less than to sustain the economic contribution of commercial and private whitewater rafting. On the most heavily used commercial whitewater rafting river in the state of Colorado (with $28.5 million in commercial rafting expenditures with a total economic contribution of $73 million), Schoengold et al. (2013) found that reduced flows significantly decreased the number of commercial whitewater rafting customers, even accounting for a host of other variables such as air temperature.

## Fishing

Economic Contribution to the Colorado Economy of Angler Spending: Angler use of lakes and rivers results in spending of nearly $2 billion in the state of Colorado GDP in 2014 (updated from Southwick, 2014). This figure includes $673 million in wages/salaries along with $127 million in state and local taxes (Southwick, 2014). In total, fishing supports 16,413 jobs throughout Colorado (Southwick, 2014) including direct jobs in the fishing sector (e.g., guides), as well direct jobs in closely related sectors such as retail, hotels, gas stations, and indirect jobs in in other sectors such as wholesale trade.

Examples of the Economic Benefits to Angler Themselves: Since the vast majority of these angler expenditures are by Colorado residents, it is important to recognize that residents receive substantial benefits beyond the amount they spend to go fishing. A study of reservoir fishing in Colorado found that trout anglers would pay $191-$196 per day beyond their current median expenditures of $112 per day (Loomis and Ng, 2012). Non-trout anglers would pay between $62 and $74 per day beyond their $118 per day expenditures. Thus, the benefits to anglers significantly exceed the costs to participate in this activity, conferring to the anglers themselves benefits beyond what their expenditures contribute to the Colorado economy.

Water Management Issues Related to Fishing: For fishing, it it important to not only maintain flows to avoid dewatering of streams, but to also time the flows. This includes maintaining adequate flows during the winter months. Further, it is important to consider the downstream consequences of flow releases from dams on angling. The Fryingpan River and operation of Ruedi Reservoir illustrate the economic implications of this interaction. The Fryingpan River was the state of Colorado's first "Gold Medal" trout stream due to its ability to produce large (14 inches or larger) trout. Anglers on the river spend $3.3 million in the local economy and support 38 jobs in the region (Shields et al., 2015). Water releases from Ruedi Reservoir influence not only the quality of fish habitat but also the "fishability" of the Fryingpan River. Too high of flow releases (above 250 cfs) during the summer in response to downstream water demands can make it difficult for anglers to wade into the river to fish and so they no longer fish the river (Shields et al., 2015). The survey of anglers on the Fryingpan River found that a gain of 48 wadable days a season would result in anglers taking more trips, hence spending more money in the local area. Specifically, 48 more wadable days would result in a $1.1 million increase in angler spending, supporting an additional 15 jobs in the local economy. If one were to add the economic benefits to the anglers from the improved quality of fishing, the economic gains associated with more optimal flow releases would be even larger. In contrast, spending by Ruedi Reservoir visitors is relatively small ($144,237 in spending and 1.2 jobs). Thus, the primary trade-off is the economic consequences to irrigators and other downstream water users if moderate releases of water from Ruedi Reservoir into the Fryingpan River was maintained throughout the summer, rather than a more demand driven fluctuations of high and low flow releases that often currently characterize water releases from Ruedi Reservoir.

### Conclusion

In order for Colorado to attract out of state water-based visitors and provide a high-quality recreation experience to all visitors, water managers need to consider optimizing benefits to all water users. In some ways, ESA and other acts set the minimum instream flow as a floor. But the relevant question is whether "economically optimum flows" that balance the benefits of additional instream flows beyond this floor with the cost of that water (direct and opportunity cost to other sectors) is greater than this minimum. When one thinks about the other sectors of the U.S. economy, rarely does one hear the discussion of what is the "minimum" size car needed, or the "minimum" size house needed, etc. Much like the minimum daily adult requirement of vitamins, most Americans find it beneficial to exceed these minimums, just as they do in the size of their cars and the size of their houses. Perhaps it is time to bring the discussions of instream flows into congruence with the way society makes decisions in other sectors of the economy.

BIG THOMPSON WATERSHED FORUM

# ENVIRONMENTAL SCHOLARSHIP AWARD 2018/2019

The Big Thompson Watershed Forum (Forum) will award an environmental scholarship in the amount of $1,500 to a student attending Colorado State University or the University of Northern Colorado for the academic year 2018-2019.

Candidates must be an undergraduate student (first-year, sophomore, junior, or senior) by the Fall 2018 semester and enrolled in an approved academic program. Acceptable fields of study include:

- Environmental/Civil Engineering
- Environmental Health & Biology
- Environmental Science/Studies
- Environmental Sociology
- Forestry/Soil/Crop Sciences
- Hydrology
- Watershed/Water Quality Sciences

Applicants must have a minimum GPA of 3.0. The winning candidate must commit to 40 hours of volunteer work with the Forum, including participation in outreach events. In addition to these events, many volunteer opportunities are available with the Forum that can provide the candidate with valuable learning experiences and networking possibilities.

*The Forum's 2017-2018 scholarship winner, Kathleen Dorman, helps students identify macroinvertebrates at the Greeley Children's Water Festival. Photo by Laurie Schmidt.*

The application deadline is September 10, 2018. For details and application instructions, please visit the Forum's web site at https://btwatershed.org/environment-scholarship/

# A Natural Hazard in Snow-Covered Mountains

Ethan Greene, Colorado Avalanche Information Center


## SYNOPSIS

Avalanches are a common occurrence annually across Colorado and other portions of the Intermountain West, disrupting lives, businesses, and infrastructure. This article highlights what defines an avalanche, clarifies the different type of avalanche events, and the dangers they pose for recreationalists. It also provides insight into local resources that are helpful to educate and prepare for in the event of an avalanche event.


Each year there are thousands of avalanches across the western U.S. These events range from relatively small amounts of snow moving downhill, to large masses of snow and ice that rip out trees and gouge the Earth's surface. This natural hazard threatens buildings and infrastructure, delays the movement of goods and services where transportation corridors run through the mountains, and has a huge impact on winter recreation.

What is an avalanche? The term includes a fairly broad array of events, but in the most general sense encompasses all snow and ice masses that are rapidly moving down an inclined surface. These debris flows can be quite small, only a few inches wide where they release and running less than 10 feet downhill. Large avalanches can begin with a fracture line over a mile wide before the debris descends thousands of feet into the valley bottom or up the opposing hillside. They flow as solids, liquids, and gases depending on their size and composition.

A common way to sort these events is to categorize them based on how the avalanche starts and the

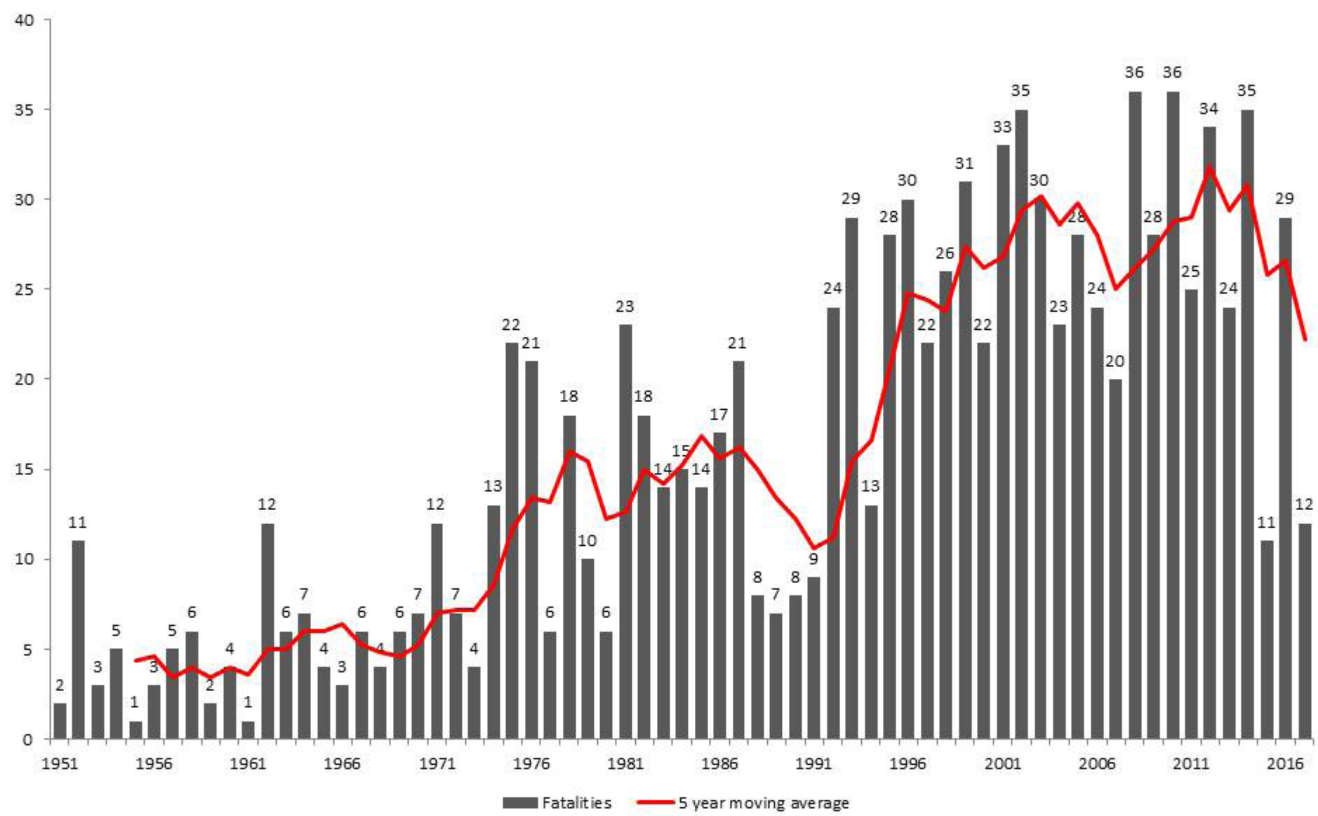
*(Above) Dry slab avalanches breaking into new snow and old snow layers in a backcountry area near Aspen. The avalanche on the right side of the image killed a backcountry skier in 2018. Photo by Art Burrows.*

amount of liquid water in the snowpack. Loose-snow or sluff avalanches release as snow grains lose cohesion with their neighbors. They start small and widen as they roll downhill forming an inverted V shape. Slab avalanches release when a cohesive mass of snow or ice breaks away from the snow or ice around it and plunges into the valley below. Fracture occurs in seconds with cracks running along a structural weakness that formed days, weeks, or months before the event. They can have jagged edges where the cohesive mass of snow tore away from the slope and the flow narrows as it moves downhill funneling between sub-ridges or into a drainage. They often travel at speeds over 50 mph, sometimes over 100 mph, and produce a damaging powder cloud on the leading edge of the debris flow. Dry slab avalanches move faster, sometimes with large blocks of snow in the debris. Wet slab avalanches move slower, with dense debris that flows like a river gouging the underlying surface and breaking trees or twisting buildings off their foundations. Both in the United States and in Colorado the deadliest avalanches are slab avalanches composed of dry snow.

Slab avalanches release when the snow fractures and cracks run along a weaker layer of snow. The seasonal snowpack is composed of layers, formed by weather events. A layer could be formed by a single snow storm. A complex storm that produces different types of precipitation could produce several layers. Wind events can move large amounts of snow around, building thin subtle layers or thick hard drifts of snow. Periods of calm weather can cause the crystals in the surface snow to change, forming weak, fragile structures. Warm temperatures or direct sun can melt the snow causing water to run through the existing layers in a complicated pattern, forming crusts of ice as temperatures drop and the melt water freezes. All of these events form layers in the snowpack and the interaction between these layers creates the potential for future avalanches.

Most avalanches release during or shortly after a large snow or wind storm. Intense snowfall or wind loading increases the weight on the existing structure in a short amount of time. That existing structure will bend and adjust to the new load, or just break, sending the new and sometimes old snow rushing downhill. During storms without avalanches, the new snow or wind drift forms a new layer and increases the depth and mass of the snowpack. When harder layers form

**U.S. Avalanche Fatalities by Avalanche Year
1950-1951 to 2016-2017**




*Number of people killed in avalanches each avalanche year (October 1 through September 31) in the United States from 1950 to 2018 (as of May 1).*

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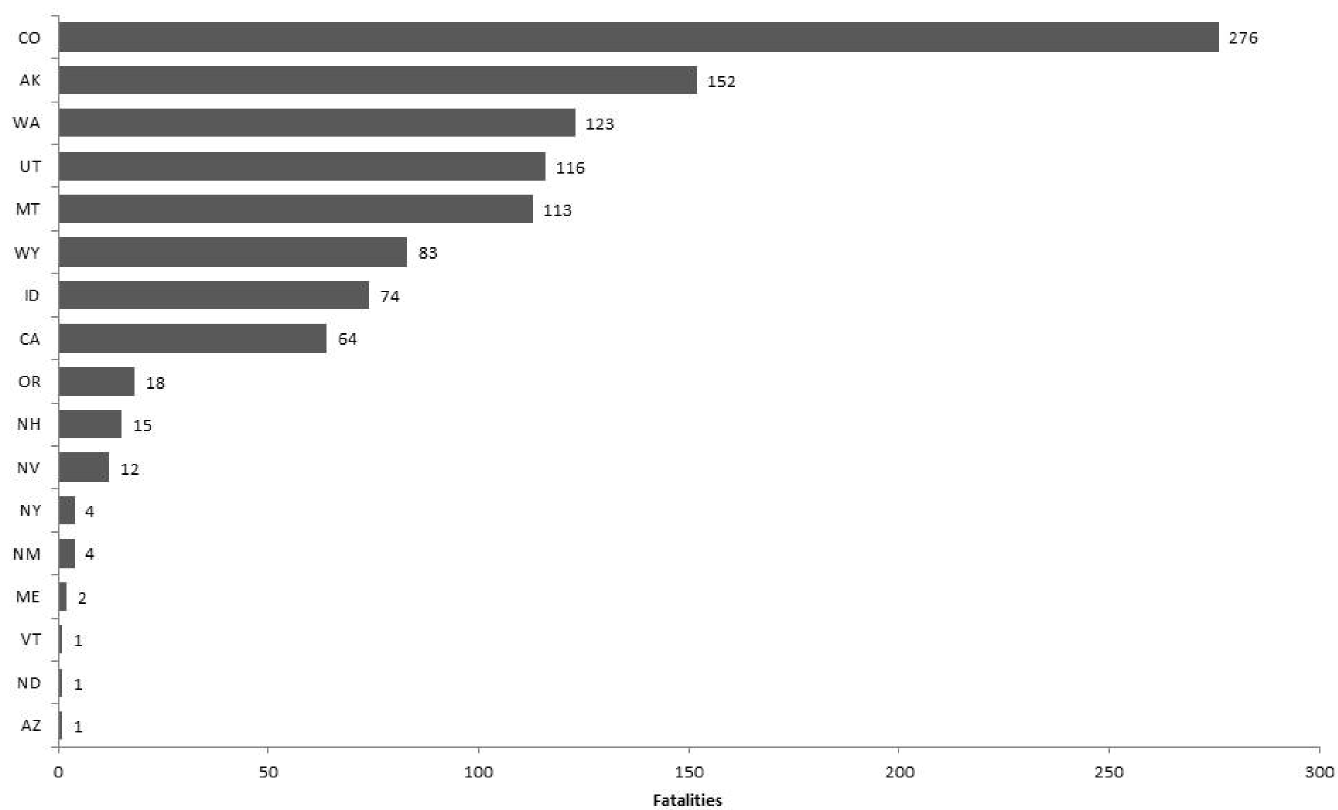
*Forecaster from the Colorado Avalanche Information Center investigates the crown face of a dry-slab avalanche. Photo by CAIC.*

over fragile weak layers of snow we have a perfect recipe for an avalanche. This avalanche may release during the next loading event, producing a larger avalanche than what would have occurred if just the new snow released. Or it may lie in wait for a person to come along crushing the snow in just the right place to release the whole hillside. This type of situation, where there is the potential for a large avalanche with a fairly small input, is what makes certain avalanche scenarios so dangerous. It is why avalanches are such an important natural hazard for the people that live, work, and play in the snow-covered mountains.

Fortunately avalanches happen in specific types of terrain, and we can use this to our advantage when we are planning roads and settlements or just heading out for a fun day in the mountains. Where the avalanche starts, the slope needs to be steep enough for the snow to move downhill once it breaks away from the hillside. Most avalanches begin on slopes that are steeper than 30°. Loose

**U.S. Avalanche Fatalities by State**
**1950-1951 to 2016-2017**




*The number of people killed in avalanches from 1950 to 2017.*

Colorado Avalanche Information Center

snow avalanches can happen on very steep slopes, especially during snow storms when the new snow sheds off of rocks and crags. To get a large avalanche we need a large amount of snow to build up on the slope. The steeper the slope the more it sheds snow as the snow falls. Thus we don't see large avalanches on slopes steeper than about 50°. This range in slope angle, 30 to 50°, is extremely important for hazard mapping or navigating in the mountains. You are unlikely to trigger an avalanche in terrain that is outside of this range. Of course once an avalanche starts it will run downhill until friction slows the flow and eventually brings it to a stop. So, there can still be a significant threat to buildings, roads, or people that are under steep slopes.

Avalanches kill people in every state in the western U.S., and a few states in the northeast. Colorado has the most avalanche deaths of any state; on average avalanches kill more people than any other weather-related hazard. Since 1950, most of the people killed in avalanches have been recreating on snow-covered slopes, but avalanches also threaten some settlements and many transportation corridors. There are a variety of ways that we try to reduce the impact of this natural hazard. In some areas, we can build structures that protect critical assets (an example of this is the snow shed protecting U.S. 550 over Red Mountain Pass). In others, we use a combination of prediction and active mitigation. Where we can move people and property out of harm's way, we take advantage of the times when a relatively small disruption in the snowpack can produce an avalanche by using explosives to trigger the avalanche.

The Colorado Department of Natural Resources and the United States Forest Service (USFS) run avalanche safety programs for people recreating on public lands. These programs collect information on snow, weather, and avalanche conditions and provide forecasts of avalanche potential across large areas of backcountry terrain. These public safety products describe the avalanche hazard as it pertains to snowmobilers,

*A large avalanche flows towards the highway near Wolf Creek Pass. This avalanche was triggered by the Colorado Department of Transportation as part of their hazard mitigation program. Photo by Mark Mueller/CAIC.*

skiers, snowboarders, snowshoers, climbers, hikers, bikers, and anyone else enjoying the winter wonderland. These groups also provide education on how to stay safe from avalanches. Anyone traveling through the mountains when there is snow on the ground should:

1. Get the Forecast – Know what sort of avalanches you might encounter and the areas where you will find them. Go to www.colorado.gov/avalanche or www.avalanche.org while you are planning your trip and before you begin your adventure. The best way to avoid getting killed in an avalanche is to avoid getting caught in the first place.

2. Get the Training – A little education could save your life. There are lots of places to get education. Start with www.avalanche.org/avalanche-tutorial/ or www.kbyg.org. If you are going spend a lot of time in avalanche terrain, take a multi-day class that includes some time in the field. Visit www.avtraining.org to find a class near you.

3. Get the Gear – If you are traveling in avalanche terrain, everyone in your party should carry an avalanche beacon, a probe pole, and a shovel. Air bag packs are also a great piece of equipment. If someone gets buried in the snow you do not have much time to find them and dig them out. You will need to call 911 and then keep your whole team together to perform a fast and efficient rescue. Practice with this equipment and know what to do if something goes wrong. About 25% of people killed in avalanche die of trauma, so be ready to treat injuries once you get your friend out of the snow.

*A large avalanche flows over cliffs near Wolf Creek Pass. This avalanche was triggered by the Colorado Department of Transportation as part of their hazard mitigation program. Photo by Mark Mueller/CAIC.*

# As the Snow Goes, So Goes a Nation of Skiers

## Climate Change and Colorado Skier Visits

Kevin Crofton, Economics, Colorado State University;
Andrew Seidl, Agricultural and Resource Economics, Colorado State University;
Stephan Weiler, Economics, Colorado State University

SYNOPSIS

Colorado's climate is a significant draw for destination ski tourism, and as the climate varies, so will the number of visitors. Yet the change in the climate of where destination skiers hail from may describe some of the variations in skier visits each season beyond what conditions are experienced in the Colorado Rockies.

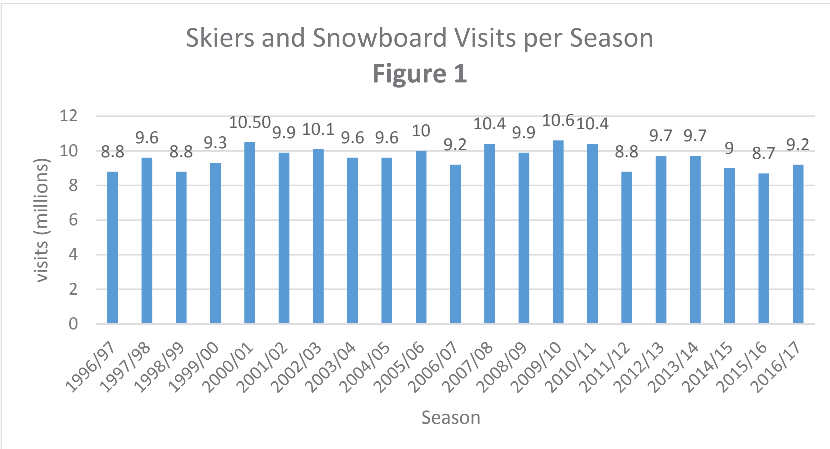
Skiers like snow…a lot! Pow pow, crud, slush, corduroy, wind slab, death cookies (var. killer croutons), ice rink, bullet proof, peanut butter, crunchy, hollow, new, Spring… Eskimos have nothing on a group of skiers describing snow conditions. More snow almost always means better skiing. If the traffic on I-70 the day after a mountain snowstorm is any indication, more snow probably means more people skiing—and more days skiing for those who choose to hit the slopes. In the 2016-17 season, U.S. ski resorts reported some 54.7 million skier-visits, up 3.7% year-on-year while snowfall increased 36% from the previous season. National Ski Areas Association (NSAA) reports fairly stable visits over the past 20 years, but a declining general trend over the past decade (Figure 1).

Gross revenues per skier day generally follow national economic trends and are on an upward trajectory over the past decade reaching just under $100 per visitor day in the 2015-2016 season (Figure 2). RRC Associates (2015) reported the Colorado ski industry generates an estimated $4.8 billion in annual economic impact, 46,000 jobs and $1.9 billion annually in labor income from the 8.4 million visitor-nights non-residents spent in Colorado's ski communities.

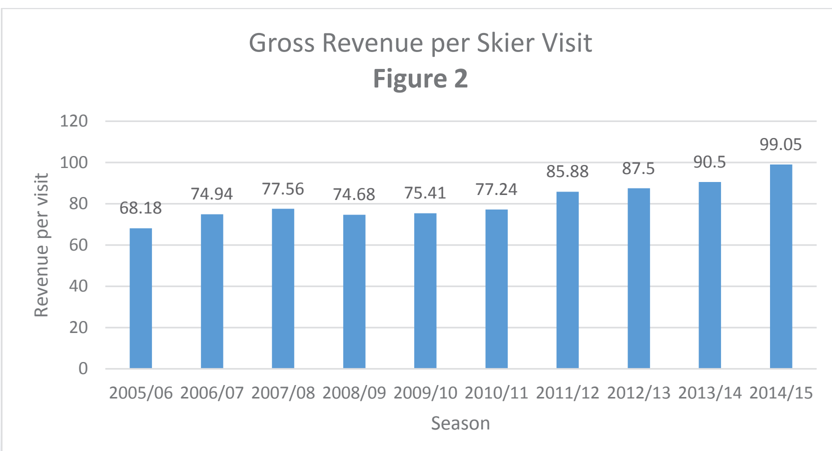
The Rocky Mountain Region experienced its second greatest number of skier visits in history at 21.7 million in the 2016-17 season. However, these totals are 2.5% below the 20-year average and Colorado resorts reported a 2% decline in

visits year-on-year from its record high of 13 million skier-days in the 2015-2016 season (NSAA, 2017).

Climate change is affecting the location, timing, and amount of snow, and therefore, the choices people may make about skiing. Colorado's climate is expected to warm between 2.5º F and 5.5º F by 2050, experience lower April 1st snowpack, have earlier runoff, and endure warmer spring and fall "shoulder" seasons, causing snowmaking to be more challenging in some areas (Jedd et al., 2015). The effect on overall precipitation is less clear and the granularity of current climate models makes it difficult to predict the expected effect in a place as diverse in climate and altitude as Colorado. Scott et al. (2007) showed ski tourism in the northeastern U.S. to be especially vulnerable to climate change. Sauders and Maxwell (2005) state that "…if the West gets less snow, one obvious effect would be less skiing and other snow sports. The season for skiing…could be shorter and the snow slushier, reducing enjoyment for skiers (and) profits for skiing dependent businesses."




*Source: NSAA.*




*Source: D. Belin, 2016.*

People from warm climates (e.g., Florida, Texas), as well as locals can choose to ski or not to ski in the Rockies. We first test the hypothesis that more snow in the Rockies is correlated with more skiing in the Rockies, regardless of whether you are from the I-25 corridor or Texas. This *pull factor* means if the skiing is better, people ski more frequently and the converse.

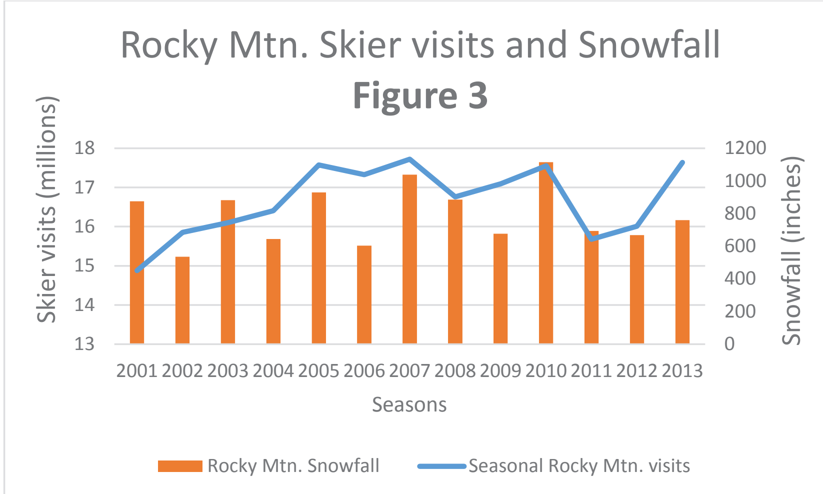
Secondly, we explore the relationship between non-Rocky Mountain climate and Rocky Mountain skier visits, thus exploring the *push factor*. Skiers from outside the Rockies have the choice of skiing at home, travel to ski, or not to ski at all. Do the Rocky Mountain ski areas actually compete

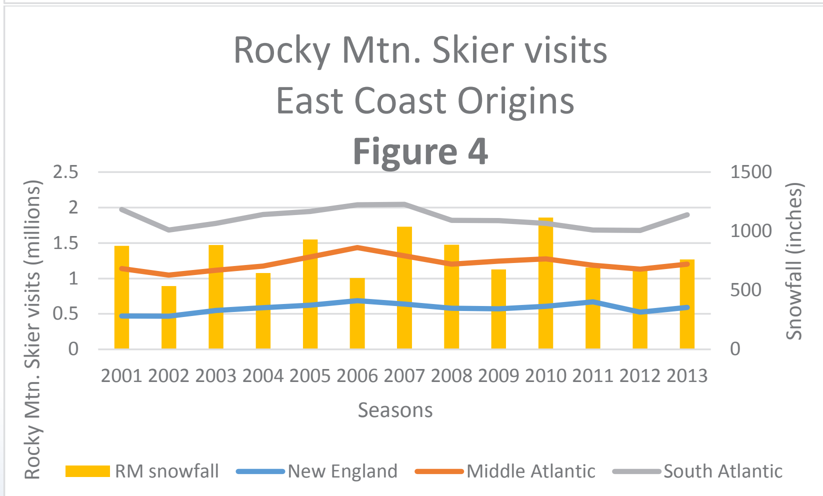
*(Below) Views from Independence Pass, Colorado. Photo by Flickr user Mark Byzewski.*

with California, Michigan, and Vermont for ski visits? If we find that better snow conditions in other states result in more ski visits in the Rockies, then the Colorado ski industry is complementary to skiing in other states and not in competition with them. The extension of this line of argument is that poor skiing conditions in other states result in fewer skier visits to Colorado, implying people simply take up substitute, warm weather, outdoor recreation activities when in the short or longer term, skiing becomes less viable in those states.

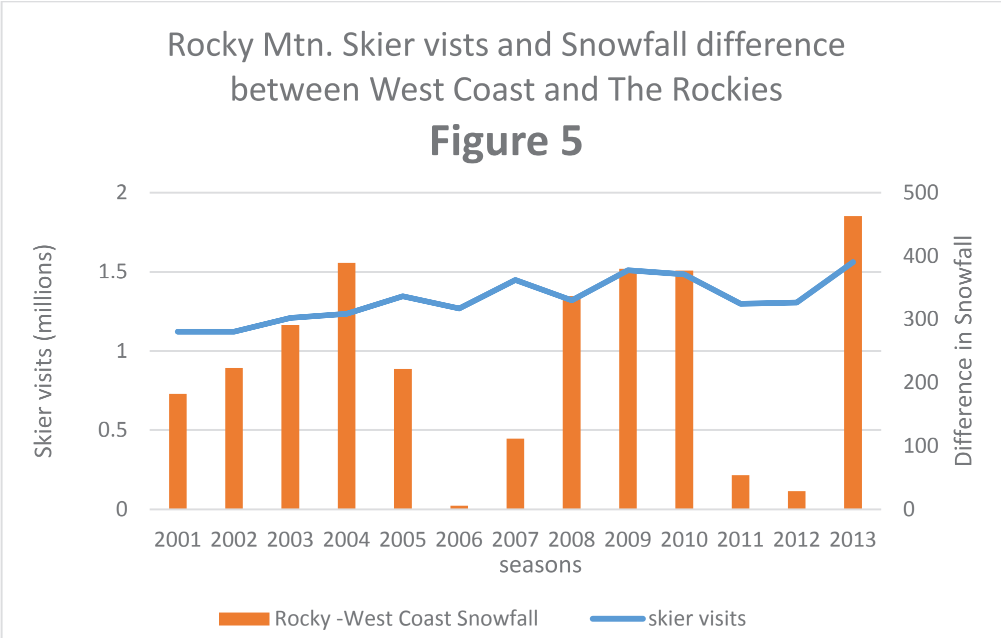
To first investigate the *pull factor* of Rocky Mountain snowfall, we can see that snowfall and skier visits seem to form a fairly close relationship (Figure 3). However, there was little statistical evidence that Rocky Mountain snowfall significantly affects Rocky Mountain skier visits. These results would support the conclusion that snowfall has little impact on skier decisions if it is the sole variable considered. It is when taking into account the skier's place of origin that the relationship of snowfall and skier visits becomes clearer, matching the intuition that there are likely differences among potential skiers from different parts of the country (Figure 4). Figure 4 focuses on East Coast skier decisions. It shows the further north an Eastern skier lives, the fewer visits to the Rocky Mountains the skier will take. The Northeast has more ski areas and better climates to support skiing, so have better substitutes for the Rockies. The three eastern subregions have comparable flight distance from their busiest airport to Denver International Airport (DIA). The variation in sensitivity to Rocky Mountain snow across East Coast subregions suggests that the pull factor of Rocky Mountain weather takes on different effects depending on the origin of the skiers.

When additional variables are considered to explain the differences in skier visits from each place of origin, Rocky Mountain snowfall becomes an important factor in non-resident choices. Some of the most powerful additional variables are population in the place of origin, as all else equal we should find more skiers within a large group of people than a small




*Dana Cowley on Baldy Mountain.*
*Photo by Kevin Crofton.*




one. Distance to travel to the Rocky Mountains also becomes a key influence, as airfare makes ski trips more expensive. Non-weather-related place of origin factors, including the number of ski areas, did not change skier choices, counter to expectations if local skiing were a substitute for destination skiing. Accounting for these factors, Rocky Mountain snowfall led to significantly more skier visits from other places of origin as well as from within the region. To quantify the *pull effect* in terms of snowfall, a 10% increase in annual snowfall over the 790-inch average results in 50,000 more annual visitors from outside the region.

The second part of our analysis considers place of origin weather as a contributing variable for traveling to the Rockies to ski. When looking solely at a location's weather, no patterns emerged. However, when weather variables of the Rockies were included, place of origin weather variables (snowfall and temperature) became important factors. This provides additional insights into how skiers may consider destination travel. Weather at home alone does not push you to ski another region without considering ski conditions in the potential destination. While the pull model benefitted from place of origin variables, the push model cannot effectively represent the choices of skiers without a relatively enticing choice entering into the decision model.

Place of origin snowfall in all of the models that included Rocky Mountain weather negatively affected skier visits to the Rockies, supporting the intuition that home ski areas are substitutes for destination skiing. The Rocky Mountain weather variables remain an important factor throughout the analyses, lending support that weather in both the origin and destination are of importance for Rocky Mountain skier visits. One of the simplest models includes the effects of Rocky Mountain snowfall and place of origin snowfall, showing that Rocky Mountain snowfall drew visitors about twice as strongly as home snowfall reduced the incentive to travel.

The variation in weather patterns throughout the United States inspired another test of whether the difference in the Rocky Mountain weather variables and place of origin weather variables produced a strong relationship with a skier's decision to travel. Skier visits showed significant attraction to the Rockies due to regional differences in snowfall and average season temperature. The effect of the difference between snowfall at home versus in the Rockies is illustrated by the case of California skiers during the 2013-2014 season. California experienced a severe drought, while Colorado had an above average season of snowfall. The result was a record number of West Coast skiers traveling to the Rockies. When the difference between snowfall in the Rockies and the West Coast is large, more skiers migrate to where the snow is relatively better, which supports elements of both *push* and *pull factors* in one variable (Figure 5).

Colorado's climate is a significant draw for destination ski tourism. In addition, the relative differences in climate between regions factors into a skier's travel decision. The relative differences in ski conditions across regions appear to shape skier decisions and could be useful to when marketing out of state. The decision to ski in the Rockies does seem to compete with skiing at home, so marketing targeted toward locations that are experiencing above average skiing conditions may be less effective than focusing on drought-stricken regions. The evolving issue to consider is whether this pattern will continue or will the option to not ski at all become more attractive, as home ski areas suffer worsening ski conditions over the longer term due to predicted climate effects rather than only seasonal 'good season vs bad season' variation. The recent trend for partnerships among ski areas across regions could hedge revenue streams for larger ski corporations or partnership agreements, lowering barriers to destination skiing through features like season passes usable at multiple destinations, to attract groups that will increasingly need to travel to enjoy skiing.

# Public Use of Snow Data to Guide Winter Recreation

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William J. Milligan IV, U.S. Geological Survey—David A. Johnston Cascades Volcano Observatory

(Top) Blowing snow on Flattop Mountain during the sunrise. Photo by Steven Bratman.

## SYNOPSIS

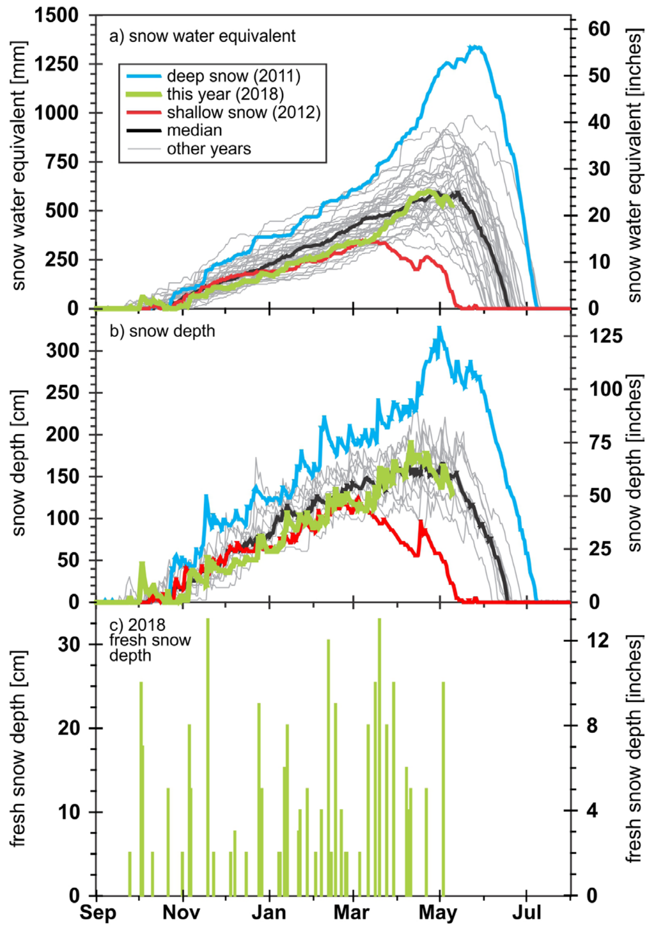
Winter recreation is an important part of Colorado's economy. Recreationalists get information about winter and snow conditions from various sources. This article highlights how much information recreationalists gather, people's perceptions of winter, and highlights that snow conditions do not mirror measured conditions.

Billions of dollars are spent each winter on snow-based outdoor recreation in Colorado. The ski resort industry generates an economic impact of almost 5 billion dollars, while several more billion are added to Colorado's economy from backcountry activities, such as skiing, snowboarding, snowshoeing, snowmobiling, and more recently, fat bikes. While a large portion of winter tourism revenues are generated by out-of-state visitors, Colorado residents enjoy easy access to outdoor recreation opportunities, also contributing a great deal of revenue to the winter economy.

### Information for Winter Recreation

Snow adventure-seekers often use online data sources to determine current and future snow conditions in real-time. In Colorado, these websites are hosted by ski resorts, various weather agencies and organizations (e.g., www.weather.gov),

*Figure 1. Time series plots showing the a) snow water equivalent and b) snow depth for 2011, 2012, 2018, other years, and the median value. Plot c) is of the daily fresh snow depth for 2018.*



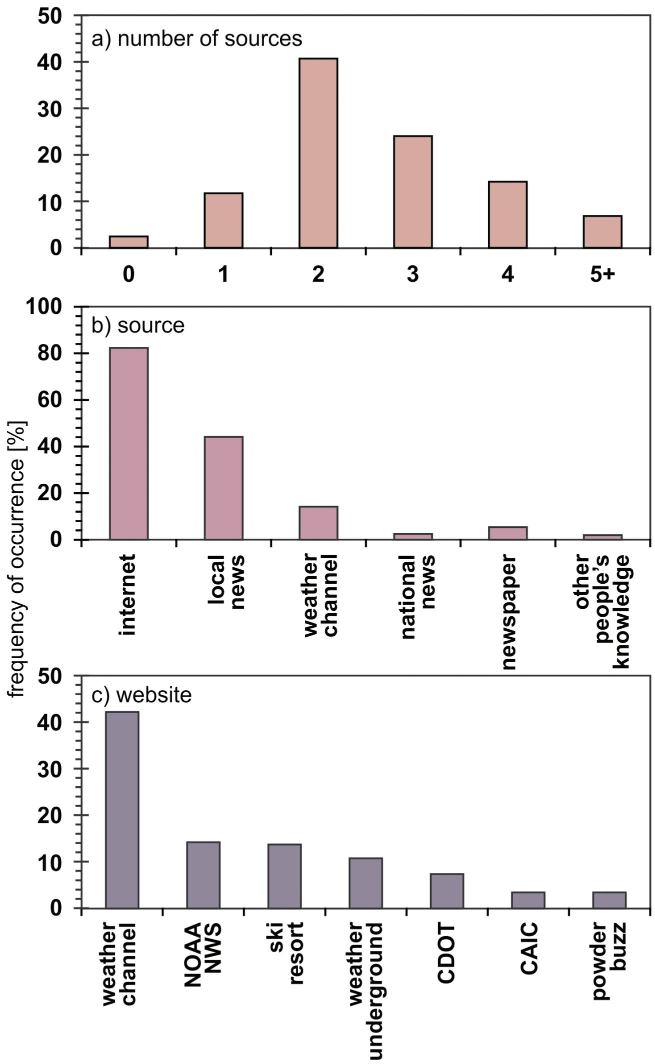



*Figure 2. Results from the information sources questions, showing: a) the number of information sources sought, b) type of information source, and c) the specific website.*

the Colorado Avalanche Information Center (CAIC, avalanche.state.co.us), and the Natural Resources Conservation Service (NRCS, National Water and Climate Center snow data, www.wcc.nrcs.usda.gov). Recreationalists also evaluate travel conditions via the Colorado Department of Transportation (CDOT, www.codot.gov or www.cotrip.org).

To better determine how and what people think about snow and winter weather, we designed and administered a questionnaire to identify the language people used in describing snow and winter weather. A second questionnaire was later administered to over 200 individuals across the Northern Front Range of Colorado. Respondents were asked to make comparisons between the winter that has just occurred, the previous winter, and other winters before it, in terms of precipitation amounts, temperature, and wind characteristics. We also asked about perceptions of longer-term climate trends, both in the Front Range and in the mountains of Colorado. Among the demographic information collected was the amount and type of information that recreationists sought. We wanted to determine if the amount of information that they sought impacted their perceptions of snow and winter weather. Data were collected in 2012, which in the Colorado Mountains was among the lowest measured snow years. The previous year, 2011, was among the highest measured snow years in Northern Colorado (Figure 1).

Most people used two or more sources when seeking information about winter and snow conditions (Figure 2a). Of these sources, over 80% were considered "internet" sources (Figure 2b), though almost half referred to the local television news for information. At the time, over 40% of those surveyed used the Weather Channel website for their information while only 30% of respondents used government websites (NOAA-NWS, CAIC, CDOT).

To gauge the accuracy of surveyed responses, perceptions were compared to historical weather and climate data. The number of people who responded correctly depended upon the question asked, i.e. most people knew that the 2012 winter was dry in the mountains of Colorado and that air temperatures have been warming (Figure 2). However, less than half of the respondents knew that 2012 was much drier than 2011 or that 2012 was warmer than average (Figure 2). For the six questions summarized in Figure 3, there was an average of 49% correct responses from those who sought three or more information sources. This decreased slightly to 45% for those who only sought one. Interestingly, those who sought two information sources had the lowest number of correct responses, especially for the questions related to temperatures during the last winter and previous winters. None of these differences were statistically significant.

## Snow Data

The survey we administered to the public was designed to ask about sources of information used when considering winter and winter recreational activities. Specific questions were not asked about the use of snow data, and yet snow data have been collected in Colorado since 1936. Early snow collection efforts were spearheaded by various well-known hydrologists, including Colorado A&M Professor Ralph L. Parshall (Figure 4). In the late 1970s, the NRCS began installing automated snow monitoring systems (Figure 5), called snow telemetry (SNOTEL) stations. Today, the SNOTEL network provides the most extensive mountain snowpack information across the Western United States with over 800 stations delivering real-time data every hour. The primary purpose of the data collection is for runoff forecasting, with data usually shown as the 30-year median, current year cumulative precipitation, and the amount of water stored in the snowpack, which is known as the snow water equivalent or SWE (Figure 1a).

However, recreational users are generally less interested in the amount of water stored in the snowpack and are more interested in snow depth data (Figure 1b). Snow depth is the

Joe Wright (551)
Colorado SNOTEL Site - 10,120 ft
Reporting Frequency: Daily; Date Range: 2018-04-11 to 2018-05-09

(As of: Wed May 09 12:14:50 GMT-08:00 2018)
**Provisional data, subject to revision**

| Date | Snow Water Equivalent (in) Start of Day Values | Snow Depth (in) Start of Day Values | Precipitatio Accumulatic (in) Start of Day Values | Air Temperatur Observed (degF) Start of Day Values |
|---|---|---|---|---|
| 2018-04-11 | 22.2 | 68 | 31.8 | 40 |
| 2018-04-12 | 22.2 | 66 | 31.8 | 46 |
| 2018-04-13 | 22.3 | 67 | 32.1 | 18 |
| 2018-04-14 | 22.4 | 68 | 32.1 | 16 |
| 2018-04-15 | 22.9 | 69 | 32.8 | 26 |
| 2018-04-16 | 23.2 | 68 | 33.0 | 38 |
| 2018-04-17 | 23.2 | 66 | 33.0 | 41 |
| 2018-04-18 | 23.2 | 66 | 33.1 | 16 |
| 2018-04-19 | 23.2 | 66 | 33.1 | 13 |
| 2018-04-20 | 23.2 | 65 | 33.3 | 30 |
| 2018-04-21 | 23.4 | 70 | 33.7 | 22 |
| 2018-04-22 | 23.6 | 69 | 33.8 | 30 |
| 2018-04-23 | 23.6 | 64 | 33.8 | 29 |
| 2018-04-24 | 23.5 | 62 | 33.8 | 30 |
| 2018-04-25 | 23.3 | 62 | 33.8 | 17 |

*The division of the correct responses to the climate questions categorized by the number of information sources. Individuals were asked about the amount of precipitation and temperature. They were also asked to compare the 2011 winter to the 2012 winter, as well as previous winters and overall trends. The respondents came from the Northern Front Range of Colorado and were to consider the winters within the mountains of Colorado.*

criteria used to determine the start of the snowmobile season, specifically a minimum snow depth of 12 inches (30 cm). A minimum snow depth is not specified by land management agencies to open the slopes at a ski resort, but it is typically 18 to 24 inches (45 to 60 cm) and it is based on the nature of the underlying terrain, such as the presence of rocks and vegetation, and how much the new snow will compact. Once the slopes are open for winter recreation, users typically look at the amount of fresh snow to ski on (Figure 1c). While these data are readily available from the resorts, they are not as easily found for backcountry locations. The NRCS data provides the only means for recreationalists to see when it snowed in the vicinity of SNOTEL stations through measurement of fresh snow added to the snowpack derived from change in snow depth.

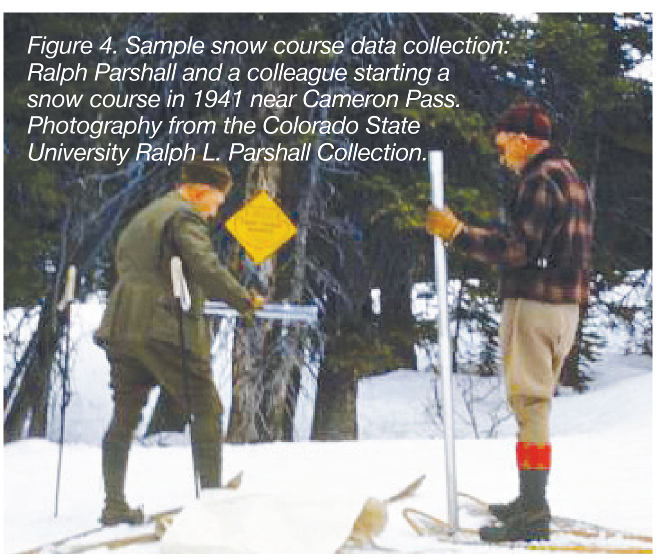


*Figure 4. Sample snow course data collection: Ralph Parshall and a colleague starting a snow course in 1941 near Cameron Pass. Photography from the Colorado State University Ralph L. Parshall Collection.*

*Figure 5. A Snow Telemetry (SNOTEL) site with Steven Fassnacht explaining the workings of the station. Photo by Niah Venable.*

## Future Uses of Snow Information

Since the completion of the primary snow and winter weather questionnaire in 2012, more new information sources have become available. Increasingly, sources are tailored to advanced users, in the form of social media with the information often derived from other people's expert knowledge, such as that presented in online forums (e.g., powderbuzz, Figure 1c). The foundation of this knowledge however, remains in the snow data collected by national snow monitoring efforts, the ski industry, and research agencies.

As shown by our survey results, most people use multiple sources of information to understand and make decisions about winter weather and recreation. Despite the use of these multiple sources however, many have misperceptions of the seasonal and spatial variability of precipitation and temperatures, particularly over the longer term. This finding has implications for current and future recreationalists understanding possible impacts to winter activities from a changing climate, which will affect their winter recreational spending decisions that our economy relies upon.

# Announcing the CSU Water Center's
# 2018-2019 Grantees

Grantees catalyze water research, education, and engagement through interdisciplinary collaboration and creative scholarship among CSU faculty and students. Congratulations to the research teams and faculty fellows!

### Measuring Impacts of Forest Disturbance on Streamflow

This research team seeks to better understand the impacts of forest disturbance on Northern Colorado's water supply by bridging the divide between forest ecologists, remote sensing scientists, hydrologists, and political scientists.

- **Team Investigators:** Paul Evangelista (Natural Resource Ecology Laboratory) and Tony Cheng (Forest and Rangeland Stewardship, Colorado Forest Restoration Institute)

### Next Generation Soil Moisture Measurement Technology for Research, Water Management, and Environmental Monitoring

This research team will develop new soil moisture measurement technology to provide real-time water content data for a broad range of research and applied applications.

- **Team Investigators:** Jay Ham, Allan Andales, and Maria Capurro (Soil and Crop Sciences); Russ Schumacher and Peter Goble (Atmospheric Science, the Colorado Climate Center); and Tom Sale (Civil and Environmental Engineering)

### Who Changes the Rain? Linking the Social Dynamics of Pastoralism and Atmospheric Water Recycling to Enable Sustainable Development Goal Achievement

This research team seeks to develop a first-of-its-kind modeling system linking household-scale behavior to regional-scale moisture recycling to understand of how humans interact with the atmospheric water cycle.

- **Team Investigators:** Pat Keys (School of Global and Environmental Sustainability); Kathleen Galvin (Anthropology, the Africa Center); and Randall Boone (Ecosystem Science and Sustainability)

### Food-Energy-Water Systems (FEWS) Justice: Urban and Rural Corridors in the Rio Grande-Bravo Basin

This research team seeks to identify critical environmental justice issues and opportunities for just transitions in the Rio-Grande Basin *(pictured above)* and bring FEWS justice to the forefront of water governance in the Basin states and Mexico.

- **Team Investigators:** Stephanie Malin (Sociology); Melinda Laituri (Ecosystem Science and Sustainability); Constance DeVereaux (LEAP Institute for the Arts); Steve Mumme (Political Science); Josh Sbicca (Sociology); Sybil Sharvelle (Civil and Environmental Engineering); and Faith Sternlieb (Ecosystem Science and Sustainability)

### Development of a Novel Framework for Estimating Moisture Susceptibility Attributable to Natural Flood Hazards in the U.S.

This research team will develop a conceptual framework to estimate residential housing moisture susceptibility in homes following large-scale flooding.

- **Team Investigators:** Ryan Morrison and Ellison Carter (Civil and Environmental Engineering) and Kristen Rasmussen (Atmospheric Science)

### Examining Extreme Cities: Seeking Solutions for Water Management in the 21st Century

This project will assess the state of water solutions for extreme cities, provide linkages with CSU's international research activities, and engage students to raise awareness and understanding today's critical water challenges.

- **Faculty Fellow:** Melinda Laituri (Ecosystem Science and Sustainability)

### Addressing Non-Salmonid Fish Passage in Semi-Arid Regions

This project will further research on fish passage challenges and solutions in the U.S. Great Plains region and Australia's Murray-Darling Basin, increasing CSU's international collaborations in the area of fish passage and ecological connectivity of rivers.

- **Faculty Fellow:** Chris Myrick (Fish, Wildlife, and Conservation Biology)

COLORADO CLIMATE CENTER

*Corn field in Lafayette, Colorado. Photo by Flickr user Let Ideas Complete.*

# Exploring Wind Patterns Over Colorado Agricultural Lands

Peter Goble, Colorado Climate Center


## SYNOPSIS

Colorado's surface wind climatology is not as well understood as its temperature and precipitation climatology. This is due to a relative dearth of historic data. In this study, the Colorado Climate Center uses data from agricultural weather stations going back to the mid-1990s in order to characterize normal wind patterns across the state.


## Introduction

Historical climate is most predominantly assessed using temperature and precipitation data due to data availability, but many other variables are responsible for shaping a region's climate. The Colorado Climate Center (CCC) is seeking to gain more comprehensive information about our state's climate utilizing the Colorado Agricultural Meteorological Network (CoAgMET), or "Colorado's Mesonet." CoAgMET weather stations are equipped with the tools necessary to measure temperature, warm season precipitation, wind speed and direction, solar radiation, humidity, and reference evapotranspiration. In this article, we take a closer look at wind speeds measured by CoAgMET sites since 1996. Where and when is it most windy? Are our winds changing over time? How are our windspeeds related to Pacific sea surface temperatures El Niño Southern Oscillation (ENSO)?

## Analysis Methods

There are over 70 CoAgMET stations now active in Colorado, but the majority are still quite young. The oldest active CoAgMET stations have been logging data since the early 1990s. For this article, only data from stations with a record going back to at least January 1st, 1996, and minimal data gaps were used.

Average monthly wind speed was computed from daily data for each station  every month in the time series (January of 1996 through April of 2018.) Stations were also grouped geographically with an emphasis on the (northern) Front Range, Eastern Plains, and West Slopes. Some stations were left out on account of having no near neighbors geographically with a similarly robust time series.

CoAgMET did not begin tracking wind gusts until later, January of 2008. Still, a pseudoclimatology of wind gust data was computed from years 2008-2017. Where missing data did exist, it was replaced with a value matching the average standardized anomaly of all reporting stations in the same region for the same day.

CoAgMET stations record wind at a height of two meters above ground level. Wind gusts recorded by wind towers at airports are typically recorded at a height of 10 meters. Blades on wind turbines often oscillate between about 30 meters at the bottom and 100 meters at the top of a rotation, and experience even much higher wind speeds. Wind speeds near the earth's surface nearly always increase with height. The magnitude of wind increase with height is not a constant. It depends on surface roughness and the stability of the atmosphere.

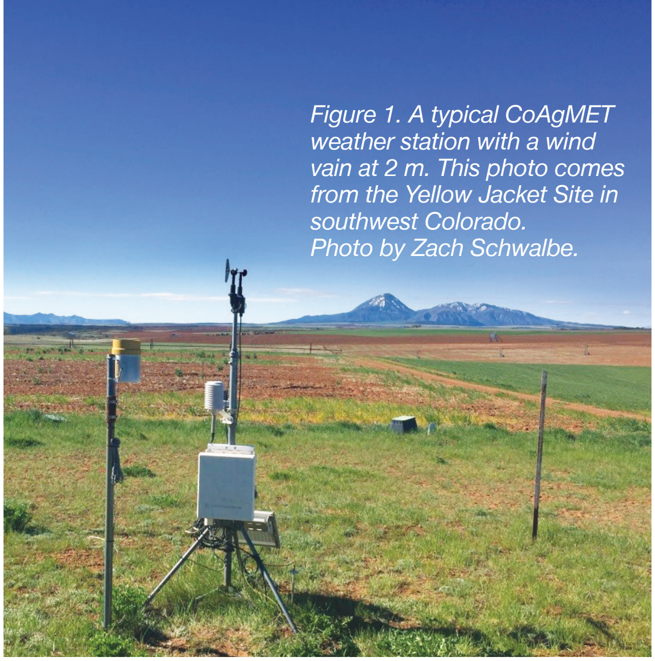


*Figure 1. A typical CoAgMET weather station with a wind vain at 2 m. This photo comes from the Yellow Jacket Site in southwest Colorado. Photo by Zach Schwalbe.*

Resultantly, these data make for poor direct comparison with 10-meter tower data and wind energy data.

## An Abbreviated Climatology of Wind

Spring was identified as Colorado's windy season. April is the windiest month of the year at all 18 stations used in this study. May is the second windiest month on average with March very close behind. It is hypothesized that spring is the perfect time of year for peak surface wind movement due to a combination of two key factors: 1) temperature difference in the northern hemisphere between subtropics and high latitudes maximizes in spring, which leads to stronger frontal passages, and 2) the increase in day length and midday sunshine intensity from winter to spring allows for greater daytime insolation. This leads to more vertical mixing of near surface air with the free atmosphere aloft, and allows air with greater momentum to reach the earth's surface. Average wind speeds reach a minimum in wind speeds and gusty days over Colorado in August and September (Figure 4). This is likely linked to a poleward shift of large-scale frontal boundaries during the warm season.

Windy days are a staple of the climate of the Eastern Plains. The three stations used nearest Colorado's eastern border were the three stations with the highest average wind speeds. Despite being less consistently windy than the Eastern Plains, CoAgMET stations on the Front Range were comparable to the Eastern Plains in terms of wind gust strength and number of gusty days. Front Range stations even exceeded the Eastern Plains in average gusty days in April (Figure 4). The Front Range's peak in wind gusts are enhanced by Chinook

CoAgMET Stations Used

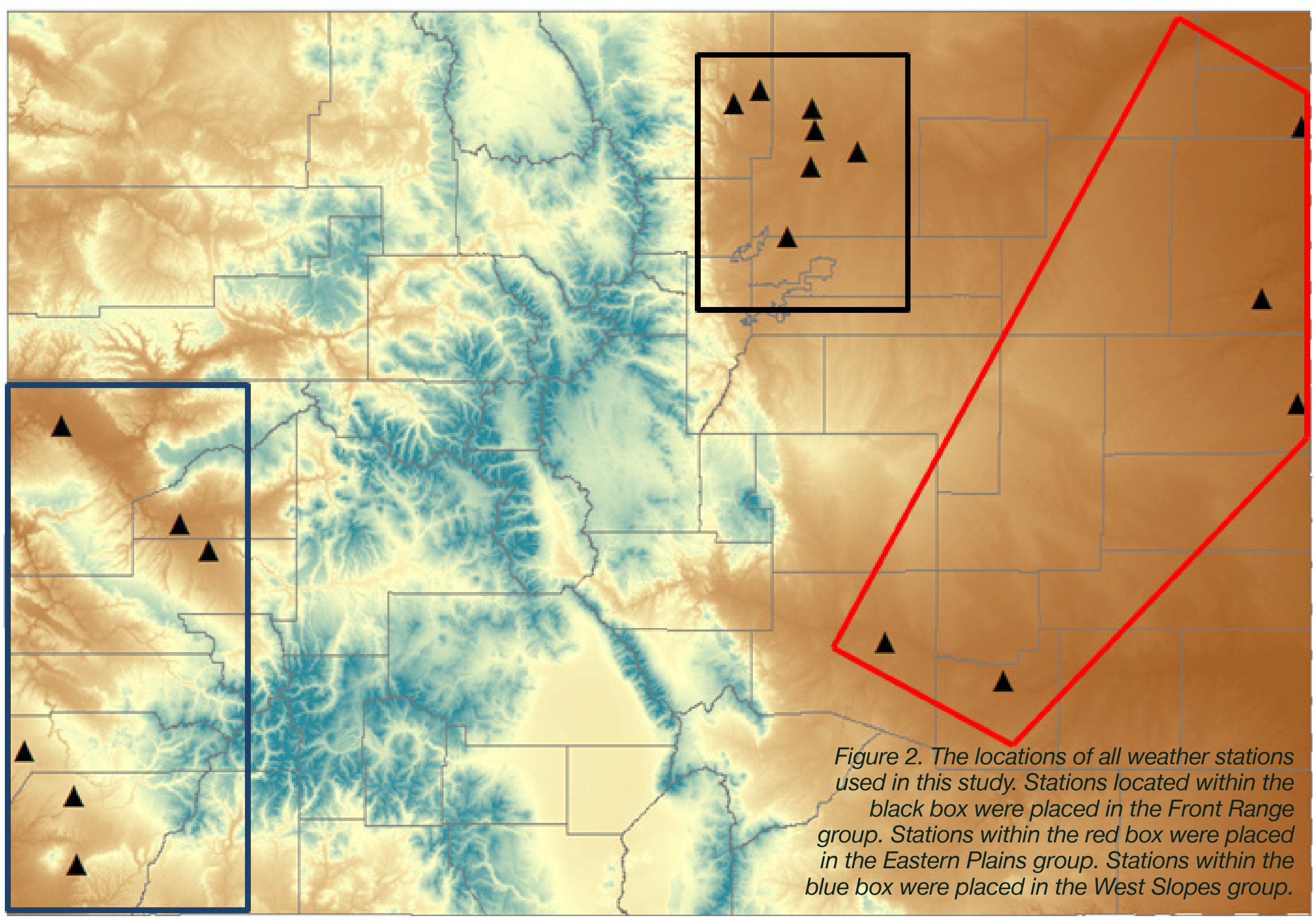


*Figure 2. The locations of all weather stations used in this study. Stations located within the black box were placed in the Front Range group. Stations within the red box were placed in the Eastern Plains group. Stations within the blue box were placed in the West Slopes group.*

wind events. Chinooks, also known as "snow eaters," are eastward bursts of air that gain momentum and heat content as they cascade down the lee side of the Rockies. These wind events are most common when high pressure is present over the Great Basin, and low pressure exits southern Wyoming out onto the Central Plains. Wind speeds and gusty days rise more from mid-fall through mid-winter for the Front Range and Eastern Plains than for the West Slopes. It is hypothesized that lack of wintertime wind on the West Slopes is driven by pooling of cold air in the valleys. Cold air drains off of mountain slopes into valleys during long winter nights. With minimal hours of sunlight, low solar intensity, and often snow-covered ground, this air is not heated rapidly during the daytime. It tends to be cool and dense, and therefore stays in place, rather than mixing with the free atmosphere above. These pools of near-surface cold air are typically associated with calm or light winds.

Surface wind characteristics are also strongly related to a given site's microclimate. Site-specific average wind speed varied from 3.9-6.3 mph for the Front Range, 5.3-8.6 mph for the Eastern Plains, and 3.3-6.5 mph for the West Slopes. Station elevation and station exposure both play key roles. On the Western Slopes, the Yellow Jacket station is only about 20 miles from the Cortez Station, but is windier by a factor of 1.4. The Yellow Jacket station is 900 ft higher and is more exposed, particularly to winds out of the west.

## Change and Variability

Average monthly wind speeds generally vary by a factor of about 1.5 interannually. Day-to-day average wind speeds may vary by as much as a factor of 10. When averaging together a group of stations, and averaging by season rather than month (as in Figure 4), some of this variability is washed out.

Average wind speeds have declined from 1996-2018 for all regions in all seasons with one exception—West Slopes during the spring.

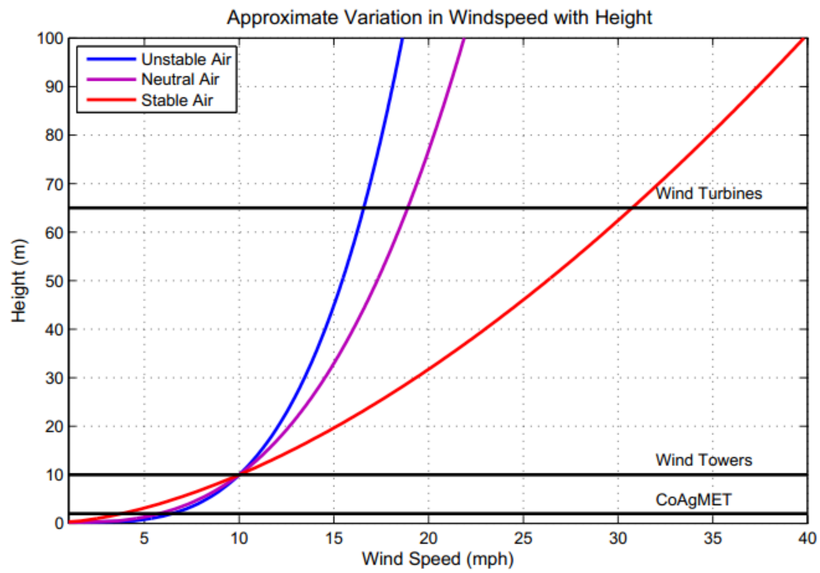



*Figure 3. An approximation of change in wind speed (mph) as a function of height (m) for winds registering 10 mph at 10 m height. Approximations are given for unstable air (blue), neutral air (purple), and stable air (red).*

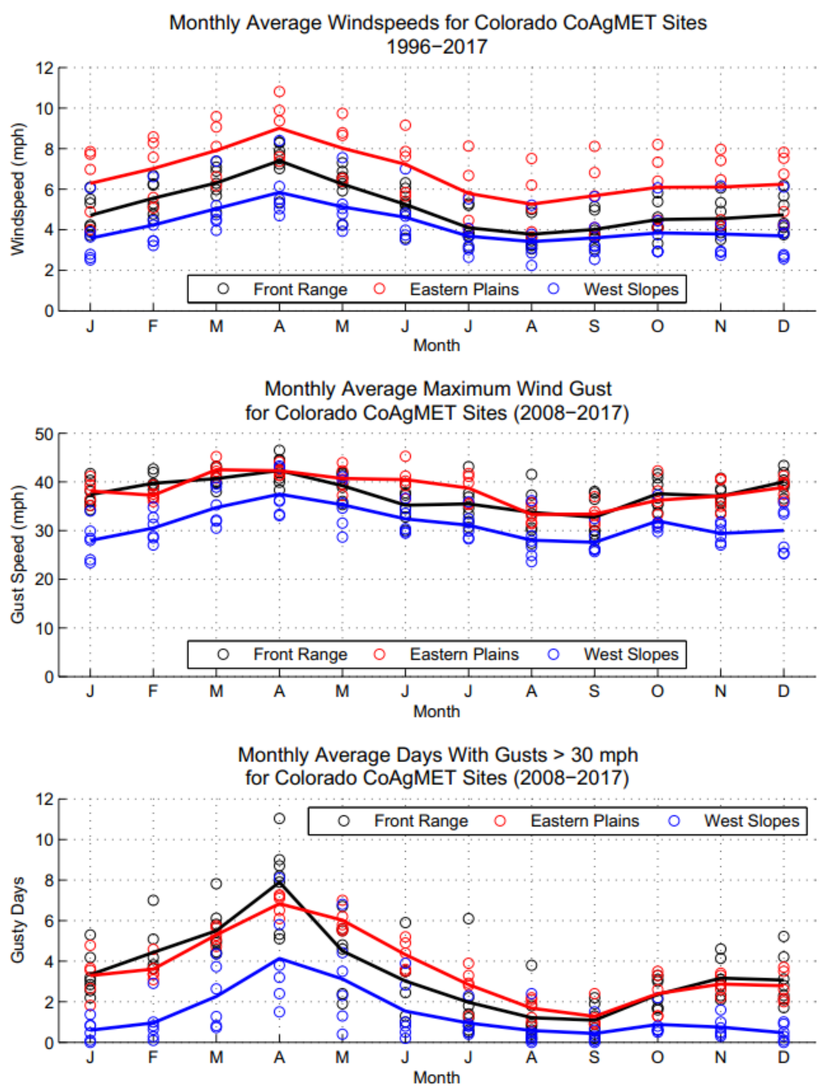



*Figure 4. Average wind speed (top), maximum wind gust (middle), and number of days with a wind gust exceeding 30 mph (bottom). Each dot represents an individual CoAgMET station. Solid lines represent averages for Front Range (black), Eastern Plains (red), and West Slopes (blue) stations.*

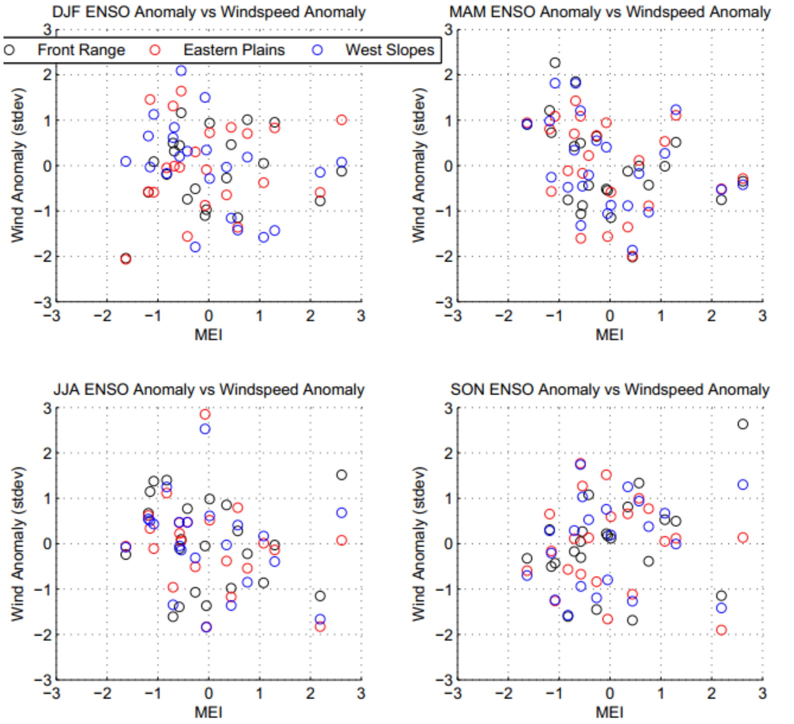



*Figure 5. (Above) Average wind speed as a function of year for winter (upper left), spring (upper right), summer (lower left), and fall (lower right). Yearly averages are given for the Front Range group (black), Eastern Plains group (red), and West Slopes group (blue). Solid gray lines are trend lines for each group.*

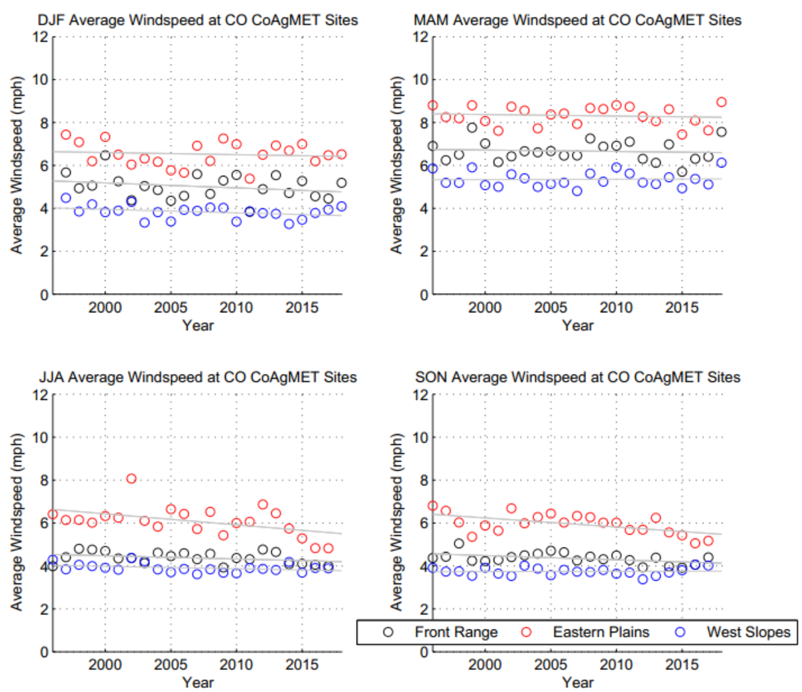



*Figure 6. (Above) Standardized seasonal wind speed as a function of ENSO state for winter (upper left), spring (upper right), summer (lower left), and fall (lower right). Values are given for the Front Range group (black), Eastern Plains group (red), and West Slopes group (blue). Solid gray lines are trend lines for each group.*

Declines have been greatest both in absolute magnitude and percent of normal for the Eastern Plains in summer and fall. These trends are both significant at 99% confidence. No trends in any other region, or for any other season, are statistically significant. 22 years of data is also a small sample for detecting a long-term trend.

Seasonal wind speed averages are only weakly linked to the ENSO (Figure 6). ENSO explains less than 5% of the variance in wind speeds in summer and fall. Winter wind speeds are weakly related to ENSO on the West Slopes in winter. 15% of West Slope winter wind variance was explained by the ENSO Multivariate Index (MEI) with La Niña preferred for windier conditions. ENSO appears to have a modest influence on springtime winds. It explains 31%, 16%, and 23% of variance in average springtime wind speeds for the Front Range, Eastern Plains, and Western Slopes respectively. La Niña is linked to higher average wind speeds in all cases.

## Conclusions

The CoAgMET is still relatively new in the climate world, but presents some exciting future opportunities for exploring Colorado's climate through surface observations in the years to come. This glimpse at wind patterns across the state is one early example.

While large variations in average wind speed, wind gusts, and gusty days exist from site-to-site, our CoAgMET 2m wind speed data support eastern Colorado's reputation for consistent wind, and the Front Range's reputation for strong gusts. From the locations observed, it appears that the state of Colorado has a seasonal wind cycle that peaks in intensity in the middle of spring, and reaches a minimum at the beginning of fall. Winds tend to stay low through the winter on the West Slopes, but not east of the Continental Divide.

Seasonal wind speeds are only very weakly linked to the ENSO MEI. Windier springs are preferred when La Niña conditions are present. Data from 1996-2018 seem to suggest that Colorado has lost some of its wind. The only statistically significant losses are on the Eastern Plains during spring and summer. 22 years is still a fairly short time series for detecting trends, and our current spring is a windy one. We will see what the winds of change blow our way.

# A Turning Point

WATER RESOURCES ARCHIVE

## Reclamation and Recreation

*Ival Goslin and Arthur Watkins at Rainbow Bridge, 1971. From the Ival Goslin Collection, Water Resources Archive, CSU Libraries.*

Patricia Rettig, Water Resources Archive,
Colorado State University Libraries

"These people, the Easterner, the Southerner, the Midwesterner, the lawyer, the doctor, the merchant, the butcher, the baker, the candlestick maker, should be enlisted in the cause for recreation through reclamation."
–Ival Goslin, November 30, 1961 (p.7)

### SYNOPSIS

Recreational uses of Bureau of Reclamation reservoirs became increasingly important as the U.S. population pursued more outdoor activities by the 1950s. Officials interested in building more dams began advocating for inclusion of recreation as a way to incentivize approval in the face of environmental opposition. Speeches by Gilbert Stamm and Ival Goslin reveal the details in this article.

Many people recognize the decade of the 1960s as a time of significant change in the United States. However, few probably think of the pivot the Bureau of Reclamation took to embrace recreation as part of its prime advocacy for dam-building projects.

In the earliest decades of the U.S. Bureau of Reclamation (formed in 1902 as the Reclamation Service), recreation was not a consideration. Dams were built for the single purpose of creating reservoirs to store water for irrigation. As time went on, other benefits were added to projects, including power production, flood control, and recreation. The 1930s construction of Hoover Dam included all of these multipurpose features. By the late 1950s, the Bureau was incorporating "recreation functions and values in its project planning" even though no national policy required it (Stamm,1961, p.2). As part of that planning process, the Bureau partnered with the National Park Service for recreational development.

Earlier in the 1950s, a surging post-war economy coupled with a new national highway system spurred a boom in outdoor recreation across the country. The population was also growing rapidly, and visits to both national parks and Reclamation reservoirs saw exponential growth. The prediction was for more of the same, with economic benefits accompanying the increasing recreation.

"The handwriting is on the wall," Gilbert Stamm said in a 1961 speech. At the time, this Colorado State University alumnus served as the chief of the Division of Irrigation and Land

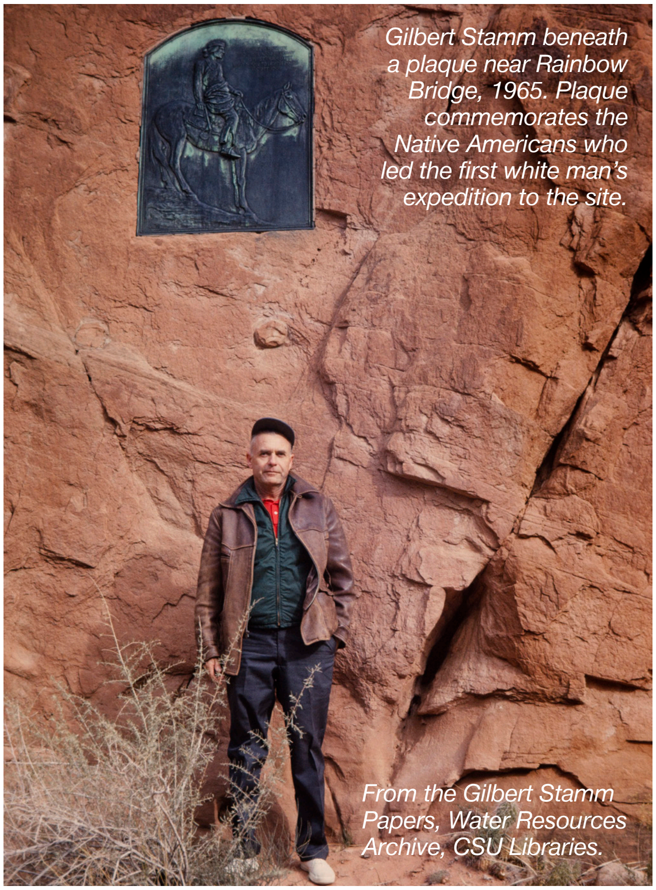
Use at the Bureau of Reclamation. He would lead the Bureau as commissioner a dozen years later.

The Tenth Annual Irrigation Operators Conference held in Boise, Idaho, provided the occasion for Stamm's remarks, titled "Recreation: Its Place in Irrigation Development, Present and Future." He said further, "We will enjoy much broader support for Reclamation development if we recognize these recreation benefits and accommodate them to the greatest degree possible" (p.8).

A colleague of Stamm's with a focus on water projects in the Upper Colorado River Basin shared the same view. In his own speech also given in 1961, Ival Goslin echoed the predicted trend of increasing visits to water-based recreation facilities. He stated, "Bear in mind that this trend will continue because the facts show that people prefer their relaxation in conjunction with water" (p.4). At the time, Goslin worked as the executive secretary of the Upper Colorado River Commission and monitored developments across the basin. His remarks, titled "Recreation and Reclamation," were made to the Annual Meeting of the Colorado River Water Users Association in Las Vegas, Nevada.

Bureau officials and others with reclamation interests in the West witnessed two unpredicted events effecting their work in the late 1950s. One was the vast increase in outdoor recreation, a trend mentioned by both gentlemen having aims to finance and build western reservoirs. This inclusion may have been motivated by Congressional creation in 1958 of the Outdoor Recreation Resources Review Commission, a body that was preparing to recommend federal policies. Both men mentioned the commission's pending report.

The other, perhaps more significant, event of the late 1950s curiously escaped but mentioned by both men. Though its culmination was a full five years before both speeches, it was hardly a forgettable occurrence. Perhaps neither wanted to highlight it for their audiences though,



*Gilbert Stamm beneath a plaque near Rainbow Bridge, 1965. Plaque commemorates the Native Americans who led the first white man's expedition to the site.*

*From the Gilbert Stamm Papers, Water Resources Archive, CSU Libraries.*


*Lake Mead Recreation Boulder Beach, 1980.*
*From the Gilbert Stamm Papers, Water Resources Archive, CSU Libraries.*

Ival Goslin at Echo Park, 1954. From the Ival Goslin Collection, Water Resources Archive, CSU Libraries.

as it had proved a challenge to operations as usual.

In 1956, opposition to a Bureau dam proposed downstream of Echo Park on the Green River in Colorado garnered defeat. Conservation groups rallied, for the first time in American history, to actively oppose the dam, waging heated political battles as yet unwitnessed by dam proponents. Though Goslin alluded to it, neither man explicitly said the writing was on the wall for such opposition to remain if not increase as American environmentalism found its footing.

While we may not be able to know the reasons behind this omission by both speakers, it gives us something to think about. In the times of trending recreation at reservoirs, raising specific awareness about past opposition would not help the cause of building more dams. But linking that public desire for recreation with the agency desire for dams was a new approach that possessed great potential to be effective.

Because both Stamm and Goslin were speaking to water users, they addressed some challenges of including recreational aspects in planning for new reservoirs or being retroactively implemented at existing facilities. Conflicting interests included recreators requesting minimum fluctuations during summer, which went against the needs of irrigators. Goslin pithily put it: "I recently visited a reservoir where there was a bitter three-way battle with overtones that included the fishermen who were ready to shoot the water ski enthusiasts, who, in turn, were ready to commit anything from a good cussing to mayhem on the farmers who were lowering the water surface in order to irrigate their crops" (p.3).

Looking to the future, Stamm advocated working "to obtain needed authority and to develop plans and procedures for the inevitable increase in future recreational use of project reservoirs" (p.9). He raised some questions that policy could address. Goslin suggested that government evaluators were not yet paying proper attention to recreation needs: "Our bureaucrats charged with evaluating project benefits have kept their heads in the sand, too long oblivious to the national, state and local benefits of recreation. Application of the foot to the posterior of an ostrich might be the proper solution for removal of this bird's head from the sand" (p.4).

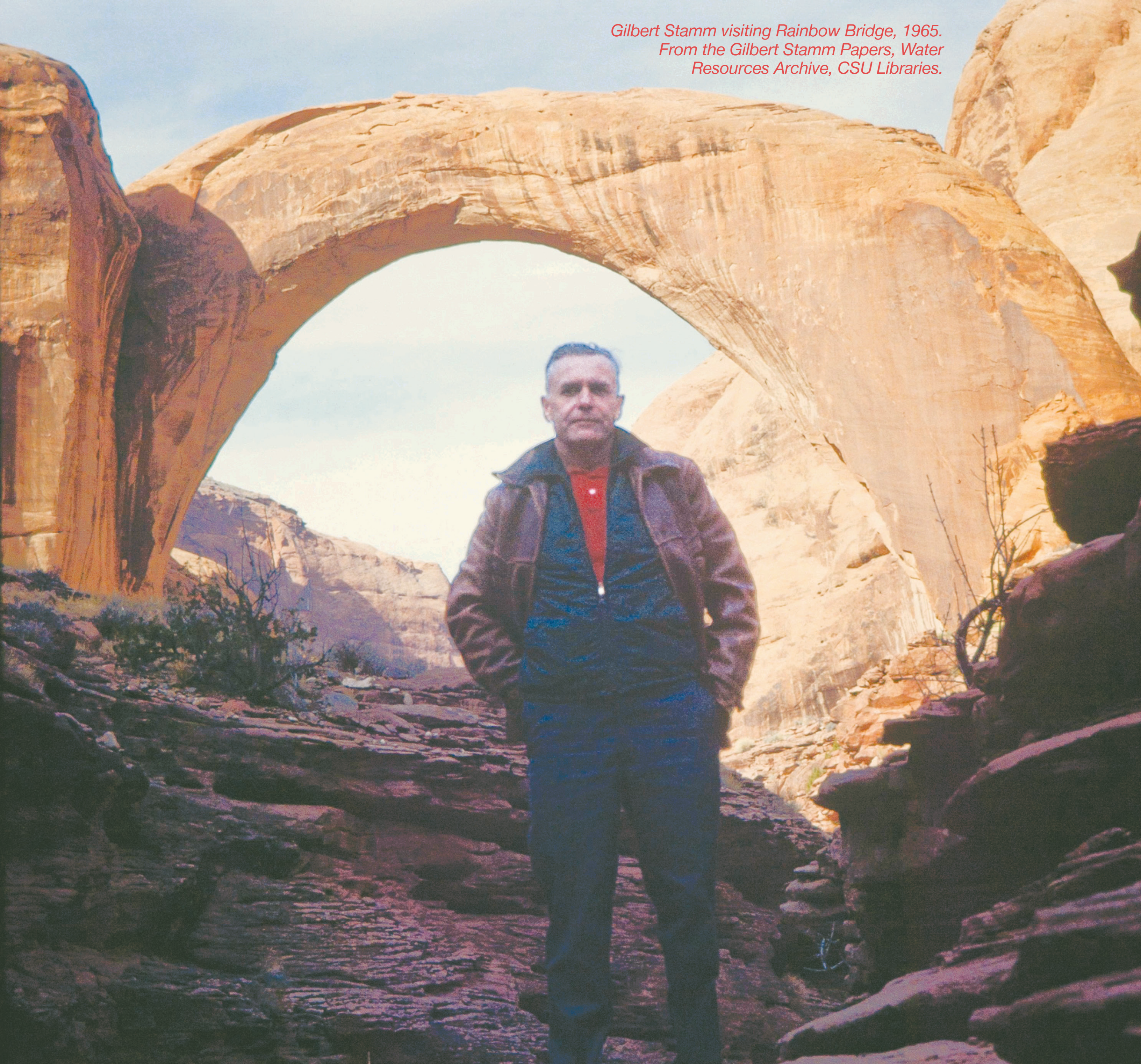
The two speakers concluded with different outlooks for

*Ival Goslin at Glen Canyon Dam gates, June 1980. From the Ival Goslin Collection, Water Resources Archive, CSU Libraries.*

their audiences. Stamm advised his audience of irrigators that, as the ones directly affected, they should pay attention to emerging legislation and push for appropriate policies and procedures, especially when the costs of creating and maintaining recreational facilities could fall on the irrigators. Goslin's perspective goes back to the quote at the start of this article. He thought the recreating public should be educated about the mutually beneficial relationship enabled by reclamation projects.

Speeches of water leaders can give insight into the issues of their times. Also occurring at the time of these speeches was the construction of Glen Canyon Dam, which was a compromise in the Echo Park battle and which would form Lake Powell, drawing more recreators to that part of the Colorado River than had ever been there before. Times were changing, with many consequences.

The two speeches examined here are in collections at the Water Resources Archive in Colorado State University's Morgan Library. These speeches, and more like them, are available through the Archive's website (https://lib.colostate.edu/water). Additional thousands of documents and photographs on recreation, reclamation, and more are accessible via the Archive. For more information, consult the Water Resources Archive website or contact the archivist (970-491-1939; Patricia.Rettig@ColoState.edu) at any time.



*Gilbert Stamm visiting Rainbow Bridge, 1965. From the Gilbert Stamm Papers, Water Resources Archive, CSU Libraries.*

*(Above) CSU PhD candidate John Hammond installing a streamflow sensor on a bridge over Portland Creek outside of Ouray, Colorado, at the new San Juan transitional station in September 2017. Photo by Gigi Richard.*

# Water Yield Sensitivity to Snow Loss in Colorado Headwater Streams

Gigi Richard, Physical and Environmental Sciences, Colorado Mesa University;
Abby Eurich, Ecosystem Science and Sustainability, Colorado State University;
John Hammond, Geosciences, Colorado State University;
Stephanie Kampf, Ecosystem Science and Sustainability, Colorado State University

## SYNOPSIS

A collaborative monitoring effort between faculty and students at Colorado Mesa University (CMU) and Colorado State University (CSU) contributes to an examination of how snowpack and streamflow interact across the full elevation gradient of Colorado streams. Data collected at the West Slope monitoring stations in water year 2017 revealed that the lower elevation Grand Mesa site experienced greater mid-winter snowmelt and an earlier rise in soil moisture, which can be connected to streamflow timing. For the Grand Mesa sites, our measurements to date highlight how sensitive the snowpack is to small changes in temperature.

*Table 1. Site visits for the grant period between March 1, 2017, and February 28, 2018.*

| GM Persistent | GM Transitional | GM Intermittent | CNM Intermittent | SJ Persistent | SJ Transitional | SJ Intermittent |
|---|---|---|---|---|---|---|
| 3/18/2017* | 3/18/2017* | 3/4/2017* | | | | |
| | | 4/2/2017* | | | | |
| 5/6/2017* | 5/6/2017* | 5/12/2017 | | | | |
| 6/18/2017* | 6/18/2017* | 6/18/2017* | | | | |
| 7/30/2017 | 7/30/2017 | 7/30/2017 (site removed) | | | | |
| 8/26/2017 | 8/26/2017 | | | | | |
| | | | | 9/30/17 (site installation) | 9/30/17 (site installation) | |
| | | | | 10/22/2017 | 10/22/2017 | |
| 11/4/2017 | 11/4/2017 | | | | | |
| 12/1/2017 | 12/1/2017 | | 12/1/17 (site installation) | | | |
| | | | 12/29/17 (install rain gage) | | | 12/28/17 (site installation) |
| 1/24/2018* | 1/24/2018* | | 1/20/2018 | 1/3/2018 | 1/3/2018 | |
| | | | | | 1/28/2018* | |

*snow or soil moisture transect performed

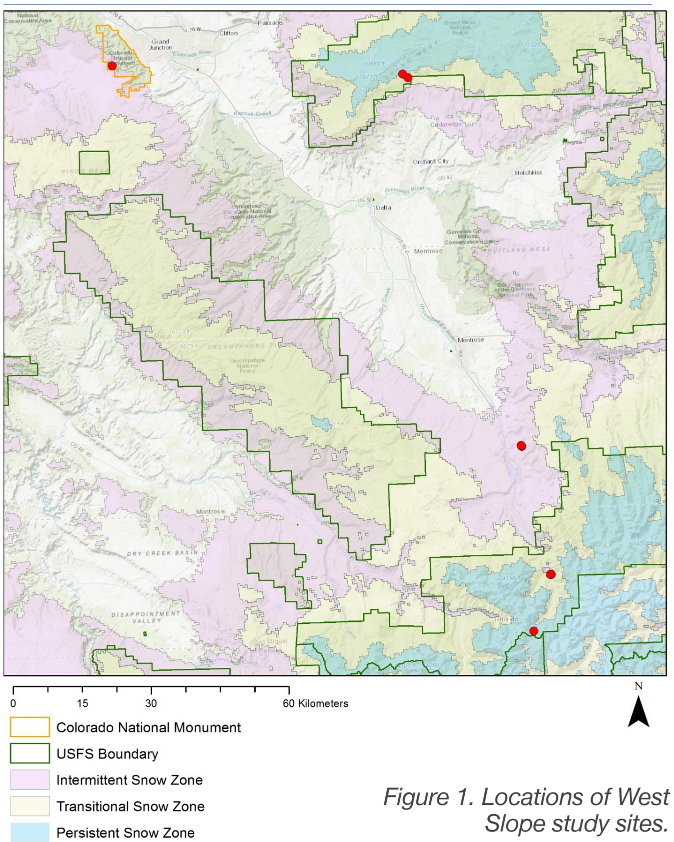



*Figure 1. Locations of West Slope study sites.*

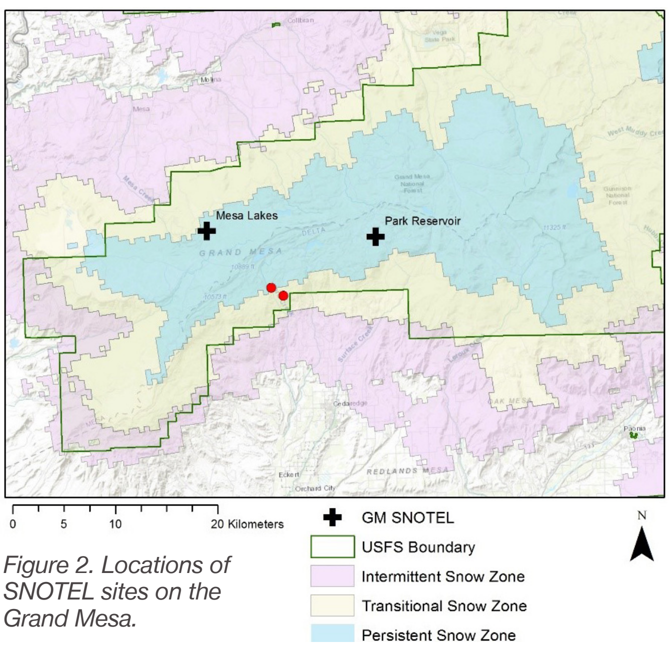



*Figure 2. Locations of SNOTEL sites on the Grand Mesa.*

## Introduction

This project is part of a larger collaborative effort between faculty and students at Colorado Mesa University (CMU) and Colorado State University (CSU) and contributes to an examination of how snowpack and streamflow interact across the full elevation gradient of Colorado streams. The component of the research described here focused on streams on the West Slope of the Colorado Rockies. Specifically, the grant funding was used to accomplish the following:

- Support CMU undergraduate students and faculty for data collection at three existing monitoring stations on the Grand Mesa and for the establishment of three new sites in the Uncompahgre River watershed. The data collected will be integrated into a longer-term data set that can help inform streamflow prediction, particularly in transitional elevations that are most sensitive to drought and warm temperatures.
- Replace malfunctioning equipment and add three new monitoring stations to better capture the snowmelt and runoff generation from the persistent, transitional, and intermittent snow zones on the Grand Mesa, the Colorado National Monument, and the San Juan mountains.
- Support data organization and processing for preparation of a water year (WY) 2017 snowpack report for the Grand Mesa.

*Table 2. WY 2017 data summary for the Grand Mesa persistent and transitional sites.*

| Water Year 2017 | 10/01/16-09/30/17 | Grand Mesa Persistent (Elevation 3,019 m) | Grand Mesa Transitional (Elevation 2,939 m) |
|---|---|---|---|
| PRISM | Total Precipitation | 1,030 mm | 890 mm |
| | Avg. Temperature | 4.7 °C | 5.7 °C |
| Snow | Peak SWE | 816 mm | 606 mm |
| | Date of Peak SWE | 03/06/17 | 01/23/17 |
| Soil Moisture | Average SM 5 cm | 30.9% | 26.1% * |
| | Average SM 20 cm | 32.1% | 25.3% * |
| | Average SM 50 cm | 34.0% | 27.2% * |
| Discharge | Total Discharge (Q) | 259 mm ** | |
| | Date of Peak Q | 05/13/17 | |

*Missing Data: 07/31/17-09/30/17
**Missing Data: 10/01/16-12/10/16; baseflow value as streamflow used for these dates

## Summary of Work Accomplished

### *Data Collection*

CMU and CSU faculty and students performed a total of 32 site visits between March 1, 2017 and February 28, 2018 (Table 1). Each site visit entailed downloading data from the stream gage, soil moisture sensors, rain gage, and snow-depth camera, conducting a snow depth and density or soil moisture transect, and a streamflow measurement. The data collection supported by these grant funds are part of a larger data collection effort that began in April 2016 with the installation of the Grand Mesa stations and will continue into

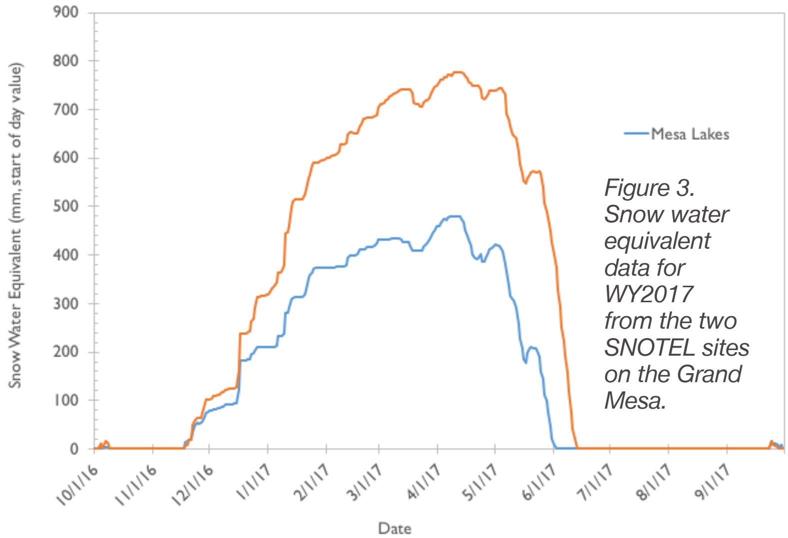
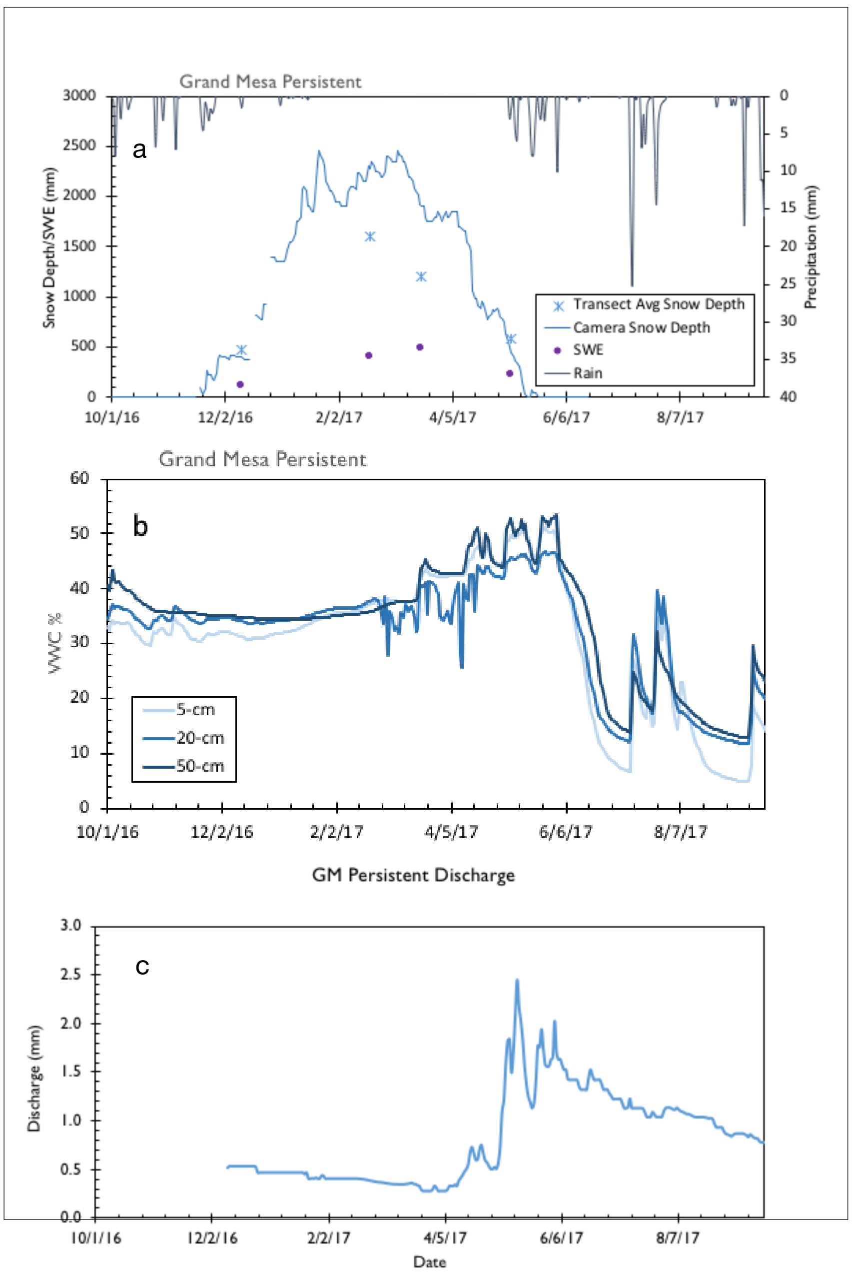


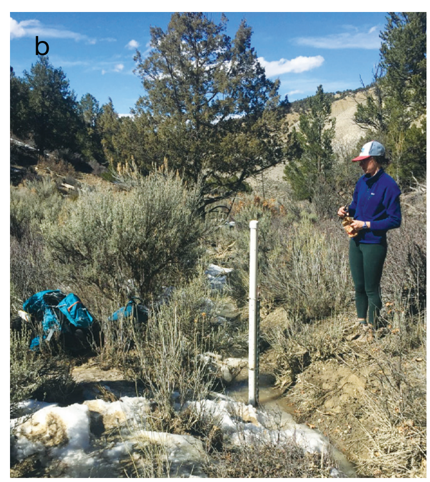

*Figure 3. Snow water equivalent data for WY2017 from the two SNOTEL sites on the Grand Mesa.*




*(Left) Figure 4. a) Snow depth, snow water equivalent, and precipitation and b) soil moisture, and c) discharge from Grand Mesa persistent zone monitoring site for WY 2017.*


*a) CSU graduate student Abby Eurich and CMU professor Dr. Gigi Richard at the new San Juan persistent station in Senator Beck Basin on Red Mountain Pass following installation of the new stream gage in September 2017. Photo by John Hammon.*

*b) CMU undergraduate student Meghan Cline at the streamflow monitoring station at the San Juan intermittent site near Ridgway, Colorado. Photo by Gigi Richard.*



the future via funds from other sources and volunteer efforts at the six West Slope monitoring stations.

Data collected from the site visits have been organized on Dropbox for ease of sharing between CMU and CSU. Data from the Grand Mesa persistent and transitional sites are summarized below and will be incorporated into further analyses by Dr. Stephanie Kampf's research team at CSU. Seven CMU undergraduate students were supported by these grant funds to assist in the field data collection, data management and organization, and data processing.

## Site Installation and Equipment Updates

Three new monitoring stations were installed during the study period and one station was relocated (Figure 1). The Grand Mesa intermittent site stream had no streamflow from April 2016 through July 2017, so equipment was removed on July 30, 2017 with the intention of moving the equipment to another watershed on the Grand Mesa. Access issues, the topography of the Grand Mesa, and the abundance of diversions on the Grand Mesa made it challenging to find an unregulated intermittent catchment on the Grand Mesa. A new intermittent watershed in the Colorado National Monument was selected instead. The equipment from the Grand Mesa intermittent site was repurposed at the new Colorado National Monument site on December 1, 2017. The new site is within the National Park Service (NPS) boundaries and permitted by NPS. The stream is tributary to Ute Canyon.

Three new sites were installed in the Uncompahgre River drainage in the San Juan (SJ) mountains. The SJ persistent site, in Senator Beck Basin on Red Mountain Pass, is a collaboration with the Center for Snow and Avalanche Studies (CSAS) in Silverton, Colorado. CSAS already monitors snow depth and density, streamflow in the summer, and weather conditions throughout the year. In September 2017, we installed a second stream gage (capacitance rod), staff gage, and soil moisture sensors at three depths near the CSAS Swamp Angel Study Plot. The San Juan transitional site, installed on September 30, 2017, is located on Portland Creek on Ouray County property. The San Juan intermittent site, installed on December 28, 2017, is located on Bureau of Land Management property west of Ridgway Reservoir. The new SJ transitional and intermittent sites both include new Decagon soil moisture,

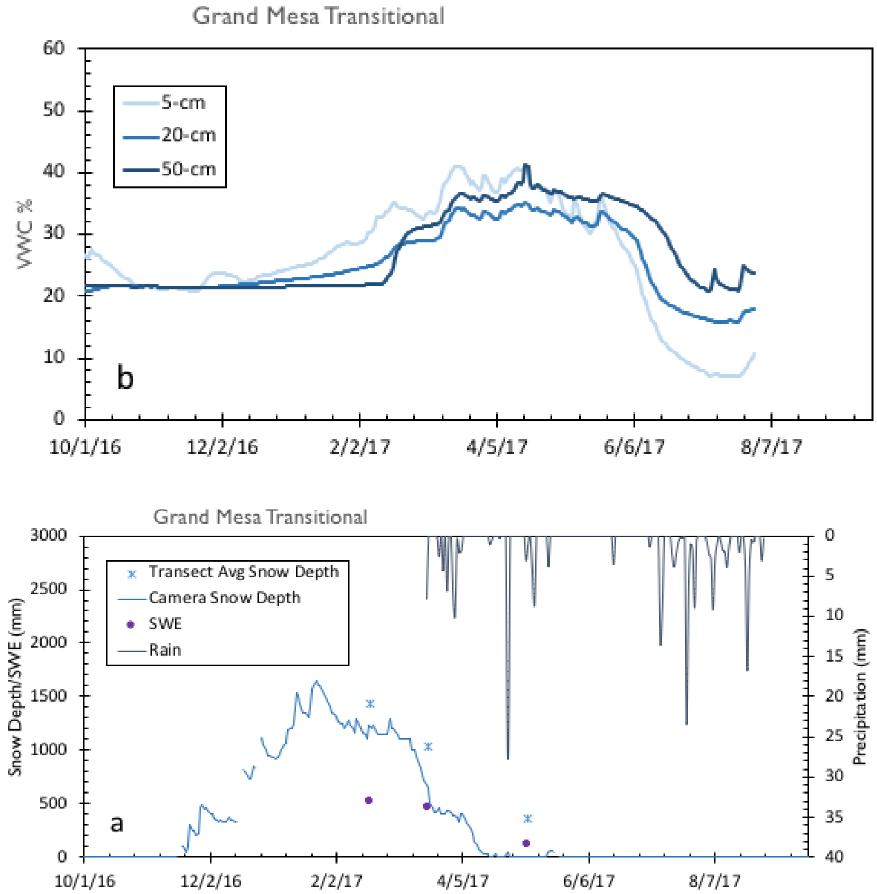



*Figure 5. a) Snow depth, snow water equivalent, and precipitation and b) soil moisture from Grand Mesa transitional zone monitoring site for WY 2017.*

air temperature, and soil temperature sensors, Decagon data loggers, Rainlog rain gages with Hobo data loggers, pressure sensors for flow depth and air pressure, snow cameras, and staff gages. The SJ transitional site is also equipped with an Arduino sensor to measure stage in Portland Creek.

## Water Year 2017 Snowpack Report

Data from the Grand Mesa persistent and transitional sites were summarized for water year 2017 (Table 2). The stream at the Grand Mesa intermittent site in Shirttail Creek had no streamflow from March 2016 through July 2017 and as a result, those data are not included in the summary. Two snow telemetry (SNOTEL) stations are located on the Grand Mesa: Mesa Lakes, elevation 3,048 m and Park Reservoir, elevation 3,036 m (Figure 2) and the water year 2017 data from the SNOTEL stations have been compared to our Grand Mesa stations.

Snow accumulation at the SNOTEL sites on top of the Grand Mesa peaked on April 9 at 78 cm SWE (Park Reservoir) and April 7 at 48 cm SWE (Mesa Lakes) (Figure 3). After a few phases of melt and snow accumulation, snow melted rapidly, and the sites were snow-free by June 2 and June 13. Our persistent snow monitoring site is slightly lower in elevation than these SNOTEL sites and its peak SWE was 816 mm on March 6, comparable to the Mesa Lakes site (Figure 4). This site had several periods of mid-winter and spring melt, and it was snow-free by May 16. Further downslope at our transitional monitoring site, snow peaked in the winter at 606 mm, and there was very little accumulation through the spring (Figure 5).

Soil moisture remained relatively constant through the winter at the persistent site then began to rise with the spring melt, reaching its highest levels just after the site was snow-free. The streamflow began to rise from early snowmelt in April and flow peaked during the final stage of snowmelt. Soil moisture rose in response to summer rains but never to levels as high as those during peak snowmelt, and these rainfall responses were not evident in the streamflow hydrograph, which gradually declined for the rest of the water year (Figure 4). Greater mid-winter snowmelt at the transitional site led soil moisture to rise earlier, and this site retained high soil moisture until June, when it started to dry (Figure 5). Unfortunately, the streamflow data for the transitional site have not been reliable.

These findings contribute to a longer-term study of streamflow generation across snow zones. For the Grand Mesa sites, our measurements to date highlight how sensitive the snowpack is to small changes in temperature. Compared to the top of the mesa snowpack, which peaked in the spring, the transitional site reached peak snow accumulation in January, with very little snow added in the spring months. This led to more mid-winter infiltration into the soil, which can then change streamflow timing. The Grand Mesa sites also produce less streamflow than comparable sites on the east slope of the Rockies. This may be because the basaltic rocks on the mesa and the unconsolidated boulder fields allow high infiltration of melt water.




*a) CMU students Ivan McClellan, Jordan Veith, and Meghan Cline preparing for a snow transect at the Grand Mesa persistent site in April 2018. Photo by Gigi Richard.*

*b) CMU/CU-Boulder mechanical engineering student Ross Fischer at the Grand Mesa transitional site in August 2017. Photo by Gigi Richard.*

*c) CSU graduate student Abby Eurich at the installation of the Colorado National Monument intermittent monitoring station in December 2017. Photo by Gigi Richard.*

*Faculty* PROFILE

# Michael Falkowski

Ecosystem Science and Sustainability, Colorado State University

Photo by Karina Puikkonen.

I am a remote sensing scientist with broad research interests in ecosystem ecology, landscape ecology, and applied land management. I have been at Colorado State University (CSU) since August of 2015, and have also held faculty positions at the University of Minnesota and Michigan Technological University. Although my research program includes projects focused on unique problems, there is one common thread throughout—the use and development of cutting edge remote sensing and geospatial technologies, in combination with fundamental field measurements and statistical analyses, to gain a better understanding of natural and managed environments, while supporting land management and conservation whenever possible.

At the beginning of my academic career, my research included the development of remote sensing, spatial modeling methods, and advancing the theory that underlies these methods, to solve applied problems in the natural resource and forestry disciplines. This work involved the use of LiDAR data very high spatial resolution satellite imagery to measure vegetation structure and biomass in forested environments. Today my research group tackles a variety of issues including wildlife habitat assessment via remote sensing, hyperspectral remote sensing of plant water status and composition, remote sensing of climate induced biophysical change in boreal wetland systems, Landsat time series analysis of disturbance, and land cover change across a 40+ year timespan. We are also currently finishing a pilot study focused on using remote sensing and economic modeling to understand the spatial extent and economic impacts of rural-to-urban water transfers across Colorado's Front Range.

Although my research spans theoretical and applied realms, I find stakeholder engagement the most rewarding aspect of my current research activities. As an example, my recent work on the Greater Sage Grouse has been both challenging and rewarding, and nicely demonstrates the applied aspects of my research program. Sage Grouse populations have been declining across their range due to loss and fragmentation of habitat, which has been attributed to multiple drivers including urbanization, energy development, conversion of grasslands to agriculture, and expansion of conifer tree species into native grasslands. My research team has been working closely with the Natural Resources Conservation Service (NRCS) Sage Grouse Initiative to develop proactive approaches to conserve and restore habitat for the Greater Sage Grouse. We have actively participated in this initiative by processing and analyzing large volumes of high spatial resolution imagery to characterize critical habitat attributes across 400 million acres of sagebrush ecosystems in the Western United States. We subsequently leverage this information in spatial optimization models to prioritize areas for habitat restoration, while balancing wildlife habitat requirements with societal needs including both agriculture and energy production. It has been incredibly rewarding to see the products from this research being leveraged to support real-world land management decisions. I truly believe that our research will have a much larger impact on society if we engage directly with stakeholders and land managers to understand their science and data needs, ultimately cogenerating research priorities and results that will be quickly applied.

I teach a variety of technical and quantitative courses at graduate and undergraduate levels in remote sensing, spatial science, and related natural resource topics. I thoroughly enjoy teaching as I believe effective teachers can have a very large impact on society. Several students over the years have pursued careers in geospatial science based on their experiences in courses I have taught, which is very rewarding.

In September of 2018, I will take a two-year hiatus from my duties at CSU while I serve as a Program Scientist in NASA's Terrestrial Ecology program at their Headquarters Office in Washington, D.C.

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# Water Calendar

## September

**9-12 33rd Annual WateReuse Symposium; Austin, TX**
This symposium provides the opportunity to discover new water reuse policies, operation, and technology.
watereuse.org/news-events/conferences/annual-watereuse-symposium/

**10-12 Colorado Open Space Alliance Conference—Ripple by Ripple, Water is the Driving Force in Nature; Grand Junction, CO**
This conference will focus on watershed management, human impacts on water, restoration projections, and natural threats to water resources.
coloradoopenspace.org/conference/

**14 Colorado River District Annual Seminar; Grand Junction, CO**
A series of presentations addressing Upper and Lower Basin drought contingency planning, challenges with conservation efforts, and degradation of depleted rivers.
coloradoriverdistrict.org/annual-seminars/

## October

**9-11 Sustaining Colorado Watershed Conference; Avon, CO**
This conference expands cooperation and collaboration throughout Colorado for natural resource conservation, protection, and enhancement by informing citizen groups, agencies, consultants, and legislators about current issues and through networking opportunities.
coloradowater.org/scw-conference-2018/

**16-19 11th Annual International Conference on Irrigation and Drainage; Phoenix, AZ**
This conference aims to present and discuss various concerns regarding water reuse and non-traditional sources of water for irrigated agriculture.
uscid.org/18azconf.html

**24-25 South Platte Forum; Loveland, CO**
A multi-disciplinary forum, providing the opportunity to exchange information and ideas about resource management in the South Platte River Basin.
southplatteforum.org/

**For more events, visit www.watercenter.colostate.edu**


*Arkansas Recreational River in Colorado. Photo by the Bureau of Land Management.*

# USGS Recent Publications

**Hydrologic derivatives for modeling and analysis—a new global high-resolution database;** 2017, U.S. Geological Survey Data Series 1053; Kristine L. Verdin

**Origin of methane and sources of high concentrations in Los Angeles groundwater;** 2018, Journal of Geophysical Research-Biogeosciences; Justin T. Kulongoski, Peter B. McMahon, Michael T. Land, Michael T. Wright, T.A. Johnson, Matthew K. Landon

**Widespread legacy brine contamination from oil production reduces survival of chorus frog larvae;** 2017, Environmental Pollution; 231,42-751; Blake R. Hossack, Holly J. Puglis, William A. Battaglin, Chauncey W. Anderson, R. Ken Honeycutt, Kelly L. Smalling

**Assessment of dissolved-selenium concentrations and loads in the lower Gunnison River Basin, Colorado, as part of the Selenium Management Program, from 2011 to 2016;** 2018, U.S. Geological Survey Scientific Investigations Report 2018–5001, 23, M.F. Henneberg

**Bioactive contaminants of emerging concern in National Park waters of the Northern Colorado Plateau, USA;** 2018, Science of the Total Environment, 636, 910-918; R.H. Weissinger, B.R. Blackwell, K. Keteles, W.A. Battaglin, P.M. Bradley

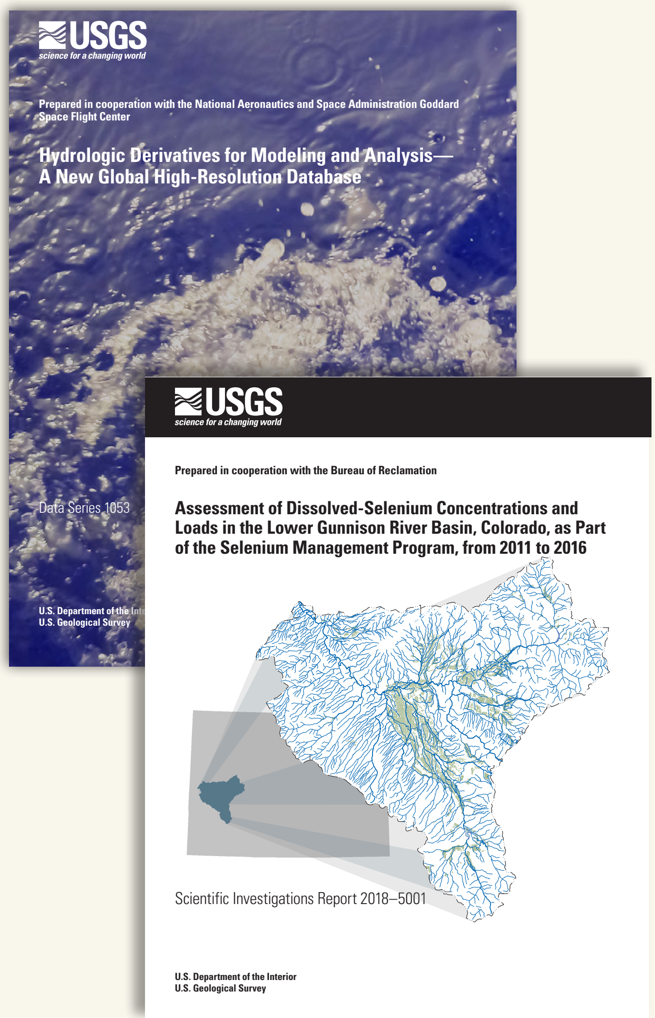
**Methane in groundwater from a leaking gas well, Piceance Basin, Colorado, USA;** 2018, Science of the Total Environment, 634, 791-801; P.B. McMahton, J.C. Thomas, J.T. Crawford, M.M. Dornblaser, A.G. Hunt

**Minnesota mine shaft tracer data, Lion Creek Watershed near Empire, Colorado, July-November 2017;** 2018, U.S. Geological Survey Data Release; R.L. Runkel, R.B. McCleskey

**Quantifying differences in responses of aquatic insects to trace metal exposure in field studies and short-term stream mesocosm experiments;** 2018, Environmental Science & Technology, 52,7, 4378-4384; Y. Iwasaki, T.S. Schmidt, W.H. Clements

**Snow sublimation in mountain environments and its sensitivity to forest disturbance and climate warming;** 2018, Water Resources Research, 54, 1191–1211; G.A. Sexstone, D.W. Clow, S.R. Fassnacht, G.E. Liston, C.A. Hiemstra, J.F. Knowles, C.A. Penn

**Snow model simulations and supporting observations for the north-central Colorado Rocky Mountains during water years 2011 through 2015;** 2018, U.S. Geological Survey data release; G.A. Sexstone, D.W. Clow, C.A. Penn



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*Boats float idly in Grand Lake, Colorado. Photo by Daniel Weber.*

# References


### As the Snow Goes, So Goes a Nation of Skiers: Climate Change and Colorado Skier Visits

Belin, D. (2016). Eye on the Industry: 2014-15 Economic Analysis of U.S. Ski Areas. *National Ski Areas Association Journal,* 24-30.

National Ski Areas Association (NSAA). (2017). Skier Visits Up to 54.7 Million in 2016-17 (Press Release). Retrieved from http://www.nsaa.org/press/press releases/skier-visits-up-to-547-million-in-2016-17/

Jedd, T., Seidl, A., and Wilhelmi, O. (2015). Outdoor Recreation and Tourism Sector In E. Gordon & D. Ojima (Eds.), Colorado Climate Change Vulnerability Study (pp.127-138). Fort Collins, Colorado: University of Colorado Boulder and Colorado State University

RRC Associates. (2015). Economic Study Reveals Ski Industry's $4.8 Billion Annual Impact to Colorado (Press Release). Retrieved from https://www.coloradoski.com/media_manager/mm_collections/view/183

Saunders, S., and Maxwell, M. (2005). Less Snow, Less Water: Climate Disruption in the West. Louisville, Colorado: Clear the Air and The Rocky Mountain Climate Organization.

Scott, D., Dawson, J., and Jones, B. (2007). Climate Change Vulnerability of the U.S. Northeast Winter Recreation-Tourism Sector Climate Change Vulnerability of the U.S. Northeast Winter Recreation-Tourism Sector, Mitigation and Adaptation Strategies for Global Change, 13(5-6), 577-596.

### Colorado Water and the Experience Economy

David Knight, Human Dimensions of Natural Resources, Colorado State University

Beckmann, C. (July,2015). Attracting and Serving the U.S. Adventure Traveler. Adventure Travel Trade Association. Monroe, Washington: Adventure Travel Trade Association.

Colorado State Government (2017). Colorado Water General Fact Sheet. Retrieved from http://cwcbweblink.state.co.us/WebLink/ElectronicFile.aspx?docid=201910&seahid=c2d9b2ec-b7ba-468e-ae85-55187801a497&dbid=0

Colorado State Government (2015). Colorado's Water Plan. Retrieved from https://www.colorado.gov/pacific/sites/default/files/CWP2016.pdf

Gossling, S., Peeters, P., Hall, C.M., Ceron, J.P., Dubois, G., Lehmann, L.V., & Scott, D. (2012). Tourism Water Use: Supply, Demand, and Security: An International Review. Tourism Management, 33, 1-15.

Hall, C.M. (1992). Adventure, Sport and Health Tourism. In Weiler & Hall (Eds.) Special Interest Tourism. London, England: Belhaven Press.

Hutchins-Cabibi, T. (2010, Fall). Headwaters. Denver: Colorado Foundation for Water Education (p. 20). Retrieved from https://issuu.com/cfwe/docs/hw24final

Outdoor Industry Association (OIA). (2017a). Colorado Outdoor Recreation Report. Retrieved from https://outdoorindustry.org/state/colorado/

Outdoor Industry Association (OIA). (2017b). The Outdoor Recreation Economy. Retrieved from https://outdoorindustry.org/wp-content/uploads/2017/04/OIA_RecEconomy_FINAL_Single.pdf

Pine, J., & Gilmore, J. (1999) The Experience Economy. Boston, MA: Harvard Business School Press.

Sealover, E. (2017, June). Colorado Bursts into Top 10 Tourist-Attracting States with Record Year. Denver Business Journal. Retrieved from https://www.bizjournals.com/denver/news/2017/06/28/colorado-bursts-into-top10-tourist-attracting.html

UNWTO (United Nations World Tourism Organization). (2014). Global Report on Adventure Tourism. Madrid: UNWTO.

Waskom, R. (2012). Editorial. Colorado Water, 29(1), 1.

Weaver, D. (2006). Sustainable Tourism: Theory and Practice. London: Butterworth-Heinemann.

Worthington, D. (2017, June). Colorado's Outdoors Creates Economic Powerhouses Out of Recreation and Tourism Industries. Denver Post. Retrieved from https://www.denverpost.com/2017/06/27/colorado-outdoor recreation-tourism-consumer-spending/

### Economic Contribution to the Colorado Economy and Benefits to Visitors from Water Based Recreation

Greiner, J., Werner, J., and Calloway, K. (2016). Commercial River Use in the State of Colorado 1988-2016.

Loomis, J. & McTernan, J. (2014). Economic Value of Instream Flow for Non-Commercial Whitewater Boating Using Recreation Demand and Contingent Valuation Methods. Environmental Management, 53: 510-519.

Loomis, J. & Ng, K. (2012). Comparing Economic Values of Trout Anglers and Nontrout Anglers in Colorado's Stocked Public Reservoirs. *North American Journal of Fisheries Management,* 32(2): 202-2010.

McTernan, J. (2011). The Economic Value of Whitewater Sports in the Cache La Poudre Canyon, Colorado. Masters Thesis. Department of Agricultural and Resource Economics, Colorado State University, Fort Collins, Colorado.

Schoengold, K., Shrestha P., & Eiswerth, M. (2013). The Joint Impact of Drought Conditions and Media Coverage on the Colorado Rafting Industry. *Journal of Natural Resources Policy Research*, 5:183-198.

# References Continued


Shields, M., Loomis, J., Hill R., &Tatersall Lewin, H. (2015). Lower Fryingpan River and Ruedi Reservoir Economic Impact Study. Colorado State University. Fort Collins, Colorado.

Southwick Associates. (2014). The Economic Contributions of Outdoor Recreation in Colorado: A Regional and County-Level Analysis. Fernandina Beach, Florida: Southwick Associates.

Walsh, R., Aukerman R., & Milton, R. (1980). Measuring Benefits and the Economic Value of Water in Recreation on High Country Reservoirs. Completion Report OWRT Project B 175-Colorado. Fort Collins, Colorado: Colorado Water Resources Center, Colorado State University


### Tourism and Recreation at the Water Resources Table


Blomquist, L. & Sloan, L. (2016). OREC Survey Results 2016. Denver, Colorado: Colorado Outdoor Recreation Industry Office.

Bureau of Labor Statistics. (2017). American Time Use Survey-2016 Results. Washington, D.C. 26.

Colorado Department of Parks and Wildlife. (2014). 2014 Colorado Statewide Comprehensive Outdoor Recreation Plan. Denver, Colorado. 187.

Colorado Outdoor Recreation Industry Office. (2018). Helping Colorado's Outdoor Industry  Thrive. Retrieved from https://choosecolorado.com/programs-initiatives/outdoor recreation-industryoffice/

Colorado State Demography Office. (2017). Population totals for Colorado and Sub-State Regions. https://demography.dola.colorado.gov/population/population-totals-colorado substate/#population-totals-for-colorado-and-sub-state-regions.

Colorado Tourism Office. (2017). Colorado Tourism Roadmap: Moving the State Forwardthrough a Statewide Strategic Initiative. 24.

Colorado Water Conservation Board. (2016). Colorado's Water Plan. 567. https://www.colorado.gov/pacific/cowaterplan/plan

Garner, E. (2017). Colorado Population Trends in Aging. Colorado Department of Local Affairs, State Demography Office.

Longwoods International. (2017). Colorado Travel Year 2016. Toronto. 217.

Outdoor Industry Association. (2017). The Outdoor Recreation Economy. Boulder, Colorado. 20.

The Outdoor Foundation. (2017). 2017 Outdoor Recreation Participation Report 2017. Washington, D.C. 45.


### A Turning Point: Reclamation and Recreation


Patricia Rettig, Water Resources Archive, Colorado State University Libraries

Goslin, I.V. (1961). Recreation and Reclamation. Fort Collins, Colorado: Ival V. Goslin Water Resources Collection, Water Resources Archive, Colorado State University Libraries. Retrieved from http://hdl.handle.net/10217/14773

Stamm, G.G. (1961). Recreation: Its Place in Irrigation Development, Present and Future. Fort Collins, Colorado: Papers of Gilbert G. Stamm, Water Resources Archive, Colorado State University Libraries. Retrieved from http://hdl.handle.net/10217/27894