Colorado Climate

Water Year 2003 Vol. 4, No. 1-4

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On the cover: Photos courtesy of (beginning with upper left and going clockwise) Toshi Matsui, M.J. Brodzik, Tara Green, Stacey Seseske (lower right and center), Tom Bliss, and D. Burrows.

From the Editors' laptop:

As you may know by now, we have failed to keep up with our original schedule of quarterly (four per year) issues of the Colorado Climate Magazine. We have been publishing "Colorado Climate" as a high quality science magazine since Winter 1999-2000, but we have been falling farther and farther behind. We are almost two full years behind schedule. Yikes!! We have some great excuses if you want to hear them. Drought comes to mind and the huge load of extra responsibilities that brought to us here at the Colorado Climate Center. But the bottom line is we told you there would be quarterly issues of "Colorado Climate" and we let you down. We are very sorry and want to try to make it up to you.

Our plan to get back on track is as follows. We simply do not have the time or resources to produce our publications in rapid succession. Therefore, for the next two issues, we are going to summarize and combine an entire Colorado Water Year into one issue. There will be one issue for 2003 covering the months of October 2002 through September 2003. Then this will follow a few months later with a comparable issue for 2004. If all goes well and this plan works, we will return to quarterly issues beginning with the winter of 2005 and will be more or less back on schedule. That will make all of us feel a lot better.

Be assured, if you are a paying subscriber, we WILL stick to our original promise of 4 issues for $15 until we get caught up, even if an issue covers an entire year. Thank you very much for your patience and tolerance. Regardless of how and when we write and publish, the weather remains as fascinating and variable as ever. We may think we know a great deal about weather and climate – the causes and the results. Yet every year brings something new and different.

What follows is a condensed summary of the 2003 Water Year. In an effort to catch up, we will skip the over some of the daily details. But we will still try to paint an accurate picture of what the year was like and what the most significant weather events and anomalies were. Years from now, when someone reads these summaries, they should have at least a reasonable idea of what we experienced and lived through.

If you have a photo or slide that your would like considered for the cover of Colorado Climate, please submit it to the address at right. Enclose a note describing the contents and circumstances including location and date it was taken. Digital photographs can also be considered. Submit digital imagery via attached files to: odie@atmos.colostate.edu. Unless otherwise arranged in advanced, photos cannot be returned.

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Barbara Dennis and Sandy Thode, Publications and Printing

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An unusually heavy snowfall in north central Colorado: or odd things that happen during severe droughts – A Meteorologist's View

by John F. Weaver, NOAA Research Meteorologist, CIRA/RAMM

On the morning of 19 March 2003, residents living along the east slope of the Rocky Mountains in north-central Colorado awoke to find themselves buried under two-to-four feet of extremely wet, heavy snow. The snow was so heavy that in Fort Collins alone 37 structures were completely destroyed and more than 200 severely damaged as roofs, walls, and entire buildings collapsed. Had this been a large tornado outbreak, the massive amount of destruction that occurred in dozens of Colorado cities up and down the northern Front Range[1] would have made national news for days. However, other than for a couple of thirty second spots on the networks, very little national attention was given the event. In large part, the lack of interest in the wide ranging impact of this record-breaking snowstorm[2] prevailed locally. Perhaps the explanation lies in the absence of violence that characterized the two-day-plus affair. After all, snow is nothing more than beautiful white crystals floating softly to earth. Ironically, the storm occurred during the worst drought in Colorado history, so most local residents were simply glad to have the moisture.

From a forecast point of view, the storm was not a surprise. The occurrence of a heavy snow event was accurately predicted, as was the fact that the storm would last for at least 48 hours. Computer model guidance correctly indicated that the heavier precipitation would begin over the Front Range on the evening of Monday, 17 March, and continue for at least 48 hours (e.g., Figs. 1, 2). The guidance even hinted at two periods of heavier activity. The first would start on the evening of the 17th, and taper off late the next morning. A second round would begin on late afternoon of the 18th, and continue into the morning of the 19th. That's pretty much what occurred, though the model forecast precipitation amounts were significantly understated for the populated areas along the Front Range corridor (e.g., Fig. 2).

There were misgivings amongst forecasters as to when (and in some cases whether) the changeover from rain to snow would occur. All of the computer models predicted that the 1000-500 hPa thickness (a measure of the "coldness" of the lower and middle layers of the atmosphere) was theoretically too high (i.e., too warm) to allow frozen snow crystals to reach the ground. In fact, several indicators suggested that snow levels would go no lower than about

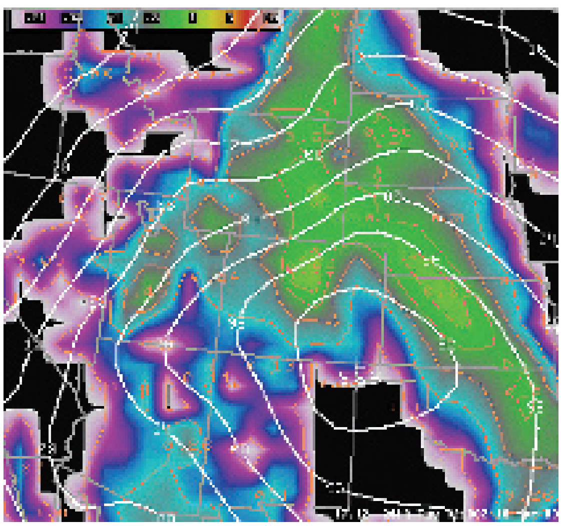


Figure 1. Computer-model output (eta 24-hr, forecast from 12:00 UTC, 17 March 2003) depicting forecast precipitation and surface pressures. The precipitation forecast is for the period 11:00 pm on 17 March through 5:00 am LST on 18 March 2003. The output shows 0.95" of liquid precipitation, or around 10"-12" at the snow:liquid ratios that were expected to occur. The interim, 6-hr map (not shown) indicates that the precipitation would be spread evenly over the 12-hr period (1 in = 25.4 mm).

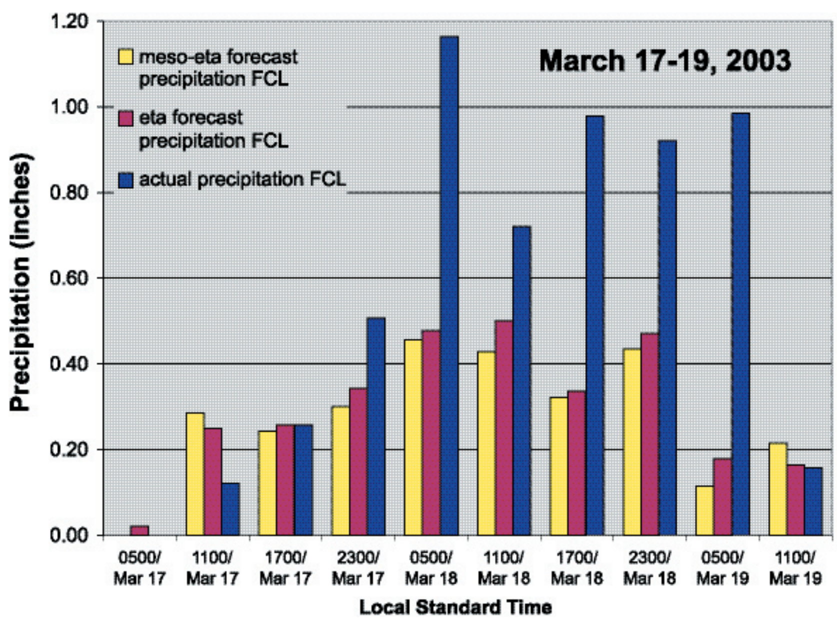
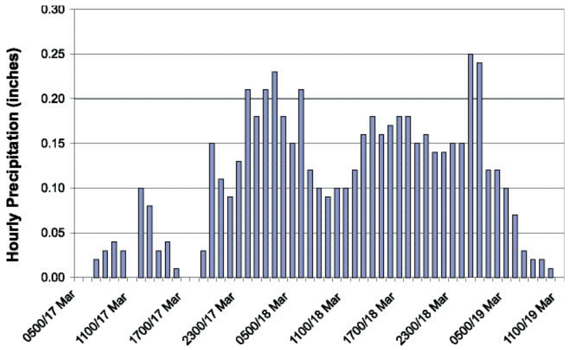


Figure 2. Meso-eta model (amounts from the eta-12 km grid output, extrapolated to a 29 km grid increment), and standard 80 km eta model (amounts from the eta-12 km grid output, extrapolated to an 80 km grid) precipitation forecasts (in inches) from the morning of 17 March 2003, plotted in yellow and red, respectively. Plotted in blue are actual liquid-equivalent precipitation amounts in 6-hr increments from observations taken at the Colorado State University Campus in central Fort Collins (FCL) (1 in = 25.4 mm).

1 The geographical designation "Front Range" refers to the easternmost range of peaks of the Rocky Mountains, but the terms "Front Range," or "Front Range corridor" are also used locally to indicate the populated area just east of the Rockies in Colorado. In this article, the second meaning will apply.

2 The March 2003 snowstorm has erroneously been called a "blizzard," and there was certainly enough snow involved to qualify. However, to meet the official definition there would have to have been either sustained winds, or frequent gusts, to at least 35 mph (56 km/h) for a significant period of time, and there were not.

Figure 3. *Hourly, liquid-equivalent precipitation (in inches) measured at the Colorado State University site (FCL) in central Fort Collins. Amounts shown are for the hour ending at the times appearing on the abscissa. (1 in = 25.4 mm)*



6,000 feet (1830 m). The majority of the larger northern Front Range cities are situated about a thousand feet lower than that. Nevertheless, most Colorado forecasters ultimately agreed that diurnal cooling, combined with the cold precipitation, would chill things sufficiently to allow the changeover to occur just after sunset. My own assessment was that the rain would turn to snow around 6:00 pm, with snow totals reaching upwards of 10"-15" (25-38 cm) by the time the storm was over.

A pre-event, light rain began falling in northern Colorado early on the morning of 17 March (Fig. 3), and continued generally light-to-moderate throughout most of the day. It tapered off completely just before 4:00 pm local standard time (LST), but showers began again at around 7:00 pm, as several north-south-oriented bands of convective precipitation moved across the area from east-to-west (Fig. 4). The new showers were heavier than those which had occurred earlier (Fig. 3), even producing a small, short-lived tornado about 25 miles (~40 km) east of Denver. However, as dusk transitioned to dark, all of the precipitation on the plains continued to fall as rain. Just fifty miles to the north – across much of southeastern Wyoming – it had been snowing most of the afternoon. This was troubling, since the region where it was snowing is situated at elevations of 6,000 feet, or greater. This is the precise elevation where the models predicted the rain/snow line would be found. As temperatures and dewpoints hovered in the upper thirties (Fahrenheit) throughout northern Colorado, forecasters began to worry about their predictions of heavy snow. Denver television stations had played up the coming winter weather, but by this time there seemed a strong possibility that the official National Weather Service forecast for a 12"-20" (~30-50 cm) snowfall could turn to nothing more than 2"-3" (~50-75 mm) of cold rain.

The problem may have been in the anticipated, versus actual, location of key synoptic features. Here, the computer models were only a few miles off, but it was a critical few miles. The eta-model presented a scenario where a so-called "warm conveyor belt" (i.e., a warm, moist stream of air being drawn into a developing extratropical cyclone) would move moist air up from the Gulf of Mexico into southeast Wyoming. The developing extratropical cyclone would then wrap heavy precipitation over the top of the cold air, and back into Colorado from the north (recall Fig. 1). GOES satellite imagery (Fig. 5) showed that the center of the developing system was actually a little further south than expected, and that the warm conveyor belt was feeding directly into northeast Colorado. By 9:00 pm, as a second line of relatively heavy convective rain moved across the northern Front Range, a failed forecast was beginning to look more and more likely. It was raining steadily – relatively hard at times – but the temperatures and dewpoints were all staying well above freezing.

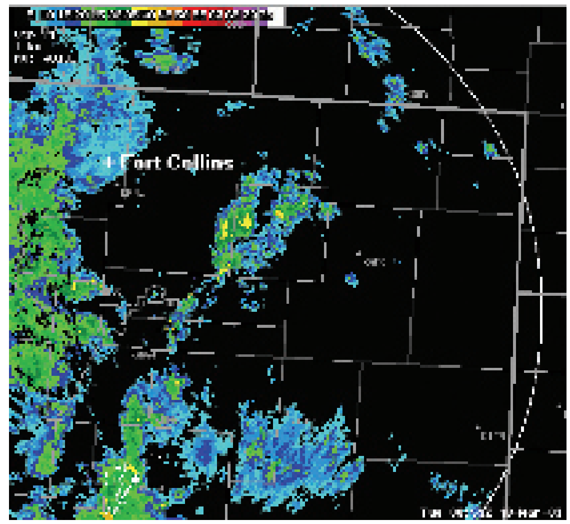


Figure 4. One line of convection moves off to the west of Fort Collins (squall lines were moving westward) as a second line forms to the east. Figure shows the 0.5 degree tilt, PPI reflectivity scan taken from the Denver, Colorado WSR-88D at around 6:00 pm on the evening of 17 March 2003.

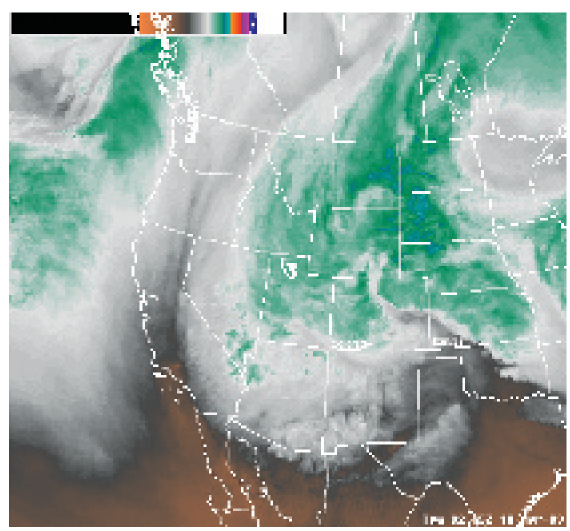


Figure 5 . GOES, 6.7 µm water vapor image taken at 7:45 pm on 17 March 2003. The image shows the moisture associated with the warm conveyor belt stretching from northeastern Oklahoma, across most of Kansas, and westward into northern Colorado. At this time the surface low pressure is moving into southeast Colorado.

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The 2003 Water Year — A Review

by Nolan Doesken

The 2003 water year in Colorado is defined as the 12 month period beginning October 1, 2002 and ending the last day of September 2003. This encompasses the winter snow accumulation period, the spring green-up and snowmelt season and ends at the conclusion of the growing season, which is also the primary irrigation season when much of the region's surface water supplies are consumed.

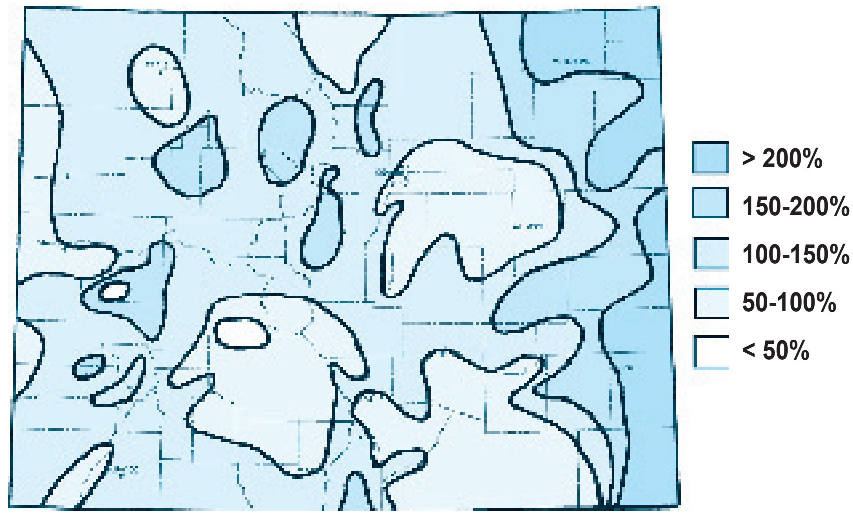
As the 2003 water year commenced, Colorado was still reeling from the drought year of 2002. Many parts of Colorado had just experienced their lowest precipitation year in recorded history and record low streamflow volumes of only about 25% of average were registered on most of Colorado's major rivers. The summer of smoke and fire was still a crisp memory in many minds, and some of the large wild fires had only recently been extinguished. Unlike other droughts that targeted only portions of the state and only certain economic sectors, 2002 hit hard all over. Drought came as a severe shock to many of Colorado's residents who had become accustomed to plentiful water supplies during the wet years of the 1980s and 1990s. Furthermore, drought extended beyond the borders of Colorado, and most of our Rocky Mountain neighbors from Canada to Mexico share the same misery.

Wet weather had finally appeared in Colorado for the first time in many month beginning with localized heavy thunderstorms in late August 2002 and spreading to almost statewide beneficial rains in September. Optimism had returned to Colorado after months of heat and discouragement.

October 2002 – A good start

The 2003 water year got off to a very good start, moisture-wise, with widespread precipitation early in the month, below average temperatures and a good start to winter with 10 days of cold, stormy weather at the end of the month. A winterlike Arctic airmass slid southward across eastern Colorado on the 29th, bring snow and cold to many areas. Halloween was just plain frigid east of the mountains, with high temperatures only in the upper teens and 20s. Boulder trick-or-treaters trudged through 8 inches of snow.

For the month as a whole, nearly all of Colorado ended up wetter than average with easternmost counties tallying more than 200% of average precipitation. This was great for the winter wheat crop as seeds germinated and got off to a good start despite very limited deeper soil moisture. Temperatures were cooler than average statewide ranging from 1 to 3 degrees F below the 1971-2000 average over western Colorado to as much as seven degrees below average east of the mountains.

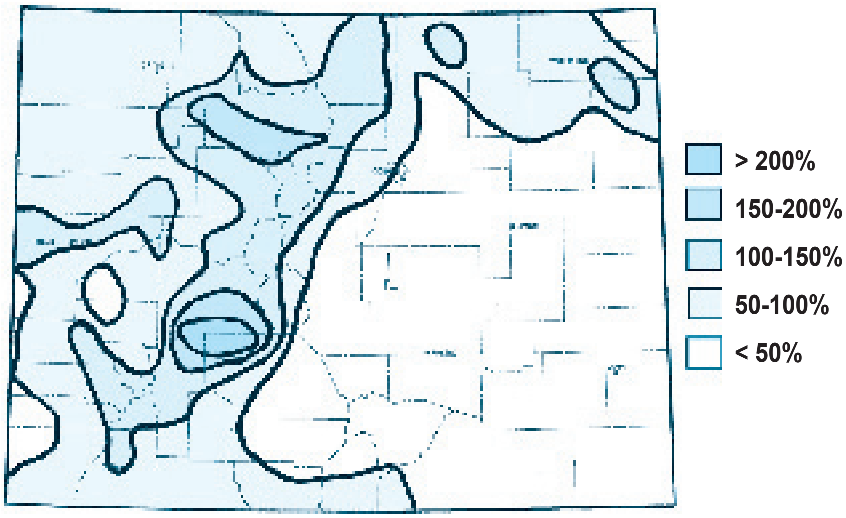


October 2002 precipitation as a percent of the 1971-2000 average.

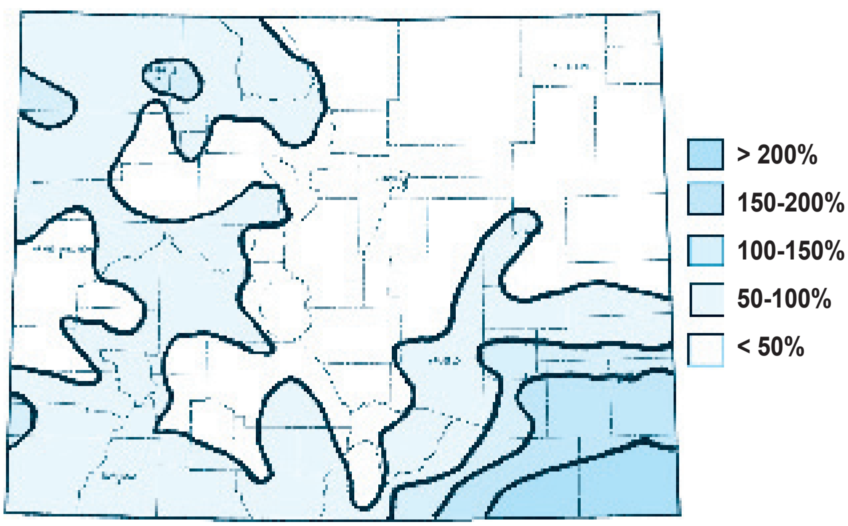
November 2002

The unseasonably cold, snowy weather continued into early November as areas of northern Colorado received more heavy snow Nov. 1st. Sunshine and more typical temperature soon returned. Then on the 8th, a major storm system with copious Pacific moisture slammed into Colorado. Eastern Colorado remained dry, but over a three-day period, one to three feet of wet snow accumulated in the higher mountains with substantial amounts of rain in the western valley. Northwesterly winds aloft then brought episodes of snow to the mountains 11-16th with cool temperatures. High pressure then developed over the West and brought dry weather for the remainder of the month. The exception was one disturbance that crossed Colorado 24-25th bringing several inches of snow to Fort Collins and parts of the mountains and Front Range.

Temperatures for November as a whole ended up slightly above average over parts of eastern Colorado but as much as one to four degrees below average over western portions of the state. A very interesting precipitation pattern was observed with a narrow zone of wetter than average conditions just west of the Continental Divide from Grand Lake and Yampa southward to Gunnison, Silverton and Durango. The Pacific storm of Nov. 8-10th with strong westerly winds contributed most of that moisture. Grand Junction, Collbran and Glenwood Springs were also wetter than average as were a few pockets in NE Colorado which caught heavy snows Nov. 1st and 24-25th. The majority of the state, however, was much drier than average with less than 50% of average over most of eastern and south-central Colorado. The big early November snow really helped the winter recreation industry both in terms of a good early base and good early publicity.



November 2002 precipitation as a percent of the 1971-2000 average.



December 2002 precipitation as a percent of the 1971-2000 average.

December 2002

As December's go, this was a gentle one. While subzero temperatures were common on clear nights in the mountains, the month as a whole was characterized by moderate temperatures for this time of year. The lowest temperatures of the month east of the mountains were in the single digits around Christmas time. With plenty of sunshine and mostly light winds, weather conditions were very pleasant during the day. Scattered and mostly very light snow showers occurred throughout the month, mostly in the mountains, but major storms and weather extremes were few.

An upper level storm system passing south of Colorado Dec. 1-3rd, dropped significant snowfall with 4"-8" across the far southeastern plains. The mountains received several inches of snowfall Dec. 16-18th, and some areas got light snow 23-24th. Christmas day was dry over most of the state, but fresh snow covered the ground in the mountains and over parts of SE Colorado. At the end of the month, another storm zipped across the state, leaving some fresh snow on the ground on New Year's Eve, especially over western Colorado.

For the month as a whole, temperatures were as much as 3 to 5 degrees F warmer than average east of the mountains. Conditions varied in and west of the mountains with slightly colder than average temperatures in some of snow-covered valleys but warmer than average in areas with little snow accumulation. Craig, Hayden, Grand Junction and Cedaredge all ended the month more than 3 degrees F above average.

December precipitation lagged well below the 30-year average over most of Colorado. A few small pockets of NW Colorado were near average. Otherwise most of the state was very dry. Little or no precipitation was reported along the Front Range urban corridor and over northeastern Colorado. Only extreme southeastern Colorado ended the month above average thanks to a pair of minor snow storms.

January 2003

January was proof that midwinter can be very comfortable in Colorado. Sunshine prevailed and outdoor projects and construction proceeded at many job sites. Temperatures soared close to record levels. Fort Collins enjoyed 9 days with high temperatures of 63ºF or higher. Pueblo recorded 4 days with highs in the 70s. Under clear skies and light winds, diurnal temperature variations were sometimes remarkable. The Pueblo airport weather station started the morning of January 19th with a temperature of 14ºF but by early afternoon hit 73ºF, a 59 degree swing. For the month as a whole, all of Colorado was warmer than average and most locations were much warmer. Anomalies ranged from less than 2 degrees F above the long-term averages at Meeker and Rangely, to more than 10 degrees above average at Alamosa, Grand Junction and some eastern foothill locations making this one of the warmest Januarys in recorded history. Except for a few mountain valley locations, most of the state experienced no subzero readings all month.

Along with the warmth came dry weather. Drought chatter was back in the vocabulary again. Storminess was limited to some early morning snow in eastern Colorado on the 1st, scattered light snows on the 5th, and a modest storm bringing up to 6 inches of snow to the town of Steamboat Springs on the 10-11th. Even a very powerful polar cold front on the 22nd failed to produce any moisture. Temperatures did drop abruptly, however, and high temperatures during the day on the 22nd were only in the teens and single digits over the eastern plains while the mountains and western valleys remained mild. Strong winds raked the Front Range on at least 3 days, with gale-force winds reported on the 15th, 19th and 30th.

For the month as a whole, January precipitation was much below average. Gunnison and Durango each reported only 14% of their average precipitation, and Kremmling only got 18%. The entire month was very dry east of the mountains as well. Several areas reported no measurable precipitation. The few areas that did get moisture got snow early on January 1 and then hardly anything the rest of the month. This was definitely not what Colorado wanted or needed. Thanks to careful snow management and snowmaking, the quality of snow for skiing and snowboarding, remained quite good, all things considered.

February 2003

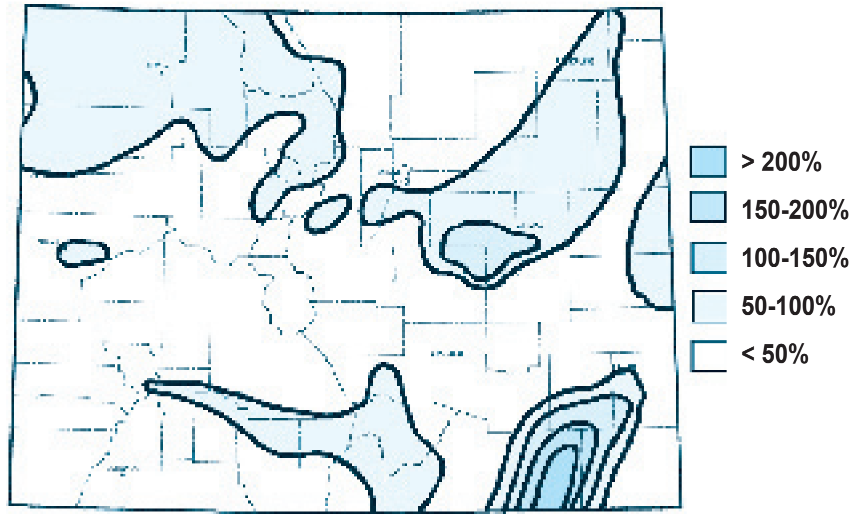
Following the extraordinarily mild January, weather conditions did an about face and February proved to be the coldest month of the winter with a steady progression of storm systems. Mountain snowpack finally showed some major improvement, and Colorado's Front Range and northeastern plains finally had snowcover after having bare ground much of midwinter.

February got off to a record-breaking with highs in the 70s on the 1st over most of eastern Colorado. That didn't last long as a major storm system swept in just in time for Ground Hogs Day covering much of the state with 2"-6" of fresh snow. This was followed by a week of cold and unsettled weather especially over and near the mountains. Taylor Park Dam, Colorado's proverbial cold spot, had the coldest temperatures of the winter Feb. 7-8th with overnight lows of −37 and −35ºF, respectively. Areas east of the mountains also saw the mercury dip below zero for the first time all winter.

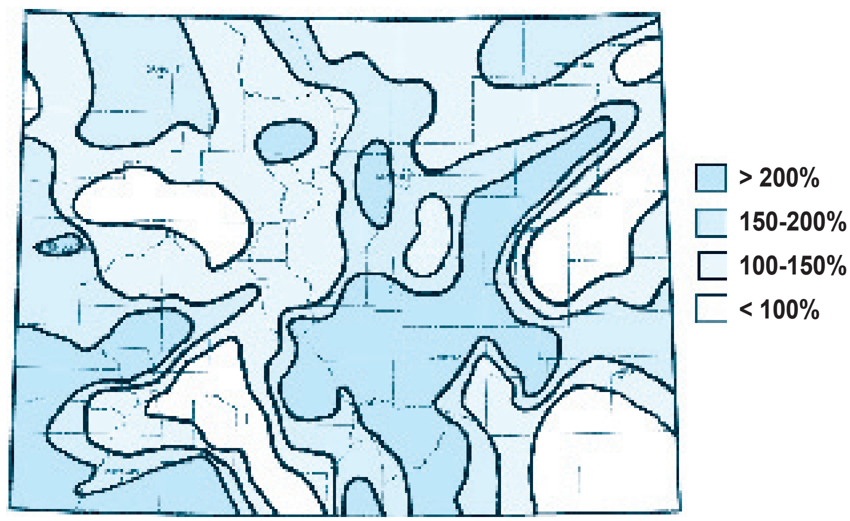
Temperatures then warmed, thanks in part to some strong downslope winds. Winds gusted to over 80 mph in wind-prone areas of the Front Range on the 9th. Most of Colorado enjoyed a few dry days until another storm moved in just in time for Valentine's Day. The forecast for a big snow did not materialize, but significant cold rains soaked SW Colorado with as much as 0.80" of moisture. Zonal (westerly) flow aloft prevailed 16-19th and pumped some moisture into western Colorado.

A good old-fashioned although short-lived Arctic cold wave arrived in NE Colorado on the 22nd and brought the coldest weather of the winter to the Front Range and eastern plains 23-24th along with periods of light snow and dangerously cold wind chill temperatures. High temperatures from Longmont and Fort Collins eastward to Sterling and Holyoke only reached 10ºF. Akron dipped to a morning low of −21ºF on the 24th. At the same time, western Colorado enjoyed mild weather. As the month ended, the Arctic air mass over the plains retreated but a major Pacific storm system moved into the Rockies bringing substantial snows to the mountains. During the final week of February, Steamboat Springs picked up nearly 30 inches of new snow in town with much more in the mountains. Mountain snows were deep and fluffy just in time for the onslaught of skiers and snowboarders in March.

For the month of February as a whole, temperatures varied tremendously ranging from 5 to 7 degrees above average in the Gunnison Valley and 0 to 3 degrees above



January 2003 precipitation as a percent of the 1971-2000 average.



February 2003 precipitation as a percent of the 1971-2000 average.

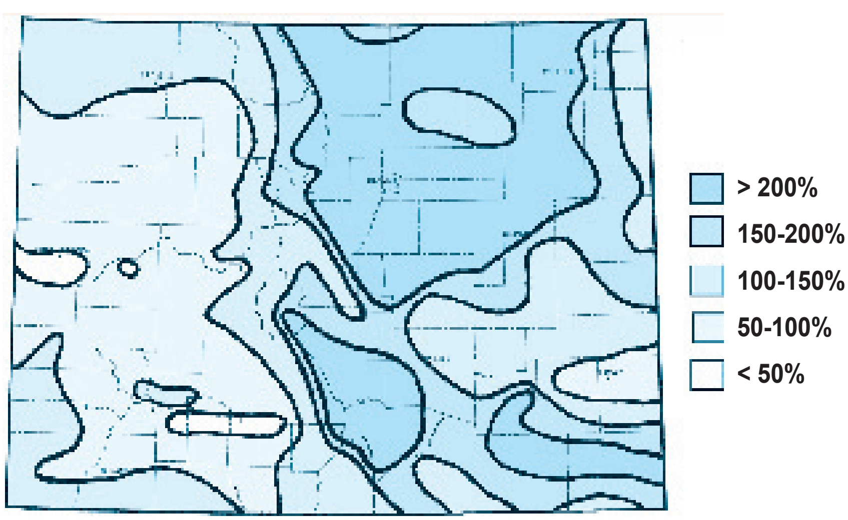
warmer than usual over most of western Colorado down to 3 to 5 degrees below average across eastern Colorado. Precipitation totals were also highly variable with 200% of average in SW Colorado and the northern Front Range up to triple the average near Pueblo, Canon City and Walsenburg down to well below average over east-central Colorado, extreme SE Colorado and the eastern slopes of the San Juan mountains.

March 2003

March began where February left off with cold, unsettled weather. Several inches of snow fell along the Front Range 1-2nd, heaviest over southern Colorado. Rye reported 10" of snow. The last true cold wave of the winter arrived in NE Colorado late on the 3rd with high temperatures only in the teens on the 4th. Meanwhile, the mountains were not as cold but enjoyed several inches of new snow. The Aspen weather station measured 7.5" early on the 5th, with 1 to 2 feet in many mountain areas.

Mild and dry weather then moved into Colorado for a prolonged 10-day stretch. Spring bulbs emerged and summer seemed close at hand. Temperatures soared into the 70s and 80s, and even a little melting of the mountain snowpack began bringing renewed fears of continued drought. Many record high temperatures were set on March 14th with upper 70s along the Front Range and 80s in SE Colorado. Holly and Las Animas both hit 87ºF, the hottest in the state for March.

Winter was not over, however, and on the 16th a Pacific storm system began spreading snow into extreme south-western Colorado. Weather forecasters had been eying this storm for nearly a week and gave Colorado residents fair warning to prepare for a big storm. By the 17th, rain and even some thunderstorms and a small tornado spread into eastern Colorado. A large "cut-off" low formed over the four-corners area and moved only slowly. Rained changed to snow overnight on the 17th along the Front Range while rains continued over the eastern plains. Snow became heavy and widespread on the 18th as moisture was pumped into the storm all the way from the Gulf of Mexico. Snow was measured in feet rather than inches near the core of the Front Range storm, and heavy snow continued into the 19th, until it finally began letting up late in the day. More details on this remarkable storm are contained in the special attached feature, but let it suffice to say that snowfall and water content measurements from Monument and Conifer northward to Fort Collins and Livermore approached or exceeded all-time records for any time of year. With 3"-5" of snow water equivalent along the Front Range urban corridor, and 5"-8" of water content in the foothills and mountains, dozens if not hundreds of buildings collapsed or sustained structural damage. Overall, this storm was similar to the December 1-5th, 1913 storm always said to be the worst in Colorado history (Wilson, W.E., 2003: Colorado is Snowbound: The Great Front Range blizzard of 1913 (and its 2003 counterpart). *Colorado Heritage*, Autumn 2003, Colorado Historical Society, 1300 Broadway, Denver, CO 80203, 2-35.)



March 2003 precipitation as a percent of the 1971-2000 average.

Insult was added to injury when another 4"-10" of snow fell late on the 20th in the foothills as another disturbance crossed the area. Total snowfall for the entire storm period was 20"-40" over most of the Front Range urban corridor north from Monument Hill. The foothills and mountains measured 40"-70" with possibly higher amounts in local areas of Boulder, Gilpin, Clear Creek and Jefferson Counties. Very heavy snow also spilled across the Continental Divide into Grand and Summit Counties. While the storm was extreme, it was not as widespread as it's 1913 counterpart. Only modest amounts fell in southern and western Colorado, and precipitation all fell as rain on the eastern plains. Scientific articles exploring the causes and dynamics of this storm are currently being written. Contact the Colorado Climate Center to find out how to access these reports.

The remainder of March was anticlimactic. More storms crossed the state 23-24th and again on the 26th bringing additional moisture. But no major cold air returned, and the big snow melted steadily. Along the Front Range there were several days with deep snowcover but temperatures well up in the 50s and 60s. March ended with a return to sunny and dry weather 29-31st. At lower elevations all snow had melted by the end of March, while in the foothills and mountains, the snow remained well into April and May.

As much as 3 degrees F higher than the long-term March averages. March precipitation totals were above average over all of central and eastern Colorado with extensive areas receiving more than double the average. For places like Estes Park, Fort Collins, Golden and Georgetown, totals were more than 4 times the March average – almost all of it coming from the one big storm. Not all of the state reaped the harvest, however. Western Colorado which was on the "wrong" side of the mountains this time, was mostly drier than average. Some areas near Grand Junction and in the Rio Grande basin received less than 40% of average.

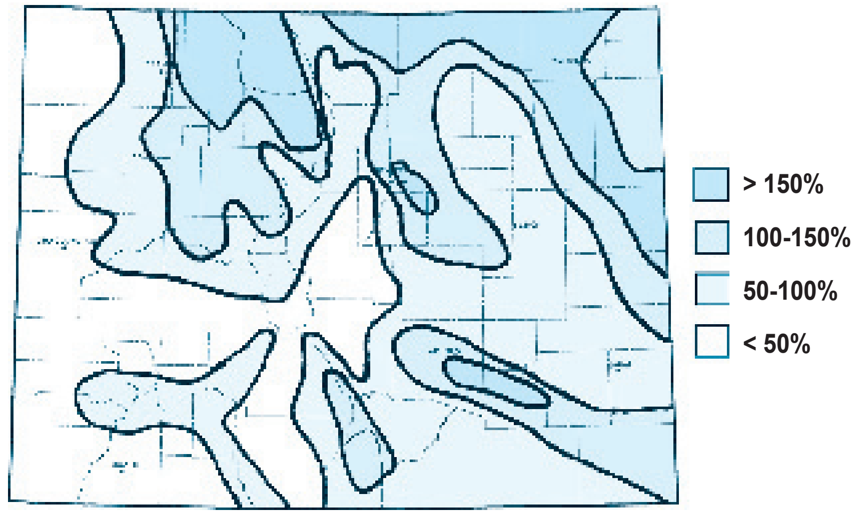
April 2003

April got off to a warm start 1-2nd, but a broad low pressure trough developed over the West and a series of disturbances brought increasing clouds and colder temperatures 3-7th. Several inches of snow fell in the mountains and across NE Colorado 5-6th. Dry and warm weather was the rule 9-14th. This mild weather was followed by a strong storm as a deep low pressure area developed over Colorado and moved eastward on the 16th. Many areas of the plains picked up between a quarter and a half inch of rain as the storm passed, and some snow accumulated in the mountains. The main story was wind, however. Many areas, especially east of the mountains, had wind gusts approaching 50 mph.

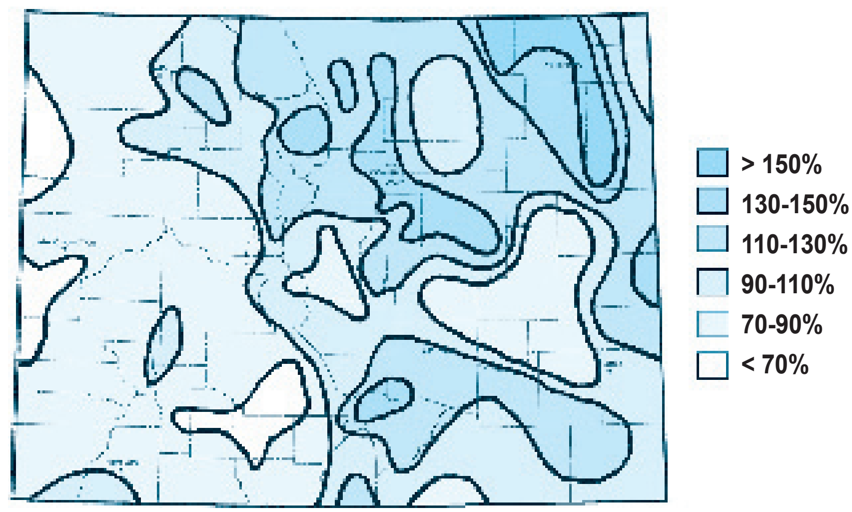
For the remainder of April, weather systems moved progressively across the country, and Colorado experienced alternating good and bad weather. With primarily Pacific air masses still affecting Colorado, temperatures remained mild. Significant storms with widespread precipitation crossed Colorado April 18-19th and again 22-24th. Southeast Colorado was hit especially hard on the 19th. Rocky Ford, still reeling from drought, enjoyed a 1.51" rain while a foot of wet snow fell on Walsenburg. The second storm took aim primarily on northern Colorado where heavy precipitation was reported. Hayden received over 15 inches of wet snow yielding well over 2 inches of water content. Breckenridge added 16" of new snow. At lower elevations, heavy rains and thunderstorm pushed eastward, and many weather station in northern and NE Colorado got 1"-2" of moisture. This continued to keep the landscape green, and provided excellent moisture to aid the growth of the 2003 Colorado winter wheat crop.

April ended with fairly normal spring weather. Significant hail was reported on each of the last 3 days of the month over various portions of eastern Colorado.

For the April as a whole, temperatures ended up above average statewide ranging from 0 to 2 degrees F above the 30-year average over the Western Slope increasing to 3 to 5 degrees warmer than usual from the Front Range eastward across the plains. April precipitation was highly varied across the state. Much above average moisture was observed across the northern mountains, northern Front Range foothills and urban corridor, the northeastern plains and a narrow band in the Arkansas Valley. However, areas of southern and western Colorado did not fare so well. Less than half the April average was reported at such places as Alamosa, Salida, Grand Junction and Montrose. Cortez reported just 13% of average. That portion of the state simply cannot shake this drought.



April 2003 precipitation as a percent of the 1971-2000 average.



Winter 2003 (October 2002-April 2003) precipitation as a percent of the 1971-2000 average.

April marks the approximate end of the mountain snow accumulation season. For the entire winter season, October through April, precipitation totals ended up above average over Colorado's northern mountains and over most areas of the Front Range and eastern plains. While better off than last year, western Colorado was again on the short end if the precipitation stick with many areas reporting only 70-90% of average for the previous seven months.

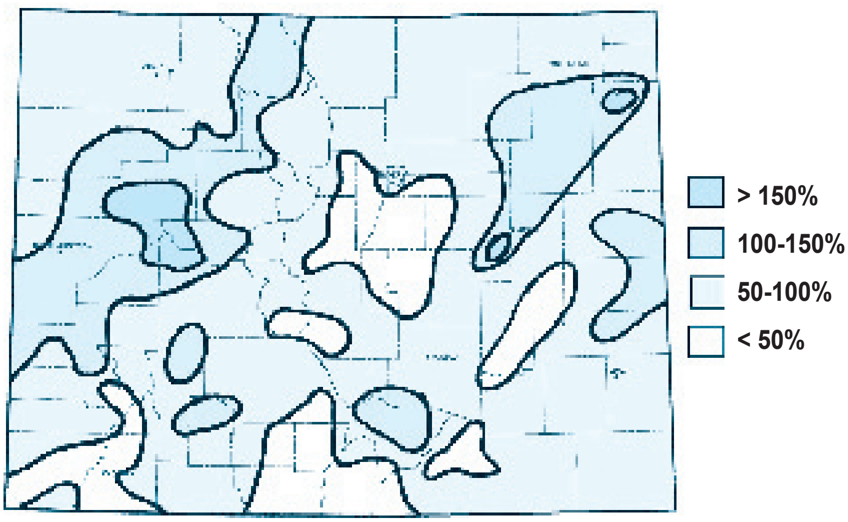
The 2003 Growing Season

The 2003 growing season, approximately May through September, began with seasonally wet weather and a cool, damp June. But just as drought recovery seemed in reach, exceptionally hot and dry weather returned and Colorado remained in drought. Here is a month by month account.

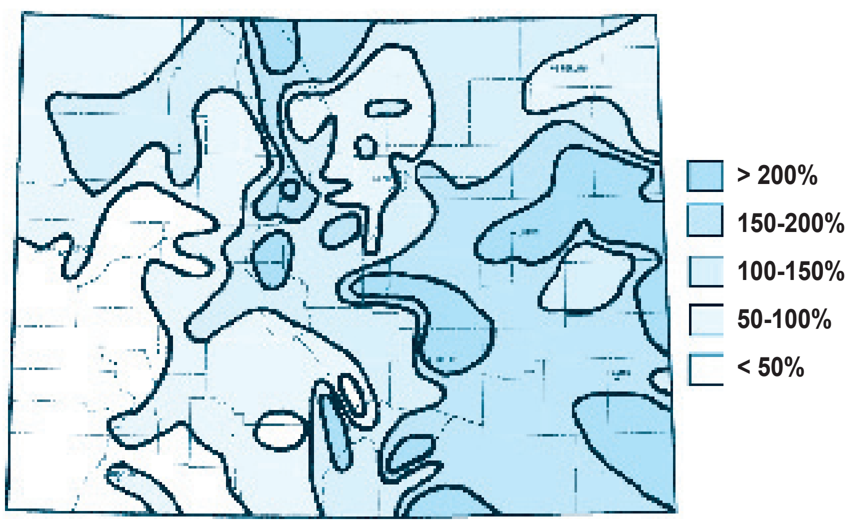
May 2003

The first half of May was cool and unsettled with plenty of clouds and precipitation. One fast-moving system crossed Colorado 3-4th. Then an upper-level trough lingered over the area 5-10th. There were several reports of severe weather (hail and small tornadoes) on the 8th over eastern Colorado. Then temperatures dropped and upslope winds increased east of the mountains on the 9th. Cold rain turned to wet snow overnight over Denver, Boulder and other parts of the Front Range. Four to as much as 15 inches of snow was reported. Trees were already leafed out, and many large branches and entire trees broke under the weight of the snow. Power outages were widespread near Denver, and tree damage was extensive. Fort Collins and Greeley received primarily rain. As much as two inches of water content fell from this storm and helping to sustain the drought recovery over the South Platte basin. Another storm moved across the area on the 15th bringing severe weather to parts of southern and southeastern Colorado and local heavy rains near Boulder.

The latter half of May was characterized by above average temperatures and below average precipitation as a ridge of high pressure built up over the western U.S. A



May 2003 precipitation as a percent of the 1971-2000 average.



June 2003 precipitation as a percent of the 1971-2000 average.

Pacific cold front clipped the area 18-19th bringing some moisture and a few reports of severe weather. Some unstable air with northwesterly winds aloft helped produce a few locally severe storms 23-26th. May ended with a major heatwave. Low elevation temperatures soared into the 90s with even a few low 100s May 29-30th. Mountain snow melted quickly and rivers flowed at or above flood stage in parts of northern Colorado. Some isolated but locally heavy rain and strong storms fell on the 30th, mostly in the eastern foothills. Cooler weather followed on the 31st.

For the month as a whole, temperatures ended up above average over all areas of Colorado ranging from near average in the Denver-Boulder area, one to three degrees above average in eastern and western Colorado to as much as 4 degrees F above the long-term average over parts of southern Colorado. Precipitation for May for the state as a whole was a little below average but ranged from very dry (less than 50% of average) over much of central Colorado, the San Luis Valley and extreme southwest Colorado up to near average precipitation over eastern Colorado, parts of the northern and southern Front Range, and much above average over west central Colorado near Aspen, Glenwood Springs and Rifle.

June 2003

June got off to a very cool and cloudy start over northern and eastern Colorado as a persisting storm center over southern Canada sent cool, camp and unstable air southward. Rain and thunderstorms were widespread each day 1-6th with quite a few reports of moderate hail across eastern Colorado. Several parts of eastern Colorado picked up more than 3" or rain spread out over the week. Despite the hail, the moisture helped the winter wheat crop thrive, and range and pasture conditions also began to improve.

By mid June, the jet stream finally began it's northward retreat, but plenty of low-level moisture remained over Colorado. Scattered but locally heavy storm hit various portions of eastern Colorado 10th-19th with numerous reports of heavy rains and moderate hail. Some of the storms struck the mountains as well, especially on the 19th. June ended with drier and warmer weather, but still relatively cool for this time of year. Isolated storms, some producing hail, were observed, especially on the 23rd, 27th, 28th and 29th.

For the month as a whole, temperatures were below average over all of eastern and northern Colorado ranging from as much as 4 degrees F below average over the northeastern plains of Colorado, to one to two degrees below average in the mountains. The cool air missed western Colorado, and in the southwest corner of the state, Cortez and Durango both ended the month about 2 degrees F above average.

Precipitation for June was highly varied. Almost all of eastern Colorado had a wet month with locally two to three times the average around Colorado Springs, Pueblo, Limon, Burlington, Lamar and Walsh. Colorado Springs, Burlington and Cheyenne Wells each totaled over 5" of rain in June. Joes, in extreme SW Yuma County measured 6.20" for the month, 258% of average. Some of the northern and central mountains also had a wet month. Southwestern Colorado missed the action, however, and many counties had less than 50% of their already-meager June averages. Montrose, for example, got only 0.06" or rain in June, 10% of average.

July 2003

After a pleasantly cool June, a large ridge of high pressure became entrenched over the Rocky Mountains during the entire month of July resulting in a major heatwave across the region. Temperatures climbed into the 90s and low 100s at lower elevations each of the first 6 days of July with mostly clear skies and intense sunshine. Forest conditions dried rapidly. A weak cold front and upper disturbance crossed northeastern Colorado on the 7th, bringing briefly cooler temperatures and thunderstorms, a few of which brought hail and strong winds.

More very hot and dry weather followed. On the 13th, exceptionally hot temperatures occurred. Pueblo hit 109ºF. A few isolated strong storms developed on the 13th and 15th. Several wild fires were ignited over western Colorado with the hot/dry weather. Starting on the 16th, higher humidity air moved up into Colorado. Afternoon clouds were more abundant, and showers and thunderstorms became more numerous. Rainfall was mostly light, but Paonia reported 0.65" of rain from a storm on the afternoon of the 16th and Crested Butte got 0.56" on the 20th.

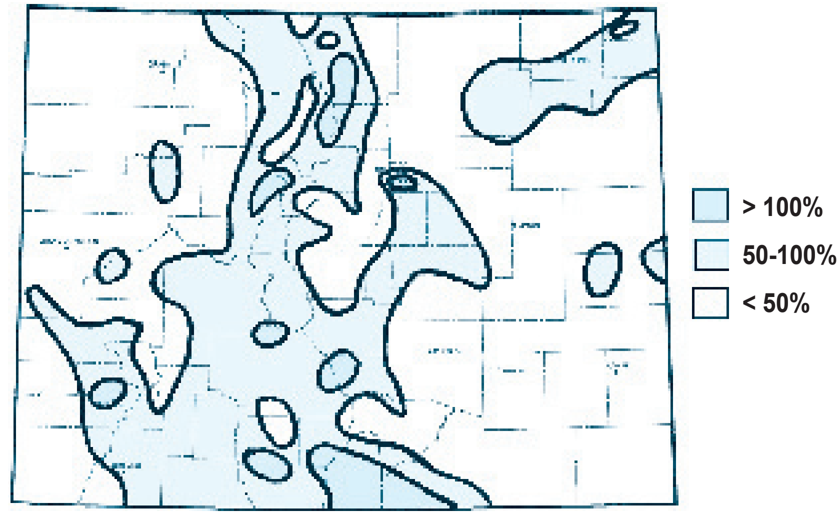
Extreme heat expanded again 24-25th as the ridge of high pressure aloft perched directly over Colorado. Temperatures at or above 100ºF were common at lower elevations both days. Then, as the month came to an end, subtle shifts in the weather pattern allowed a generous pulse of moist subtropical air to reach Colorado. With light winds aloft, a few slow moving storms developed 26-29th dropping locally heavy rains. Westcliffe struck it big with 5" of rain in 3 days, with 3.06" falling on the 26th. In the mountains, a few of these storms caused small landslides briefly blocking a few roads. It was a little cooler 29-30th, especially east of the mountains.

For the month as a whole, July temperatures were exceptionally warm across the entire state. Most areas ended up 3 to 6 degrees F above the 1971-2000 average. A few cities including Fort Collins, Greeley, Estes Park, Colorado Springs, Longmont and Sterling were 6 to 7 degrees above the July average making this the hottest or one of the hottest July's in recorded history. Coloradans are not accustomed to such hot weather. Air conditioners were hot-selling items, that's for sure.

For most of Colorado, July was also very dry. The majority of eastern Colorado picked up less than 50% of average rainfall for the month with a few spots near Flagler, Genoa and Joes with no measurable rain all month. While farmers had enjoyed a good wheat harvest this year, the dry summer weather meant disaster for unirrigated summer crops. Western Colorado was also exceptionally dry. More precipitation fell in and near the mountains, but only a few spots here and there ended the month wetter than average. These were spots where late July storms had been heavy, Wet spots included Estes Park, Vail, Sargents, Crestone, Westcliffe and San Luis. In all cases, you only had to go a few miles in any direction to find drier than average July conditions. As a result, several forest fires continued to burn on into August in western Colorado.

August 2003

The first half of August brought steady and persisting heat with above average temperatures every day. Isolated thundershowers developed somewhere in the state every afternoon. A few brought hail, high winds, and heavy rains to small areas, but most didn't amount to much. Showers were most abundant on the 3rd. Placerville in southwestern Colorado experience flooding. Holyoke added 0.73". Alamosa picked up 0.69" on the 10th. A larger area of heavy rain produced local flooding in Telluride and Silverton on the 13th. Official weather reports at both places reported about 1.4" of rain. Cortez had an unusual storm on the 14th with large hail doing at least $1 million in damages to roofs, automobiles and crops.



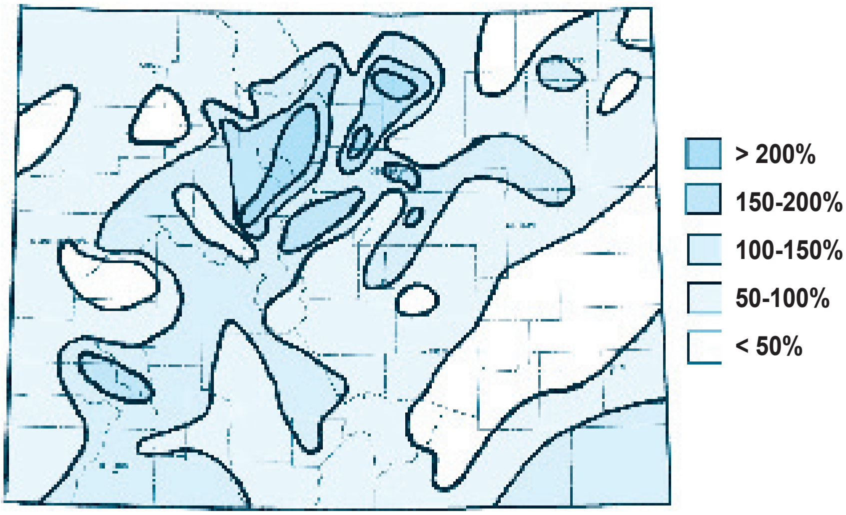
July 2003 precipitation as a percent of the 1971-2000 average.

A low pressure area passed just north of Colorado 17-19th but helped set off widespread showers and thunderstorms. Grand Lake received 1.77" of rain on the 17th with an additional 0.65" on the 18th. Boulder noted 1.32" on the 18th. Most of the state got some rain during this period along with much-welcomed cooler temperatures. Hot weather made a quick comeback with temperatures back in the 90s at lower elevations statewide, with some 100 degree readings in SE Colorado especially on the 21st and 22nd.

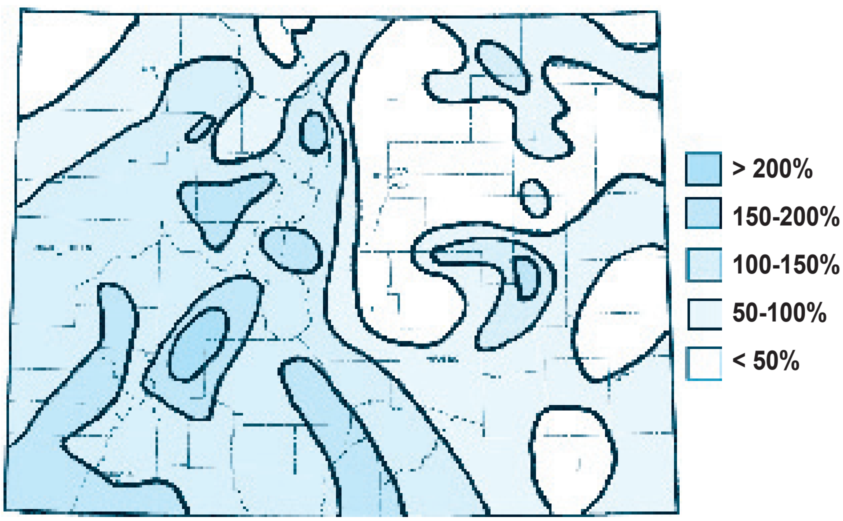
Above average temperatures continued through the 27th, but as days shortened the heat lessened. A few showers continued to develop each day. Then on the 28th a cool air mass pushed southward from Canada bringing the coolest weather to Colorado since June. The clockwise flow of air around the high pressure center north of Colorado pumped low level moisture up against the Front Range. Locally heavy storms developed all up and down the Front Range late on the 29th and again on the 30th. Fort Collins was treated to over 3 inches of rain in two days on the CSU campus. Heavy rain and lightning even temporarily interfered with the annual CU-CSU football game in Denver on the evening of the 30th. High temperatures were only around 70ºF east of the mountains on the 30th and 31st.

For August as a whole, above average temperatures were again the rule with nearly all weather stations two to as much as 5 degrees above the 30-year average. Several stations reported the hottest July-August two-month period in history. There were few daily records, but just persistent above average conditions day after day.

Precipitation for August was above average in a band from Durango, Silverton and Telluride northeastward



August 2003 precipitation as a percent of the 1971-2000 average.



September 2003 precipitation as a percent of the 1971-2000 average.

through Gunnison, Leadville, Vail, Grand Lake and on across the mountains to Loveland and Greeley. Telluride's August total was 5.27". Rainfall was also heavy in the central mountains on to the northern Front Range where a few locations received more than double the average rainfall for August. Not all of Colorado got these rains, however. Extreme western and northwestern Colorado was dry with less than half the average rainfall at places like Paonia, Delta, Rangely and Dove Creek. Much of eastern Colorado was also parched. New Raymer, Cheyenne Wells, Ordway and John Martin Dam each totaled less than 20% of average.

September 2003

The last month of the 2003 water year got off to a pleasant start with comfortable temperatures and no precipitation. Another Canadian cold front slipped into NE Colorado on the 2nd and helped set off fairly widespread "upslope" showers 2-3rd from Estes Park south to Trinidad. Eastern and western Colorado remained dry. An upper level disturbance then moved in from the west late on the 5th and produced widespread rains over nearly all of western Colorado on the 6th ending on the 7th. Most areas picked up 0.25 to 1.00" but two-day totals over 1.25" were reported. Another even larger storm followed. Rain began on the 8th and spread eastward. Widespread steady hard rains expanded over southwestern Colorado on the 9th and continued overnight. Some showers and storms made it over the mountains into eastern Colorado. Most of the western half of the state got at least 0.50". Several rounds of damaging hail occurred near Grand Junction. Drought concerns were temporarily interrupted as many stations in southwestern Colorado received over 2" and locally up to 3.5" by the morning of the 10th. Rivers rose rapidly in response to this widespread rain. Rain changed to snow at high elevations in the southwestern mountains. Mud and rock slides closed sections of highways, including Interstate 70 near Glenwood Springs. Late on the 10th a cold front and cold upper trough crossed Colorado and produced heavy snow at high elevations in the northern and central mountains. Travel was treacherous for a time over Vail Pass early on the 11th.

After such a ferocious start, the rest of September was very placid and dry. Cooler weather prevailed 11-21st. A cold front zipped across the state on the 13th setting off some showers on the eastern plains. Very cold temperatures followed with many areas reporting an early freeze early on the 14th. Temperatures warmed nicely on the 15th and 16th. Then a strong cold front accompanied by very strong winds rushed eastward on the 17th, and temperatures on the 18th were only in the 50s and 60s with colder temperatures in the mountains.

The remainder of the month was dry statewide. A strong jet stream moved air from Alaska and northern Canada towards the Great Lakes and Midwest, but Colorado was just on the edge of the activity and remained dry. Several cold fronts clipped northeastern Colorado, and September ended very chilly with highs only in the 40s near Denver. Western Colorado was protected, however, and enjoyed mild temperatures in the 70s and 80s throughout the rest of the month.

Temperatures for the month as a whole ranged from a degree or two warmer than average over extreme southwestern Colorado down to one to as many as 3 degrees F below average east of the mountains. September precipitation for the month as a whole showed above to much above average precipitation over southwestern and central Colorado. Gunnison totaled 2.56", 259% of average. Several stations in southwestern Colorado accumulated 3"-4" of moisture during the month, most falling Sept. 6-10th. Areas just west of the Sangre de Cristo mountains also fared will with 150-200% of average. East of the mountains and over extreme northern and northwestern Colorado it was quite a different picture. Most areas ended up well below average with less than 25% of average in Greeley, Longmont, Boulder, Fort Collins, Loveland, Lakewood, Castle Rock and Yuma. With the Rocky Mountains forming such a profound barrier to air masses, it is very difficult for all parts of the state to be wet at the same time, and that was certainly the case this month.

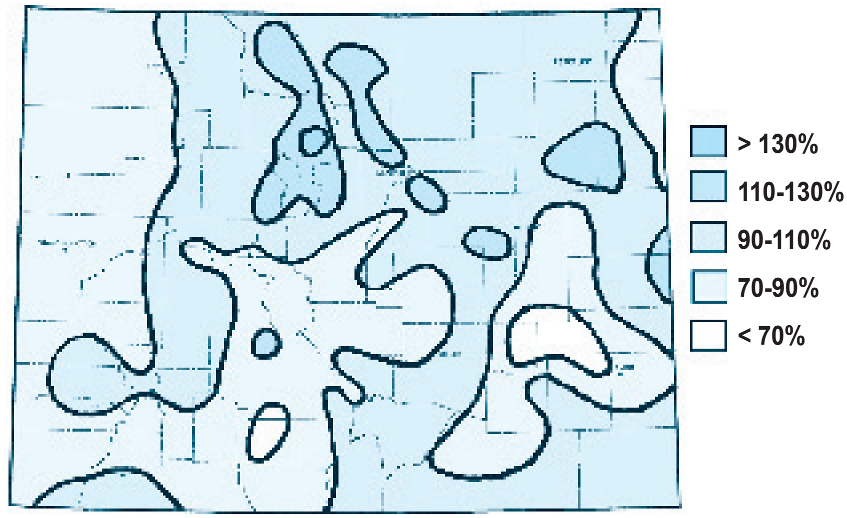
2003 Water Year Summary

The precipitation for WY2003 as a percent of average was clearly a much better year than 2002, but precipitation was not sufficient to make up for the large deficits from previous years. The only areas of Colorado that ended the year with 110% or more of average were portions of the upper Colorado River basin in Eagle, Grand and Summit counties, the Front Range north of Denver hard hit by the March snowstorm, and a few pockets of good moisture out on the plains. For the majority of the state, 2003 was another dry year. For most of southern and western Colorado, precipitation totals were less than 80% of average for the year, with pockets below 70% in the Arkansas and Rio Grande basins. 2003 precipitation deficits simply enhanced the long-term drought severity for those areas. Colorado clearly remains in the grip of a long-term and widespread drought that will require several wet seasons and perhaps even several wet years to fully recover.

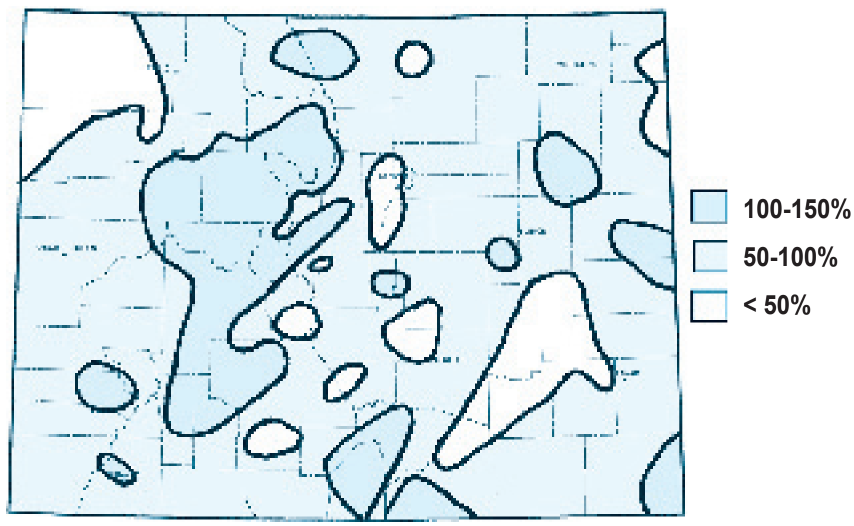
For the May-September growing season, most areas of Colorado were drier than average. This in combination with very hot July and August temperatures only served to extend drought concerns and impacts. Fortunately, only a few areas were much below average (less than 70%) including portions of the Arkansas Valleys, Front Range foothills location and northeast Colorado. Wetter than average growing season moisture was limited to the Central Mountain areas as well as a few pockets of southern and east central Colorado.

For the year as a whole, temperatures were also on the warm side (Departure from average graph, bottom right). January and July were both exceptionally warm statewide while many other months were a bit warmer than usual. Cooler than average weather in October, February, June and September helped Colorado avoid what could have been the warmest water year in history for the state. Regular episodes of cooler temperatures also reduced water demand, evaporation rates, and wildfire vulnerability helping soften a few potential drought impacts.

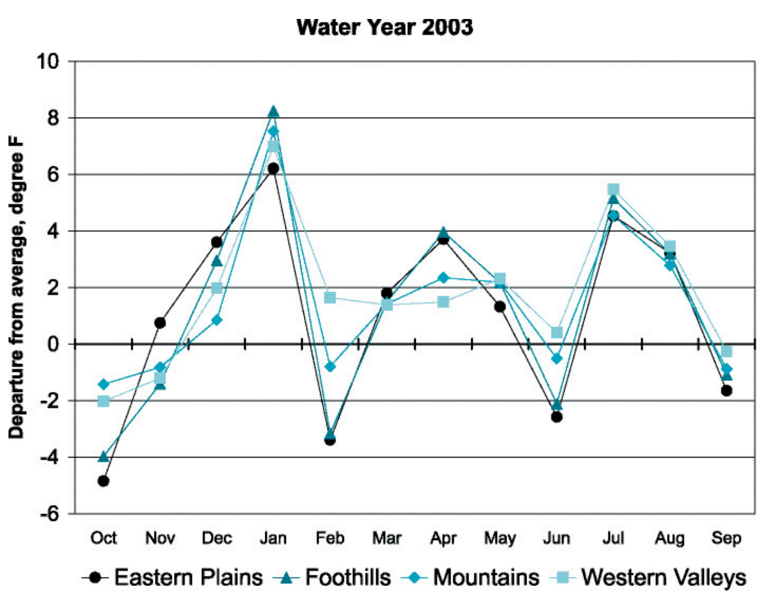
WY2003 streamflow volumes were much better than the record low levels of 2002. The figure on page 12 (upper left) shows daily discharge in cubic feet per second at three selected gauging points on rivers in Colorado. Most rivers experienced typical peak flows episodes during the snow melt surge at the end of May. However, for the year as a whole, total streamflow was again below average. Northern Colorado rivers fared best as well as rivers draining the eastern slope of the Rockies. WY2003 total volume streamflows were far below average in southwestern Colorado where some rivers such as the Rio Grande only yielded about 50% of its long-term average flow (page 12, bottom left). A drought crisis has emerged

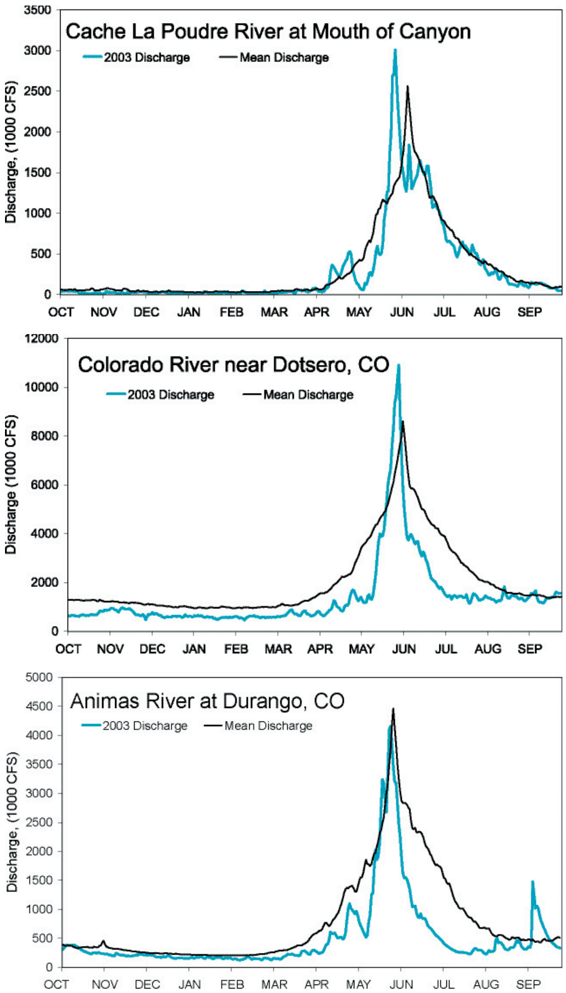


Water Year 2003 (October 2002-September 2003) precipitation as a percent of the 1971-2000 average.



Growing Season 2003 (May-September 2003) precipitation as a percent of the 1971-2000 average.





Daily streamflow discharge in cubic feet per second during the 2003 water year and period of record averages from USGS gauging stations on the Cache La Poudre River (top), the Colorado River near Dotsero (middle) and the Animas River at Durango (bottom) from NRCS.

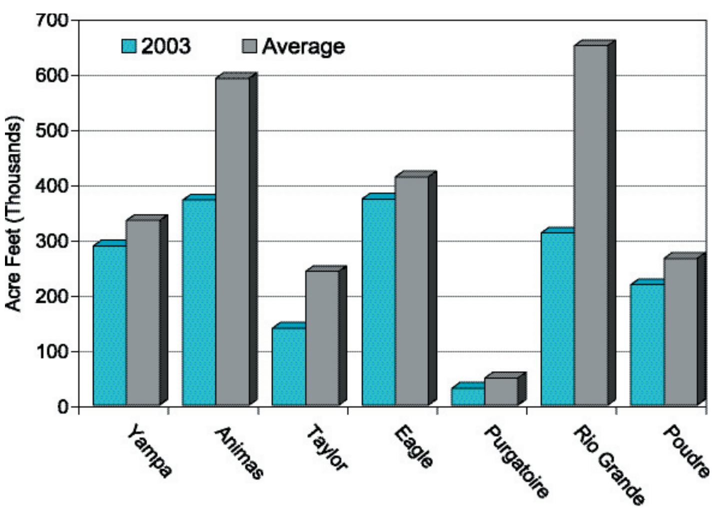
on the Rio Grande downstream from Colorado after several years of extreme low flow conditions.

With the help of wetter weather in 2003 and definitely some aggressive water conservation efforts, significant improvement in statewide reservoir storage was noted. On October 1, 2003, reservoir storage stood at 74% of average (figure below right). While nothing to get too excited about, this was still a great improvement over the same date in 2002 when reservoir storage volumes sat at just 48% of average. Considering the heat and drought of midsummer, this is a great accomplishment. Dillon Reservoir, the key component of Denver Water Department's water storage and delivery system improved greatly as did Lake Granby, the cornerstone of the Colorado-Big Thompson project.

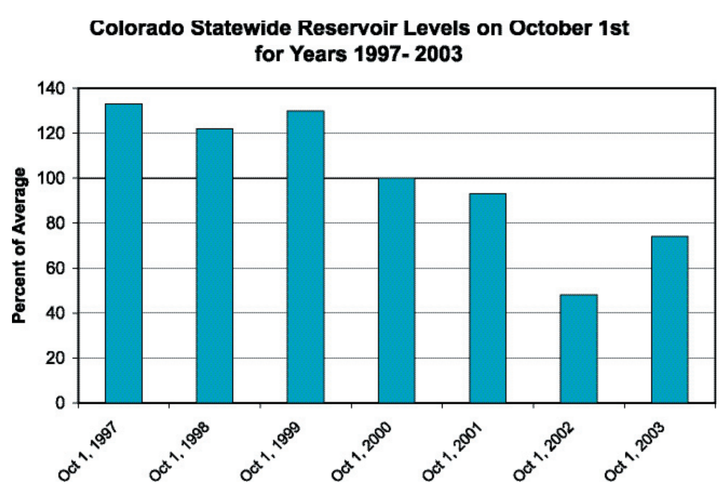
WY2003 was a great example of the hydroclimatic nature of a semiarid but high-elevation region with highly seasonal precipitation patterns. For example, a single spring snowstorm was able to greatly improve drought conditions over two large river basins even though midwinter mountain snow accumulation had been unusually low. Likewise, a single severely hot summer month was able to re-establish drought, crop losses and wild fire hazards over large areas. Late summer rains were beneficial both in terms of providing improved soil moisture conditions but also in contributing enough runoff to raise reservoir levels in some western Colorado watersheds.

This was the sixth consecutive year with below average snowpack on April 1st, a key date for water resource planning and management decisions. Peak runoff occurred a little earlier than average on most of Colorado's major rivers. But thanks in part to bold and aggressive water conservation efforts both in agriculture and in urban areas, overall surface water supplies improved in 2003. Despite mediocre streamflow, reservoir levels improved significantly. While Mother Nature holds the upper hand, it is clear that our human role in water management is huge.

Each time Colorado has experienced severe and widespread drought since the late 1800s, society has responded with aggressive and creative actions to provide more reliable water supplies and lesson the impacts of future droughts. Drought has again stirred the water management pot here in Colorado, and it will be very interesting to look back 50 years from now and see how we responded, and how the natural environment fared. ∗



2003 Water Year streamflow volumes in thousands of acre-feet compared to period-of-record averages for selected rivers in Colorado (data courtesy NRCS).



Colorado statewide reservoir level for October 1, 2003 is 74% of average (data courtesy NRCS).

Just What the Drought Doctor Ordered: A summary and observations of the March 17-20, 2003 snowstorm – A Climatologist's View

by Nolan Doesken

I have to admit, I just don't get as excited about snow as I did when I was a kid. From the age of perhaps 5 or 6 up to when I was an older teenager I would stay up much of the night if it was snowing or predicted to snow – just watching the snow come down or waiting to catch sight of the first flake. The yard light over our driveway illuminated nighttime snowflakes perfectly so I could watch from the kitchen window. It didn't snow much back in my hometown in central Illinois, but I cherished each and every flake.

Most snows only lasted a few hours, and few would keep me up all night. Many would be disappointing as snow would all too often change to rain, but once in a while, a big snow would last all day and all night. Those were the storms that I longed for.

I still love watching and waiting for snow. The only problem is that now I seem to fall asleep when it gets close to 11 pm even if it's snowing.

Before the Storm

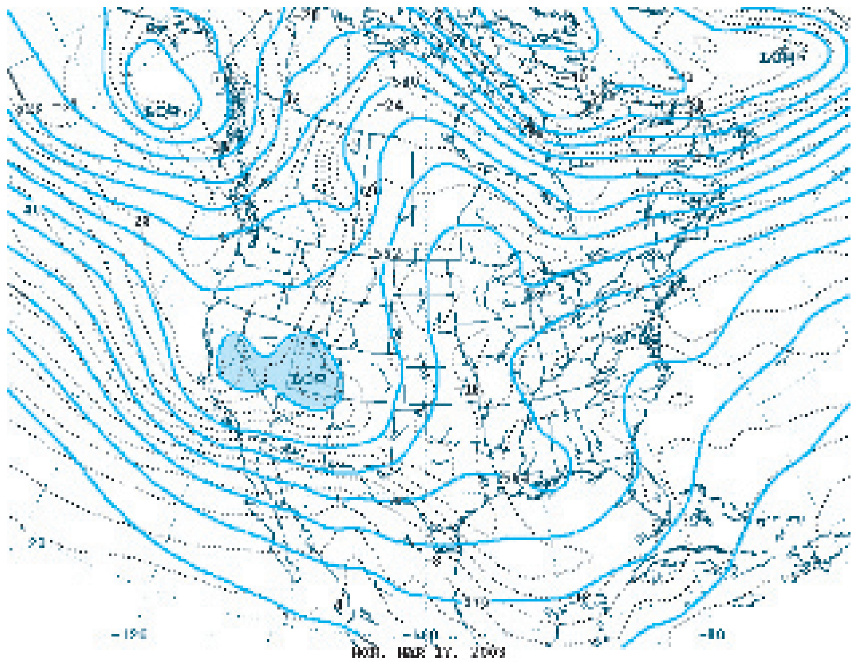
It was probably as early as March 11, 2003 when the weather chatter at work turned to snow. I wouldn't have paid much attention. After all, it felt very much like spring with warm sunny days and mild evenings. The grass would have been turning green except for the dry soil and ongoing watering restrictions. But the weather forecasters kept talking about a possible big storm for the following week. I know weather forecasting has improved. But snow is still one of the toughest forecasts to get right 5 to 7 days in advance. I knew the chances for a big storm were slim. But it was March, after all – a darn good time of year for snowstorms. Even if the storm failed to materialize, it was certainly more fun to think about snow than to continue to drag out more drought conversation. We were all sick of talking about drought.

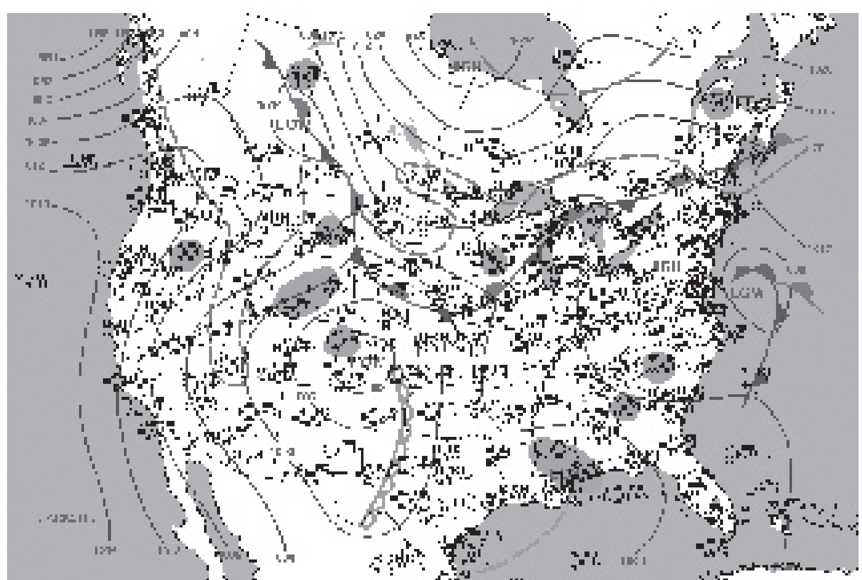
With each passing day, the temperatures got warmer. By the 13th and 14th, daytime temperatures in the mountains were close to 60ºF and snow was melting fast. At lower elevations temperatures soared in the 70s, with 80s in SE Colorado. Several new record highs were set. Of all the things that were hard to imagine, heavy snow was near the top of the list. Yet meteorologists continued to mention it in with ever increasing confidence.

Saturday, March 15th was still warm and sunny with no hints of an impending storm, but weather maps were now showing the beginnings of deteriorating weather conditions west of Colorado. Barometers indicated falling pressure, and clouds began moving into western Colorado late in the day. A few storm-savvy Coloradans took advantage of the good weather to lay in a few extra supplies, just in case.

Residents of Southwest Colorado awoke to rain on Sunday morning (16th) as the early stages of a Four-Corners storm system took shape. Heavy snow began falling but only at high elevations of southern Colorado. Eastern Colorado enjoyed another mild, spring day but with thickening clouds as the day progressed. Weather forecasters did not back down from their early forecasts. Instead they began warning residents of the Colorado Front Range, that this could be a big one, even before the first flake had fallen.

500 mb chart (above) and surface map (below) for March 17, 2003 from Daily Weather Maps.





By Monday morning, March 17th, a classic Four-Corners low pressure area was established centered southwest of Cortez, Colorado (see 500mb chart and surface map on previous page). A deep upper level low pressure trough slowed and then cut off from the main jet stream allowing this southern storm to spin like a top while moving very slowly across the southern Rockies. The counterclockwise flow around this low first drew moisture northward from the Gulf of Mexico and then pulled the warm, moist air westward towards the Colorado Front Range. Widespread light rain began falling over northern Colorado, especially in and just east of the mountains north of Monument Hill and Castle Rock. Farther north, heavy snows were falling in colder air over Wyoming. At the same time, colder air aloft moved over Colorado destabilizing the atmosphere. Thunderstorms developed east of the mountains, and there was even a report of a small tornado near Strasburg.

By Monday night, the upper level wind patterns had aligned to form a pipeline for moist Gulf of Mexico air directly into northeast Colorado. Temperatures dropped just enough to allow rain to turn to snow before midnight over most of the Front Range cities. See detailed explanation on page 2 and 17. Snow became heavy Monday night and by Tuesday morning (18th) a major storm was in full swing. From southern Wyoming southward to Monument and westward to the Continental Divide and beyond, people awoke to 6"-18" of new snow laden with water. At lower elevations from 5-6,000 feet above sea level, the snow water content was nearly 20%, meaning that 10" of new snow contained close to 2.00" inches of water. Most schools in the affected area were open on Monday but did not open on Tuesday with so much snow already on the ground.

Because of the slow movement of the upper level storm system, this same general weather pattern held for over 48 hours. It was the combination of intensity and duration that made this storm exceptional. At first, roads could be cleared of snow since ground temperatures were so warm. But by Tuesday morning even main thoroughfares began to clog with snow and slush. As wet snow continued to fall hour after hour at a high intensity, transportation ground to a halt. Power failures occurred as snow-laden trees brought down power lines. Unusually high precipitation rates for a snowstorm were noted along the northern Front Range, with many areas reporting several hours with more than 0.20" of moisture per hour (Fig. 3, page 2). This is nothing special for summer storms where 2"-3" of rain can fall in an hour, but for moisture falling in the form of snow, this is very intense.

Tuesday (18th) afternoon into early Wednesday morning proved to be the worst of the storm. Snow fell without interruption. Radar and satellite images both showed wave after wave of rain sweep westward across Colorado's eastern plains and turn to snow at elevations of around 4500 feet. While nearly all of Colorado received precipitation, the center of the storm from start to finish was the Front Range urban corridor, foothills and mountains. Douglas, Jefferson, Clear Creek, Gilpin, Boulder and Larimer Counties all stayed in the cross hairs. The heaviest snows fell from about 2 pm on Tuesday through 2 am on Wednesday. By Tuesday evening, the rain/snow line pushed farther out into eastern Colorado, with areas from New Raymer south to Genoa, Rocky Ford and Kim getting a few hours of windblown snow. Also, very heavy snow fell in the northern mountains immediately west of the Continental Divide, but the mountain snow was much fluffier and less dense.

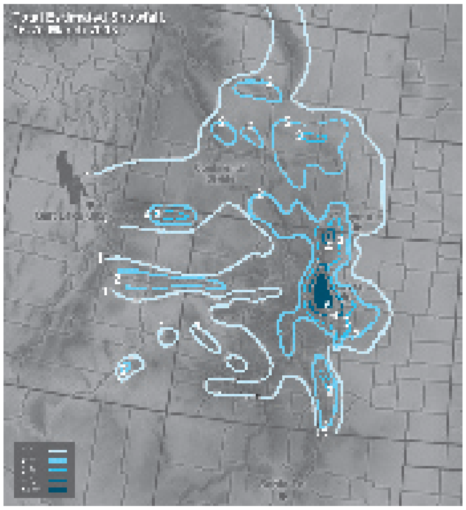
By Wednesday morning (19th) there were some indications that the storm would continue unabated for at least another 24 hours. But the upper level cut-off low pressure center moved slowly eastward. By 9 am snow began tapering off in northern Colorado. Snow came to an end statewide by late afternoon. For most of the area, the great storm of March 2003 was over and the cleanup was underway. One more burst of snow moved through on Thursday (20th) evening that brought 1 to 10 additional inches of snow to the mountains and foothills, but this was technically a separate and independent storm. It was enough, however, to slow the arduous process of digging out.

Facts, Figures and Local Variations

Total storm snowfall (the sum of each daily accumulation of fresh snow) for northern Colorado is shown in Figure 8 on page 18. The map on the next page shows the total reported snowfall for the entire central Rocky Mountain Region based on an analysis completed by the staff of the Cooperative Program for Operational Meteorology Education and Training (COMET). This analysis included data from the traditional National Weather Service observing network supplemented by the NWS snow spotter reports, automated observations from several USDA Natural Resources Conservation Service SNOTEL stations, and additional manual observations from a large number of volunteers along the Front Range that are participants in

Storm Data Compilations for Selected Stations

Station	County	Elevation (feet)	Obs Time (LST)	Monday, March 17, 2003			Tuesday, March 18, 2003			Wednesday, March 19, 2003			Thursday, March 20, 2003			Storm Total March 17-20, 2003		
				Precip (in.)	Snowfall	Snow Depth	Precip (in.)	Snowfall	Snow Depth	Precip (in.)	Snowfall	Snow Depth	Precip (in.)	Snowfall	Snow Depth	Precip (in.)	Snowfall	Snow Depth
Boulder	Boulder	5484	1700	0.26	0.0	0	2.47	11.7	11	1.96	10.8	16	0.00	0.0	13	4.69	22.5	40
Coal Creek Canyon	Jefferson	8950	Midnight	1.84	14.3	12	4.85	39.7	44	2.18	17.7	56	0.08	0.9	52	8.95	72.6	164
Colorado Springs	El Paso	6181	Midnight	0.11	T	0	0.13	1.4	1	0.03	0.3	2	0.00	0.0	0	0.27	1.7	3
Denver Stapleton	Denver	5286	600	T	0.0	0	1.16	6.6	5	3.10	22.9	22	0.28	2.3	18	4.54	31.8	45
Dillon	Summit	9065	700	0.14	2.0	2	0.50	8.0	8	0.21	4.0	11	0.11	2.0	11	0.96	16.0	32
Fort Collins	Larimer	5004	1900	0.39	0.0	0	3.30	18.0	16	1.60	14.2	23	0.00	0.0	18	5.29	32.2	57
Georgetown	Clear Crk	8520	800	0.42	6.5	7	1.34	19.1	21	3.14	34.5	46	0.32	6.8	42	5.22	66.9	116
Grand Lake 1NW	Grand	8720	1600	0.18	0.5	23	1.40	18.0	38	1.45	24.0	54	0.02	T	54	3.05	42.5	169
Greeley	Weld	4715	1600	0.08	0.0	0	0.82	4.0	4	0.80	5.0	8	0.00	0.0	6	1.70	9.0	18
Rye	Pueblo	7141	2000	0.11	T	T	2.59	21.0	21	1.96	23.3	36	0.11	1.8	26	4.77	46.1	83
Westcliffe	Custer	7860	1800	0.11	0.8	T	1.03	15.3	15	1.33	19.6	34	T	T	24	2.47	35.7	73



Total observed snowfall in feet (sum of individual daily totals) for the Central Rocky Mountain Region of Colorado-Wyoming and adjacent states for the 4-day period March 17-20th, 2003. (Figure courtesy Doug Wesley, Rick Koehler, and Heather McIntyre, of the COMET Program, Boulder, CO).

Colorado State University's CoCoRaHS (Community Collaborative Rain, Hail and Snow Network). This shows the entire area affected by heavy snow.

The greatest precipitation and snowfall occurred in a relatively narrow band along the east face of the Rockies where the moisture laden air from the Gulf of Mexico was forced by upslope winds to rise and cool as it banked up against the Front Range. Two to three feet of new snow were common from Denver through Fort Collins and northward to Cheyenne and Laramie, WY. A small area of northeast Utah and the mountains just south of Casper, WY, were also hit hard. Areas south of Denver and westward into the foothills saw 3 to 6 feet of new snow. The greatest reported accumulations of new snow were found in parts of Boulder, Jefferson, Gilpin and Clear Creek County with 70 to perhaps as much as 90 inches of new snow. Eastern Colorado received little if any snow, but substantial amounts of beneficial rain (one to two inches) were widespread.

Some storms have been more widespread like the October blizzard of 1997. A few storms that have been more intense (e.g. April 14-15, 1921 – 76" in 24 hours at Silver Lake west of Boulder) . Many have had stronger winds. What was most unusual about the March 2003 storm was the extraordinary water content of the snow. This was an exceptionally wet snow with snow to water ratios of as low as 5:1 (one inch of water for every 5 inches of snow) up to 10:1 in the higher mountains. Only at elevations above 8,000 to 10,000 feet or at locations west of the Colorado Front Range were densities more like typical Colorado snows. Storm total water content of four to six inches was widespread over the region of greatest snowfall. The 8.87 inches 3-day total including 4.85 inches of water content in 24-hours measured at the official NWS Cooperative Weather Station at Coal Creek Canyon is truly remarkable and confirms what an extraordinary storm this was for the Colorado Front Range.

Some of the interesting local features of the storm included:

- There was a relatively small areas of extreme snowfall.
- It was not terribly cold – just barely cold enough for snow over portions of the storm area with a rain/snow boundary just east of the mountains throughout the storm.
- There was a fascinating local lack of snow near the town of Lyons (just north of Boulder at the mouth of the St. Vrain River) – this is currently a topic of in-depth research.
- There were a few areas, primarily in Grand County, where a great deal of snow fell west of the Continental Divide. The easterly winds were deep enough to cross the higher terrain in that region. Otherwise, most of western Colorado was not hit hard by the storm. Steamboat Springs, for example, only reported one inch of snow plus a little light rain.
- For the most part, the storm was very well forecast by meteorologists. The public had every opportunity to plan and prepare for the storm.

Aftermath and Impacts

Major impacts from this storm included:

- Closed schools and businesses.
- Disrupted transportation – both air and ground.
- Lengthy power outages.
- Stranded residents – particularly Jefferson County but some in Boulder, Larimer, Clear Creek, Gilpin, Douglas and Park Counties. In some areas, people could not get out of their homes for 5 to 7 days, and food was brought in by snowmobile
- There were hundreds of damaged or totally collapsed roofs due to the incredible weight of the snow. Fort Collins was especially hard hit. The weight of the snow did not exceed the engineering design snow load for Larimer County, but it came close. The non-uniformity of snow accumulation due to drifting, and the redistribution of roof loads as the snow melted seemed to contribute to several roof failures. Millions of dollars in damage were reported.

Not all impacts from this storm were negative. Wet snow is wonderful for recharging soil moisture and forest moisture. This storm brought the maximum moisture to the many of the very same areas of Colorado most impacted by the drought of 2002. It was arguably the best possible drought relief anyone could have wished for. For the thousands of residents of the Front Range foothills who rely on well water, this storm single-handedly recharged aquifers and restored the ground water supplies for many mountain and foothill locations.

Another impact of the storm was the many family experiences and a lifetime of memories that this storm created. While there were many hardships, there were surprisingly few injuries or fatalities. Instead there were many rich family times and opportunities for neighbors to help neighbors. For our own family, we will always remember the two-week spring break that our children got from school, and their once-in-a-lifetime experience snow boarding off the roof of our garage onto the huge snowbanks below. Watching our dogs just step over the top of the fence thinking they were free to roam, only to flounder and sink in the deep snow on the other side.

Personally, I remember this as the storm I had always dreamed of but didn't have to shovel. Our teenage kids and their friends shoveled all of our paths and driveway and made piles so large that they could dig out full-sized snow caves. Too bad the snow melted so quickly.

Will It Happen Again?

Of course it will. We know from experience tracking our climate that it is only a matter of time before the record storms of the past are exceeded. The snowstorm of December 1-5, 1913 seemed unsurpassable, yet the March 2003 storm dropped more water in less time in several areas of the Front Range. Yes, there will be another super snowstorm – maybe next year, maybe 50 years from now, but it will happen again. Hopefully, we will still be here to experience it. ✱

Observers Struggle to Measure Accurately **by Nolan Doesken**

Colorado's many volunteer weather observers did a great job measuring and reporting this storm, but it did not come easily. The wet snow clung to the rim and sides of gauges and in some cases totally capped over the top of gauges. The National Weather Service standard rain gauge stands two feet tall, but there were many areas in the foothills and mountains of the northern Front Range where daily snowfall exceeded two feet, especially on the 18th into the morning of the 19th. Blowing and drifting was a major observational challenge in the higher mountains and on the plains. The deep, dense snow was very difficult to traverse, so even getting to the gauge to begin an observation was a problem. Many observers had trouble finding their snow measurement boards. Daily snowfall exceeded the length of the snow measurement ruler at a few sites, and many stations did not have stakes long enough for measuring the total depth of snow on the ground. A few observers even had trouble finding their large precipitation gauges in the deep snow. Rain and snow were mixed together in some areas, and snow continued to melt from beneath at many lower-elevation weather stations. Finally, melting the snow to get a measure of the water content was laborious and time consuming since there was so much ice to change from the solid to the liquid phase. All in all, weather observers faced nearly every difficulty and challenge of snow observation.

At the campus weather station at Colorado State University we had five different types of gauges and two snow measurement boards in use during the storm. Not surprisingly, they gave different answers. One gauge was totally buried beneath the snow and did not provide useful readings. The tipping bucket gauge, which is not well suited for measuring snow, totally clogged up and did not provide accurate data. Two types of recording gauges worked to some extent, but the quantity of snow diluted the antifreeze causing one of the gauges to fill and cap over. When it was all said and done, the old fashioned manual approach worked best. Observers managed to fight the elements to check and empty the gauge every twelve hours during the storm. We were fortunate to have two "overflow cans" so an empty gauge could be set out while the full one was brought in to melt. Clearly, having two gauges proved to be very important, since it took more than one hour to melt the snow. (The campus weather station in Fort Collins only has a hot plate and tea kettle for melting snow!)

With all these observational challenges, we know that not all measurements and reports were perfect. Measuring the depth and water content of snow is surprisingly difficult even for small and moderate events. But observers rallied to do their best under difficult circumstances so we scientists have the data we need to document and study this storm.

Weather observers – Thank you!!

Well-hidden raingauge. Photo by Chris Spears, CoCoRAHS volunteer, Denver.

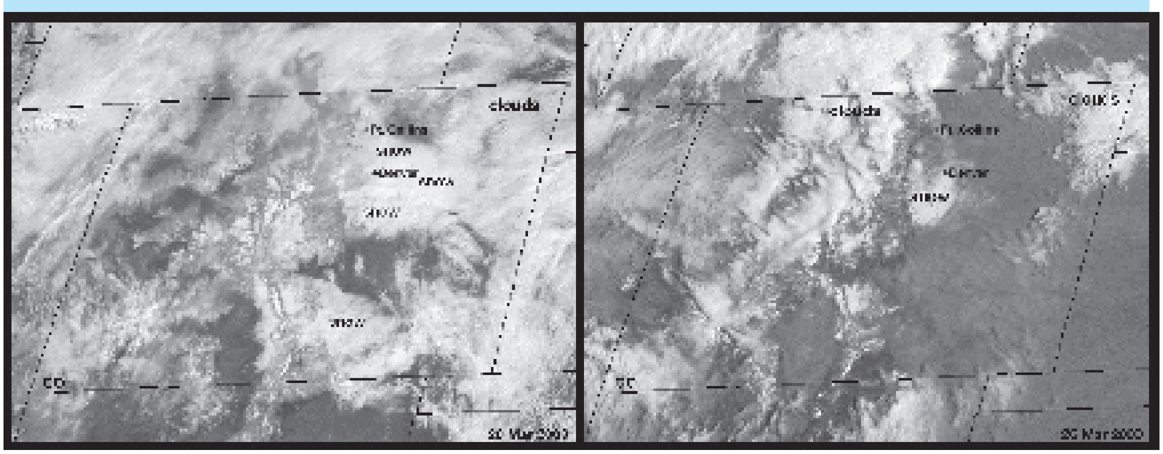
Richard Keen, NWS Cooperative observer at Coal Creek Canyon weather station, is shown here taking temperature readings from the weather shelter after the 72" March 2003 snowstorm. Photo courtesy of Richard Keen.

A Brief History of Colorado's Most Notable Snowstorms **by Nolan Doesken**

Winter 1899	Series of mighty snowstorms in the mountains and extreme cold on the plains.
December 1913	Several feet of deep, heavy and wet snow along and just east of the mountains from New Mexico to Wyoming.
April 1921	76 inches of snow in 24 hours in mountains west of Boulder – national record.
November 1946	Feet of snow blanketed eastern Colorado – many deaths.
January 1949	Frigid midwinter blizzard in northeast Colorado, Nebraska, etc.
December 1951	Mountains and Western Slope snow blitz shut down all mountain transportation.
March 1977	Eastern Colorado snow and dust blizzard.
May 1978	Late snowstorm on Front Range.
December 1982	Denver's Christmas Eve Blizzard.
November-December 1983	Nonstop mountain snow blitz.
February 1989	"Alaska Blaster" brought rare combination of subzero cold and heavy snow.
March 1990	Front Range snowstorm was so dense that snowplows bogged down, trees and power-lines downed or damaged.
July 1994	Snow cancels 4th of July Fireworks in many mountain communities.
October 1997	Nasty blizzard cripples eastern Colorado and knocks down millions of trees near Steamboat Springs.
2003 March	Similar to the December 1913 storm but more intense over a smaller region.

Comparing Two Storms **by John Weaver**

Not only did the all-time record blizzard of 1-5 December 1913 produce more total snowfall, over a slightly larger area than did the 2003 storm, but it also occurred at the beginning of the cold season instead of near its end. According to Wilson (2003), persistent cold following the December 1913 storm caused deep snow to linger well into the following year. Its effects were adversely affecting various aspects of life in Denver well into February of 1914. The deep snow associated with the 2003 event, coming as it did at the beginning of spring, disappeared quickly. Within a week, most of the snow along the Front Range was gone. The quick melt-off is evident in the two visible wavelength satellite images taken one week apart. On the left is a GOES-12 visible image taken at 17:45 UTC on 20 March 2003 showing snow cover along the eastern Front Range of Colorado the day after the storm. A cloud field covers extreme northeast portions of the state. On the right is a GOES-12 visible image taken at 15:45 UTC on 26 March 2003. More than eighty percent of the snow cover along the Front Range has vanished. ∗



What Constitutes the "Worst Storm?" **by John Weaver**

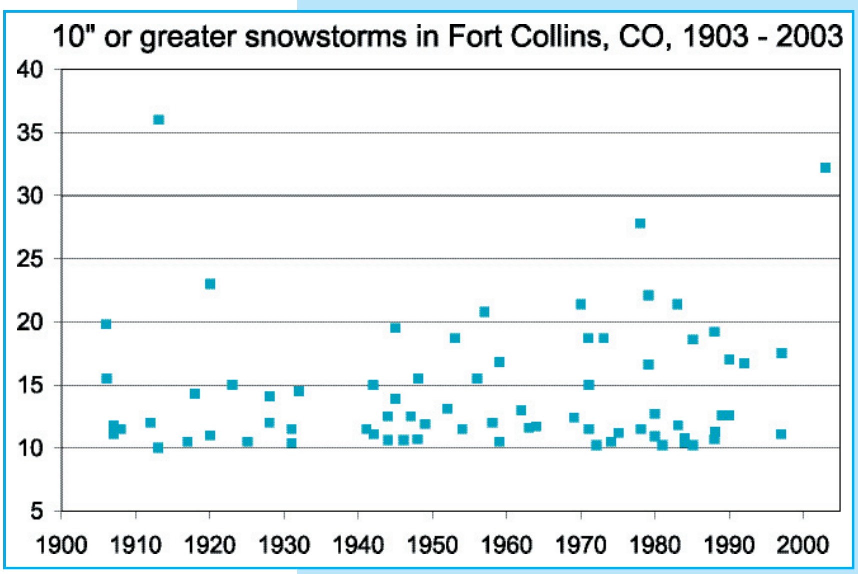
It is nearly impossible to rank snowstorms in any general way, simply because there are so many ways to do it. Trying to assess a storm's intensity in terms of so-called human impact is a serious challenge. For example, you might decide to compare storm related deaths/injuries as a measure of severity, but this would lead to a long series of questions. One would need to consider differing and/or changing population densities, time of day that the storm hits (nowadays a one foot of snow during rush-hour would have much more impact than the same storm in the middle-of-the-night), available communications technology, response and rescue resources, and many others. Dollar damage assessment might be another part of the equation, but then one would have to consider such variables as inflation, differing/changing building codes, the size of the urbanized area affected, and so on.

Making comparisons based on objective weather variables might (at least at first glance) seem to be a better approach, but in this arena the problems can be even more complex. Is a two-foot snow, at a 20:1 snow-to-water ratio, "worse" than a one-foot snow at a heavier, 5:1 ratio? Should one simply consider the greatest snow depths reported for large storms, or should the assessment include the size of the total area affected? Is one storm "worse" than another if it is followed by a period of very cold weather that causes snow to linger an inordinate amount of time, instead of melting away quickly? Would a one-foot snow, accompanied by strong winds and six-foot drifts, be "worse" than a three-foot snow with modest winds, and small drifts? What constitutes a single "storm." Should a break in snowfall of some arbitrary length of time suffice to represent the "end" of one storm, and the beginning of another? Should meteorologists make the determination based on whether a restart of snowfall is part of the same weather system?

Some climatologists contend that the snowstorm which occurred during the first week in December 1913 was actually two, separate events. Snow fell on the 1st and 2nd, then there was a period on the morning of the 3rd where the precipitation stopped entirely. By this time there was 16.5" (42 cm) of new snow on the ground in Fort Collins. Light snow began again late in the day, and continued to increase until it became spectacularly heavy on the 4th and 5th. By the time the five day period was over, a total of 36" (91 cm) had fallen. Looking back at the crude surface maps available for 1913, my guess is that both snows were part of the same low pressure system that moved up from the southwest.

It's a judgment call, but in the point-data shown here, I've chosen to classify the entire five day event as a single storm. My criteria, for this case and a few others, was as follows: 1) if there were two or three consecutive days upon which similar amounts of snow fell (within the same order of magnitude), I would class these days as a single event, and 2) if there were more than three days in a row with snow, then I would try to find maps that would confirm or deny a "single storm" interpretation. There were only five cases in category (2), and none seemed ambiguous.

The graph shows snowstorms which produced 10" (25 cm), or greater, snowfall in Fort Collins over the period 1904 through 2003. Of the one hundred years compiled, forty-nine had at least one such event, and several produced deep snow events. The months in which double-digit snowstorms occurred were at follows: March (17 times), April (15), December (10), November (9), February (8), January (7), October (5), May (2), and September (1). The graph clearly shows that, for Fort Collins, the March 2003 snowstorm (32.2" or 82 cm) was second only to the blizzard of 1913 (36.0" or 91 cm). The third greatest total shown on the graph occurred in early May 1978, when a total of 27.8" (71 cm) was recorded. ∗



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Satellite imagery offered a clue that changes were on their way. Figure 6 presents two GOES 10.7 µm infrared images that reveal an enhanced area of colder cloud tops associated with a shortwave trough (marked SW in the figure) approaching from the east. This disturbance didn't arrive along the Front Range until about 10:00 pm LST, but its arrival had a profound effect. It was at that time when most reliable observers at elevations around 5,000 ft reported a changeover from mostly rain to one hundred percent snow. By this time, FCL (on the Colorado State University campus in central Fort Collins) had reported 0.76" (~19 mm) of rain. There had been a little ice mixed in with the rain off-and-on throughout the evening, though it all melted on contact. But at 10:00 pm, the changeover took place, and snow began in earnest. By 07:00 am on Tuesday morning, 6"-12" (15-30 cm) were measured at various locations in Fort Collins, and it was still coming down[3]. The liquid equivalent at FCL (where 8" fell overnight) was 1.5" – yielding a snow/water ratio of about 5:1. Other observers in the region all reported ratios ranging from 5:1 to 7:1. These included several experienced observers who are part of the Colorado Climate Center's CoCoRaHS (Community Collaborative Rain Hail and Snow Network). CoCoRaHS is a network of trained volunteers with observers in most of the cities affected by the storm (http://www.cocorahs.org).

Tuesday morning, the intensity of the snowfall trickled off to less than half an inch per hour, but a second shortwave was rotating around the now extremely robust cyclone (Fig. 7). This second disturbance – accompanied by deeper moisture in a reinvigorated warm conveyor belt – arrived in central Colorado at around noon, and snow rates increased dramatically. This was the beginning of the second, and most persistent, segment of the event. As the hours passed, and the snow continued up and down the Front Range corridor, tree limbs began snapping, wide-expanse roofs bowed downward, and cars on the street morphed into massive white mounds. Heavy snow continued for another 24 hours, with some particularly heavy convective bursts just after midnight on the 19th. When it was over, central Fort Collins had received an additional 24" of snow, and several foothills observers reported more than 40".

By midday on Wednesday, 19 March, north central Colorado was buried (Fig. 8). Roads throughout the region were impassable, and most businesses were closed. The northern Front Range had been hit with its second largest snowfall in the region's history (Wilson 2003), and, according to *Claims* magazine, Colorado sustained the highest nationwide insured losses for the entire first quarter of 2003 as a result. The snow itself was so heavy that municipal snow plows in most cities were at first

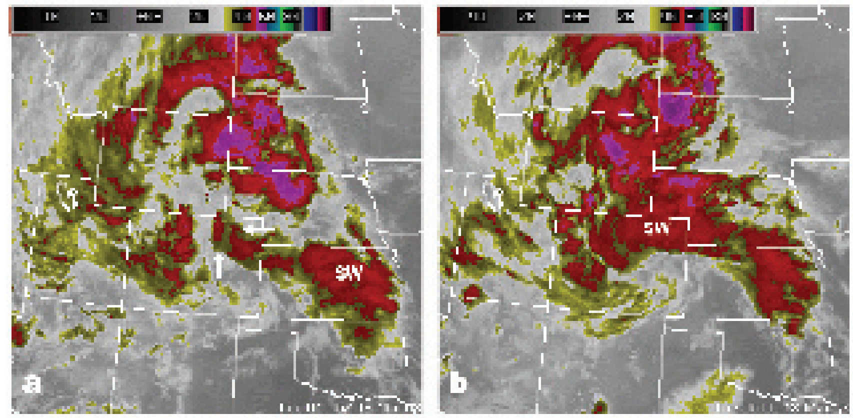

Figure 6. GOES, 10.7 µm infrared window images taken on the evening of 17 Mar. 2003. a) image taken at 6:45 pm LST showing infrared view of banded convection in northeastern Colorado (arrows) and approaching shortwave disturbance to the east southeast, over Kansas (SW), and b) image taken at 10:00 pm LST showing infrared view of shortwave at the time the rain changed over to snow along the Front Range in northern Colorado.

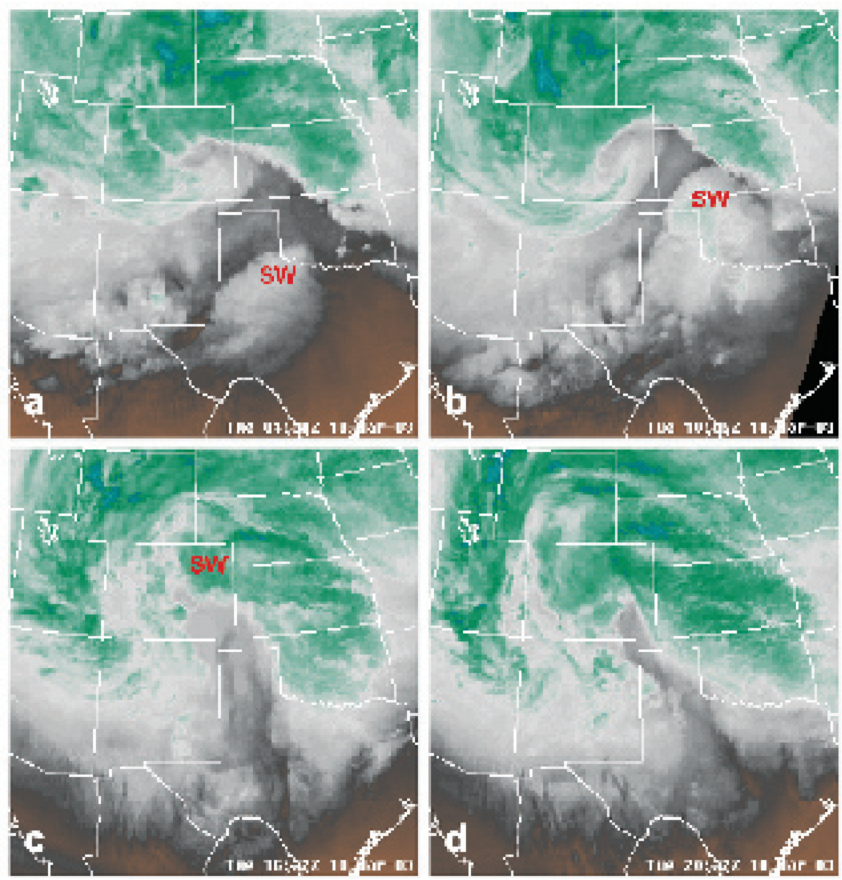

Figure 7. GOES, 6.7 µm water vapor image taken at a) 10:30 pm on 17 March, b) 3:05 am on 18 March, c) 9:22 am on 18 March, and d) 1:22 pm on 18 March 2003 showing an intensifying shortwave (marked SW in red) as it makes its way around the deepening cyclone which is still centered over southeast Colorado. Snow rates increased dramatically as this feature arrived along the Front Range. Note the expanding warm conveyor belt, especially over Kansas and Oklahoma.

[3] Interestingly enough, this first round of snow didn't present much of a problem for motorists along the urban corridor. In the week prior to the storm, daily high temperatures had ranged in the high 60s to low 70s (F), and the 2" (5 cm) soil temperatures had reached 50ºF (10ºC) the day before the storm. By early Tuesday morning, however, snow was finally beginning to accumulate on the roads.

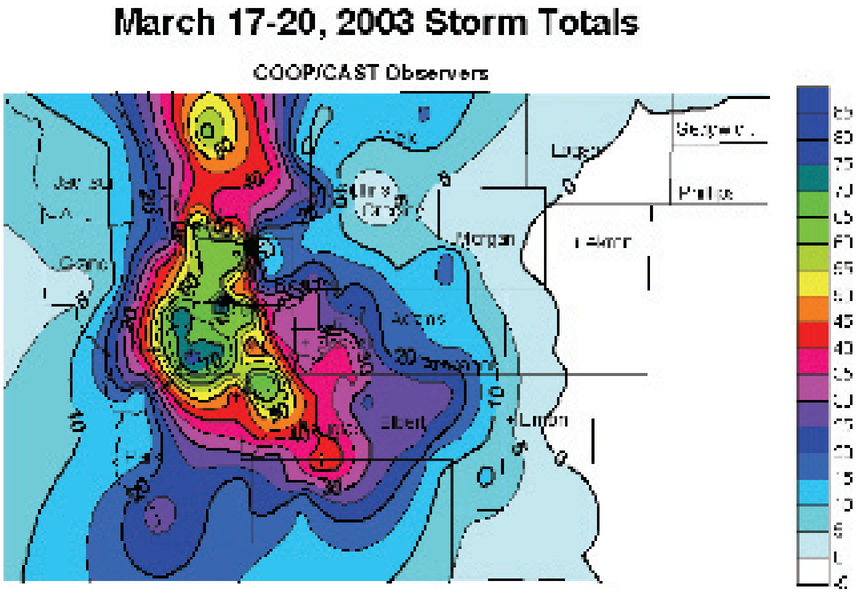

Figure 8. Map showing total snowfall (in inches) for the March 2003 snowstorm in north central Colorado. Observations were collected by National Weather Service (NWS) cooperative observers and members of the Colorado All-Season Spotter Team (CAST) – a volunteer spotter network that provides real-time weather information, year-round, to forecasters at the NWS office in Boulder, Colorado over a toll free, 800 number. Map courtesy of the Boulder, Colorado, NWS forecast office. (1 in = 2.54 cm)

Figure 9. Now what?! Shoveling the driveway doesn't help very much when the street has nearly thirty inches (~75 cm) of snow blocking it. Photo taken by the author in northeast Fort Collins late on the morning of 19 March 2003.

unable to clear roads. Many plows were damaged while trying. Thousands of residents in Jefferson county (west and southwest of Denver) were trapped in their homes for several days, and deep snow closed the major interstates. Yet – other than for hospitals, and emergency responders – no one that I've spoken with locally ever felt any real sense of danger. From a more personal perspective, I certainly didn't feel threatened at any time. The storm, to most, seemed more of an interesting phenomenon – partly fun, and partly an inconvenience. Figures 9 and 10 illustrate the absurdity of the situation. I broke two snow shovels, and finally succeeded in shoveling out my driveway, only to find deep, extremely heavy snow blocking the street. Figure 11 is an example of building damage in Fort Collins. And this was one of the salvageable structures.

CIRA research associates working for the Virtual Institute for Satellite Integration Training (VISIT) were tasked with developing a winter weather teletraining course for National Weather Service forecasters. The course focuses on satellite imagery as a value-added tool within the short-range forecast/nowcast suite of products. The March 2003 storm is one of the examples chosen for presentation. Two questions concerning the case remain partially unanswered. First, and most important, why was the changeover from rain to snow delayed for so many hours (alternatively, why did it change, at all)? Second, why did precipitation amounts right along the Front Range exceed all of the model forecast values by nearly a factor of two? The solution to neither is trivial. The "late" changeover probably had to do with the fact that northeast Colorado was directly beneath the feed of warm, moist Gulf air aloft. The warmer rain may have been modifying the cold air that was trying to move in from the north. The changeover was probably due to layer lifting (and consequent adiabatic cooling) associated with the arrival of the shortwave disturbance illustrated in Fig. 6. Once the changeover occurred, the colder air from the north gained a foothold, and the precipitation never changed back. It is likely that model underestimates of precipitation amounts just east of the foothills are directly related to local topography. The excessive precipitation in this region most probably resulted from a locally deepened boundary layer associated with cold air damming along eastern slopes of the Front Range – a phenomenon that occurs regularly in upslope precipitation situations (Richwien 1980, Gage and Nastrom 1985, Dunn 1987, or Wesley et al. 1990). The "piling up" of cold, moist air serves to extend the effect of the foothills several miles eastward. In Weld county – whose western border is just a few miles east of the mountains – both snow and liquid precipitation totals were closer to the model-predicted values. For the VISIT training, that aspect of the case is heavily emphasized for session participants in offices near mountainous terrain.

The March 2003 snowstorm was a wonderful example of the extreme weather events that occur frequently on the High Plains of the United States. The average annual precipitation along most of the Front Range corridor runs around 15" (~380 mm) per year, yet exceptionally heavy precipitation occurs somewhere in the region nearly every season. The most notable event for the City of Fort Collins was a flash flood which took place on the evening of 28 July 1997 (Petersen et al. 1999). That remarkable weather system dropped 14.5" (~370 mm) of rain onto large portions of the urban area in less than thirty hours; 10.5" (267 mm) fell in just over five. Thousands of buildings were damaged, and five people were killed.

The largest snowstorm in north-central Colorado history occurred on 1-5 December 1913 (Wilson 2003). It dumped 30"-45" of snow onto communities all along the northern Front Range, including Fort Collins and Denver, and that storm was accompanied by strong, gusty winds. It was a true blizzard. Worse, since it occurred near the beginning of winter, the snow was slow to melt off. The aftermath caused serious continuing problems for nearly two months.

The March 2003 snowstorm would certainly be classified as an extreme event anywhere in the country. A three-foot-deep, one-foot-square column of snow, at a snow-to-water ratio of 5:1 to 7:1, weighs from 27-38 pounds (12-17 kg). Putting that much weight on every square foot of a wide-expanse roof challenges even the most advanced engineering. As a witness to the event, I find it surprising that more structures weren't damaged. It was a large and quietly-ferocious beast.

But another way to look at it is to remember that the March 2003 snowstorm brought 5" (~127 mm), or more, of welcome precipitation to portions of a drought parched state, and may have represented the first glimmers of hope for an end to Colorado's long drought. ∗

Figure 10. Ironically, the athletic fields at Colorado State University had been closed until the Fall term due to drought conditions. Watering restrictions made it impossible to revitalize the dry, brittle grass. This photo of a six-foot sign was taken on the morning of 19 March 2003. Photo courtesy of Stacey Seseske (NOAA/FSL), former CSU graduate student.

Acknowledgments

The author would like to express his thanks to Drs. Mark DeMaria and Don Hillger (NOAA/CIRA), Dr. John Knaff (CIRA), Dr. Roger Pielke (Colorado Climate Center), and Mr. Robert Glancy (NWS forecast office, Boulder, CO). When writing informally there is a tendency to be a little more relaxed than when writing for a refereed journal. These folks not only kept me honest, but also helped make the piece a little more interesting with a number of valuable suggestions. Chad Gimmestad of the NWS forecast office in Boulder, CO went out of his way to provide model output data that we'd overlooked when we assembled the data set for the case here at CIRA. Finally, I'd like to thank Ms. Odie Bliss of the Colorado Climate Center, without whose help none of the fascinating statistics presented herein would have been available.

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Figure 11. Collapsed roof of the large Bed, Bath, and Beyond store on south College Avenue in Fort Collins, CO. The roof on this structure was replaced and the store reopened several months later. Photo courtesy of Ron Phillips, City of Fort Collins.

Gas Station Canopy Collapse. Photo by G. Merlo.

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South Meadow. Photo by M.J. Brodzik.

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