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THE DROUGHT OF 2002 IN COLORADO

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1. INTRODUCTION

Historical analysis of precipitation shows that drought is a frequent visitor to Colorado (McKee and Doesken, 1999). Short duration drought as defined by the three-month Standardized Precipitation Index (SPI) occur somewhere in Colorado in nearly nine out of every ten years. However, severe, widespread multi-year droughts are much less common. As of 1999, McKee, et al. showed that Colorado had experienced 5 episodes of long-duration widespread drought based on the 48-month SPI (Figure 1) with the most recent drought period ending in the late 1970s.

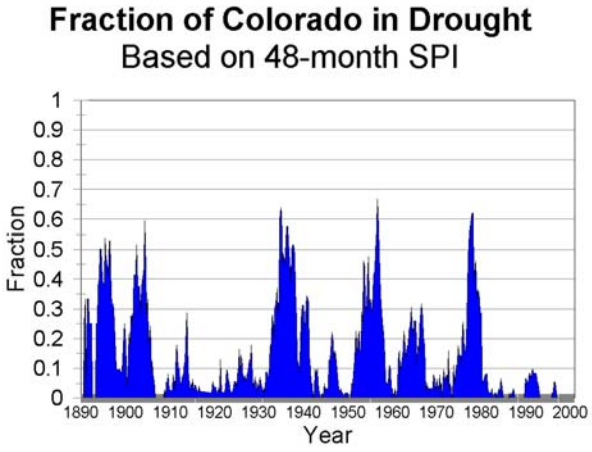

Figure 1. Time series through 1999 of percent of Colorado experiencing drought based on the 48-month SPI at or below the drought threshold value of -1.

Precipitation data for Colorado showed that the 1980s and 1990s were two of the wettest decades in Colorado since 1930 and helped raise the annual precipitation average for the 1971-2000 to the highest level experienced since such data have been compiled for several portions of the state, especially southeastern Colorado.

The people of Colorado were not thinking drought. In fact, 1999 was one of the wettest years on record (Figure 2). Data from the previous 110 years, however, showed that prolonged periods free from widespread multi-year drought were uncommon with the longest period lasting approximately 25 years just prior to the onset of the dustbowl drought of the 1930s. (Figure 1). So while the public was very comfortable with abundant water supplies for this semiarid portion of the country, climatologists were uneasy. As it turned out, they had good reason.

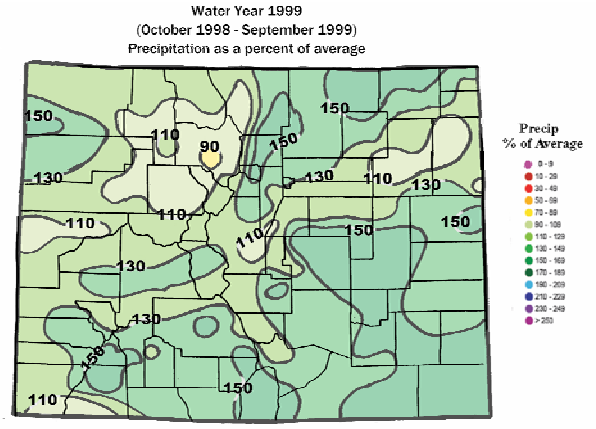

Figure 2. Precipitation for the 1999 water year (October 1, 1998 through September 30, 1999) as a percent of average.

2. AN EVOLUTION OF THE 2002 DROUGHT IN COLORADO

The drought of 2002 had its beginnings in the autumn of 1999. After a very wet spring in 1999 and a soggy August, precipitation patterns reversed and the fall of 1999 was very dry across most of Colorado. The winter of 1999-2000 followed with below average snow accumulation and much above average temperatures. The mountains of southwestern Colorado were particularly hard hit by a shortage of snow for winter recreation and summer water supply. With a very dry spring and early summer in 2000 over NE Colorado and the South Platte watershed, drought conditions emerged quickly. In fact, the whole western U.S. was by then engulfed in a severe drought that resulted in the most severe wildfire season on record. A persistently hot summer did not help matters as transpiration rates were much higher than average over irrigated areas. Precipitation for the 2000 water year is shown in Fig. 3.

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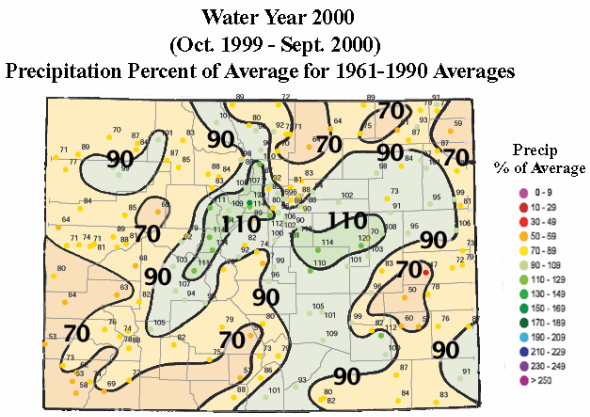

Figure 3. Precipitation for the 2000 water year (October 1, 1999 through September 30, 2000) as a percent of average.

The 2001 water year was less extreme but still tended on the dry side. Colorado's northern and central mountains were the driest with respect to average and this was very significant since that area is the source of most of the water for municipal, industrial and agricultural uses in the state (Figure 4). While spring and summer precipitation was relatively normal, hotter than average temperatures for the second summer in a row again resulted in high evaporation rates and continued depletion of soil moisture and surface water supplies. This set the stage for "The drought of 2002."

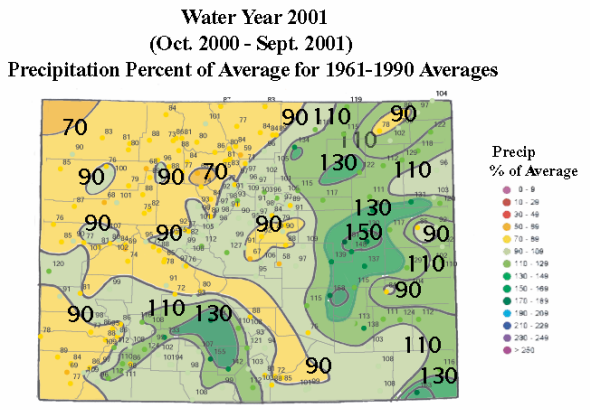

Figure 4. Precipitation for the 2001 water year (October 1, 2000 through September 30, 2001) as a percent of average.

Beginning in September 2001, storm systems were few and precipitation was sparse across the Central Rockies. Much of western and southern Colorado received less than half the average September precipitation and temperatures were several degrees Centigrade above average across the entire state. Beneficial moisture fell from two storm systems that primarily affected northeastern and east central counties of Colorado.

October weather patterns appeared more favorable as a variety of storm systems crossed the region. However, precipitation from passing storms was very light, and when the month was over precipitation totaled again less than half the average over the majority of the state. Some areas east of the mountains received no moisture at all. Temperatures were also mild ranging from about average near the Kansas border to over 2 degrees C above average over southwest Colorado.

Early November was unseasonably warm and dry. Most mountain slopes and peaks remained bare. Only in late November did significant snow fall. Dry powdery snow was widespread and quite deep in the mountains by the end of the month, although snow water content remained below average. In hindsight, the late November snow siege was really the only prolonged stormy period for the year, however, it was very helpful in starting the Colorado winter recreation season.

December brought many more opportunities for mountain snows, but most resulted in only a few inches here and there. The higher peaks and mountain ranges, particularly in northern Colorado, added some good snow, but the surrounding valleys stayed very dry. Temperatures, fortunately, were quite cold in the mountains and valleys, so there was little melting. Many areas of the state picked up less than half the December average and east of the mountains only a few millimeters of moisture was measured. Southeast Colorado fared a bit better due to a few storms coming up across Texas.

January 2002 brought seasonally cold temperatures to the state and above average snowfall for the Front Range urban corridor and the southeastern plains of Colorado. Unfortunately, January precipitation east of the mountains contributes very little to overall water supplies. In the mountains, January snows usually contribute significantly to the accumulating mountain snowpack. But in 2002, January precipitation in the mountains was much below average. Southwestern Colorado was the driest portion of the state with many stations in the San Juan, Animas and Dolores watersheds receiving less than 10% of the 30-year average.

February was also a disappointment. Despite cold temperatures and several storm opportunities, very little materialized. North central counties did best with a few stations reporting near average snowfall and water content. But for most of Colorado, February was extremely dry with many stations reporting less than 25% of the long-term average. Because of the cold temperatures and frequent small snows, Colorado's huge winter recreation industry was able to limp along with surprisingly good snow conditions, but the snowpack water content by the end of February was only 80% of average at best in portions of northern Colorado, while in southern Colorado the snow water content was only about 40-50% of average.

March did not give many hints of the severe drought ahead. Widespread storms crossed the region at least every week, and temperatures were reluctant to begin the normal spring thaw. Unfortunately, none of the storms contributed the copious wet snows that Colorado spring snowstorms typically produce. Furthermore, the storms nearly skipped southeastern

Colorado completely. Only northwestern Colorado ended up wetter than average for the month of March. Some parts of northern and central Colorado were near average. Most of Colorado however was very dry with nearly half the state less than 50% of the average.

By the end of March, the statewide snow water equivalent, as a percent of average, was a mere 52% and all portions of Colorado's mountains were far below average, Figure 5. While not as bad as the winter of 1976-77, these were still very extreme conditions for a state that derives most of its surface water from melting snow. Despite these poor figures, there was little public and government perception of severe drought. This was possible a result of the heavy snows in late November, and the seasonally cold temperatures during the winter (one of the colder winters in recent years) and the favorable winter skiing and snow boarding conditions that had been consistently portrayed by the media. Also, several of that very wet years in the 1990s had low snowpack conditions in early April only to be followed by excessive spring and summer precipitation.

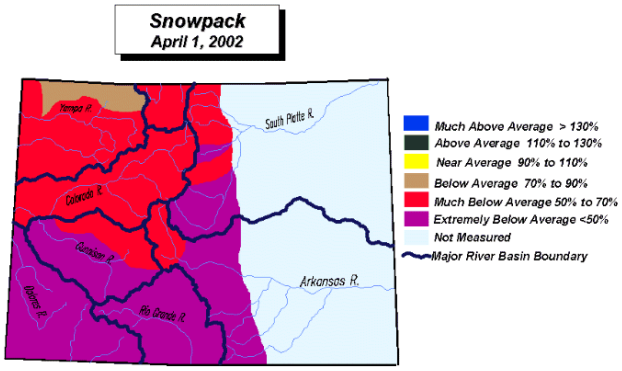

Figure 5. April 1, 2002 snowpack for state of Colorado (from the National Resources Conservation Service, http://www.co.nrcs.usda.gov/snow/data/snmap402.html)

But then came April and the reality of drought quickly hit home. The spring storms that sometimes dump heavy and widespread precipitation were non-existent in April. Almost no precipitation fell in eastern Colorado, and mountain precipitation was also meager. To make matters worse, April temperatures soared to record highs, especially in the mountains, and mountain snow melted or evaporated at an alarming rate. Relative humidity on several afternoons fell to below 10%. Fire danger, which typically stays low to moderate through early June, was already high by mid April, and the first severe forest fire of the season ignited near Bailey on April 23rd (Snaking Fire). For the month as a whole, precipitation was less than half the average over ¾ of the state (Figure 6) and less than 25% of average over broad areas. Temperatures ranged from about average near the Nebraska border to over 5 degrees C above average in the high valleys of the central mountains making this the warmest April on record for several mountain locations. Strong winds also occurred. Farmers trying to get crops planted had to

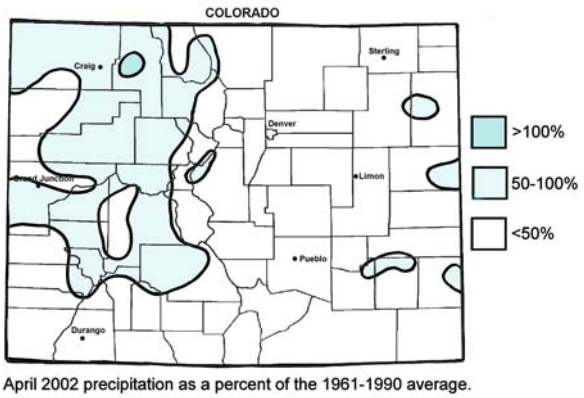

Figure 6. April 2002 precipitation as a percent of the 1961-1990 average for Colorado.

apply early irrigation water resulting in premature depletion of the already limited water supplies.

May, while not quite as much warmer than average as April, was even drier. Only the northern Front Range area received significant moisture (Figure 7). At a time of year when Colorado's rivers and streams are normally churning with snowmelt runoff, there were only brief hints of a spring snowmelt runoff. Irrigation water demand was high, but it was soon obvious that supplies would not last through the growing season. Municipalities began to face the possibility that available water supplies might not provide for the typical summertime demand. Many areas began implementing strict water conservation regulations. More forest fires erupted and each new fire seemed to spread faster than the one before.

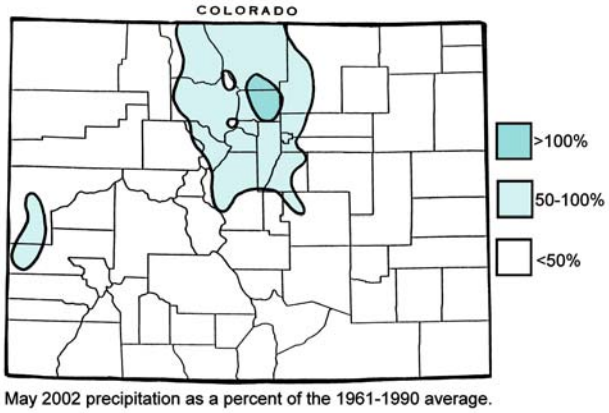

Figure 7. May 2002 precipitation as a percent of the 1961-1990 average for the state of Colorado, USA.

June arrived accompanied by relentless summer heat. Vegetation that normally grows lush and tall during the spring barely greened up. By June, relative humidity often dropped to less than 10%, and bans on outside burning were enforced statewide. Temperatures routinely climbed above 32 degrees C at lower elevations east and west of the mountains. Dry

air allowed nighttime temperatures to dip to comfortable levels most every night. Little or no precipitation fell for the entire month over western Colorado (Figure 8). East of the mountains, a few thunderstorms occurred and some local areas enjoyed respectable rainfall amounts. Parts of far eastern Colorado, for example, reported more than 10 cm of rain in June. But with persistent high temperatures, frequent strong winds, and low humidity, the rain scarcely greened the native vegetation. Winter wheat crop conditions continued their rapid deterioration, and ranchers quickly sold or moved all or parts of their herds in response to the poor range conditions and high cost of feed. The most severe fires of the season erupted in June including the Hayman fire southwest of Denver which quickly grew to be the largest documented forest fire in Colorado (557 km^2) since records have been kept.

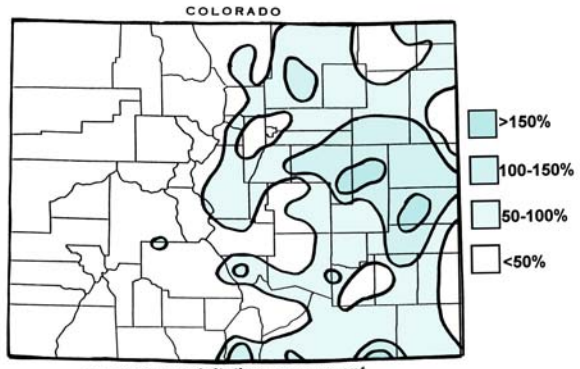

Figure 8. June 2002 precipitation as a percent of the 1961-1990 average for the state of Colorado, USA.

July brought a few changes. While precipitation was again below average statewide, and temperatures were above average for the fourth consecutive month, some increase in humidity was observed later in the month. Initially, wildfire smoke could be seen almost every day, but eventually, as humidity rose, fires spread more slowly, and some were successfully extinguished. July is normally the most lightning prolific month of the year, but in 2002 thunderstorms were few. This helped the fire situation by reducing the number of natural ignitions. There were some focused locations with showers and thunderstorms during July. A few small, localized areas, mostly in or near the mountains, ended up with near average rainfall for the month. But most areas remained dry. The eastern plains were parched with most areas reporting less than 30% of their average July precipitation. Even where irrigation water held out, crops withered under the stress of heat and low humidity. Many area water supplies came to an end, irrigation was curtailed, and crop failure ensued. By late July, Colorado was in a serious drought. Furthermore, drought conditions were not limited just to Colorado but extended over much of the Great Plains and Rocky Mountain States (Figure 9).

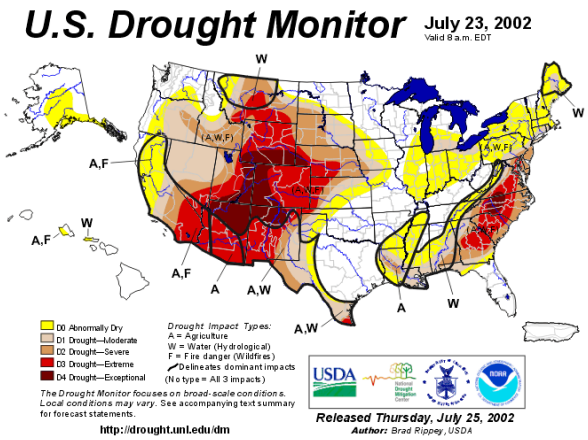

Figure 9. U.S. Drought Monitor for July 23, 2002 shows much of Colorado in "exceptional" D4 drought (from National Drought Monitor, University of Nebraska – Lincoln, http://drought.unl.edu/dm).

August arrived with some optimism. The first several days of the month were not quite as hot and subtropical moisture helped to fuel more afternoon showers and thunderstorms. But the monsoon moisture surge was brief and soon ended. By the 10th of August heat and low humidity returned accompanied by another round of fast-spreading fire activity. Crop and range conditions continued to deteriorate as did streamflows and water levels in the state's largest reservoirs. By mid-August, media reports likened this to the great Dust Bowl of the 1930s in response to unusually late occurring 38°C+ temperatures in Front Range cities. As the month neared its end, a subtle change in weather patterns brought a round of spring-like thunderstorms loaded with hail and high winds to portions of eastern Colorado. The hail did little damage, however, since so few crops were still growing in late August. For the state as a whole, August precipitation was still below average, but unlike previous months there were some large areas of eastern Colorado that received heavy rains. More than double the August average was observed from eastern Weld County down to northwest Kit Carson County.

Humid and stormy weather continued into September. For the first time since August 2001, the majority of Colorado received above average rainfall. Temperatures were still warmer than average, but with the cooler air of fall, frequent showers and a few soaking rains, grass actually began to green up a bit. Parts of Colorado accumulated at least double the average monthly rainfall. Even the bone-dry areas of southwest Colorado received some much appreciated moisture with some areas reporting over 10 cm of moisture for the month. With cooler weather imminent, and the growing season drawing to a close, the worst of the 2002 drought was at last behind us.

3. 2002 IN HISTORICAL PERSPECTIVE – HOW BAD WAS IT

- Snowpack: April 1 is the date most often used to compare snowpack regions in Colorado as this is close to the time where the accumulation of water in the mountain snowpack reaches its maximum. Figure 10. Shows how April 1, 2002 snowpack water content compares to previous years for the state of Colorado as a whole. 1977 was actually drier than 2002. However, snow melted more quickly in April and May with less additions to snowpack so by May mountain snowpack was at its lowest level for the 1968-present record.

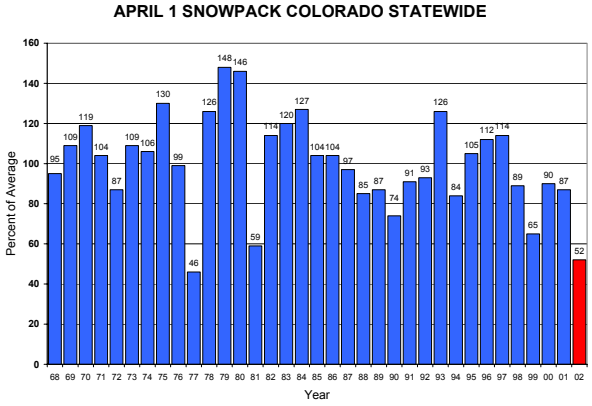

Figure 10. April 1 Snowpack percent of average for Colorado by year from 1968 through 2002 (from NRCS, Snow Survey Division).

- Accumulated Precipitation: Figure 11 shows 2002 water year precipitation as a percent of average. The driest consecutive 12–month period was the September 2001 though August 2002 period. Based on 15 of Colorado's best long-term climatic stations representing all regions of the state, nine experienced their driest year on record. The number of sites with driest on record was somewhat less for the October 2001 – September 2002 period.

  There have been individual years in Colorado that have been drier at individual points or portions of the state – 1894, 1934, 1939, 1954 and 1966 are some examples. However, what made 2002 so unusual was that all of the state was dry at the same time. All seasons were dry and all regions were dry. In a state that straddles the continental divide and where seasonal patterns and wet and dry seasons vary greatly across the state, it is very hard for all areas of the state to experience severe drought at the same time. In fact, much of the western US, both east and west of the Rocky Mountains shared in this drought experience (Figure 9).

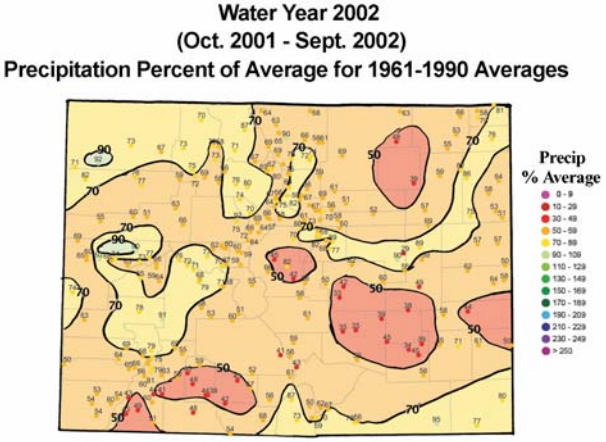

Figure 11. Precipitation for the 2002 water year (October 2001 through September 2002) as a percent of the 1961-1990 average

- Soil Moisture: By all accounts, soil moisture was nearly depleted in the upper one-meter of the soil profile over broad areas of Colorado by late August 2002. No historic data exists, however, to better quantify this. Late August and September rains helped to moisten near-surface soil moisture but did little to improve deep soil moisture.

- Streamflow: The combination of low winter snowpack, a dry and warm spring and a very hot summer, all following on already dry conditions prior to 2002 in the mountains, resulted in a year with extremely low runoff and streamflow. Figure 12 shows a historic time series of streamflow from one river along the Front Range of Colorado. 2002 was clearly the driest year in over 100 years of record based on streamflow. Similar conditions were experienced in watersheds all over the state, and these low streamflows explain clearly why irrigation water was insufficient to raise crops in many areas and why municipalities relying on surface water had to enforce strict water conservation measures. From a longer-term perspective there have been longer "streamflow droughts" such as the conditions that occurred along the Colorado Front Range in the mid 1950s. However, as an individual drought year, 2002 appears to have been unsurpassed during the period of instrumental record.

- Reservoir levels: Reservoirs are an effective means of storing water from times of abundance for use during times of scarcity. 2002 was one of those time. Figure 13 shows Colorado statewide reservoir storage as of October 1 of each year. The excess of the late 1990s helped Colorado survive the drought of 2002, but very little useable water remained even with strict enforced water restrictions.

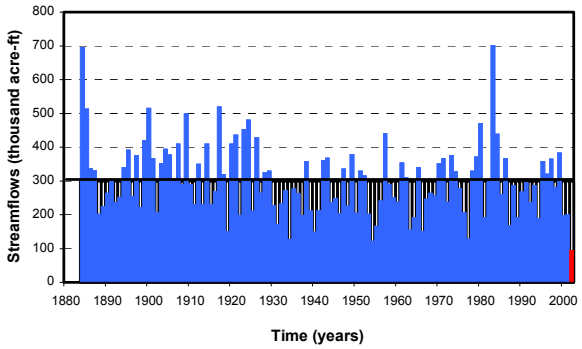

Figure 12. Annual flow records for the Poudre River along the northern Front Range in Colorado for the period 1884-2002. The figure shows some extreme drought events such as those in the 1930s, 1950s, and the drought of the 2000s. Note that the 2002 flow is the smallest value in the entire record. (From J.D. Salas, et al. 2003.)

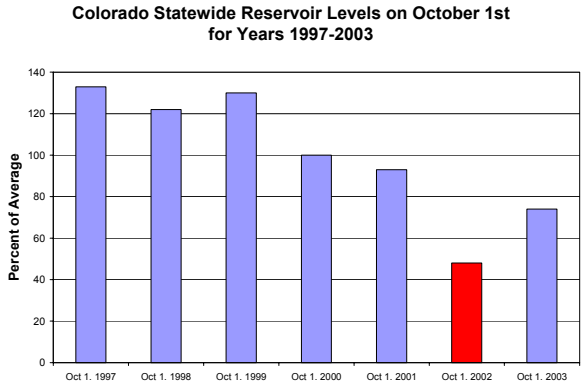

Figure 13. Time series of Colorado composite reservoir storage as a percent of average on October 1st for years 1997 through 2003 (complied from NRCS data at http://www.wcc.nrcs.usda.gov/cgibin/resv_rpt.pl?state=colorado).

4. 2003 – A SHAKY ROAD TO RECOVERY

In semiarid regions like Colorado far removed from maritime air masses, drought is never truly over. Colorado citizens wanted nothing more than to return to the years of water abundance like the 1980s and 1990s. The winter of 2002-2003 did little to end the drought. Rather deficits continued to accumulate. A wet spring in 2003 and one remarkable snowstorm, in particular, did make a difference. In just over 48 hours, three to as much as 8 inches of water was deposited in the form of extremely heavy snow along the Colorado Front Range March 17-19, 2003. This storm took a very important bite out of the drought since it watered the area of Colorado that most heavily utilizes surface water supplies. Timely moisture in April, May and June helped fuel an excellent spring runoff from Colorado's northern and central mountains, and helped a quicker than expected recovery in reservoir storage.

Nevertheless, in late 2003, drought conditions continue across much of the western U.S. going into the winter of 2003-2004 (Figure 14).

Is the drought over? Not yet. Conditions can and do change, but as of fall 2003 Colorado remains very vulnerable to more drought impacts. Coloradoans, and those who rely on water flowing out of this state should be prepared for more drought.

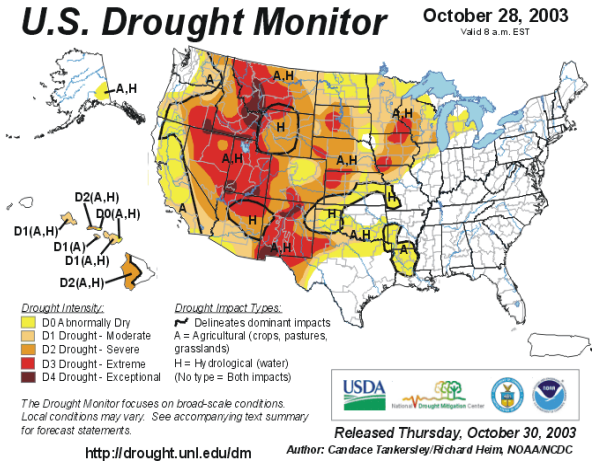

Figure 14. U.S. Drought Monitor for October 28, 2003 shows the current condition of Colorado (from National Drought Monitor, University of Nebraska – Lincoln, http://drought.unl.edu/dm).

5. REFERENCES

McKee, T.B., N.J. Doesken, and J. Kleist, 1999: Historical Dry and Wet Periods in Colorado, Climatology Report 99-1, Part A: Technical Report, Part B: Appendices, Dept. of Atmos. Sci., CSU, Fort Collins, CO, July.

McKee, T.B., N.J. Doesken, J. Kleist, C.J. Shrier, 2000: A history of drought in Colorado: Lessons learned and what lies ahead. *Water in the Balance*, Colorado Water Resources Research Institute, No 9, February, 19 pp.

Salas, J.D., Fu, C., Cancelliere, A., Dustin, D., Bode, D., Pineda, A., and Vincent, E., 2003: Characterizing the severity and risk of droughts of the Poudre River, Colorado. *ASCE Jour. of Water Resources Planning and Management*, accepted for publication.

6. ACKNOWLEDGEMENTS

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