Intermountain West Climate Summary

by The Western Water Assessment

Issued January 25, 2007

January 2007 Climate Summary

Hydrological Conditions – Drought persists in Wyoming, but the eastern half is expected to see some improvement towards wetter conditions in the next three months. Utah and Colorado are not classified as in drought at this time.

Temperature – Temperatures were above average in most of Wyoming, and parts of central Colorado and northeastern Utah in December.

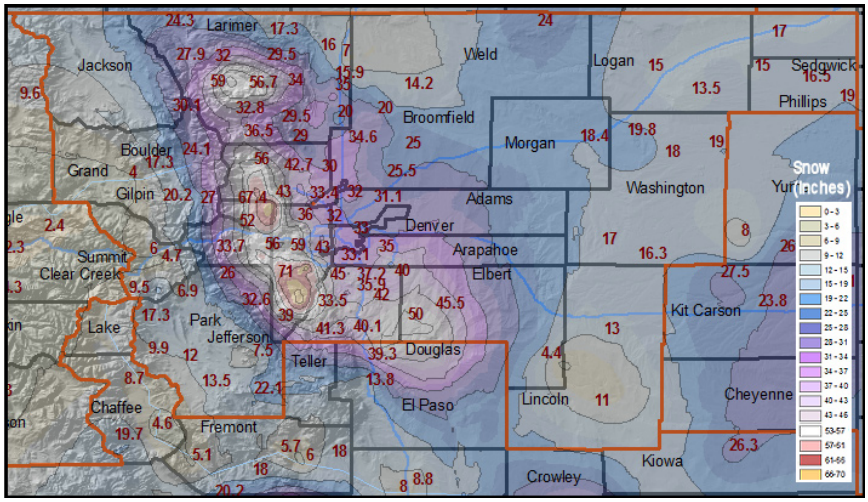
Precipitation/Snowpack – Wyoming, eastern Utah, and western Colorado had below average precipitation in December, while eastern Colorado has had above average precipitation.

ENSO – El Niño is a factor in climate forecasts thru the spring, but it is beginning to weaken. Due to the expected weakening over the next few months, there is considerable uncertainty about the impacts of El Nino in spring 2007 (April-May-June), and it is expected to have little influence after the spring.

Climate Forecasts – Effects of the continuing El Niño this winter include increased odds for wetter conditions in the southern part of the Intermountain West region, and drier and warmer conditions in the northern part.

Record snowfall in December 2006 for parts of Colorado

Denver and the surrounding Front Range communities experienced record levels of snowfall in the last two weeks of 2006. According to NWS Denver/Boulder, two significant winter storms pounded Denver and surrounding areas within a week of each other, and gave Denver the third snowiest December in history. The snowfall totaled 27.7 inches, which when added to the other two days with measurable snowfall this winter comes to a total of 29.4 inches. Maximum snow depth occurred on the 21st and 22nd with 21 inches. The snowiest Denver December is 57.4 inches recorded in 1913 and the average snowfall for December is 8.7 inches. One moisture record was set on December 20th when 0.73 inch of liquid equivalent was recorded, which shattered the old record of 0.24 inches set in 1918. Denver concluded 2006 with an annual precipitation amount of 8.64 inches, which places 2006 into the 7th driest Denver year.



Graphic shows map of combined snow totals for both December storms.

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Climatic and Hydrologic Trends in the Western U.S.: A Review of Recent Peer-Reviewed Research

By Brad Udall, WWA and Gary Bates, NOAA/ESRL/PSD

Introduction

A number of recent scientific papers address the nature of annual snowpack levels and subsequent streamflows in relation to changing temperature and precipitation trends. This article will review the major findings of five peer-reviewed studies on the topics of snow water equivalent (SWE), streamflow amounts and timing, temperature and precipitation trends, and the proportion of rain versus snowfall over the last three years (2004-2006). The authors of these studies represent the National Oceanic Atmospheric Administration (NOAA), the Natural Resources Conservation Service (NRCS), the United States Geological Survey (USGS), and several universities including the University of Colorado, the Scripps Institution of Oceanography at the University of California, San Diego (Scripps), and the University of Washington (UW). Many of the studies were produced in part by NOAA-funded Regional Sciences and Assessments (RISAs) like the Western Water Assessment including the Climate Impacts Group at UW, and the California Applications Program at Scripps.

It is important to note that many of our observing systems were not constructed and maintained with the goal of detecting long-term trends. Therefore, changes in instrumentation, station locations, time of measurement and other factors can affect temperature data. In addition, precipitation, especially winter precipitation, is challenging to measure accurately. For example, snow data is subject to nearby weather modification efforts, vegetation growth near the site, and changes in instrumentation. Finally, stream gages suffer from changes in stream channel geometry, and human impacts upstream. In all of these studies the scientists attempted to correct for data problems by using specifically identified 'clean' datasets, by culling records that seem incorrect, and by other measures. Despite these efforts, the data still suffer from a variety of shortcomings. Nonetheless, the authors are quite clear that the major findings of these studies are robust. Regonda et al., for example, say, "…we believe that the (data) limitations do not affect the interpretation of the results."

Trends in Snow Water Equivalent

Three of the current studies investigated trends in snow water equivalent (SWE). Two of the studies, Mote el al. and Regonda et al., looked at historical trends, and one study, Hamlet et al., created a modeled snow water equivalent dataset back to the early 1900s in order to investigate snow trends before snow measurements were widely made.

Phil Mote, Alan Hamlet, Martyn Clark, and Dennis Lettenmaier wrote Declining Snowpack in Western North America, published in the *Bulletin of the American Meteorological Society* in 2005.[1] This research utilized 824 snow stations from the NRCS, the California Department of Water Resources, and the Ministry of Sustainable Resource Management for British Columbia. The found decreases in April 1 snow water equivalent between 1950-1997 at the majority of sites, with the largest decreases found in western Oregon and Washington, and northern California (Figure 1a). Decreases in the Northern Rockies of Montana and Wyoming were generally between 15% - 30%, while a number of stations in southern Utah, Colorado and elsewhere in the Southwest, indicated increasing trends in SWE. Some of this increasing trend can be attributed to changes in long-term climatic signals such as the Pacific Decadal Oscillation (PDO) and the El Nino Southern Oscillation (ENSO).

Author	Title	Data Used (Source)			
		Snow	Temp/ Precip	Streamflow	Other
Alan Hamlet, Philip Mote, Martyn Clark, Dennis Lettenmmaier	*Effects of Temperature and Precipitation Variability on Snowpack Trends in the Western United States*	March 1, April 1, May 1 SWE via VIC Model (NRCS, CA, BC Snow Data)	Temps, Precip (Eischeid, PRISM)		PDO, ENSO Influence
Noah Knowles, Michael Dettinger, Dan Cayan.	*Trends in Snowfall versus Rainfall in the Western United States*	Daily Snow Water Equivalent(NCDC COOP Data)	Temps (COOP), Precip (COOP) Fraction of Snow vs. Rain		PDO, ENSO influence
Philip Mote, Alan Hamlet, Martyn Clark, Dennnis Lettenmaier	*Declining Snowpack in Western North America*	April 1 SWE (NRCS, CA Snow Survey, BC)	Temps, Precip (PRISM)		PDO, ENSO influence
Satish Regonda, Balaji Rajagopalan, Martyn Clark, John Pitlick.	*Seasonal Shifts in Hydroclimatology over the Western United States*	March, April, May SWE (NRCS)	Temps, Precip (COOP)	Runoff Timing, Means (USGS HCDN)	PDO, ENSO Influence
Iris Stewart, Dan Cayan, Mike Dettinger	*Changes toward Earlier Streamflow Timing Across Western North America*		Temps (PRISM, COOP)	Runoff Timing by 3 measures, Means (USGS HCDN)	PDO, ENSO influence

Table 1. A list of the authors, study title, and variables considered. Data source for each variable is in parentheses.

[1] All except Clark participate in the Climate Impacts Group at the University of Washington, the sister program to the Western Water Assessment. Clark was the Director of the Western Water Assessment until 2005.

Trends in SWE were found to be closely related to mean winter temperature, with the warmest snow-dominated basins experiencing the greatest relative decreases in SWE.

Satish Regonda, Balajj Rajagopalan, Martyn Clark and John

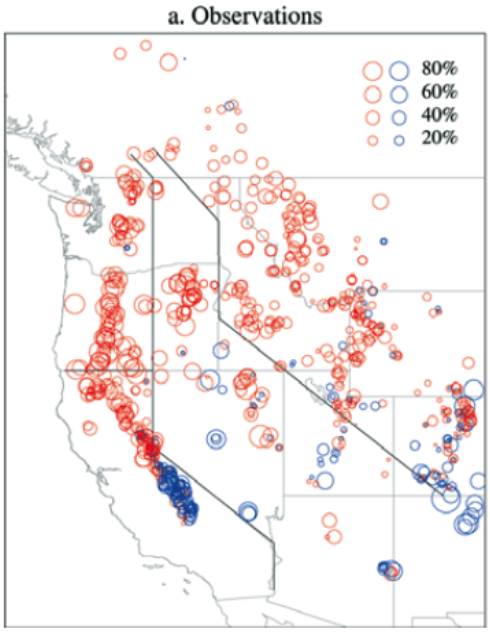

Figure 1a. Linear trends in April 1 Snow Water Equivalent for 824 snow data stations from 1950 to 1997. Negative trends in red, positive trends in blue with circle size proportional to trend size. (from Mote el al. Figure 1)

Pitlick wrote Seasonal Shifts in Hydroclimatology over the Western United States, published in the *Journal of Climate* in 2005.[2] This research looked at 469, 501, and 239 NRCS snow stations for March 1, April 1 and May1 SWE, respectively, containing data for at least 80% of the years between 1950 and 1999. For March, April and May, almost all of the surveyed stations in Washington, Oregon, Idaho, and Montana show statistically significant decreases in SWE of 15cm (6 in) or more (Figure 1b, March and May not shown). Note that these results are reported only in absolute numbers, not percentages, and the study did not include California snow survey data. Unlike the Pacific Northwest, the Intermountain states of Wyoming, Utah and Colorado do not exhibit any spatially coherent trend in SWE. Regonda et al. also present the same data for March, April and May by elevation (Figure 1c for April 1). While there is significant scatter in this data, stations below 2500m (8200 feet) clearly exhibit the most SWE loss. An accompanying elevation map also shows that almost all of the stations in Utah, Wyoming and Colorado are above 2500m. Therefore, the higher elevations in the Intermountain West seem to help the region continue to have average SWE, while lower elevations mountains elsewhere are seeing a decline in SWE.

Alan Hamlet, Phil Mote, Martyn Clark, Dennis Lettenmaier wrote Effects of Temperature and Precipitation Variability on Snowpack Trends in the Western United States, published in the *Journal of Climate* in 2005. This study used the Variable Infiltration Capacity (VIC) hydrologic simulation model[3] to examine trends in SWE across the western U.S. between 1915-2003. The authors pursued a modeling study for three reasons: extensive snow data only starts in the 1950s, the influences of ENSO and PDO confound analysis, and existing snow data is present only for a small geographical subset of the West. Hamlet et al. reconstructed SWE on March 1, April 1, and May 1.

The authors found that, "Widespread warming has occurred in the western U.S. from 1916-2003, resulting in downward trends in 1 April SWE over large areas of the domain… results show that almost all the upward trends in SWE are due to modest upward precipitation trends and that many of the downward trends in SWE are caused by widespread warming." In addition, they state, "These temperature related trends are not well explained by decadal climate variability associated with the PDO," and ENSO variability is on a shorter time scale than the observed changes in temperature trends. However, "decadal variability [i.e. PDO] probably does account for the trends in winter precipitation" that "have occurred over portions of the record." In many high elevation areas of the Interior West[4], SWE was found to be relatively

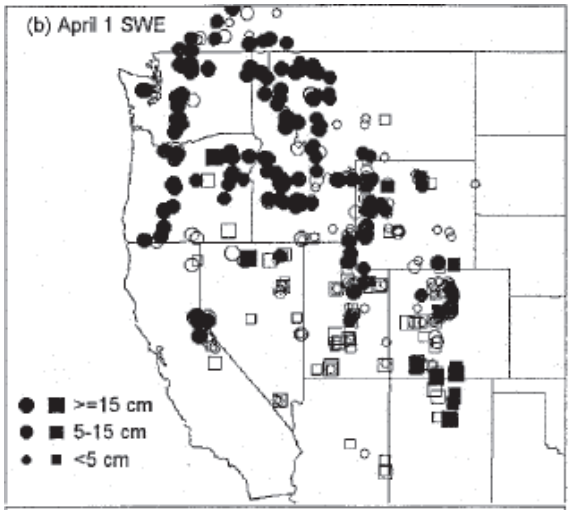

Figure 1b. Changes in snow water equivalent in cm from 1950 to 1999 for April 1 (501 stations) . Circles indicate decreasing trends, squares increasing trends. Solid shapes are statistically significant and the size of the shape is proportional to the change. Compared to Mote et al, measurements are in absolute numbers (15cm = 6in), not percentages and this data extends two more years. (from Regonda et al. Figure 4)

[2] University of Colorado and associated with the Western Water Assessment.
[3] VIC is a water & energy balance model with some subgrid scale approximations for vegetation, elevation and soil dynamics.
[4] Note the distinction in this article between Interior West (AZ, CO, ID, MT, NM, NV, UT, WY) and Intermountain West (CO, UT, WY).

insensitive to recent temperature trends and changes in SWE at those sites are primarily due to trends in precipitation.

Trends in Streamflow Timing and Amounts

Two of the recent studies expressly dealt with streamflow timing and amounts. Stewart et al. looked at several different measures of streamflow timing including onset of the major pulse associated with spring, an annual center of mass measure, i.e. when the date when half the annual flow has occured, and the fractional totals of annual flow in March, April, May, and June. Regonda et al. performed a center of mass analysis. Both briefly considered changes in mean flow.

Iris Stewart[5], along with Dan Cayan and Mike Dettinger wrote Changes toward Earlier Streamflow Timing Across Western North America, published in the *Journal of Climate* in 2005. They used 241 U.S. (specifically, USGS Hydro Climate Data Network (HCDN) gages, stations relatively free from the impacts of humans) and 53 Canadian (Environment Canada) snowmelt-dominated streamflow gages with at least 30 years of data from 1948 to 2002 in the eleven western states and Canada. In general, all three of these measures show a consistent (66% of all gages) 1-4 week earlier shift throughout the West in recent decades compared with the 1950s to 1970s (Figures 1d). These trends were found to be strongest in the interior Pacific Northwest, western Canada and coastal Alaska for mid-elevation gages. In the Western U.S., the months with the greatest trends in earlier streamflow, as measured by changes in average monthly fractional amount, are March and April. Over the period studied (1948-2002), mean annual streamflows have remained constant or increased slightly at most locations. The primary cause for earlier snowmelt and streamflow was found to be a large-scale increase of winter and spring temperatures by about 1-3 ^{O}C over the period studied. The authors also investigated how much of the trends in streamflow timing might be attributed to the known climatic drivers like PDO and ENSO. The authors concluded that, "A significant part of the long-term regional change in streamflow timing can be attributed to decadal climatic variation in the Pacific basin though the Pacific Decadal Oscillation (PDO)…yet, there remains a sizeable residual fraction --in addition to natural variation -- of the streamflow timing trend that is not explained by PDO and appear(s) to be related to temperature increases consistent with observed changes in global temperature."

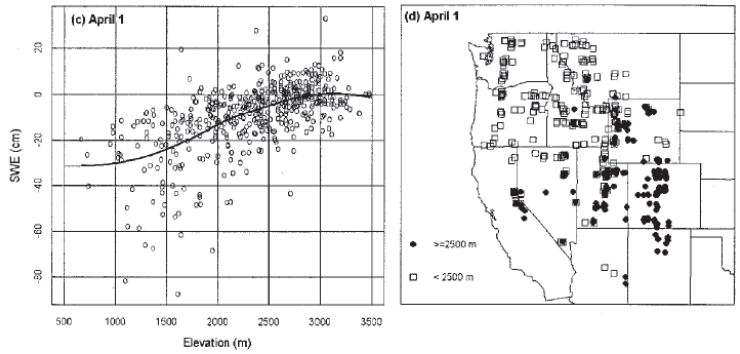

Figure 1c. Changes in snow water equivalent for April 1 SWE by elevation on left (501 stations), and elevation of stations right. Figures for March 1 and May 1 are substantially similar. Note how 2500m (8200 feet) is the approximate line between stations losing SWE and not losing SWE on average. Also note that most Intermountain stations are higher than 2500m. (from Regonda et al. Figures 5c and d)

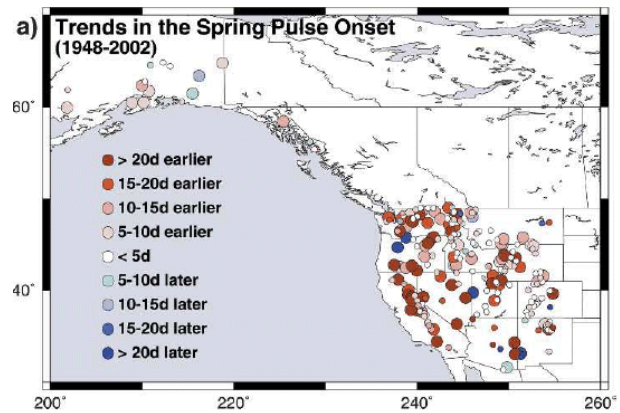

Figure 1d. Trends in spring pulse onset measured in days for the 1948 to 2002 period for 294 gages. Red circles represent earlier streamflows and blue circles represent later streamflows. Larger circles represent greater changes. Trends in date of center of annual streamflow mass look similar to this graphic. (from Stewart Figure 2a)

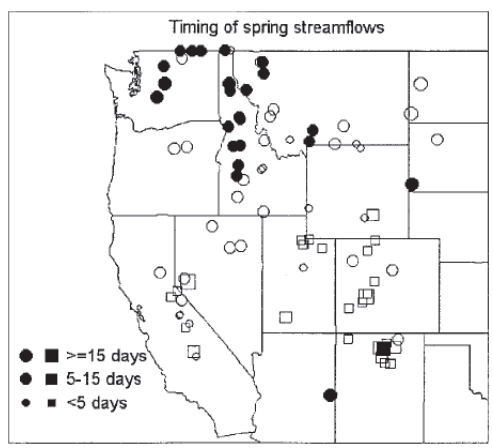

Figure 1e. Changes in the center of mass of annual streamflow timing in days for 89 USGS HCDN gages from 1950 to 1999. Circles indicate earlier runoff, squares later runoff, with filled shapes statistically significant, and shape size proportional to trend. Compared to Stewart et al, the data began two years later and ended three years sooner and had significantly fewer gages (89 vs. 294). (from Regonda et al. Figure 2)

[5] Post-doctoral scientist at the California Applications Program at Scripps, a sister program to the Western Water Assessment.

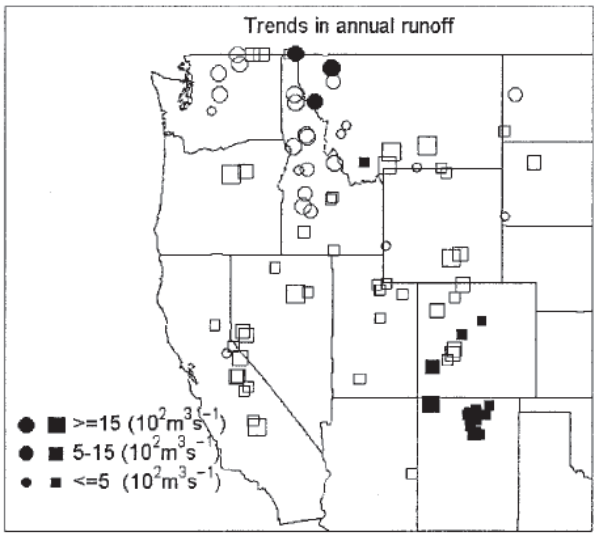

Figure 1f. Trends in annual streamflow in cubic meters from 89 stations during 1950 to 1997. Circles indicate less runoff, squares more runoff, with filled shapes statistically significant, and shape size proportional to trend. Note: data is given in absolute numbers and hence analysis of relative size of trend is not possible. (from Regonda et al. Figure 8)

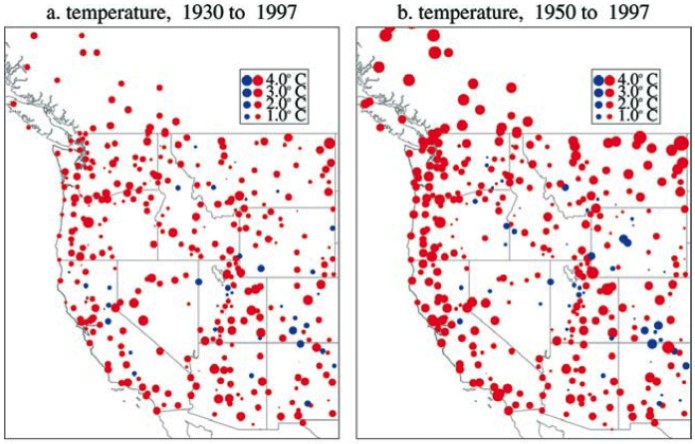

Figure 1g. Nov-Mar temperature trends from 1930 and 1950 to 1997 in oC per century. Red is warming, blue is cooling, with size of circle proportional to trend. (from Mote et al. Figure 6)

Intermountain water managers should note that the Stewart et al. findings for Utah, Colorado and Wyoming are, in general, outliers from the overall findings (Figure 1d). Spring pulse onset and center of mass have changed little in Colorado, and somewhat in Wyoming and Utah depending on the exact area. The fractional flow analysis shows that March flows have changed little in the three states while the June fractional flows appear to have significantly decreased (not shown). Stewart et al. did not show results for May, which might shed light on the June decreases.

Regonda et al. used 89 snowmelt-dominated streams with continuous records from 1950 to 1999, also from the USGS HCDN dataset. They found that for a majority of gages the date when half of the annual flow (i.e. center of mass) occurs happens earlier by 10 to 20 days, but these trends are only statistically significant in the Pacific Northwest (Figure 1e). More importantly to Intermountain water managers, this trend is highly linear with elevation. The lowest stations show the greatest advancement while stations above about 2500m (8200 feet), show little change (not shown). In Utah, Colorado and Wyoming the pattern reverses, with more gages showing later runoff (but none of these gages are statistically significant). This later runoff may result from increased precipitation in these states (Figure 1f and see 1k below) and is discussed below under Trends in Precipitation.

Trends in Temperature

Four of the recent studies investigated changes in both temperature and precipitation trends. A wide variety of temperature datasets were used.

Mote et al. used two separate temperature datasets: one was a combination the U.S. Historical Climatology Network (USHCN - a subset of National Weather Service Cooperative (COOP) data), and the Historical Canadian Climate Database (HCCD). Both are relatively free from data problems. The other was a 'gridded' data set developed by Jon Eischeid of the University of Colorado and a widely-used temperature and precipitation dataset known as Parameter-elevation Regressions on Independent Slopes Model (PRISM) from Oregon State University. Mote et al. report temperature trends from both the 1930 to 1997 and 1950 to 1997 periods for the entire West using the first dataset (Figure 1g). Significant west-wide warming occurred during both of these periods, with the 1930-97 period showing less warming (1-2 ^{o}C (34-35 ^{o}F) per century compared to 2-3 ^{o}C (35-37 ^{o}F) per century) due to the inclusion of the very warm 1930s at the start of the period. The few sites that show cooling in the Intermountain West are in the southern San Juan Mountains in Colorado, in the Wasatch Mountains in Utah, and widely scattered in Wyoming.

Regonda et al. found that an overwhelming majority of National Weather Service cooperative weather (COOP) stations with continuous records from 1950 to 1999 showed a trend towards earlier spring warm spells (defined as 7 days greater than 12 ^{o}C /53 oF) during the period (Figure 1h). This warm spell analysis is unique and was not repeated by other studies. This trend was statistically significant at many stations in Colorado, Utah, Wyoming and the entire Pacific Northwest. In California, Arizona and New Mexico this warming trend was evident, but in general was not statistically significant. Regonda et al. note that at a few stations in the Sierras, Colorado and Utah, generally higher than

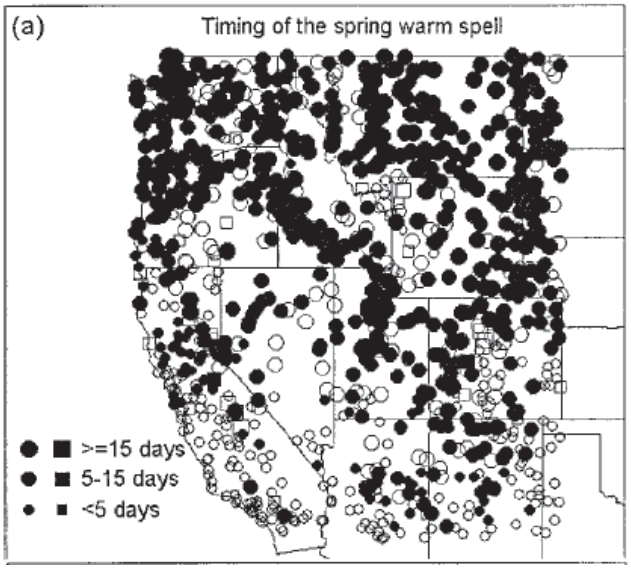

Figure 1h. Trend in days for first spring seven-day long warm spell above 12 °C/53 °F from NWS COOP stations from 1950 to 1999. Circles are earlier spells, squares are later spells, with solid shapes statistically significant. Size of shape is relative to size of trend. (from Regonda et al. Figure 6)

2500m (8200 feet), there is a trend towards later warm spells, but this is rarely statistically significant.

Stewart et al. found temperature trends increasing throughout the 11 western states with warming of between 0.5 - 2.0 °C (33-35.5 °F) during the 55-year period from 1948 to 2002. No map or seasonal information was provided. They used temperature data from Eischeid, discussed above, and from NOAA Climate Division averages.

Noah Knowles[6], Mike Dettinger and Dan Cayan[7] looked at how the character of precipitation is changing in Trends in Snowfall versus Rainfall in the Western United States, published in the Journal of Climate in 2006. Knowles et al. were primarily interested in changes in the proportion of rain to snow (see below) but they also looked at temperature trends from 634 NWS COOP stations across the 11 Western states from 1949 to 2004. Positive temperature trends were found at the vast majority of stations across the West, with wet-day daily minimum and maximum temperatures increasing by 1.4 °C (2.5 °F) and 1.0 °C (2 °F), respectively, over the period studied. The greatest warmings were generally in the Interior West, in January and March, and at higher elevations (Figure 1i). The March warming in the Intermountain West is particularly striking (Figure 1j).

Trends in Precipitation

Three of the studies looked at trends in precipitation. All three studies attempted to investigate the influence of the PDO and the ENSO on these trends.

Mote et al. show precipitation for both 1930 to 1997 and 1950 to 1997 utilizing data from the USHCN and HCCD stations (Figure 1k). The period starting in 1930 shows very large increasing precipitation trends across the West. The 1950 to 1997 period shows increases, with the important exception of western Washington, western Oregon and a small portion of Northern California. Mote et al. describe the SWE results (Figure 1a) as a competition between long-term warming and precipitation increases and decreases. In the Southwest higher precipitation has overcome warming leading to higher SWE, while SWE in the Pacific Northwest has declined substantially because of the double blow of increased temperatures and decreased precipitation.

Regonda et al. using COOP stations with continuous daily records from 1950 to 1999 show a distinct north-south demarcation in winter precipitation trends with stations south of Wyoming showing more precipitation, and stations north showing less precipitation (Figure 1l). There is, however, significant scatter within this general pattern. The authors suggest that this pattern bears similarity to ENSO and PDO cycles, and these drivers might explain a large portion of the precipitation trend. They also say that the increases in winter precipitation in the Interior West may have offset the increases in temperature, the timing and volume of snowmelt has not significantly changed. In the Pacific Northwest, they agree with Mote et. al. that decreases in precipitation combined with warming has had a particularly strong effect on the timing of snowmelt.

Stewart et al. looked at precipitation trends as part of additional research not described. While hinting that the trends were

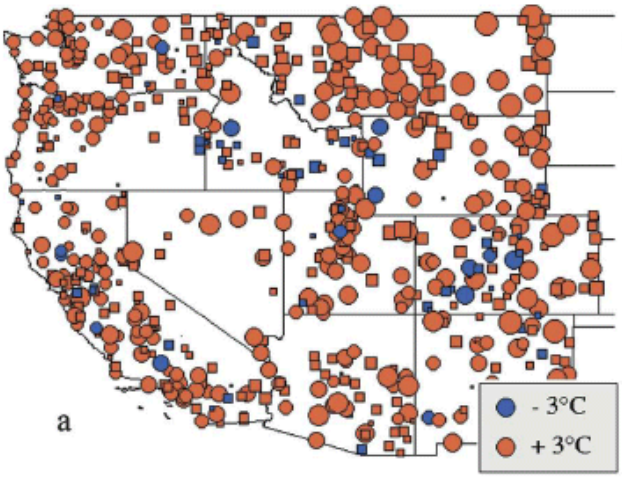

Figure 1i. November to March warming trend in wet-day miniumum termperatrues from 1949 to 2004 in °C using NWS COOP data. Red indicates an increase in temperature and blue indicates a decrease. The size of the circle is proportional to the degrees of temperature change. The circles represent significant findings and the squares are not significant. (from Knowles et. al. Figure 5)

[6] United States Geological Survey
[7] Both of the Scripps Institution of Oceanography.

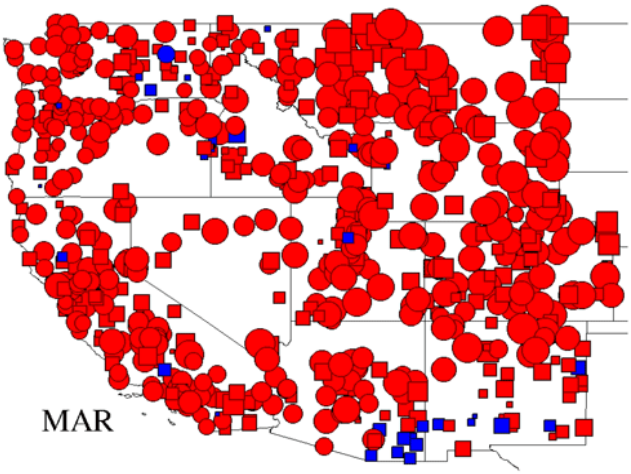

Figure 1j. Trend in average minimum temperature in March from 1948 to 2004 in °C . Scale is the same as in Figure 1i. Notice the large minimum temperature warming in March in the Intermountain West. (from Knowles et. al. Figure 9)

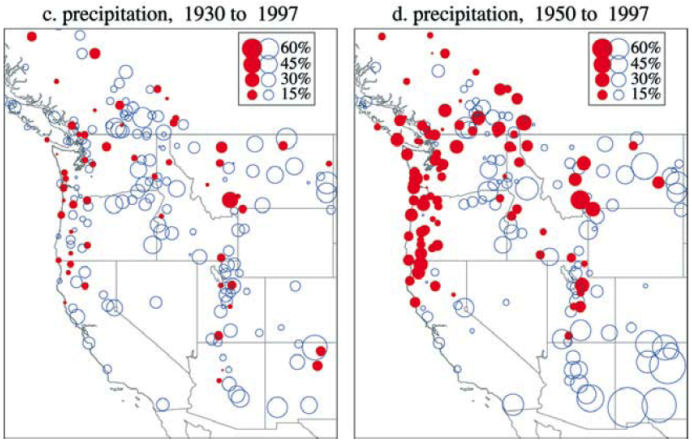

Figure 1k. Nov to Mar precipitation trends during periods shown using approximately 400 USHCN and HCCD stations. Red is a decrease, blue is an increase, with size of circle proportional to trend. (from Mote et al. Figure 6)

small, they describe the trends as statistically significant decreases in the Pacific Northwest and western Canada. They found no trends in California or the Rocky Mountains.

Trends in Snowfall versus Rainfall

Knowles et al. examined daily temperature, precipitation and snowfall records from observations dating from 1949 to 2004 at NWS COOP stations in the Western U.S to determine if the annual ratio of winter snowfall liquid water equivalent (SFE) to winter total precipitation (P) has changed (SFE/P). Snowfall liquid water equivalent is similar to Snow Water Equivalent except that it is a running total of the water amounts in each snowfall during the winter season rather than a total of the water equivalent from snow on the ground.

Over the period 1949-2004, they found that November-March SFE/P has decreased over the vast majority of stations across the West, although results are somewhat mixed over the interior West including Colorado, Utah and Wyoming (Figure 1m). They concluded that "most of the significant changes in SFE were found to be unrelated to changes in total precipitation," and hence that the proportion of winter precipitation falling as rain must have increased during this period.

As noted above, positive temperature trends were found by Knowles et al. at the vast majority of stations across the West. Of the cold season months, January and March have particularly widespread (and significant) warming trends. The impact of this warming on SFE/P in the Interior West is, however, less due to the colder mean winter temperatures. Knowles et al. found that "the largest reductions (in SFE) were shifts from snowfall to rainfall driven by warming and occurred at relatively warm, low to moderate elevations."

Conclusions

For the most part, these six studies are remarkably consistent in their findings. Multiple independent datasets confirm (1)widespread warming in the West, (2) statistically significant declining snowpacks in the Pacific Northwest and California, and (3) advances in spring runoff timing in the Pacific Northwest and California. The data also show some long-term precipitation trends with a slight increase in precipitation in the southern states of the West but little change in long-term streamflow means across the West.

Many of the studies attempted to remove the influences of known changes in precipitation and temperature from PDO and ENSO. In general, these authors agree that the loss of snow, and advanced spring runoff is partly, but not entirely, due to these effects. They suggest that significant west-wide warming over the last 50 years has also played a significant role in the major changes described above.

Findings for the Intermountain West are, however, quite different. These studies show few consistent, statistically significant trends in streamflow runoff timing, streamflow mean amounts, and snow water equivalent. There has been some increase in precipitation in the Intermountain West south of Wyoming, in part due to large scale climatic cycles (e.g. PDO and ENSO). The key statistically significant finding is that the Intermountain West has warmed considerably and this warming trend is apparently greater than other parts of the West. It appears that despite the warming, winter temperatures well below freezing along with some increases in precipitation have protected the snowpack from losses. It should be noted that the SWE studies of Mote et al. and Regonda et al. used data that stopped in 1997 and 1999,

respectively, prior to the current drought. How the inclusion of the recent 2000-2004 drought would change these results is not known. But what is known is that snowpack losses in 2002, 2004, and 2006 in the Intermountain West were quite significant, and were caused in part by substantial spring time warm periods without precipitation.

The conclusions of many of these studies contain explicit warnings for water managers. Stewart el al. say, "Almost everywhere in western North America, a 10% - 50% decrease in the spring-summer streamflow fractions will accentuate the typical seasonal summer drought with important consequences for warm-season supplies, ecosystems, and wildfire risks." Regonda et al. conclude, "If the trends in temperature, snowfall, and streamflow demonstrated in this paper persist and even intensify, changes in water management practices will be necessary to adapt to the altered hydrologic regime." Mote et al. ask, "Are these trends in SWE an indication of future directions?...The increases in temperature over the West are consistent with rising greenhouse gases, and will almost certainly continue. ..It is therefore likely the losses in snowpack observed to date will continue and even accelerate with faster losses in milder climates like the Cascades and the slowest losses in the high peaks of the northern Rockies and southern Sierra."

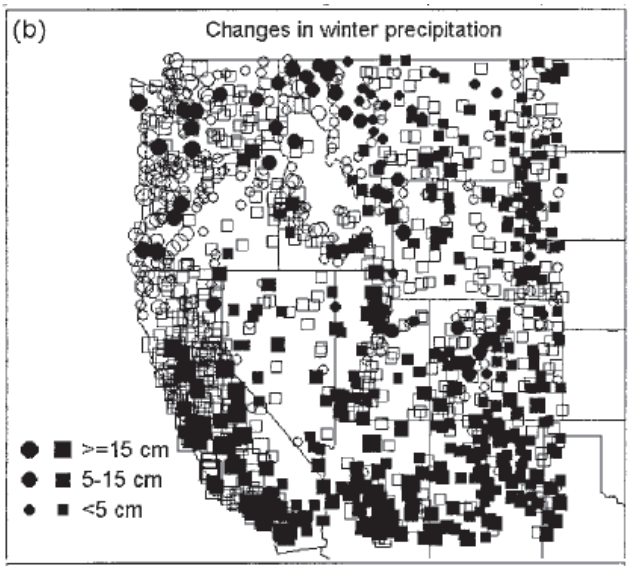

Figure 1l. Trend in winter precipitation in cm from 1950 to 1999. Circles are less precipitation, squares are more precipitation, with solid shapes statistically significant. Size of shape is relative to size of trend. Note the increase in the southern portion and decrease in northern portion. The authors suggest this is in part due to increases in certain phases of ENSO and PDO. (from Regonda et al. Figure 6)

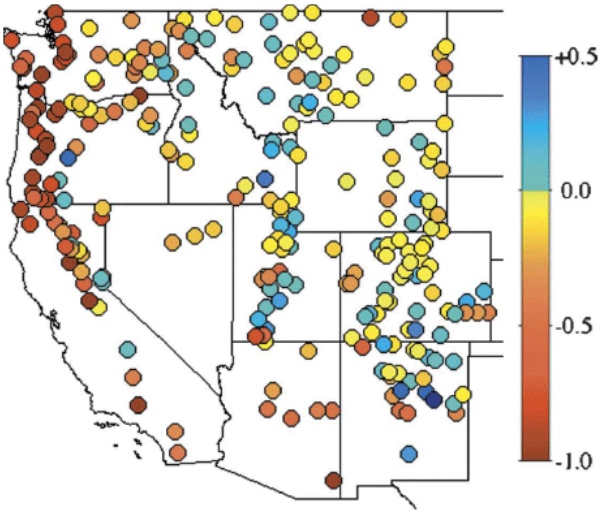

Figure 1m. Fractional change from 1949 to 2004 in winter snowfall equivalent after correcting for changes in winter precipitation amounts. Blues indicate increasing SFE/P (more snow) and yellows-reds decreasing SFE/P (less snow). Data is from NWS COOP stations. (from Knowles et. al. Figure 7)

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Temperature 12/1/06 - 12/31/06

Monthly average temperatures for December 2006 for the Intermountain West region ranged from lows in the mid-teens in western and south central **Wyoming** and north central **Colorado** mountains to highs in the mid-30s in southeast **Utah**, southeast **Colorado** and the Colorado Front Range (Figure 2a). Northern and western **Wyoming** had the highest departure from average with temperatures ranging from 2 – 8° F above average. Central and northeast **Colorado** and northwest **Utah** had above average temperatures as well, 0 - 4° F. On the other hand, central and southwest **Utah** and south central **Wyoming** recorded the lowest departure from average with temperature of 2 – 6° F below average (Figure 2b).

In comparison to December 2005 (Figure 2c) temperatures in 2006 were higher in **Wyoming**, lower in **Utah** and similar in **Colorado**. **Wyoming** had the largest difference between years, with temperatures above average by 2 – 8° F in December 2006, whereas in December 2005, much of western and southern **Wyoming** were average to below average by 2 - 6° F. **Utah** had lower average temperatures in December 2006 by 0 - 8° F than in 2005. The Salt Lake City NWS reported that several record low minimum temperatures were set during the month of December throughout **Utah**.

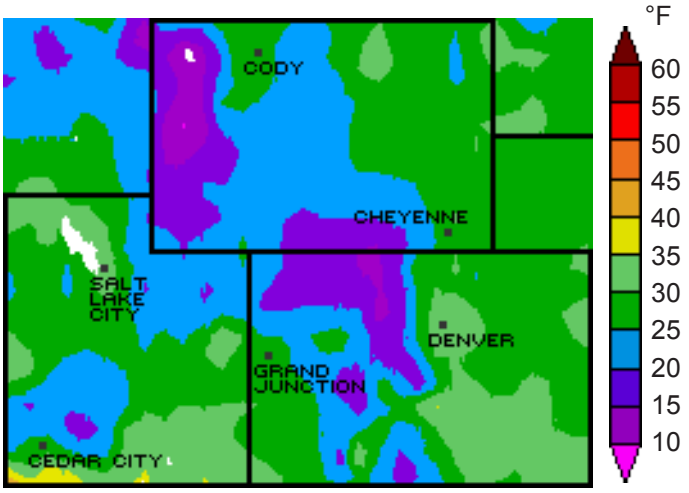

Figure 2a. Average temperature for the month of December 2006 in F°. Figures 2 (a-c) courtesy of High Plains Regional Climate Center

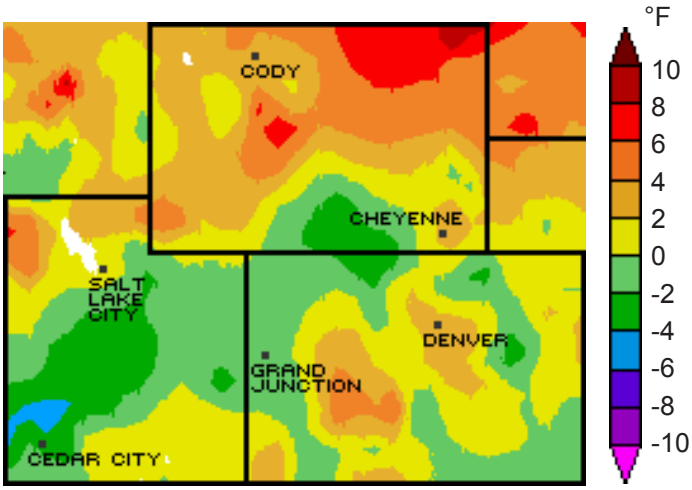

Figure 2b. Departure from average temperature for the month of December 2006 in °F.

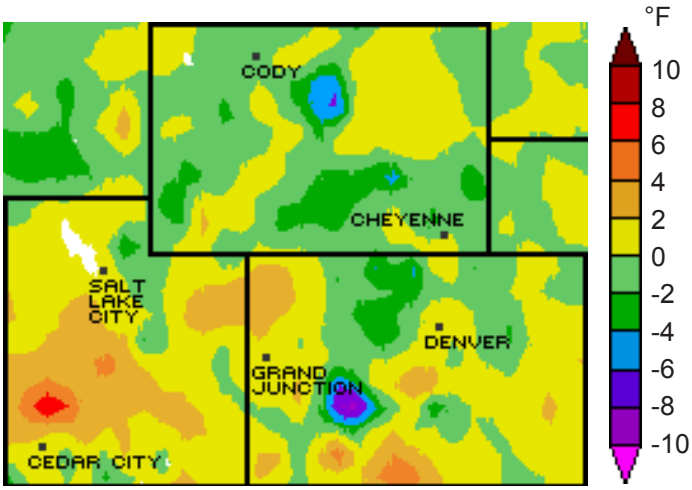

Figure 2c. Departure from average temperature in °F for last year, December 2005.

Notes

Figures 2a-c are experimental products from the High Plains Regional Climate Center. These data are considered experimental because they utilize the newest data available, which are not quality controlled. These maps are derived by taking measurements at individual meteorological stations and interpolating (estimating) values between known points to produce continuous categories. Interpolation procedures can cause aberrant values in data- sparse regions. For maps with individual station data, please see web sites listed below. Average refers to the arithmetic mean of annual data from 1971- 2000. Departure from average temperature is calculated by subtracting current data from the average. The result can be positive or negative.

On the Web

- For the most recent versions of these and maps of other climate variables including individual station data, visit: http://www.hprcc.unl.edu/products/current.html.
- For information on temperature and precipitation trends, visit: http://www.cpc.ncep.noaa.gov/trndtext.htm.
- For a list of weather stations in Colorado, Utah, and Wyoming, visit: http://www.wrcc.dri.edu/summary

Precipitation 12/1/06 - 12/31/06

Total precipitation for December 2006 in the Intermountain West regions ranged from 0 to 3+ inches (Figure 3a). North central and southeast **Colorado**, areas in the San Juan Mountains in southwest **Colorado**, and northwest and south central **Wyoming** received the highest totals. Most of the rest of the Intermountain West region received from 0.5 to 2 inches. However, eastern **Utah**, northwest **Colorado**, and northeast **Wyoming** only received from 0 to 0.5 inches of precipitation in December. According to NWS Denver/Boulder, December 2006 finished as the third snowiest December for Denver. One precipitation record was set on December 20th when 0.73 inches of water equivalent was recorded, breaking the old record of 0.24 set in 1918.

Due to abundant moisture amounts received from December snowfall, percent of average precipitation is above 200% for central and eastern **Colorado** and the southeast corner of **Wyoming** (Figure 3b). However, much of the rest of **Wyoming** remains at 40 – 80 % of average in the southwest and central areas, and at below 40% of average in the northeast corner. **Utah** is at 120 – 150% of average in the southwest section, while much of the northeast is at 40 – 80 % of average. Percent of average precipitation since the start of the water year (Figure 3c) is near average or above for all of **Colorado** and **Utah**, with southeast **Utah** and the eastern half of **Colorado** at 200% of average. Most of western and southern **Wyoming** is near average, while the north central and northeast sections of **Wyoming** are at 40 – 80 % of average.

Notes

The data in Figs. 3 a-c come from NOAA's Climate Prediction Center. The maps are created by NOAA's Earth System Research Laboratory and are updated daily (see website below). These maps are derived by taking measurements at individual meteorological stations and interpolating (estimating) values between known data points to produce continuous categories. The water year runs from October 1 to September 30 of the following year. As of October 1, 2006, we are in the 2007 water year (Figure 3c). The water year is more representative of climate and hydrological activity than the standard calendar year. It reflects the natural cycle of accumulation of snow in the winter and run-off and use of water in the spring and summer. Average refers to the arithmetic mean of annual data from 1996-2005. This period of record is only ten years long because it includes SNOTEL data, which have a continuous record beginning in 1996. Percent of average precipitation is calculated by taking the ratio of current to average precipitation and multiplying by 100.

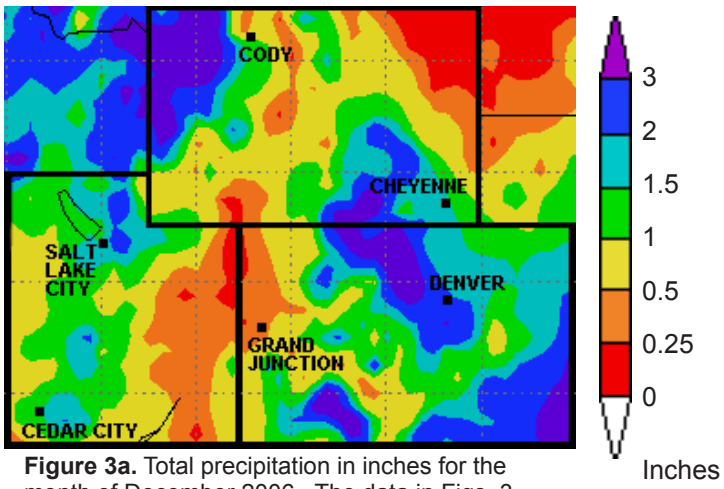

Figure 3a. Total precipitation in inches for the month of December 2006. The data in Figs. 3 a-c come from NOAA's Climate Prediction Center. Figs. 3a-c are created by NOAA's Earth System Research Laboratory.

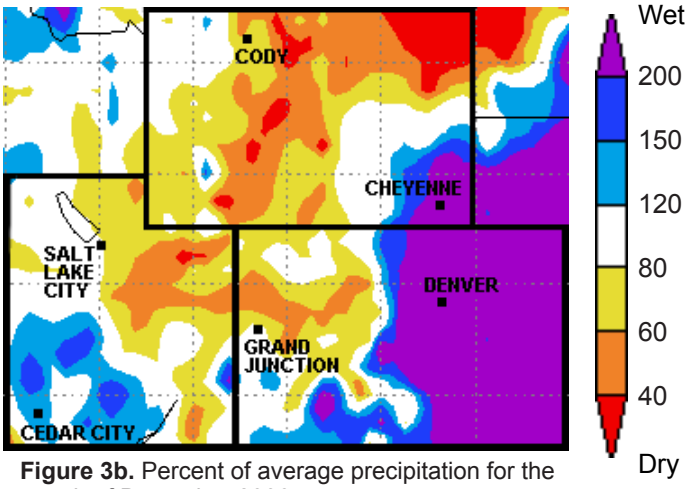

Figure 3b. Percent of average precipitation for the month of December 2006.

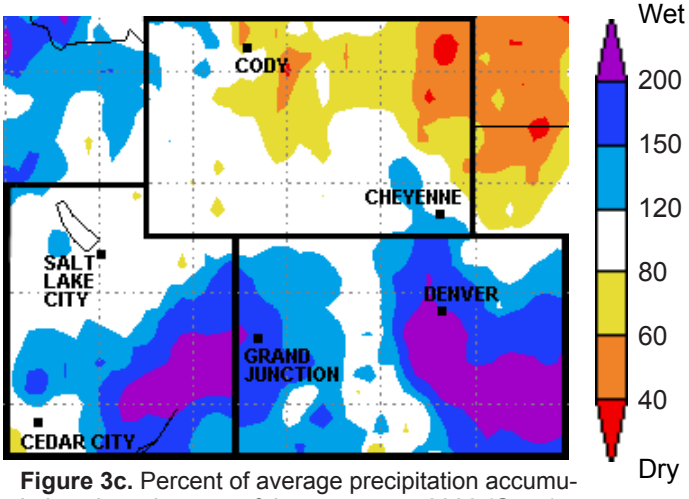

Figure 3c. Percent of average precipitation accumulation since the start of the water year 2006 (Oct. 1, 2006 – Dec. 31, 2006).

On the Web

- For the most recent versions of these and maps of other climate variables including individual station data, visit: http://www.hprcc.unl.edu/products/current.html.
- For precipitation maps like these and those in the previous summaries, which are updated daily visit: http://www.cdc.noaa.gov/Drought/.
- For National Climatic Data Center monthly and weekly precipitation and drought reports for Colorado, Utah, Wyoming, and the whole U. S., visit: http://lwf.ncdc.noaa.gov/oa/climate/research/monitoring.html.
- For a list of weather stations in Colorado, Utah, and Wyoming, visit: http://www.wrcc.dri.edu/index.html.

U.S. Drought Monitor conditions as of 1/18/07

According to the National Drought Monitor on January 18, 2007, drought intensity status has decreased for much of **Colorado** and southeast **Utah** from the previous month. The drought category for central **Colorado** was lowered from D0 – D1 to non-drought conditions, though northern and southwest sections are still in abnormally dry to moderate drought. **Wyoming** status remains mostly unchanged with D3 (extreme) drought status over much of the central, northern and eastern counties and D1 – D2 (moderate to severe) over the rest of the state.

According to the U. S. Drought Monitor Impacts Reporter, agricultural and livestock concerns continue in **Wyoming** due to drought conditions. With forage extremely short, hay is costing $150/ton, and calves are being weaned up to 6 weeks early at lower weight. In northeast **Colorado**, a Morgan County official attributes overall losses in the county's value of agricultural land parcels to sustained drought conditions, estimating that 30,000 agricultural acres now sit idle, due to drought and related water shortage problems. The valuation of agricultural land in the county fell during 2006 by about 12 percent. Impact reports from southeast **Utah** say that low water levels in Lake Powell are revealing hiking paths and rock formations in Glen Canyon Dam not seen the lake was filling. Over the past five years, the water level has declined by almost 150 feet, revealing archaeological sites and slot canyons that haven't been seen in thirty years.

Notes

The U. S. Drought Monitor (Figure 4) is released weekly (every Thursday) and represents data collected through the previous Tuesday. The inset (lower left) shows the western United States from the previous month's map.

The U. S. Drought Monitor maps are based on expert assessment of variables including (but not limited to) the Palmer Drought Severity Index, soil moisture, streamflow, precipitation, and measures of vegetation stress, as well as reports of drought impacts. It is a joint effort of the several agencies; the author rotates among the agencies.

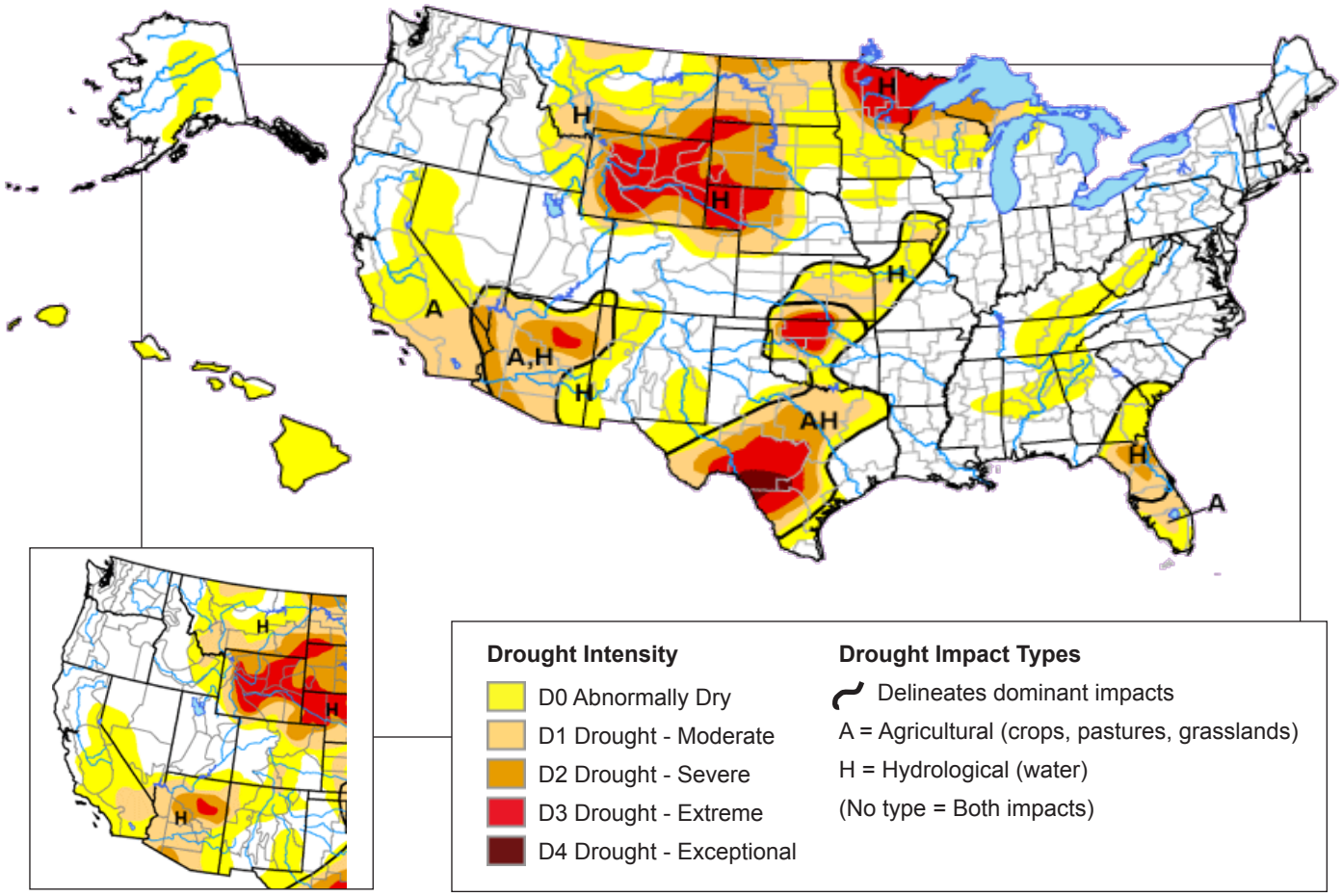

Figure 4. Drought Monitor released January 18, 2007 (full size) and last month December 21, 2006 (inset, lower left) for comparison.

On the Web

- For the most recent Drought Monitor, visit: http://www.drought.unl.edu/dm/monitor/html
  This site also includes archives of past drought monitors
- Drought Impact Reporter (National Drought Mitigation Center): http://droughtreporter.unl.edu/

Intermountain West Snowpack data through 1/1/07

Snowpack conditions across the Intermountain West are mostly below or near average, with the exception of the Front Range (east of the Continental Divide) in **Colorado** where some basins report up to 129% of average snowpack (Figure 5). The South Platte, Arkansas, and parts of the Rio Grande River Basins in **Colorado** experienced abnormally high snowfall totals in December, so they have the highest snowpack percentages in the region. In other parts of **Colorado**, the Colorado River Basin has about average snowpack levels, but the northwest and southwest corners have only 70% - 89% of average snowpack levels.

In the rest of the Intermountain West, most of **Wyoming** and **Utah** have 70% - 89% of average snowpack levels because they did not experience the storms that **Colorado** did in December. In **Utah**, snowpacks range from 69% in southeast **Utah** to 89% on the Uintah Mountains. The Bear, Weber, and Sevier River Basins and southwest **Utah** area all near 80% and the Provo River Basin is at 73% of average. In **Wyoming**, like **Utah**, most of the state has 70% - 89% of average snowpack. However, much of the central mountains of the Big Horn and Wind River Basins have 50% - 69% of average snowpack, and the northeast part of the state has below 50% of average. There are some pockets of above average snowpack in the southeast part of **Wyoming**, in the North Platte River Basin.

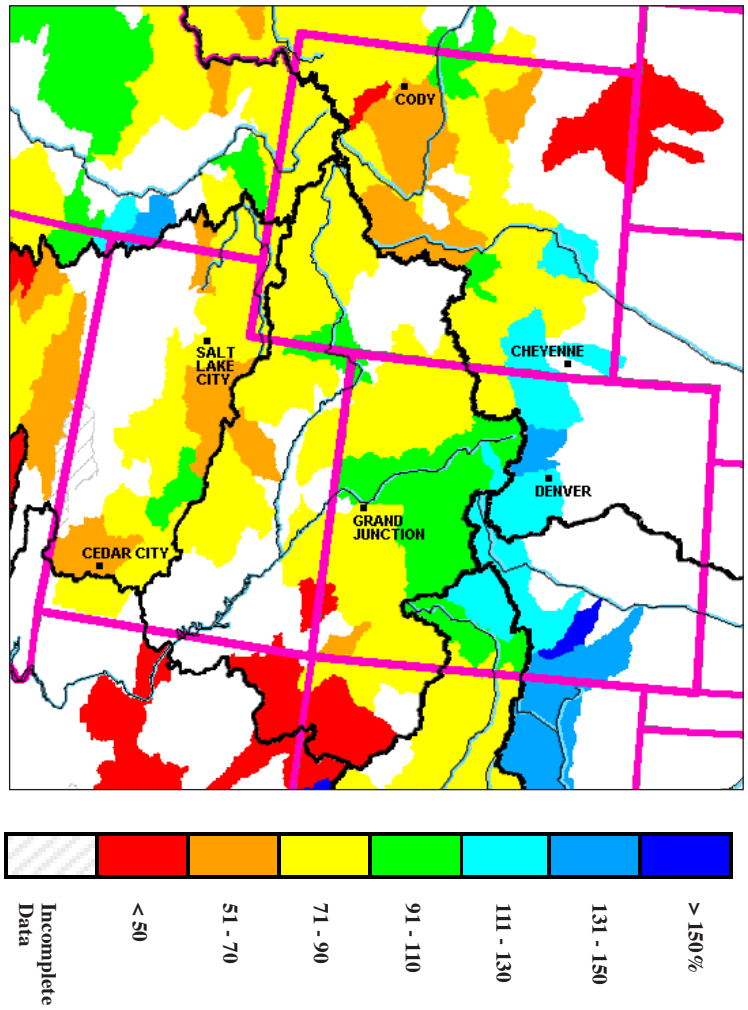

Figure 5. Snow water equivalent (SWE) as a percent of average for available monitoring sites in the Intermountain West as of January 1, 2007 courtesy of the Natural Resources Conservation Service.

Figure 5 shows the SWE based on SNOTEL and snow course sites in the Intermountain West states, compared to the 1971-2000 average values. The number of SNOTEL or snow course sites varies by basin. Individual sites do not always report data due to lack of snow or instrument error, these basins with incomplete data are designated in white on the map. To see the locations of individual SNOTEL sites, see each state's water availability page.

Notes

Snow water equivalent (SWE) or snow water content (SWC) refers to the depth of water that would result by melting the snowpack at the measurement site. SWE is determined by measuring the weight of snow on a "pillow" (like a very large bathroom scale) at the SNOTEL site. Knowing the size of the pillow and the density of water, SWE is then calculated from the weight measurement. Given two snow samples of the same depth, heavy, wet snow will yield a greater SWE than light, powdery snow. SWE is important in predicting runoff and streamflow. Snowpack telemetry (SNOTEL) sites are automated stations operated by NRCS that measure snowpack. In addition, SWE is measured manually at other locations called snow courses. (See page 22 for water supply outlooks.)

On the Web

- For graphs like this and snowpack graphs of other parts of the western U.S., visit: http://www.wcc.nrcs.usda.gov/snowcourse/snow_map.html.
- For snow course and SNOTEL data updated daily, please visit one of the following sites:
  - River basin data of SWE and precipitation: http://www.wrcc.dri.edu/snotelanom/snotelbasin.
  - Individual station data of SWE and precipitation for SNOTEL and snow course sites: http://www.wcc.nrcs.usda.gov/snowcourse/snow_rpt.html or http://www.wcc.nrcs.usda.gov/snotel/.
  - Graphic representations of SWE and precipitation at individual SNOTEL sites: http://www.wcc.nrcs.usda.gov/snow/snotel-data.html.

Regional Standardized Precipitation Index data through 12/31/06

The Standardized Precipitation Index (SPI) can be used to monitor conditions on a variety of time scales. 3- and 6-month SPIs are useful in short-term agricultural applications and longer-term SPIs (12 months and longer) are useful in hydrological applications. The 12- month SPI for the Intermountain West region (Figure 6) reflects precipitation patterns over the past 12 months (through the end of December 2006) compared to the average precipitation of the same 12 consecutive months during all the previous years of available data.

The SPI has not changed very much from the last IMW Climate Summary in November 2006. **Wyoming** is still dry, **Utah** is average to moderately wet, and **Colorado** is average. The driest parts of the region are in central and south-central **Wyoming**, in the Wind River and Upper Platte climate divisions, which are in the extremely dry category. The rest of **Wyoming** is in the normal to very dry categories. Only the Lower Platte division in the southeast became less dry, moving from the very dry to the moderately dry category. **Utah** also had some climate divisions move into drier categories. The Northern Mountains and Uinta Basin divisions in northeastern **Utah** moved from the moderately wet to the near normal category. In **Colorado**, some climate divisions moved into wetter categories. The Platte, Kansas, and Rio Grande Drainage basins moved from the moderately dry to the near normal category, and now the whole state is in the near normal category.

Notes

The Standardized Precipitation Index (SPI) is a simple statistic generated from accumulated precipitation totals for consecutive months compared to the historical data for that station. Near normal SPI means that the total precipitation for the past 12 months is near the long-term average for one year. An index value of –1 indicates moderate drought severity and means that only 15 out of 100 years would be expected to be drier. An index value of -2 means severe drought with only one year in 40 expected to be drier. (courtesy of the Colorado Climate Center)

The SPI calculation for any location is based on the long-term precipitation record for a desired period. This long-term record is fitted to a probability distribution, which is then transformed into a normal distribution so that the mean SPI for the location and desired period is zero. Positive SPI values indicate greater than median precipitation, and negative values indicate less than median precipitation. Because the SPI is normalized, wetter and drier climates can be represented in the same way. The SPI is valuable in monitoring both wet and dry periods.

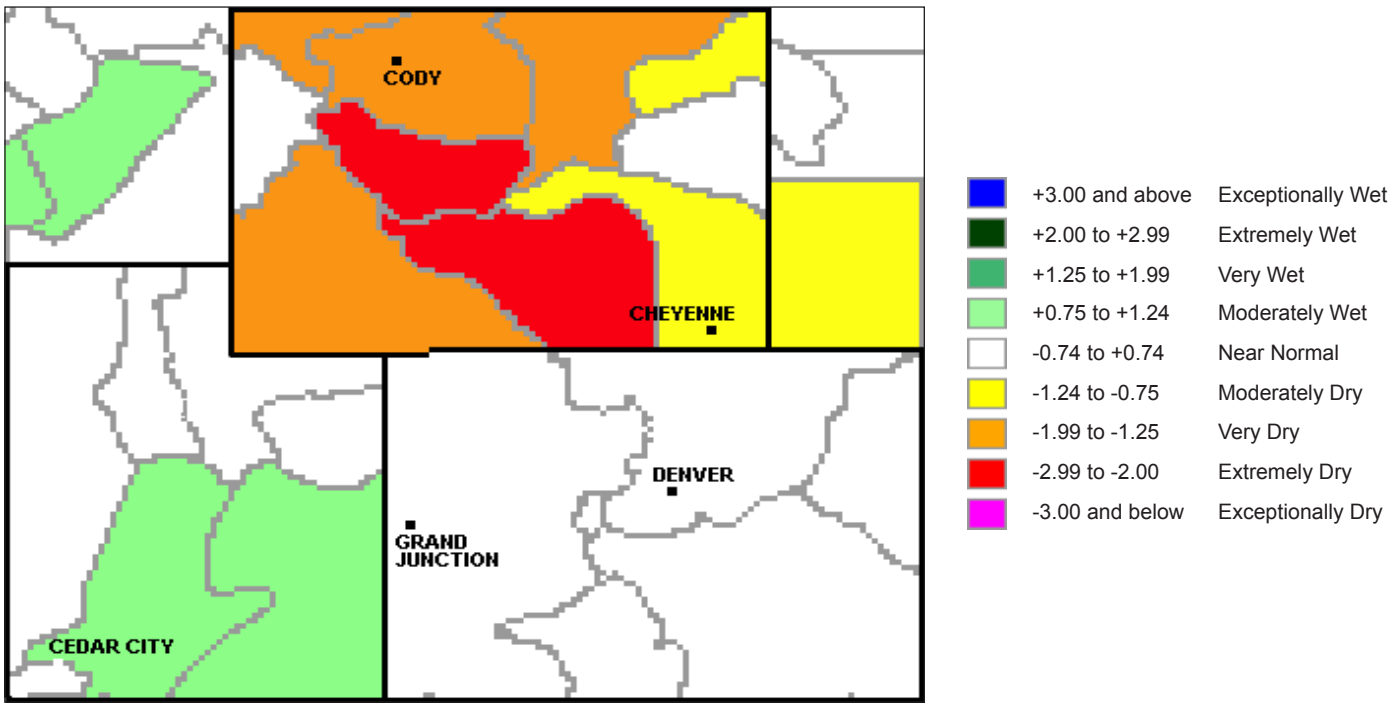

Figure 6. 12-month Intermountain West regional Standardized Precipitation Index. (data through 12/31/06)

On the Web

- For information on the SPI, how it is calculated, and other similar products for the entire country, visit http://www.wrcc.dri.edu/spi/spi.html.
- For information on past precipitation trends, visit: http://www.hprcc.unl.edu/products/current.html.

Colorado Water Availability

New maps of Colorado's SNOTEL SWE, with more detailed features, are available this month from the National Resources Conservation Service (NRCS) (Figure 7a). Snowpack conditions for the state are 96% of average. SWE percentages are highest in areas along the northern Continental Divide ranging from 100-160% of average (Figure 7a). The NWS reported 27 inches of snow accumulation for the Denver Metro area from the December 20-21 and December 28-30 storms, contributing to the 131% of average SWE for the South Platte basin for early January. Meanwhile, SWE percent of normal for the San Miguel, Dolores, Animas, and San Juan River Basins is 75% of average and the Upper Colorado Basin is 103% of average as of early January.

Despite high levels of snowfall in December in the Colorado Front Range, SWSI numbers for January are mostly in the near normal category across the state. SWSI numbers for individual basins have all decreased or remained the same since last month, with the exception of the South Platte and Arkansas River basins, and the Colorado River basin is the only one in the abundant supply category (Figure 7b). The Arkansas basin has the second highest SWSI (1.4), which is a great improvement over last year when that basin had below average snowfall all winter. On the other hand, the Yampa and White River basins did not benefit from high levels of snow in December. They have below average seasonal precipitation totals, and the January SWSI value of 0.4 fell from the 2.4 SWSI value on December 1st. Still, the first runoff forecasts for 2007 provided by the NRCS indicate that near average to above average spring and summer streamflow volumes are expected across most of the state, and the majority of the snow accumulation season still lies ahead (see page 22).

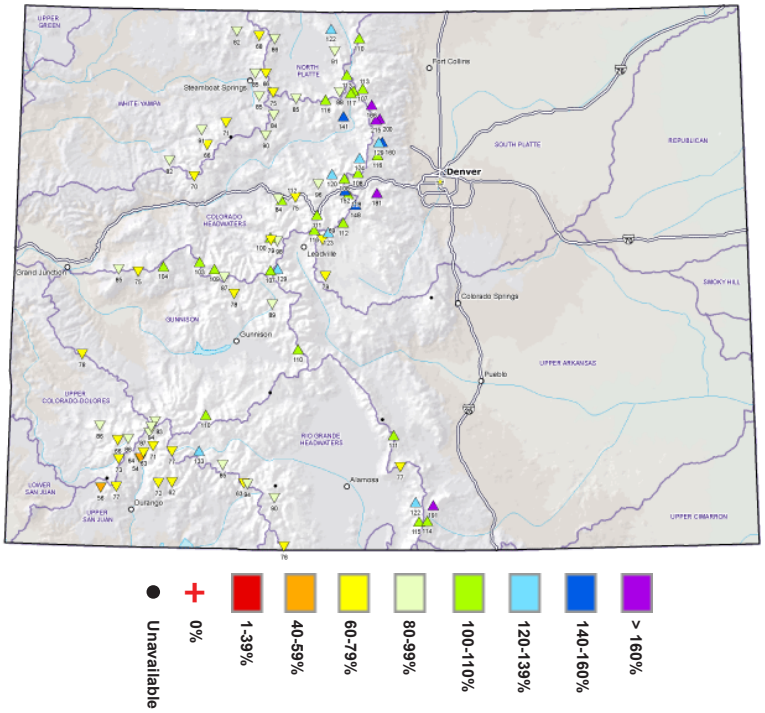

Figure 7a. Current snow water equivalent (SWE) as a percent of normal for SNOTEL sites in Colorado as of January 4, 2007, courtesy NRCS. For current SNOTEL data and plots of specific sites, see http://www.cbrfc.noaa.gov/snow/snow.cgi or http://www.wcc.nrcs.usda.gov/gis/

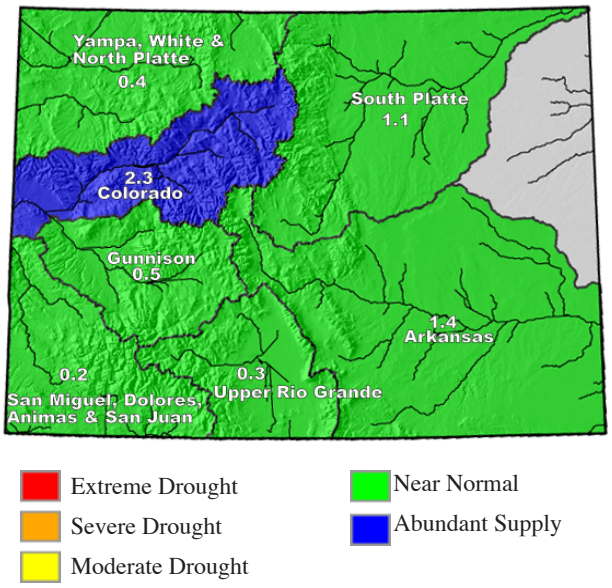

Figure 7b. Colorado Surface Water Supply Index. The map is an indicator of mountain-based water supply conditions in the major river basins of the state as of January 1, 2007, courtesy NRCS.

Notes

Figure 7a shows the SWE as a percent of normal (average) for SNOTEL sites in Colorado, courtesy of the Natural Resources Conservation Service (NRCS). The Surface Water Supply Index (SWSI- Figure 7b), developed by the Colorado Office of the State Engineer and the NRCS is used as an indicator of mountain-based water supply conditions in the major river basins of the state. The Colorado SWSI is based on snowpack, reservoir storage, and precipitation for the winter period (November-April). This differs from summer calculations that use streamflows as well. SWSI values in Figure b were computed for each of the seven major basins in Colorado on the first of each month, and reflect conditions through the end of the previous month.

On the Web

- Now available from the NRCS are new SWE as a percent of normal state maps like in Figure 7a available at: http://www.wcc.nrcs.usda.gov/gis/snow.html.
- For monthly reports on water supply conditions & forecasts for major CO river basins, visit: http://www.co.nrcs.usda.gov/snow/snow/snow_all.html and click on "Basin Outlook Reports."
- Information on regional weather forecasts and information, visit NWS Denver/Boulder Weather Forecast Office at http://www.crh.noaa.gov/bou/.
- The Colorado Water Availability Task Force is scheduled to meet mid-February. Information, including agenda & minutes of upcoming & previous meetings are available at: http://www.cwcb.state.co.us/Conservation/Drought/taskForceAgendaMinPres.htm.

Wyoming Water Availability

New maps of Wyoming's SNOTEL SWE, with more detailed features, are available this month from the National Resources Conservation Service (NRCS) (Figure 8a). The current SWE in Wyoming is below average in most basins. SWE values are highest in the southeast where they are at 100% – 139% of average. Overall, the rest of the state has below average snowpack levels. The western Upper Snake, Upper Bear, Big Sandy, and Lower Green River basins range from 60% – 99% of average. SWE values are lowest in the Big Horn and Powder River basins, ranging from 40% – 99 % of average, with a few stations with less than 40% of average SWE.

The Surface Water Supply Index (SWSI) values show similar pattern of spatial distribution to snowpack (Figure 8b). According to the state climatologist, Steve Gray, most of the recent storms bypassed the worst drought areas. The driest basins are the Wind and the Powder Rivers, which are in moderate to extreme drought. Other basins facing drought include the Big Sandy, Big Horn, Lower North Platte, and Upper Green. On the other hand, the Upper Snake, Shoshone, Upper North Platte and Laramie River basins are in the slightly wet category.

According to the latest Drought Status Update (not shown) released January 12, 2007 by Wyoming Water Resources Data System, a drought warning remains in effect for most of Wyoming, with the northeast section of the state designated as an area of potential significant deterioration. You can find more information about the Wyoming Drought Status at: http://www.wrds.uwyo.edu/wrds/wsc/dtf/drought.html.

Notes

Figure 8a, courtesy of NRCS, shows the SWE as a percent of average for each of the major river basins in Wyoming. According to the WY NRCS, "The Surface Water Supply Index" (SWSI – Figure 8b) is computed using only surface water supplies for each drainage basin. The computation includes reservoir storage, if applicable, plus the runoff forecast. The index is purposely created to resemble the Palmer Drought Index, with normal conditions centered near zero. Adequate and excessive supply has a positive number and deficit water supply has a negative value. The SWE does not use soil moisture and precipitation forecast, but the runoff forecast may include these values."

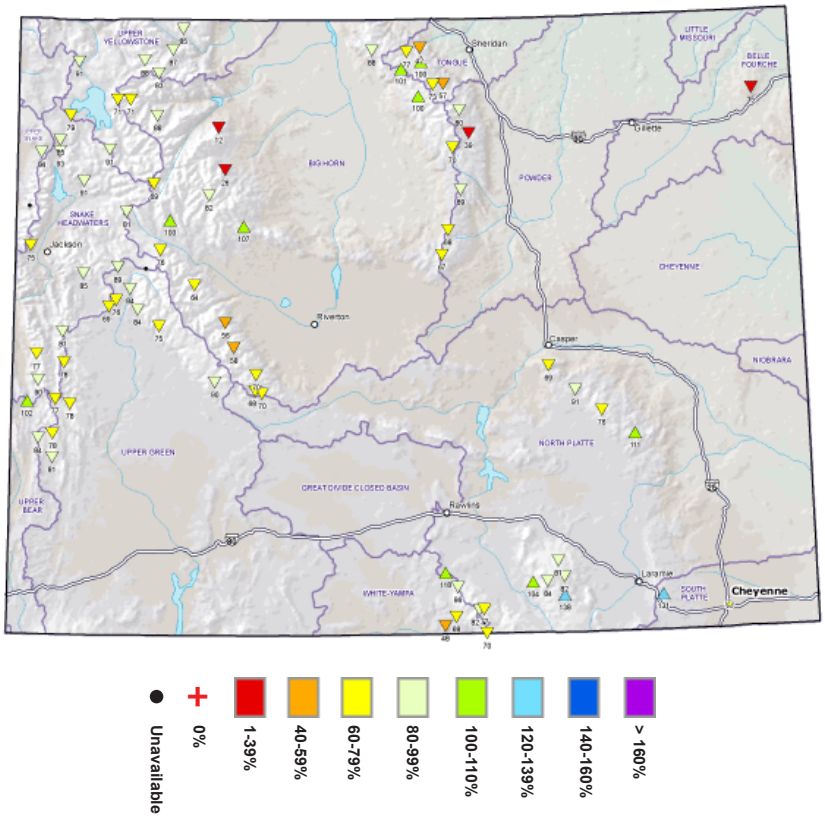

Figure 8a. Current snow water equivalent (SWE) as a percent of normal for SNOTEL sites in Wyoming as of January 4, 2007. This is provisional data. For current SNOTEL data and plots of specific sites, see http://www.wcc.nrcs.usda.gov/gis/snow.html

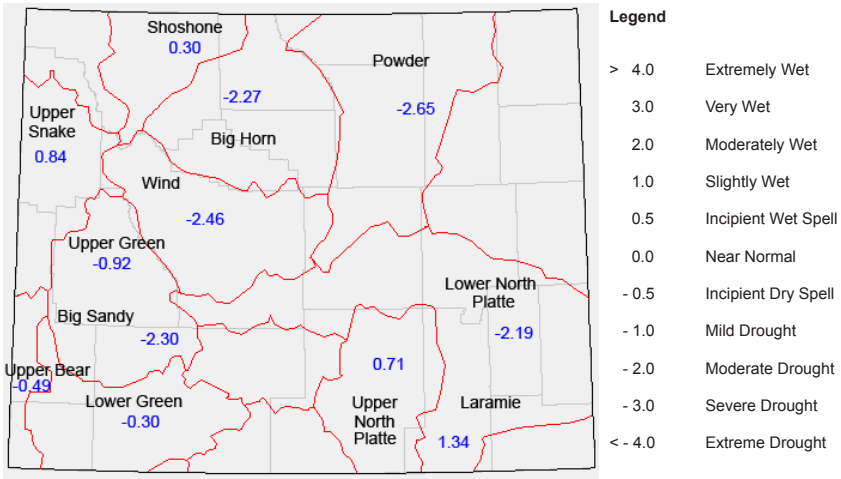

Figure 8b. Wyoming Surface Water Supply Index (data through 1/07/07) courtesy of USDA/NRCS

On the Web

- Information on current Wyoming snowpack, SWE, and SWSI, along with more data about current water supply status for the state, can be found at: http://www.wrds.uwyo.edu/wrds/nrcs/nrcs.html.
- The Palmer Drought Index is found on NOAA's drought page: http://www.drought.noaa.gov.
- Wyoming Water Resource Data system's drought page is located at: http://www.wrds.uwyo.edu/wrds/wsc/dtf/drought.html.

Utah Water Availability

New maps of Utah's SNOTEL SWE, courtesy of the Natural Resources Conservation Service (NRCS) are available this month, with more detailed features than the SWE graphics we used in the past (Figure 9a). The current SWE as a percent of average varies throughout the state of Utah as of January 4, 2007, but is below average over all. The northwestern basins have the highest SWE of 90 – 143% of average, while the northern, central, and southern basins are generally 40 – 80 % of average. Parts of the Weber, Provo and Sevier River basins, generally have from 40% - 80 % of average SWE. This snowfall pattern differs from last year, when northern and central Utah SNOTEL sites had the highest SWE, with many sites reporting from 140 - 160 % of average.

The Utah Surface Water Supply Index (SWSI) shows a similar pattern to the SNOTEL sites, with more water available in the northwest and central mountains and less at the northern sites. In general, with the exception of the Bear and Weber Rivers in the north and the Beaver in the south, all Utah basins are at or above average SWSI. The West Uintah, Upper Sevier, and Provo River basins have the highest SWSI values, with West Uintah at 2.83. The north central Bear and Weber River basins are below average, with the Bear basin the lowest with SWSI values at -2.26 (Figure 9b).

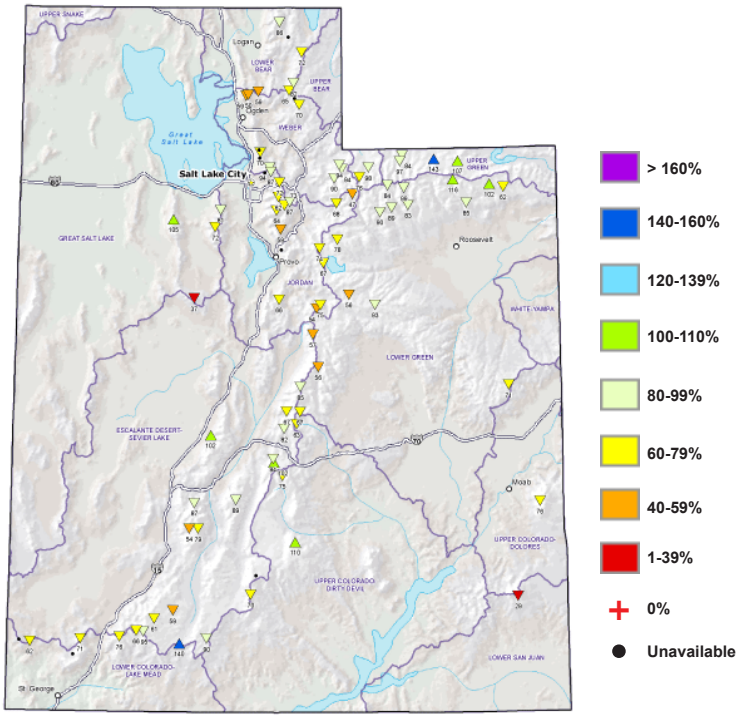

Figure 9a. Current snow water equivalent (SWE) as a percent of normal for SNOTEL sites in Utah as of December 31, 2006. This is provisional data and is provided by USDA/NRCS National Water and Climate Center. For current SNOTEL data and plots of specific sites, see http://www.cbrfc.noaa.gov/snow/snow.cgi or http://www.wcc.nrcs.usda.gov/gis/

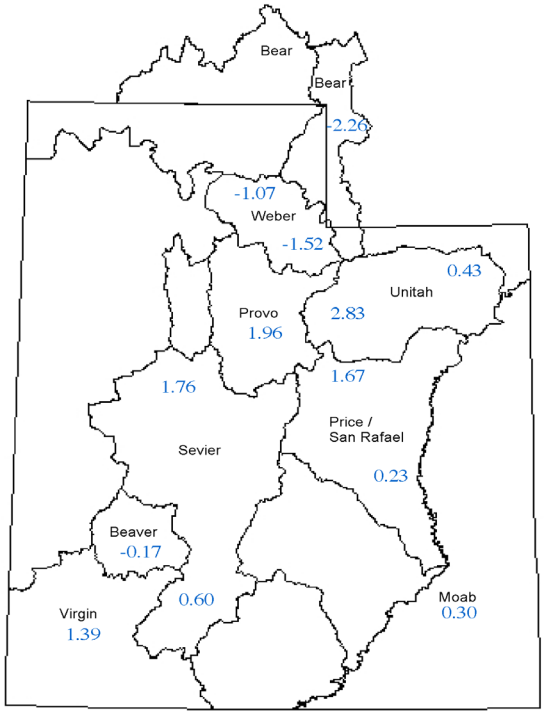

Figure 9b. Utah Surface Water Supply Index (data through 1/1/07). Maps are courtesy of Utah NRCS.

Notes

Figure 9a shows the SWE as a percent of normal (average) for SNOTEL sites in Utah. According to the UT NRCS, "The Surface Water Supply Index (SWSI - Figure 9b) is a predictive indicator of total surface water availability within a watershed for the spring and summer water use seasons. The index is calculated by combining pre-runoff reservoir storage (carryover) with forecasts of spring and summer streamflow, which are based on current Snowpack and other hydrologic variables. SWSI values are scaled from +4.1 (abundant supply) to -4.1 (extremely dry) with a value of zero (0) indicating median water supply as compared to historical analysis. SWSI's are calculated in this fashion to be consistent with other hydroclimatic indicators such as the Palmer Drought Index and the [Standardized] Precipitation Index." See page 13 for the SPI.

On the Web

- For current maps of SWE as a percent of normal as shown in Figure 9a, go to http://wcc.nrcs.usda.gov/gis/.
- The Utah SWSI, along with more data about current water supply status for the state, can be found at: http://www.ut.nrcs.usda.gov/snow/watersupply/.
- The Palmer Drought Index is found on NOAA's drought page: www.drought.noaa.gov.

Temperature Outlook February - June 2007

According to the NOAA/CPC, the ongoing El Niño event is expected to continue through the winter and diminish in the late spring. El Niño is a factor for the temperature forecasts for the next few months because, even with some weakening, its effects on the atmosphere are climatologically stronger and more reliable in late winter than at any other time of year. While the long-lead national temperature forecasts for the western U.S. are often dominated by warming trends; this trend is expected to be counteracted by the projected cooling effects of El Nino in the southern tier of the U.S. Thus, the southwestern and southern U.S. are likely to have temperatures in the average range between February and April, including parts of **Colorado** and **Utah** (Figures 10a-b).

The one-month outlook for February projects a increase in the chance for warmer than average temperatures in most of **Wyoming** (Figure 10a). The outlooks for subsequent 3-month forecast periods project an increased chance for above average temperatures for larger areas of the IMW region (Figures 10b-c). The April-June forecast period (Figure 10d) has the highest shift in probabilities towards above average temperatures, with a 50% for upper tercile temperatures in southwestern **Utah**.

An updated February 2007 temperature forecast will be available on January 31st, on the CPC web page. Because of the shorter lead time, the updated monthly forecast maps often have increased skill over the half-month lead forecasts.

Notes

The seasonal temperature outlooks in Figures 10a-d predict the likelihood (chance) of above-average, near-average, and below-average temperature. The numbers on the maps refer to the percent chance that temperatures will be in one of these three categories, they do not refer to actual temperature values.

The NOAA-CPC outlooks are a 3-category forecast based largely on the status of El Niño and recent trends. As a starting point, the 1971-2000 climate record for each particular 1 or 3 month period is divided into 3 categories or terciles, each with a 33.3 % chance of occurring. The middle tercile is considered the near-average (or normal) temperature range. The forecast indicates the likelihood of the temperature being in one of the warmer or cooler terciles--above-average (A) or below-average (B)--with a corresponding adjustment to the opposite category; the near-average category is preserved at 33.3% likelihood, unless the anomaly forecast probability is very high. For a detailed description of how this works, see notes on the following page.

Equal Chances (EC) indicates areas for which the models cannot predict the temperature with any confidence. EC is used as a "default option" representing equal chances or a 33.3% probability for each tercile, indicating areas where the reliability (i.e., 'skill') of the forecast is poor.

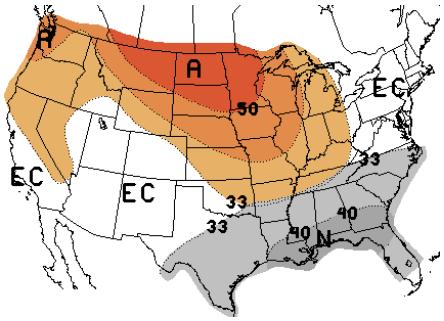

Figure 10a. Long-lead national temperature forecast for February 2007. (released January 18, 2007)

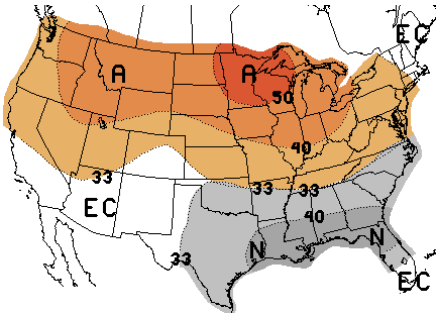

Figure 10b. Long-lead national temperature forecast for February – April 2007. (released January 18, 2007)

A = Above
- 60.0–69.9%
- 50.0–59.9%
- 40.0–49.9%
- 33.3–39.9%

B = Below
- 40.0–49.9%
- 33.3–39.9%

EC = Equal Chances

N = Normal (Gray Colors)

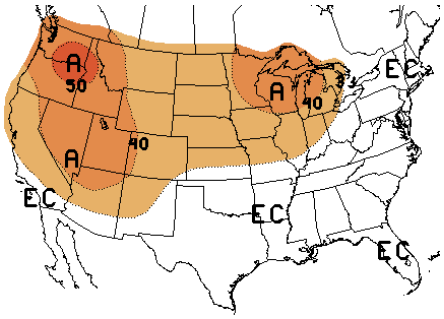

Figure 10c. Long-lead national temperature forecast for March – May 2007. (released January 18, 2007)

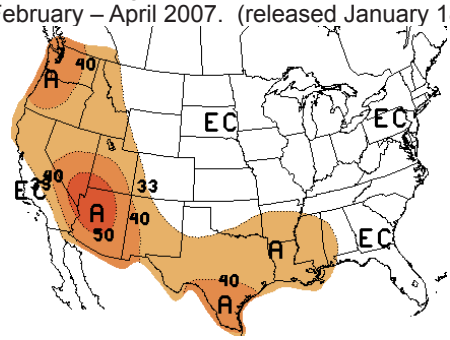

Figure 10d. Long-lead national temperature forecast for April – June 2007. (released January 18, 2007)

On the Web

- For more information and the most recent forecast images, visit: http://www.cpc.ncep.noaa.gov/products/predictions/multi_season/13_seasonal_outlooks/color/churchill.html. Please note that this website has many graphics and may load slowly on your computer.
- The CPC "discussion for non-technical users" is at: http://www.cpc.noaa.gov/products/predictions/90day/fxus05.html
- For IRI forecasts, visit: http://iri.columbia.edu/climate/forecast/net_asmt/.
- More information about temperature distributions at specific stations in Colorado, Utah, Wyoming, and across the West can be found at the Western Regional Climate Center, http://www.wrcc.dri.edu/CLIMATEDATA.html.

Precipitation Outlook February - June 2007

According to the NOAA/CPC, the ongoing El Niño event is expected to continue through the winter and diminish in the late spring. El Niño is a factor in the precipitation forecasts for the next few months because, even with some weakening, its effects on the atmosphere are climatologically stronger and more reliable in late winter than at any other time of year. The typical El Niño winter precipitation signal favors below average precipitation in the Pacific Northwest, which may include northern **Utah** and **Wyoming** and above average precipitation in the southwest, which may include parts of **Colorado** and **Utah**. The CPC monthly and seasonal forecasts issued January 18th are based on models and precipitation composites from weak and moderate El Niño events, and weak trends towards above median precipitation in the Pacific northwest and parts of the Great Basin (including **Utah**) in the early summer (May-July 2007, not shown).

In February, most of **Wyoming** has an increased risk of below average precipitation; this risk continues for the February-April forecast period for western **Wyoming**. Consistent with El Niño composites, there is an enhanced risk for above average precipitation across the southern U.S in the February-May forecast period, due to an enhanced southern jet stream associated with El Niño. This region includes the southern half of **Utah** and **Colorado** in February-April and most of **Colorado** in March-May.

An updated February 2007 precipitation forecast for February 2007 will be available on January 31st, on the CPC web page. Because of the shorter lead time, the updated monthly forecast maps often have increased skill over the half-month lead forecasts.

Notes

The seasonal precipitation outlooks in Figures 11a-d predict the likelihood (chance) of above-average, near-average, and below-average precipitation. The numbers on the maps refer to the percent chance that precipitation will be in one of these three categories, they do not refer to inches of precipitation.

The NOAA-CPC outlooks are a 3-category forecast based largely on the status of El Niño and recent trends. As a starting point, the 1971-2000 climate record for each particular 1 or 3 month period is divided into 3 categories or terciles, each with a 33.3% chance of occurring. The middle tercile is considered the near-average (or normal) precipitation range. The forecast indicates the likelihood of the precipitation being in one of the wetter or drier terciles--above-average (A) or below-average (B)--with a corresponding adjustment to the opposite category; the near-average category is preserved at 33.3% likelihood, unless the anomaly forecast probability is very high.

Thus, using the NOAA-CPC precipitation outlook, areas with light brown shading display a 33.3-39.9% chance of below-average, a 33.3% chance of near-average, and a 26.7-33.3% chance of below-average precipitation. A darker brown shade indicates a 40.0-50.0% chance of below-average, a 33.3% chance of near-average, and a 16.7-26.6% chance of below-average precipitation, and so on. Correspondingly, green shades are indicated for areas with a greater chances of above average precipitation.

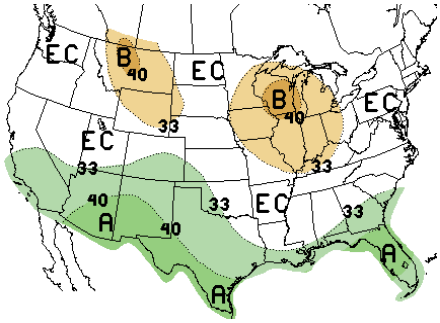

Figure 11a. Long-lead national precipitation forecast for February 2007. (released January 18, 2007)

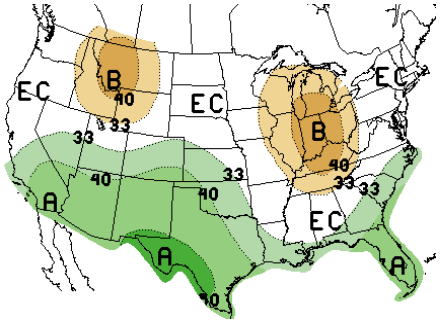

Figure 11b. Long-lead national precipitation forecast for February – April 2007. (released January 18, 2007)

A = Above
- 40.0–49.9%
- 33.3–39.9%

B = Below
- 40.0–49.9%
- 33.3–39.9%

EC = Equal Chances

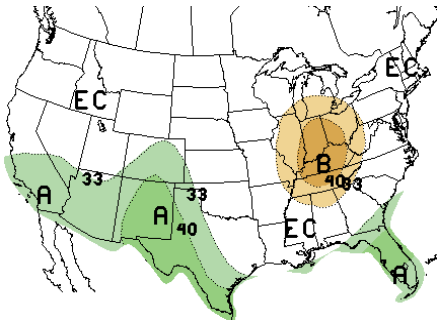

Figure 11c. Long-lead national precipitation forecast for March – May 2007. (released January 18, 2007)

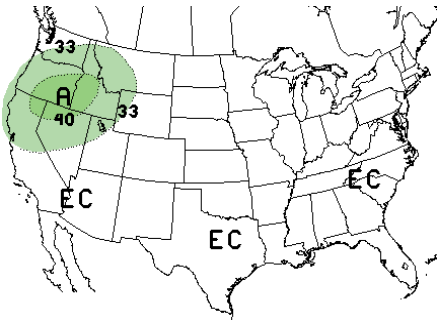

Figure 11d. Long-lead national precipitation forecast for April – June 2007. (released January 18, 2007)

On the Web

- For more information and the most recent CPC forecast images, visit: http://www.cpc.ncep.noaa.gov/products/predictions/multi_season/13_seasonal_outlooks/color/churchill.html. Please note that this website has many graphics and may load slowly on your computer.
- The CPC "discussion for non-technical users" is at: http://www.cpc.noaa.gov/products/predictions/90day/fxus05.html
- For IRI forecasts, visit: http://iri.columbia.edu/climate/forecast/net_asmt/.
- More information about temperature distributions at specific stations in Colorado, Utah, Wyoming, and across the West can be found at the Western Regional Climate Center, http://www.wrcc.dri.edu/CLIMATEDATA.html

Precipitation Outlook cont.

According to the Experimental Forecast Guidance for the Interior Southwest, while moderate El Niño conditions have developed over the course of fall 2006, they appear to be fading fast since December. Unusually heavy snow storms have dropped excessive moisture over the eastern plains of Colorado and northern New Mexico, while Utah and Arizona have remained mostly dry.

The updated guidance for January-March 2007 indicates a shift in the odds for wet conditions of 20% or more for Arizona, most of New Mexico, southern Utah, as well as western and most of southern Colorado (Figure 11e). Dry conditions are favored for northern Utah and northeastern Colorado. According to Klaus Wolter, who creates this forecast, while much of this forecast pattern is consistent with El Niño, the wetness in Colorado's north-central mountains, as well as dryness on our northeastern plains is not typical, although not unprecedented.

While El Niño tends to be unfavorable for Colorado's mid-winter snow pack, the forecast for JFM forecast continues to project late winter snows in contrast to typical dry El Nino conditions in the northern and central mountains of Colorado. Through early February, Wolter thinks that there will be a southward shift in the storm track, favoring precipitation in Arizona and New Mexico as would be typical during El Niño winters, but also expects continued cold temperatures over much of the domain. However, forecasters are concerned that after early February, rapidly fading El Niño conditions may negate the expected beneficial moisture to much of the southwestern U.S. during the first half of 2007.

The updated outlook into the spring season (April-June; not shown) is not as optimistic as last month's version, but continues with a shift in the odds for wet conditions over all but southern New Mexico and from northwest Colorado into central Utah. The final forecast discussion and the new forecast for April-May-June 2007 will be available on the SouthwestCast webpage on January 26th.

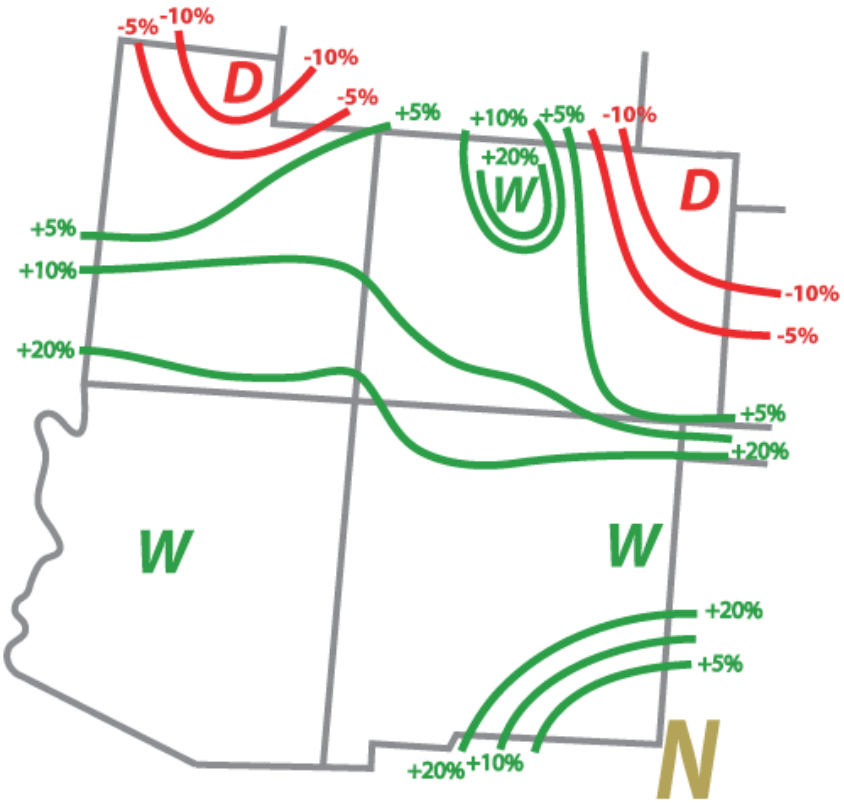

Figure 11e. Experimental guidance for seasonal precipitation in the southwest for January - March. (issued January 22, 2006)

Notes

The experimental guidance for seasonal future precipitation in Figure 11e shows most recent forecast of shifts in tercile probabilities for July - September 2006. In order to be shown on this map, a forecast tilt in the odds has to reach at least 3% either towards wet (above-average), dry (below-average), or near-normal (average). Shifts towards the wettest (driest) tercile are indicated in green (red), and are contoured in 5% increments, while near-normal tilts of at least 3% are indicated by the letter "N". Shifts over 10% considered significant. Positive (negative) shifts between three and five percent are indicated by a green (red) plus (minus) sign, while minor shifts of one or two percent are left blank in this display.

On the Web

- The CDC experimental guidance product, including a discussion and executive summary, is available on the web at: http://www.cdc.noaa.gov/people/klaus.wolter/SWcasts/index.html.

Seasonal Drought Outlook through February 2007

Source: NOAA Climate Prediction Center

The Seasonal Drought Outlook issued by the NOAA Climate Prediction Center depicts general, large-scale trends for about a 3-month period, and is developed by experts based on their subjective judgement of various forecasts. The latest outlook (Figure 12) is for conditions through April 2007. Drought is expected to persist during this period across **Wyoming** due to long range forecasts of below average precipitation and above average (Figures 10,11). Drought conditions are expected to intensify in western, while there may be some improvement in the eastern portion.

On the other hand, the green areas over northeastern **Colorado** and eastern Nebraska indicate expected improvement of one category as classified in the U.S. Drought Monitor through April 2007. These areas currently range from DO to D3 on the Drought Monitor (Figure 4).

Notes

The delineated areas in the Seasonal Drought Outlook (Figure 12) are defined subjectively and are based on expert assessment of numerous indicators, including outputs of short- and long-term forecasting models. "Ongoing" drought areas are schematically approximated from the Drought Monitor (D1 to D4). For weekly drought updates, see the latest Drought Monitor text on the website: http://www.drought.unl.edu/dm/monitor.html. NOTE: The green improvement areas imply at least a 1-category improvement in the Drought Monitor intensity levels, but do not necessarily imply drought elimination.

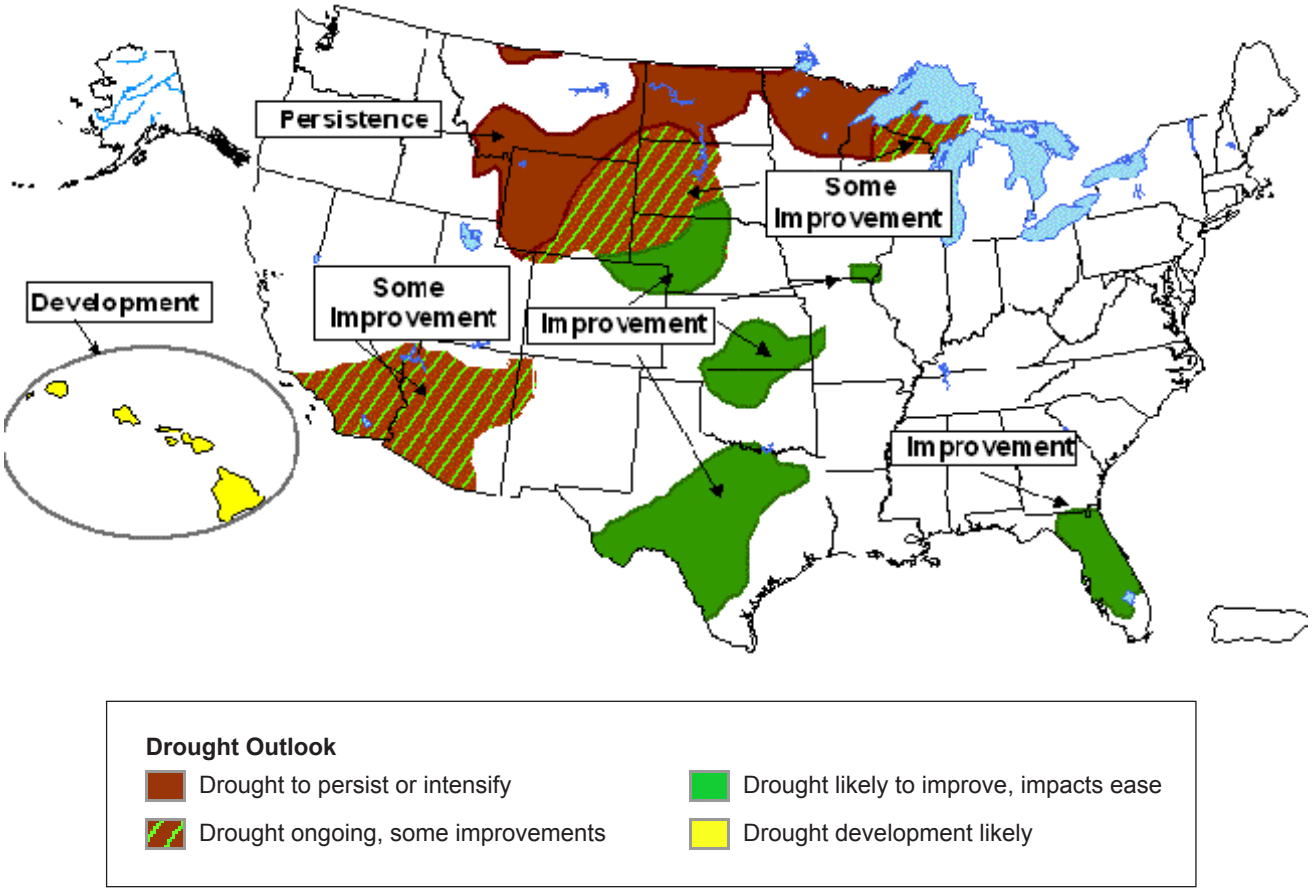

Figure 12. Seasonal Drought Outlook through April 2007 (release date January 18, 2007).

On the Web

- For more information, visit: http://www.drought.noaa.gov/.
- Drought termination probabilities: http://www.ncdc.noaa.gov/oa/climate/research/drought/current.html

El Niño Status and Forecast through April 2007

According to both the NOAA/CPC and the IRI, El Niño conditions are likely to continue through the March-May 2007 season. However, there are signs that the event is weakening: equatorial sea surface temperature (SST) anomalies are greater than 1ºC across the central and eastern Pacific (Figure 13a), but these departures are smaller than last month, and the peak magnitude of the anomalies appears to have passed. The latest consensus forecast from CPC for SST anomalies indicates a slightly earlier weakening of El Niño conditions than was forecast last month. There is considerable uncertainty about the future of the current event. Its strength and persistence will depend on whether and how tropical atmospheric wave activity in the western pacific (known as the Madden-Julien Oscillation, or MJO) affects wind anomalies and thus the maintenance or weakening of El Niño. For a primer on the MJO and its effects, see http://www.cdc.noaa.gov/MJO/MJOprimer/

In summary, CPC predicts that sea surface conditions in this region will continue to decrease, but stay above average in the Nino 3.4 region until the spring or summer (Figure 13b). The models all agree that El Niño is decreasing, but they do not agree about the rate at which the sea surface temperatures will return to average. Therefore, forecasters at the NOAA/CPC predict that a weak or moderate Eli Niño will continue to influence the climate of the U.S. for the next few months, but this influence is not expected to be significant past the late spring of 2007 (See pages 17 - 19 for climate forecasts.)

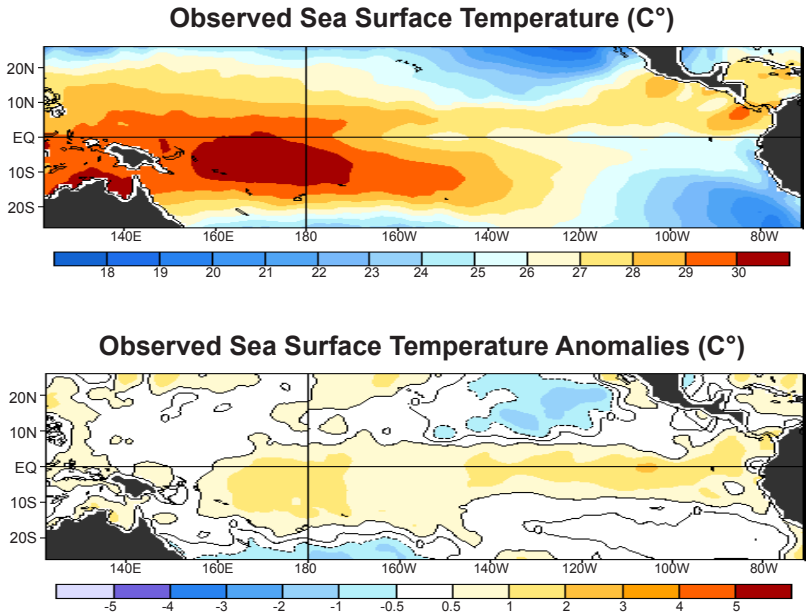

Figure 13a. Observed SST (upper) and the observed SST anomalies (lower) in the Pacific Ocean. The Niño 3.4 region encompasses the area between 120ºW-170ºW and 5ºN-5ºS. The graphics represent the 7-day average centered on January 10, 2007.

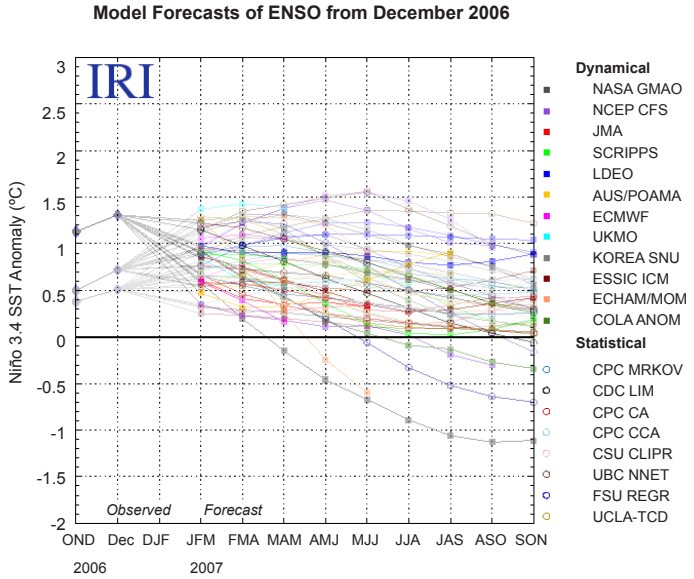

Figure 13b. Forecasts made by dynamical and statistical models for sea surface temperatures (SST) in the Niño 3.4 region for nine overlapping 3-month periods from January through November 2007 (released January 18, 2007). Forecast graphic is from the International Research Institute (IRI) for Climate and Society.

Notes

Two graphics in Figure 13a produced by NOAA show the observed SST (upper) and the observed SST anomalies (lower) in the Pacific Ocean. This data is from the TOGA/TAO Array of 70 moored buoys spread out over the Pacific Ocean, centered on the equator. These buoys measure temperature, currents and winds in the Pacific equatorial band and transmit data in real-time. NOAA uses these observations to predict short-term (a few months to one year) climate variations.

Figure 13b shows multiple forecasts for SST in the Niño 3.4 region for nine overlapping 3-month periods from September 2005 to July 2006. "Niño 3.4" refers to the region of the equatorial Pacific from 120ºW to 170oW and 5ºN to 5oS, which is one basis for defining ENSO sea surface temperature anomalies. Initials at the bottom of the graph represent groups of three months (e.g. SON = Sept-Nov). The expected skills of the models, based on historical performance, are not equal to one another. The skills also generally decrease as the lead-time increases. Forecasts made at some times of the year generally have higher skill than forecasts made at other times of the year. They are better when made between June and December than between February and May. Differences among the forecasts of the models reflect both differences in model design and actual uncertainty in the forecast of the possible future SST scenario.

On the Web

- For a technical discussion of current El Nino conditions, visit: http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/enso_advisory/.
- For updated graphics of SST and SST anomalies, visit this site and click on "Weekly SST Anomalies": http://www.cpc.ncep.noaa.gov/products/precip/CWlink/MJO/enso.shtml#current.
- For more information about El Nino, including the most recent forecasts, visit: http://iri.columbia.edu/climate/ENSO/.

Spring and Summer Streamflow Forecasts for the 2007 runoff Season

The spring and summer streamflow forecasts are varied across the Intermountain West region as of January 1, 2007 (Figure 14). The highest streamflows (110% - 150% of average) are expected to be in the Arkansas and Upper South Platte Rivers in southeastern and central **Colorado**. The lowest projected streamflows (<50% of average) are in the Belle Fouche and Little Powder River basins in northeastern **Wyoming** and the Dolores River Basin in southeastern **Utah**/southwestern **Colorado**. The rest of the region is projected to have between 70% and 109% of average streamflows.

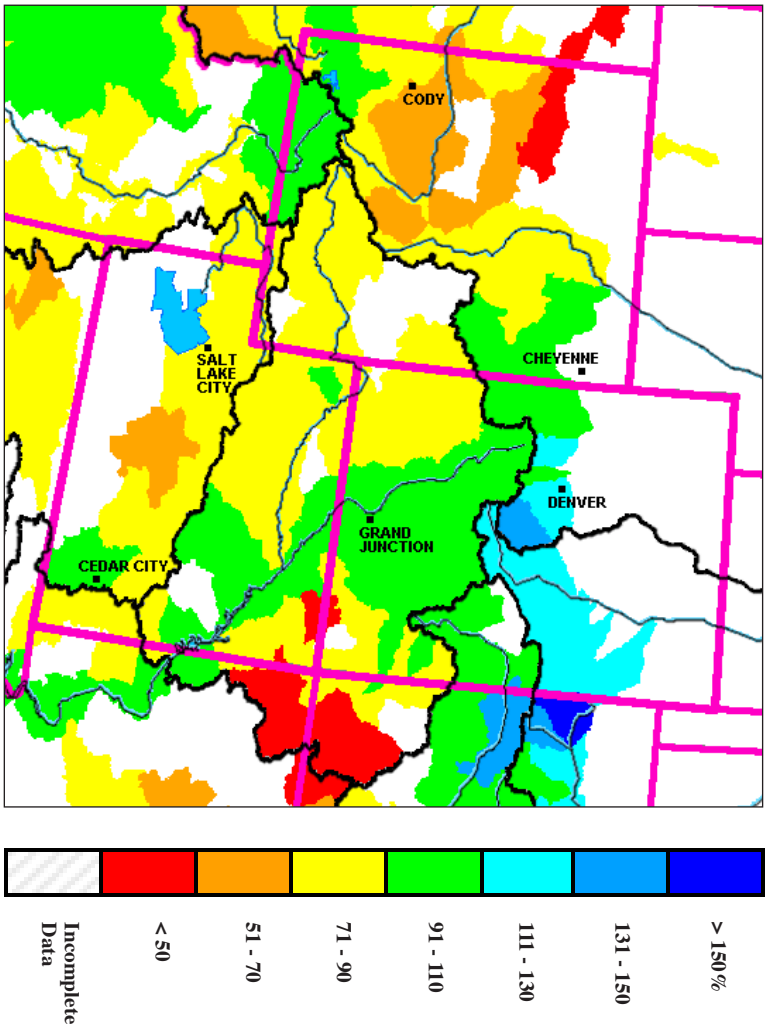

Figure 14. NRCS outlook for natural streamflows for spring and summer in the Intermountain West region as a percent of average streamflows. (data through January 1, 2007 courtesy of Natural Resources Conservation Service)

Notes

This page provides the NRCS spring and summer streamflow forecasts for the entire Intermountain West region. The official NOAA streamflow forecasts are developed by individual river basin forecast centers. (See 'On the Web' box below for links to the official NOAA forecasts.)

Forecasts of natural runoff are based principally on measurements of precipitation, snow water equivalent, and antecedent runoff, influenced by precipitation in the fall before winter snowfall (Figure 14). Forecasts become more accurate as more of the data affecting runoff are measured (i.e. accuracy increases from January to May). In addition, these forecasts assume that climatic factors during the remainder of the snow accumulation and melt season will have an average affect on runoff. Early season forecasts are, therefore, subject to a greater change than those made on later dates.

On the Web

For more information about NRCS water supply forecasts based on snow accumulation and access to the graph on this page, visit: http://www.wcc.nrcs.usda.gov/wsf/.

The official NOAA streamflow forecasts are available through the following websites of individual River Forecast Centers:

- Colorado Basin (includes Great Basin): http://www.cbrfc.noaa.gov/
- Missouri Basin (includes South Platte and North Plate: http://www.crh.noaa.gov/mbrfc/
- West Gulf (includes Rio Grande): http://www.srh.noaa.gov/wgrfc/
- Arkansas Basin: http://www.srh.noaa.gov/abrfc/

Assessing Water Supply Conditions for Utah

Brian McInerney, NWS Salt Lake City Weather Forecast Office and Christina Alvord, Western Water Assessment

Introduction

The timing and volume of spring runoff determines the annual water supply in Utah and surrounding Intermountain West states. Because water supply estimates are important for water managers' annual planning, the National Weather Service (NWS) develops forecasts of water supply, based on hydrologic, climate, and geomorphic parameters. This article describes how the Salt Lake Weather Service Forecast Office (WFO) in conjunction with the Colorado Basin River Forecast Center (CBRFC) forecasts spring snowmelt runoff and resulting water supply conditions as they adjust throughout the course of a water year. The Salt Lake WFO disseminates the information to water managers, and federal, state and local agencies.

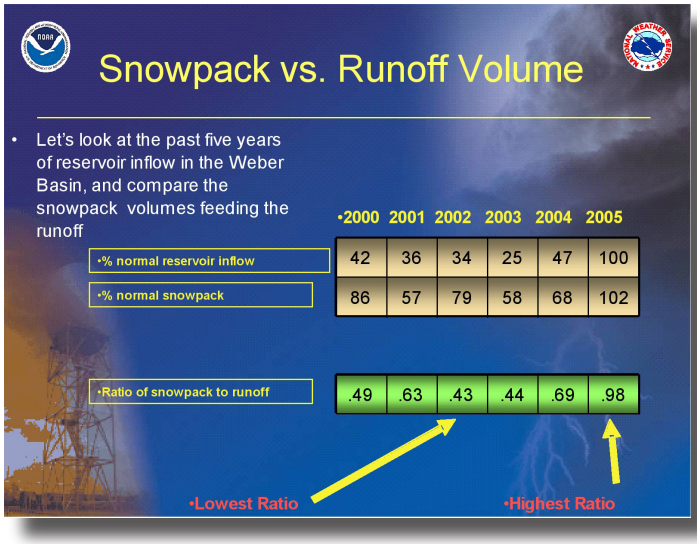

Figure 15a: Snowpack runoff ratio is a function of percent of reservoir inflow over percent of normal snowpack. As an example, the 2002 snowpack recorded 79% of average snowpack, but only yielded 34% of the expected streamflow into basin reservoirs, resulting in a snowpack runoff ratio of 43%.

Autumn

The first hydrologic parameters that forecasters use to assess water supply conditions are the amount of autumn rainfall, resulting soil moisture, and groundwater conditions for the months of September, October, and parts of November. During the autumn months widespread, low intensity/long duration rainfall events can saturate soil levels 24 inches deep, but a persistent high-pressure ridge can block storm activity. The Utah Natural Resources Conservation Service (NRCS) recently began tracking soil moisture at various Snotel sites across the state (Figure 15a).

Groundwater conditions are also monitored during the fall months. Groundwater is the water that sits beneath the surface (between 24 inches and 500 feet) in porous rock formations called aquifers. The USGS records groundwater levels late fall and makes comparisons to past years. If the ground water levels are lower than normal, the NWS anticipates that a greater portion of the spring runoff will infiltrate through the soil layer to recharge groundwater levels instead of flowing over the ground to rivers and reservoirs. Autumn soil moisture and groundwater are only the first pieces of the water supply puzzle.

Winter

The second aspect of water supply is determined in part by the accumulation of snow during the months of December, January, February, and March. Snow accumulation during the winter months is critical because if statewide percent of normal snowpack levels are below 60% by January 1st, the probability of reaching average snowpack by April 1st is slim.

Presence and strength of El Nino is an important indicator of amount and location of precipitation deposition in Utah, and is the main water supply component evaluated during the winter. During moderate to strong El Nino episodes, storms tracking from the Southwest bring warmer than normal temperatures and above average precipitation to the southern half of Utah. In non-El Nino years, storms tend to track towards the Pacific Northwest region of the U.S., away from Utah.

Spring

Snowpack conditions, temperature, rate of snowmelt, and amount and aerial extent of precipitation in April, May and June are the final components of the water supply equation. Snowpack levels entering into the spring months are largely indicative of water supply conditions during this time, however, rate and behavior of snowmelt is also important. A common misconception is that 100% of the total snowpack on April 1st will produce 100% streamflow volumes in May and June. This is not necessarily true every year (Figure 15a). Snowpack to runoff ratios are largely influenced by spring weather conditions. For example, as a result of a cool wet spring, snowmelt enters surface water systems in a shorter time frame, which enhances total snowmelt volume.

A cool, wet spring preserves snowpack conditions until the warm temperatures in May and June melts the snowpack all at once, yielding higher streamflow volumes. In comparison, a warm dry spring lengthens the period of snowmelt, promot-

ing greater evaporation, seepage, and transpiration over an extended period of time. Water supply conditions are based on multiple physical parameters to the extent that a dry and hot spring could threaten water supplies even if snowpack conditions are above average.

Measurement of the above parameters is necessary to accurately forecast spring snowmelt runoff and resulting water supply conditions. As we are in early January, water supply conditions are still uncertain at this time. We must wait until the physical parameters of snow collection evolve, then as we move into spring, snowmelt runoff forecasts will once again be adjusted based on spring weather and snowpack conditions. Snowmelt runoff volume forecasts are issued by the CBRFC and graphical versions are generated by the Salt Lake WFO for use by Utah water managers about every month. (Figure 15b, c). You can see Salt Lake WFO monthly forecasts at http://www.wrh.noaa.gov/slc/river/presentations. CBRFC forecasts are available January-June at: http://www.cbrfc.noaa.gov/wsup/wsup.cgi.

Sources

National Weather Service Forecast Office, Salt Lake City, UT: http://www.wrh.noaa.gov/slc/

CBRFC: http://www.cbrfc.noaa.gov/wsup/wsup.cgi

NRCS: Climate Information, including soil moisture charts and the Utah Soil Moisture Update Report: http://www.ut.nrcs.usda.gov/snow/data/monthly/Soil%20Moisture%20Charts.pdf

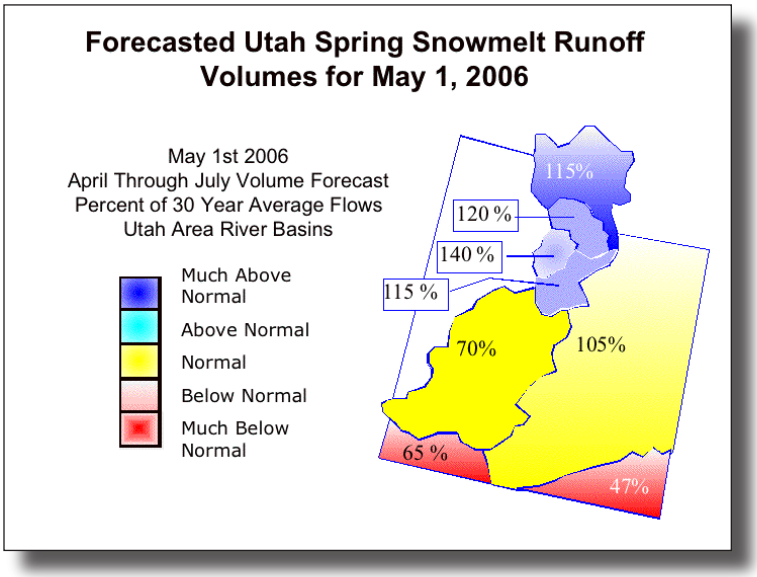

Figure 15b: Graphic example of statewide snowmelt runoff volume forecasts for May 1, 2006 generated by the Salt Lake WFO.

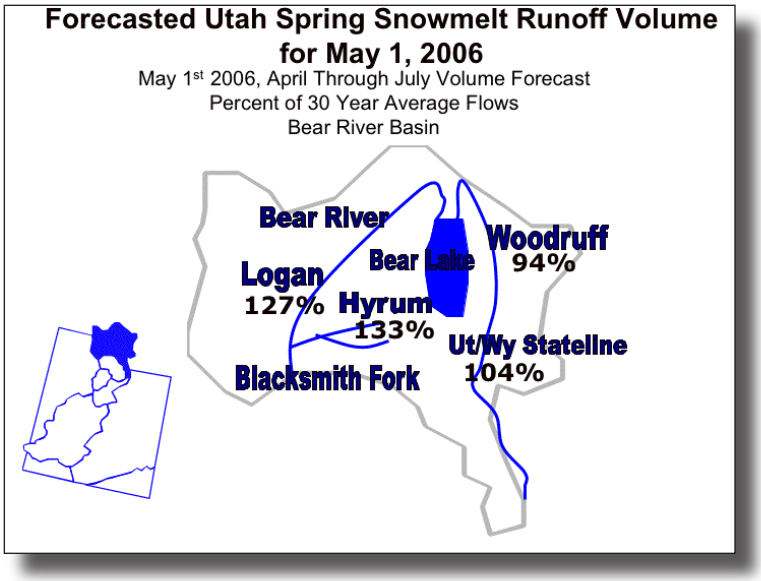

Figure 15c: Snowmelt runoff volume forecasts for the Bear River Basin in Northern Utah for May 1, 2006. These snowmelt volume forecasts are presented at monthly water supply meetings at the WFO office in Salt Lake City.

On the Web

- Salt Lake WFO monthly water supply outlook presentations are available at: http://www.wrh.noaa.gov/slc/river/presentations.
- For CBRFC forecasts visit: http://www.cbrfc.noaa.gov/wsup/wsup.cgi.
- Additional information about the Salt Lake WFO is available at: http://www.wrh.noaa.gov/slc/, or contact Brian Mc McInerney at brian.mcinerney@noaa.gov.