Intermountain West Climate Summary

by The Western Water Assessment

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May 2007 Climate Summary

Hydrological Conditions – Drought is expected to persist over Utah, western Colorado, and western Wyoming, but there has been some decrease in drought status in northern and eastern Wyoming. Streamflow forecasts continue to be below average for the region, except east of the Continental Divide in Colorado.

Temperature – Temperatures were above average around most of the region in April, except eastern Colorado, which had below average temperatures.

Precipitation/Snowpack – Precipitation was below average around most of the region in April, except parts of eastern Colorado and southern Utah, which received above average precipitation. Seasonal snowpack is below average, except in the South Platte Basin, and has begun melting early in many areas due to warm weather.

ENSO – ENSO-neutral conditions prevail in the Pacific, and there is about a 55% chance of La Niña conditions developing by the fall (Sep-Nov 2007).

Climate Forecasts – La Niña or El Niño are not a factor in climate forecasts for the region for the impacts during the June-August 2007 season; La Niña may influence the fall.

New WWA Website: A Paleo Perspective on Colorado River Streamflow

http://wwa.colorado.edu/resources/paleo/lees/

Until recently, the primary source of information on variability in Colorado River streamflows was the gauged records, which are about 100 years long at most. But the recent drought, with unprecedented low flows at many gauges in the Colorado River basin, has called into question whether the gauged record is an adequate baseline for water planning. In this website, Colorado River Streamflow: A Paleo Perspective, the authors (Jeff Lukas and Connie Woodhouse) assess the gauged record of Colorado River streamflow in the context of multi-century flow reconstructions from tree rings. They describe the Colorado River system and its management, then the century-long gauged record of flow, and then the use of tree rings to extend, or reconstruct, the gauged record 400 years or more into the past, providing a more complete picture of past flow variability. They then take a closer look at the most recent streamflow reconstructions for Lees Ferry, and how they compare with previous reconstructions.

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Recent Conditions

Forecasts

On the Web: http://wwa.colorado.edu

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Recent Research on the Effects of Climate Change on the Colorado River

By Brad Udall of Western Water Assessment

Water managers in the seven Colorado River Basin states cannot adequately plan for a future of increased climate variability and change unless they can anticipate how future climate will affect streamflows in the Colorado River. Since 1979, there have been six major studies on how changes in temperature and precipitation might affect annual runoff[1] in the Colorado River (see Table 1a) along with several minor studies. This article compares both the methodology and the results of six major studies, focusing on the projected changes in runoff due to climate change. The article begins with an overview of the study methods, and then reviews each study. It ends with a discussion on study limitations and general conclusions.

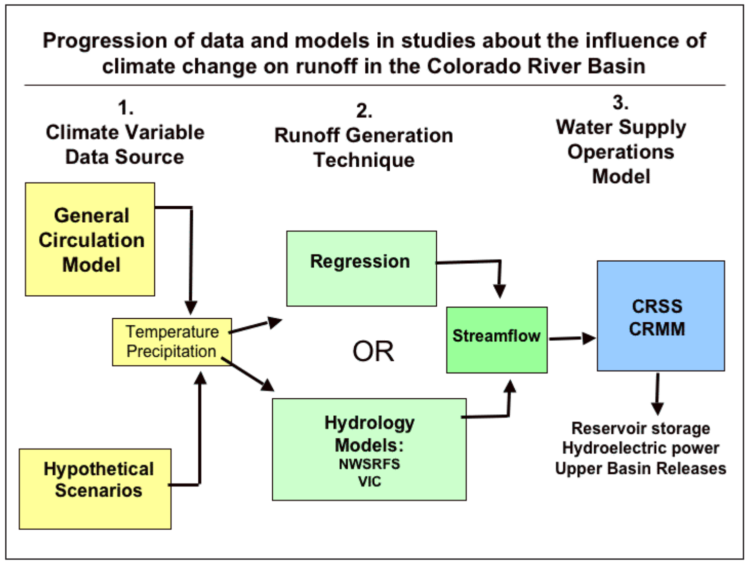

Figure 1a: Progression of data through the models used in recent research on the influence of climate change on the runoff of the Colorado River. All the studies used either a GCM or scenarios to generate future climate variables and either a regression equation or hydrology model to generate changes in runoff, but only three studies then use a water supply operations model (See Table 1a).

Overview of Study Methods

The six studies differ in three key ways: (1) sources of future climate information, (2) techniques used to generate runoff from climate, and (3) uses of 'operations models' used to predict reservoir impacts. (See Figure 1a for the progression of data through models in these studies.) Each difference in method is described below.

The first key difference in the studies is how future changes in temperature and precipitation were derived for use as inputs to runoff models. To generate climate variables, the studies used either arbitrary **scenarios** (e.g. +/- 2ºC and +/- 10% of average precipitation), or the output of General Circulation Models (**GCM**s), which use increases in concentrations of greenhouse gases to predict changes to temperature and precipitation. The GCMs used in these studies vary from the relatively crude models used in the 1991 Nash and Gleick study to the state of the art models used by Hoerling and Eischeid (2006) and Christensen and Lettenmaier (2006).

The second key difference in the study methodologies is how they model changes in streamflow from changes in climate. Some studies **used empirical or statistical (regression)** relationships based on the observed associations between climate factors (i.e. temperature, precipitation, or drought) and past streamflows. Other studies use a **hydrologic model** run on a daily or sub-daily timestep which mimics natural processes such as snow accumulation and melt, evapotranspiration, groundwater recharge, and surface runoff using water balance (i.e., conservation of mass) and energy constraints. Hydrologic models are significantly more complicated than the regression approach, but such precision does not necessarily lead to higher accuracy.

Finally, three out of six studies use streamflow projections in an **operations model**, which considers the effects of changes in runoff on water resources system variables like reservoir storage. Note that results of the operations models strongly depend on initial conditions and should not be interpreted as predictions but used instead to find system sensitivities to changes in future runoff.

Geohydrological Implications of Climate Change on Water Resource Development (Stockton and Boggess, 1979)

Charles Stockton[2] of the University of Arizona (U of A) tree-ring Laboratory, and William Boggess wrote a report prepared for the U.S. Army Corps Engineering Research Center. The authors investigated how four different climate change scenarios could impact the water supplies of the United States.

The scenarios were the four combinations of +/- 2ºC and +/- 10% change in precipitation, and were generically called *warmer and drier, cooler and wetter, cooler and drier*, and *warmer and wetter*. At the time of this report, scientists were discussing both the potential for a new ice age, (global temperature records indicated a cooling from 1940 to 1970) as well as future warming due to increased carbon dioxide. Hence, the study considered all possible future climates. Stockton and Boggess utilized empirical relationships developed by Walter Langbein (Langbein, 1949) of the USGS in the 1940s showing the observed relationship between precipitation, temperature, and runoff across the United States to predict future runoff.

In all parts of the U.S. except the Upper Colorado basin, they determined that the *warmer and drier* and *cooler and wetter* scenarios set the lower and upper bounds on runoff changes since the changes in temperature and precipitation in *warmer and wetter* and *cooler and drier* scenarios usually offset each other. For the Upper Colorado River, Stockton and Boggess calculated that annual runoff would decrease by about one-third to approximately 10 maf under the warmer and drier, and, surprisingly, under the warmer and wetter scenarios. Under cooler and wetter, annual flow doubled to 30 maf, while under the cooler and drier scenario runoff was effectively unchanged.

[1]This article uses streamflows and runoff interchangeably.
[2]This is the same Stockton of the 1976 Stockton and Jacoby Colorado River tree-ring reconstruction.

Study	*Climate Variable Source* ***(Scenario/GCM)***	*Runoff Generation Technique* ***(Empirical-Statistical/Hydrologic model)***	*Selected Runoff Results*	*Operations Model Used*	*Notes*
Stockton and Boggess, 1979	Scenario	**Empirical**: Langbein's 1949 US Historical Runoff- Temperature-Precipitation Relationships	+2C and -10% Precip = ~ -33% reduction in Lees Ferry Flow		Results are for the warmer/drier and warmer/wetter scenarios.
Revelle and Waggoner, 1983	Scenario	**Statistical Regression** on Upper Basin Historical Temperature and Precipitation	+2C and -10% Precip= -40% reduction in Lee Ferry Flow		+2C only = -29% runoff, -10% Precip only = -11% runoff.
Nash and Gleick, 1991 and 1993	Scenario and GCM	**NWSRFS Hydrology model** runoff derived from 5 temperature & precipitation Scenarios and 3 GCMs using doubled CO2 equilibrium runs.	+2C and -10% Precip = ~ -20% reduction in Lee Ferry Flow	Used USBR CRSS Model for operations impacts.	Many runoff results from different scenarios and sub-basins ranging from decreases of 33% to increases of 19%.
Christensen et al., 2004	GCM	UW **VIC Hydrology model** runoff derived from temperature & precipitation from NCAR GCM using Business as Usual Emissions.	+2C and -3% Precip at 2100 = -17% reduction in total basin runoff	Created and used operations model, CRMM.	Used single GCM known not to be very temperature sensitive to CO2 increases.
Hoerling and Eischeid, 2006	GCM	**Statistical Regression** on PDSI developed from 18 AR4 GCMs and 42 runs using Business as Usual Emissions.	+2.8C and ~0% Precip change at 2035-2060 = -45% reduction in Lee Fee Flow		
Christensen and Lettenmaier, 2006	GCM	UW **VIC Hydrology Model** runoff using temperature & precipitation from 11 AR4 GCMs with 2 emissions scenarios.	+4.35C and -2% Precip at 2070-2099 = -11% reduction in total basin runoff with a high emissions scenario	Also used CRMM operations model.	Other results available, increased winter precipitation buffers reduction in runoff.

Table 1a. Summary of models and results for changes to runoff in the Colorado River. This table is an overview of the major differences in the methods and results of the six studies in this article.

Effects of a Carbon Dioxide-induced Climatic Change on Water Supplies in the Western United States (Revelle and Waggoner, 1983)

Roger Revelle, of the Scripps Institution of Oceanography, and Paul Waggoner, of the Connecticut Agricultural Experiment Station, wrote a chapter in a report published by the National Academy of Sciences. The authors investigated how future warming and drying in the Colorado River might affect runoff. The key part of the article was the generation of a multiple linear regression between temperature and precipitation in the Upper Basin and unimpaired flow at Lee Ferry. Using data from the period 1931 to 1976 they established the following relationship[3]:

Lee Ferry Flows (in cubic meters) = 9274 + 52 (**Precipitation** in mm) – 2400 (**Temperature** in Celsius)

The equation shows that a 2ºC increase would lead to a decline in runoff of by 4800 million cubic meters (mcm) (3.9 maf or -29%) and a 10% decrease in precipitation would reduce flow by 1730 mcm (1.4 maf or -11%)[4]. With both a 2ºC increase and 10% precipitation decrease, total annual flow would decline by 40%. They note that the regression shows that a 28% increase in precipitation is necessary to balance a 2ºC increase. The equation explains 73% of the variance in streamflow during the 1931-1976 calibration period.

Sensitivity of Streamflow in the Colorado River basin to Climatic Changes (Nash and Gleick, 1991) and The Colorado River basin and Climatic Change (Nash and Gleick, 1993)

Linda Nash and Peter Gleick of the Pacific Institute for Studies in Development, Environment, and Security wrote two similar articles on future Colorado River flows under varying assumptions of a changing climate. The 1993 article is an expanded version of the 1991 study and includes results of modeling simulated future flows with the Bureau of Reclamation's (USBR) Colorado River Simulation System (CRSS) operations model.

In the 1991 study, the authors considered a total of 15 different scenarios for temperature and precipitation conditions, 10 from assumed futures (all combinations of 2ºC and 4ºC temperature increases, and changes in precipitation of -20%, -10%, 0%, +10% and +20%) and five based on GCM simulations from NASA (+4.8ºC, +15% Precip change), NOAA (+4.7ºC, 0% Precip change) and the UK Met Office (+6.8ºC, +20% Precip change). These scenarios generated meteorological inputs for use in the National Weather Service River Forecasting System (NWSRFS) hydrologic model[5]. The authors used the NWSRFS model to generate runoff projections for three relatively unimpaired sub-basins of the Colorado River basin above Lake Powell and for Lake Powell itself.

In all, fifty-two different scenarios were evaluated. The results follow expectations that higher temperatures and lower precipitation should generate less runoff. Thirty-seven scenarios (71%) resulted in flow decreases and fifteen scenarios (29%) resulted in flow increases. Projections of changes in annual runoff varied from a 33% decrease to a 19% increase. A 2ºC increase was roughly offset by a 10% increase in precipitation and a 4ºC increase was roughly offset by 15 - 20% increase in precipitation. A 2ºC increase with no change in precipitation caused runoff declines of 4 -12%, a 2ºC increase with 10% less precipitation caused runoff to decline by about 20%, and a 4ºC increase with no change in precipitation caused runoff declines of 9 - 21%. Temperature increases also caused the peak flow to shift earlier in the year.

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[3] Another version of the equation is: Lee Ferry Flows (in maf) = 42.1 + 1.07(Precip in inches) -1.08(Temp in Fahrenheit)
[4] 1931-1976 Upper Basin average temperature was 4.18ºC and basin average precipitation was 333 mm.
[5] NWSRFS is the operational model used by the NOAA National Weather Service River Forecast Centers, and specifically the Colorado Basin River Forecast Center (CBRFC), to predict annual and seasonal streamflows.

In the 1993 study, Nash and Gleick added some minor enhancements to the study and used USBR's CRSS model to investigate how changes in inflows would affect reservoir operations and system reliability. Like many other studies such as the Severe and Sustained Drought study (1995), the 1993 study showed that system storage and hydropower production are very susceptible to reduced flows. For example, 20% less runoff caused a 60 – 70% reduction in mean annual storage and a 60% reduction in power generation. These results were very dependent on assumptions made about shortage allocation, reservoir starting conditions, and other operational factors. For example, CRSS did not properly address with required Upper Basin compact deliveries.

The Effects of Climate Change on the Hydrology and Water Resources of the Colorado River basin (Christensen, et al., 2004)

This study was part of the Accelerated Climate Prediction Initiative funded by the Department of Energy. Niklas Christensen, Andrew Wood, Nathalie Voisin, Dennis Lettenmaier and Richard Palmer, all at the University of Washington, used the National Center for Atmospheric Research (NCAR) Parallel Climate Model (PCM) to generate temperature and precipitation changes from greenhouse gas emissions during three future 21st century periods, 2010-2039 (Period 1), 2040-2069 (Period 2), and 2070-2098 (Period 3). They used the output of PCM in a hydrology model to create runoff projections, which they then used in an operations model.

PCM was run using the 'Business as Usual' future emissions scenario, which results in CO_2 levels of approximately 710ppm by 2100[6]. By starting PCM from slightly different initial conditions, the authors created three future climate runs for each period. The results for Periods 1, 2 and 3 were reported as an average of the three runs. A 50-year "control run" starting in 1995 with no additional greenhouse gas emissions was also completed. Due to lags in the climate system, the control run showed warming of about 0.5ºC which is in rough agreement with what many believe to be 'committed warming' should greenhouse gas emissions stop immediately.

Monthly temperature and precipitation output from PCM was downscaled to 1/8 degree (approximately 8 mile grid boxes) daily data for use by a daily hydrological simulation model, the Variable Infiltration Capacity (VIC) model. VIC simulates snow accumulation and melt, soil moisture, evapotranspiration, runoff and baseflow. VIC was calibrated using climate and natural flow data from 1950 to 1989. Calibration runs indicated a flow match at Imperial Dam near Yuma, Arizona, within 1% of calculated natural flow at the site. Temperatures increased from 0.5 – 2.4ºC, precipitation decreased by 1- 6%, and runoff was reduced by 10 – 18% in the four runs (See Table 1b). A spatial analysis of these reductions indicated that a considerable enhancement of evapotranspiration increases occurred in the high elevation areas where a large portion of runoff occurs. Peak runoff advanced from June in the historical data to May in the latter parts of the control and 21st century runs.

VIC output was used in a monthly operations model, Colorado River Reservoir Model (CRRM), based roughly on USBR's CRSS model. Most of the modeling held 2000 Upper Basin demands constant at 2000 levels to simplify analysis. As expected from similar studies, the CRRM model found that reservoir reliability is extremely sensitive to inflow reductions, due to a nearly full allocation of the Colorado River. Average reservoir levels drop significantly even with small reductions in runoff. For example, required deliveries from Lake Powell were met 92% of the time in the historical data, and 72% in the control run and 59%, 73%, and 77% in periods 1-3, respectively.

Period	Temperature	Precipitation	Runoff
Control (1995)	+0.5ºC	-1%	-10%
Per. 1: 2010-2039	+1.0ºC	-3%	-14%
Per. 2: 2040-2069	+1.7ºC	-6%	-18%
Per. 3: 2070-2098	+2.4ºC	-3%	-17%

Table 1b. Model results: changes in temperature and precipitation provided by NCAR PCM, and runoff results from VIC hydrology model. (Data from Christensen et al., 2004).

Past Peak Water in the Southwest (Hoerling and Eischeid, 2006)

Martin Hoerling and Jon Eischeid of the NOAA Earth System Research Laboratory in Boulder published their findings 2006 in Southwest Hydrology, a publication (not peer-reviewed) published by a National Science Foundation-funded effort at U of A. They predicted future Colorado River flows based on the Palmer Drought Severity Index (PDSI) calculated for the Upper Colorado River basin[7]. Note that the PDSI was developed for use in the Great Plains states, not areas with snow-driven hydrology. Using historical data from 1895 to 1989, they first created a simple linear regression for the Upper Colorado basin:

Lee Ferry Flows (in MAF) = 14.5 + 1.69*(**PDSI**)

This regression explains 63% of the variance at Lees Ferry over the 105-year calibration period. Using a verification period from 1990 to 2005, the equation explains 85% of the variance in the flows. The authors caution that it is unclear if this relationship between flows and PDSI is strictly applicable to the substantial changes anticipated in future climate.

Hoerling and Eischeid then calculated the PDSI using data from 42 different climate simulations using 'Business As Usual'[8] greenhouse gas emissions from 18 different coupled atmosphere-land-ocean GCMs completed for the recent IPCC Fourth Assessment Report (2007). The models in the study project an average temperature increase of 1.4ºC during 2006-2030 and 2.8ºC during 2035-2060, compared to 1895-2005. The climate models show little net change in precipitation over the next century, yet drought as determined by the modeled PDSI would be a very common occurrence in the future. Average PDSI is projected to be the same as during the 2000-2003 drought (<-3). Twentieth century droughts were driven by precipitation decreases with enhancement by increasing temperatures but the authors propose

[6] Current CO_2 levels are approximately 380 ppm and are increasing at about 1.5 – 2.0 ppm/year. The Business as Usual emissions scenario means that greenhouse gas emissions will continue increasing at the current rate.
[7] PDSI is a frequently used metric of drought conditions and is calculated by combining temperature, precipitation, evapotranspiration and soil moisture. The index can vary from -4 (extreme drought) to +4 (extreme wetness).
[8] The Business as Usual emissions scenario is called A1B in the IPCC Fourth Assessment Report (2007).

that a "near perpetual state of drought will materialize in the coming decades as a consequence of increasing temperature."

With the above changes in temperature and no changes in precipitation, the authors found that streamflows in the river over the next twenty-five years would average 10 maf, approximately the same as during the recent 1999-2004 drought. From 2035 to 2060, the flows would drop to 7 maf on average. The modeled individual years vary considerably from these averages with some close to the historical mean of 15 maf in the next twenty years (see Figure 1b).

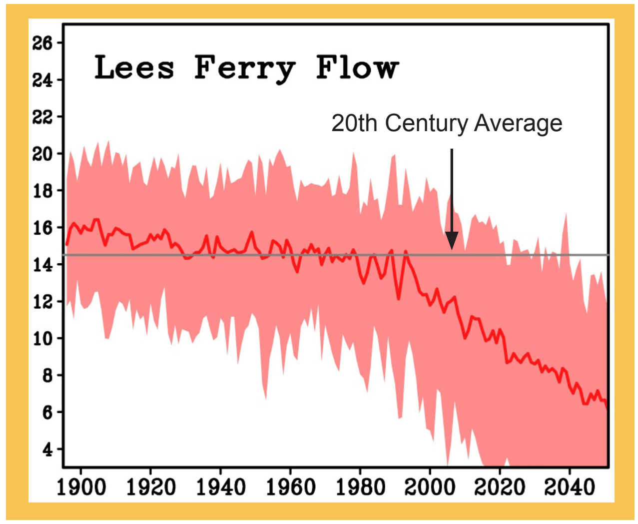


Figure 1b. Projected Lee Ferry future flows. Solid line is average of 42 runs, and red cloud shows 10% to 90% range of individual simulations (from Hoerling and Eischeid, 2006).

A Multimodel Ensemble Approach to Assessment of Climate Change Impacts on the Hydrology and Water Resources of the Colorado River basin (Christensen and Lettenmaier, 2006)

Niklas Christensen and Dennis Lettenmaier, submitted another study for publication in 2006[9]. Like the Hoerling and Eischeid study, this study is based on GCM model results prepared for the 2007 IPCC Fourth Assessment Report. The authors used the same approach as the 2004 Christensen paper with downscaled GCM data feeding the VIC hydrology model and the resultant streamflows then used in CRMM. The same reporting periods (Periods 1-3) were used but the authors used 11 major climate models, rather than using only the NCAR PCM. The GCMs used two different future emissions scenarios, A2, a relatively high scenario with 2100 CO2 levels of 850 ppm, and B1, a relatively low scenario with 2100 CO2 levels of 550 ppm[10].

Runoff changed by 0%, -7% and -8% in the B1 for periods 1-3, respectively, and by 0%,-6% and -11% in A2 for the same periods (See Table 1c). These reductions are larger than the precipitation declines and are believed to be driven by increasing temperatures.

For the operations models (CRRM), Upper Basin demands were fixed at year 2000 levels to ease analysis. In general, CRMM reservoir levels are higher than that reported in the 2004 study, although the authors claim that the results are within the same range of sensitivity. During 2070-2099, as compared to the 1950-99 base case, runoff declines of 11% average cause storage to decline by 13%, under the A2 scenario.

Emissions Scenario	Period	Temperature	Precipitation	Runoff
A2	Per.1: 2010-2039	+1.2 ºC	-1%	0%
	Per.2: 2040-2069	+2.6 ºC	-2%	-6%
	Per.3: 2070-2099	+4.4 ºC	-2%	-11%
B1	Per.1: 2010-2039	+1.3ºC	+1%	0%
	Per.2: 2040-2069	+2.1ºC	-1%	-7%
	Per.3: 2070-2099	+2.7ºC	-1%	-8%

Table 1c. Model results: changes in temperature and precipitation provided by 11 GCMs from the IPCC Fourth Assessment Report, and runoff results from VIC hydrology model. (Data from Christensen and Lettenmaier, 2006).

Study Limitations

All studies discussed herein suffer from limitations relating to GCMs, future applicability of statistical and empirical relationships based on historical data, hydrology model assumptions, and/or operational model assumptions. Each of these areas is discussed below.

These studies utilize three different generations of GCMs, dating from the early 1990s, late 1990s and mid 2000s. As our computational capabilities have increased, so has our understanding and ability to model climate and thus it should be expected that the GCM-derived climate inputs for the most recent studies (Hoerling and Eischeid, 2006, Christensen and Lettenmaier, 2006) are significantly more robust than older results (Nash and Gleick, 1991, 1993). In general, temperature projections are considered much more reliable than precipitation, even in the latest models. As noted by the IPCC, even with many advances over the years, global climate models still do not adequately resolve precipitation in mountainous areas. It is noteworthy, however, that the most recent GCM results for precipitation in the Colorado River basin show consistent results across models with very little change in projected precipitation relative to historical conditions.

Studies which use empirical/statistical relationships between temperature, precipitation and runoff (Stockton and Boggess, 1979, Revelle and Waggoner, 1983, Hoerling and Eischeid, 2006) have been criticized for failing to consider how these relationships might change in a future climate due to evapotranspiration and vegetation changes, and changes in seasonality of runoff. Such changes might substantially alter the relationships between temperature, precipitation, and runoff, which could invalidate the findings.

Hydrology models can potentially overcome many of the limitations inherent in the statistical approach by modeling many of the physical processes which control runoff such as snow accumulation and melt, groundwater recharge, and evapotranspiration from plants. In theory as the climate changes, these models should correctly handle new physical conditions. Unfortunately,

[9]This summary is based on the paper submitted for publication and hence the results reported here are subject to change.
[10]A2 and B1 refer to specific emissions scenarios used in GCMs in the IPCC reports. For more information see the IPCC Special Report on Emissions Scenarios (http://www.grida.no/climate/ipcc/emission/index.htm).

these models require large amounts of data, much of which is imprecisely known. Furthermore, in order to resolve very complex and sometimes poorly known relationships, the models may overly simplify important physical processes. For example, the VIC model uses a two-meter subsurface layer to model all interactions with soil moisture and groundwater, despite the fact that surface water/groundwater interactions frequently involve various forms of aquifers with significant storage capacity.

Three of the studies use an operations model, Nash and Gleick (1993), Christensen et al. (2004) and Christensen and Lettenmaier (2006). Nash and Gleick utilize an older version of USBR's CRSS model and the Christensen studies utilize a model (CRRM) created at the University of Washington. While the results of these two models are intriguing, assumptions about reservoir starting contents and system operating policies can significantly alter results. In particular, numerous critical policy-laden decisions about how to operate the system under low flow conditions have never been resolved and these implementations either ignore these issues, or implement a solution that has no standing in the Law of the River.

Conclusions

The first studies of the potential impacts of climate change on the Colorado River basin were completed almost thirty years ago. As the years have progressed, scientific studies have relied less and less on arbitrary assumptions about future temperature and precipitation and more and more on the results from GCMs. For many years, most GCMs agreed that temperatures would increase in the Colorado River Basin over the next century, but there was no consensus on changes in precipitation. Scientists believed that reduction in runoff from increased temperatures might be offset by increased precipitation as recently as the 2001 IPCC Third Assessment and the 2000 National Assessment of the Potential Consequences of Climate Variability and Change. However, starting with Christensen in 2004 and continuing through the most recent IPCC Fourth Assessment Report (2007), the likelihood of significantly increased precipitation counter-balancing increased warming appears to be reduced. The most recent GCMs now suggest that precipitation will remain approximately the same in the basin, and current GCM temperature projections by 2100 are in rough agreement with most of the scenarios and GCM results used over the years. ***Under these conditions, all past studies indicated that runoff would be reduced.***

What remains uncertain is exactly how much reduction in runoff will occur if current precipitation projections hold. In the most recent Colorado River studies, runoff reductions range from the -11% projected by Christensen and Lettenmaier (2006) in 2100, to the -45% projected by Hoerling and Eischeid (2006) in about 2050[11]. Notably, these two numbers roughly bracket the range of all past studies that do not contain large precipitation increases. While both of these studies utilize the latest temperature and precipitation results from IPCC GCMs, they use very different techniques to generate flow. Hoerling and Eischeid's method implicitly emphasizes how higher temperatures will increase atmospheric demand for water and reduce runoff. Christensen and Lettenmaier imply that snowmelt runoff during the relatively cool spring will still be reasonably efficient in generating streamflow. Which method is more correct? Research is on-going to discover their strengths and weaknesses.

Sources

Christensen, N. S., A. W. Wood, et al., (2004). "The Effects of Climate Change on the Hydrology and Water Resources of the Colorado River Basin." *Climatic Change,* **62**(1-3): 337-363.

Christensen, N. and D.P. Lettenmaier, (2006). "A Multimodel Ensemble Approach to Assessment of Climate Change Impacts on the Hydrology and Water Resources of the Colorado River Basin." *Hydrology and Earth System Sciences Discussion*, **3**, 1-44.

Hoerling and Eischeid, (2006). "Past Peak Water in the Southwest." *Southwest Hydrology*, January/February, 18-19, 35.

IPCC: Houghton, J. T. and Y. Ding, eds. (2001). Climate Change 2001: The Scientific Basis. Cambridge: Cambridge University Press.

IPCC (2007). "Contribution of Working Group I to the Fourth Assessment Report of the IPCC." Report can be found at: http://ipcc-wg1.ucar.edu/index.html.

Langbein, 1949. "Annual Runoff in the United States." *U.S. Geological Survey Circular,* **5**. U.S. Department of the Interior, Washington, DC, 1959.

Milly, P. C. D., K. A. Dunne, et al. (2005). "Global Pattern of Trends in Streamflow and Water Availability in a Changing Climate." *Nature,* **438**(7066): 347-350.

Nash, L.L.and P. Gleick, (1991): "The Sensitivity of Streamflow in the Colorado Basin to Climatic Changes, *J. Hydrology*, **125**, 221-241.

Nash, L.L. and P. Gleick, (1993): "The Colorado River Basin and Climate Change: The Sensitivity of Streamflow and Water Supply to Variations in Temperature and Precipitation," *EPA, Policy, Planning and Evaluation*. EPA 230-R-93-009 December.

Severe and Sustained Drought Statistics, (1995). http://www.hydrosphere.com/publications/ssd/ssd.htm

Seager, R., M. Ting, et al., (2007). "Model Projections of an Imminent Transition to a More Arid Climate in Southwestern North America." *Science*: 1139601.

Revell, R.R. and P.E. Waggoner, (1983). "Effects of a Carbon Dioxide-Induced Climatic Change on Water Supplies in the Western United States." Changing Climate. National Academy of Sciences, National Academy Press, Washington, D.C.

Stockton, C.W. and W.R. Boggess, (1979). "Geohydrological Implications of Climate Change on Water Resource Development. Final Report." U.S. Army Coastal Engineering Research Center. 224 pp.

[11] Three other recent generalized studies on future runoff projections for the U. S. Southwest not referenced in this article all support a reduction of flow in the Colorado River basin in the future: Milly et al. 2005, Seager, Ting et al, 2007, and the recent IPCC AR4, 2007 regional projections. See Sources for citations.

Temperature 4/1/07 - 4/30/07

Monthly average temperatures for April 2007 for the Intermountain West region ranged from the low-20s in south central **Wyoming** to the upper-50s in northwest and eastern **Utah** (Figure 2a). Temperatures across **Colorado** were divided with above average in the west and below average in the east. **Utah** temperatures were above average statewide and **Wyoming** was mostly above average except for areas in the north central and southeast (Figure 2b). **Colorado** had both the highest and lowest departure from average with temperatures ranging from 8°F above average in the west to 6°F below average in the east.

The NWS Salt Lake City reports that record high temperatures were set in **Utah** in early April. Then, a few record low temperatures occurred mid-month, but the end of April brought many more record highs across the state. The maximum temperature on April 29 (89°F) broke the record for the highest maximum temperature in April (previously set in 1992). That temperature also set a record for the highest temperature at the earliest point in the season. The minimum temperature the next day on April 30 (57°F), was the highest minimum temperature recorded for that day (previously set in 1977).

In comparison to April 2006 (Figure 2c), temperatures in April 2007 were lower throughout much of the IMW region. Eastern **Colorado** had the largest difference between years, with temperatures below average by 2 – 6°F in April 2007, whereas in April 2006, temperatures were above average by 2 – 8°F. Much of eastern **Wyoming** was above average in 2006, but near or below average in 2007.

Notes

Figures 2a-c are experimental products from the High Plains Regional Climate Center. These data are considered experimental because they utilize the most recent data available, which have been subject to minimal quality control. 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 incorrect 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.

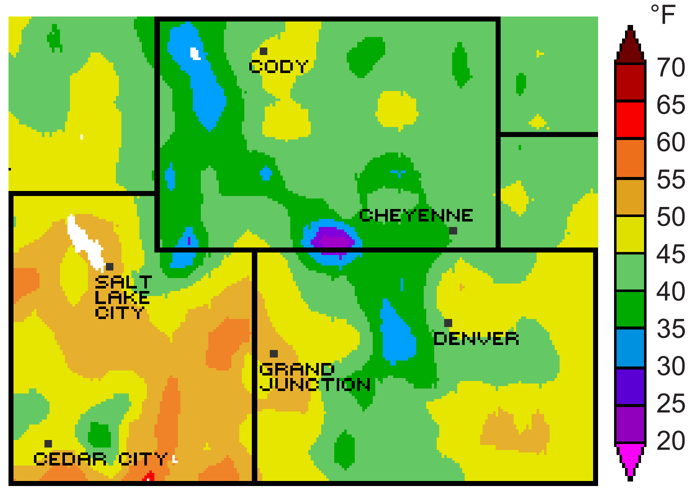


Figure 2a. Average temperature for the month of April 2007 in °F.

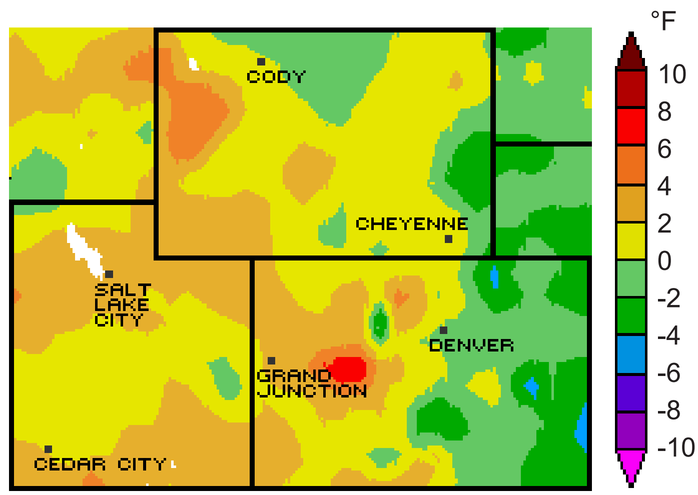


Figure 2b. Departure from average temperature for the month of April 2007 in °F.

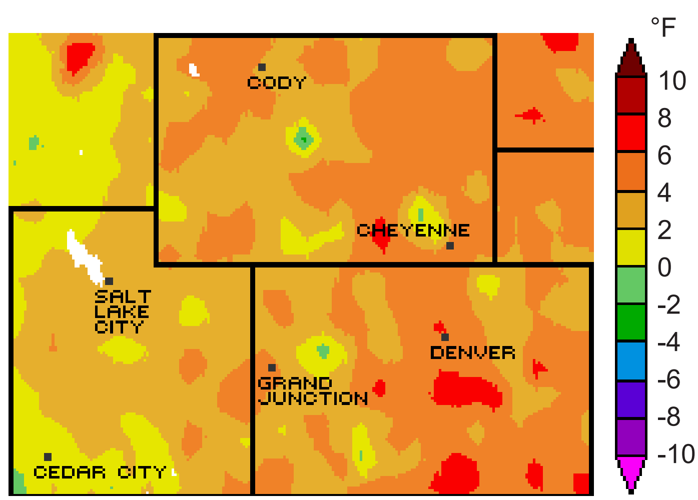


Figure 2c. Departure from average temperature in °F for last year, April 2006.

Precipitation 4/1/07 - 4/30/07

Total precipitation for April 2007 in the Intermountain West regions ranged from 0.25 to 3+ inches (Figure 3a). Central and eastern **Colorado**, and northwest **Wyoming** received the highest totals of 3+ inches. Eastern **Wyoming**, southwest **Colorado**, and south central **Utah** received from 1-3 inches. Southwest **Wyoming**, northwest **Colorado** and northeast **Utah** received the least precipitation amounts of < 0.25 to 1 inch.

Much of southwest and northeast **Wyoming**, northwest **Colorado**, and the northern half of **Utah** received the lowest percent of average precipitation in April with 40 – 80% of average (Figure 3b). Parts of northeastern **Colorado**, southeast **Utah**, and northwest **Wyoming** received 120 - 150 % of average, with some of these areas in **Colorado** any **Wyoming** receiving above 150% of average. The remainder of the states received near average precipitation in April. The NWS Denver-Boulder reports that between April 23 - 24, 2.10 inches of rainfall was recorded at Denver International Airport (DIA). This is a 24-hr precipitation record surpassing the old record of 1.29 inches set way back in 1891. The DIA weather station recorded a total of 2.65 inches of precipitation in April, which was 0.72 inches above average.

Percent of average precipitation since the start of the water year is near average or above for most of **Colorado** and **Utah** (Figure 3c). Southeast **Utah** and eastern **Colorado** are at 120-200% of average. Most of **Wyoming** is now near average, with a few areas at 40–80% of average.

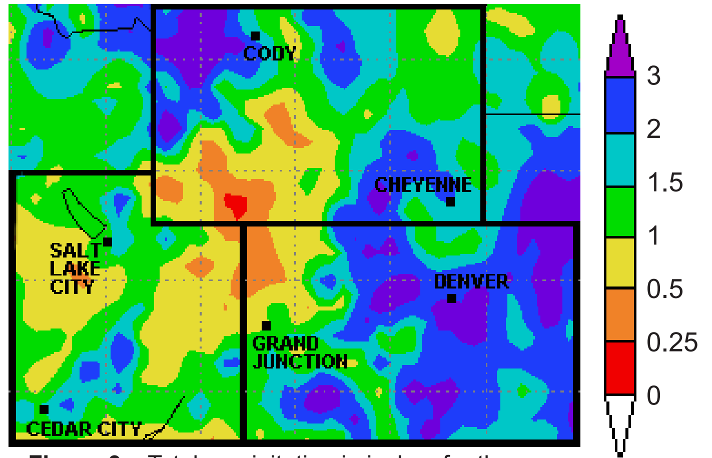


Figure 3a. Total precipitation in inches for the month of April 2007.

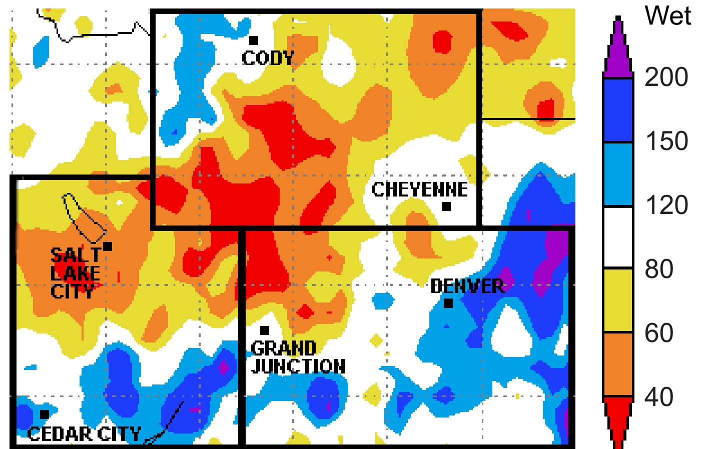


Figure 3b. Percent of average precipitation for the month of April 2007.

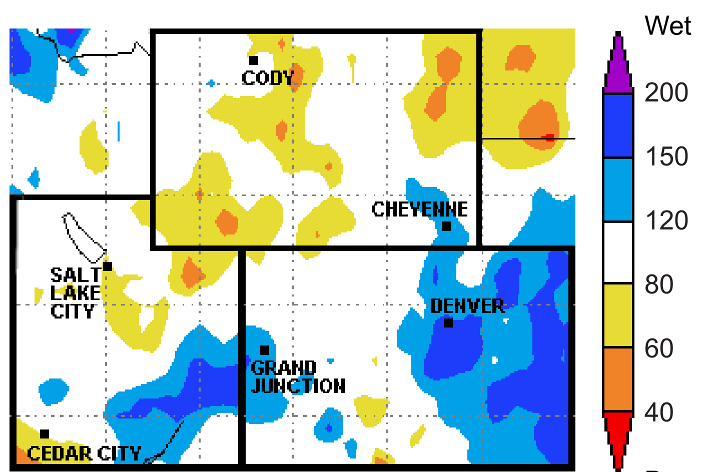


Figure 3c. Percent of average precipitation accumulation since the start of the water year 2007 (Oct. 1, 2006 – Apr. 30, 2007).

Notes

The data in Figures 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 at high elevation sites. Prior to 1996, this dataset did not include SNOTEL. Percent of average precipitation is calculated by taking the ratio of current to average precipitation and multiplying by 100.

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 5/15/07

According to the National Drought Monitor on May 17, drought intensity status did not change in **Utah** and most of **Colorado**, but it decreased from last month in central and eastern **Wyoming** (Figure 4). Eastern **Wyoming** moved from mostly severe (D2) and moderate (D1) to mostly abnormally dry (D0) to no drought status. However, the area designated extreme (D3) to severe (D2) in southwest and western **Wyoming** expanded slightly. Drought status remains the same, mostly moderate (D1), in **Utah** and western **Colorado**. The northeast corner of **Colorado** has decreased in drought status from abnormally dry (D0) to non-drought status. Central and eastern **Colorado** do not have drought designation at this time.

According to the Drought Impact Reporter, livestock producers in 26 **Colorado** counties received almost $1.3 million in drought assistance funds because of drought-decimated pastures last spring. The Colorado Department of Agriculture reported that the award amounted to roughly $5 per animal.

In **Wyoming**, there is insufficient forage to support the livestock and wild animals that live on the land due to eight years of drought. The Wyoming Game and Fish Department increased the number of hunting licenses to be issued this year in an attempt to regain a balance between the number of animals on the land and the amount of forage available to sustain them after years of drought. There will be an emergency removal of wild horses from the Fifteen-mile Wild Horse Herd Management Area in northwestern Wyoming to prevent their starvation. The Bureau of Land Management will relocate roughly 140 horses between August 5 and 8 from the 83,000 acre area.

In southwest **Utah**, St. George has entered stage 1 of a drought plan that includes mandatory water restrictions. The city of Hurricane has approved a water ordinance that asks for voluntary water use restrictions, which may become mandatory if drought conditions increase.

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 of this monitor is David Miskus, CPC/NOAA.

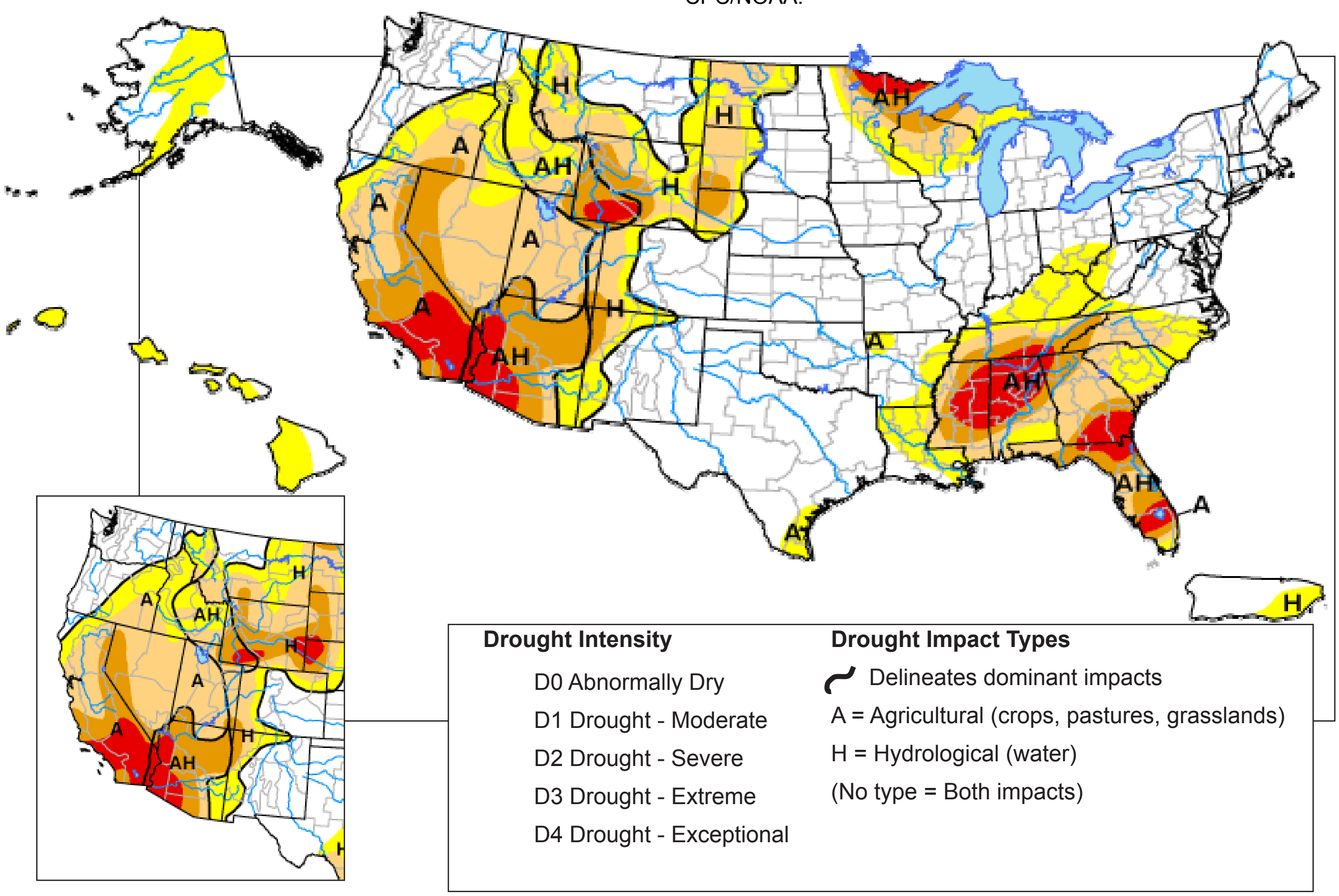


Figure 4. Drought Monitor released May 17, 2007 (full size) and last month, April 19, 2007 (inset, lower left) for comparison.

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 5/1/07

May 1 snowpack conditions are below average for the Intermountain West Region, with the exception of a few small basins in the Front Range of **Colorado** (Figure 5). The lowest snowpack percentages in **Colorado** were reported in the Yampa and White River basins, which declined to only 42% of average, the lowest percentage since 2002 when snowpack readings were only 32% of average. Other basins with well below average snowpack readings include the San Juan, Animas, Dolores, and San Miguel basins at only 52% of average. According to daily SNOTEL data, only two basins in **Colorado** approached or exceeded their normal peak snowpack levels during April. Those include the Arkansas, which accumulated 100% of the average seasonal maximum, and the South Platte, which reached 110% of the average seasonal maximum during April.

In **Utah,** the combination of record or near record low snowpack levels and accelerated snowmelt in April left snowpacks in the range between 3% over southeast **Utah** to 33% of average on the Bear River. Snowpack levels in southern **Utah** are much lower than snowpack levels in northern Utah. According to the NRCS, rapid snowmelt is likely and snowpacks are not expected to last past mid May, which is about a month earlier than average.

Most of the snowpack in **Wyoming** is below average, except the Powder/Tongue River basins, which is about 100% of average. The lowest basin is the Belle Fouche, which has 0% of average snowpack, meaning that it has already melted. All of the basins west of the Continental Divide are below 70% of average.

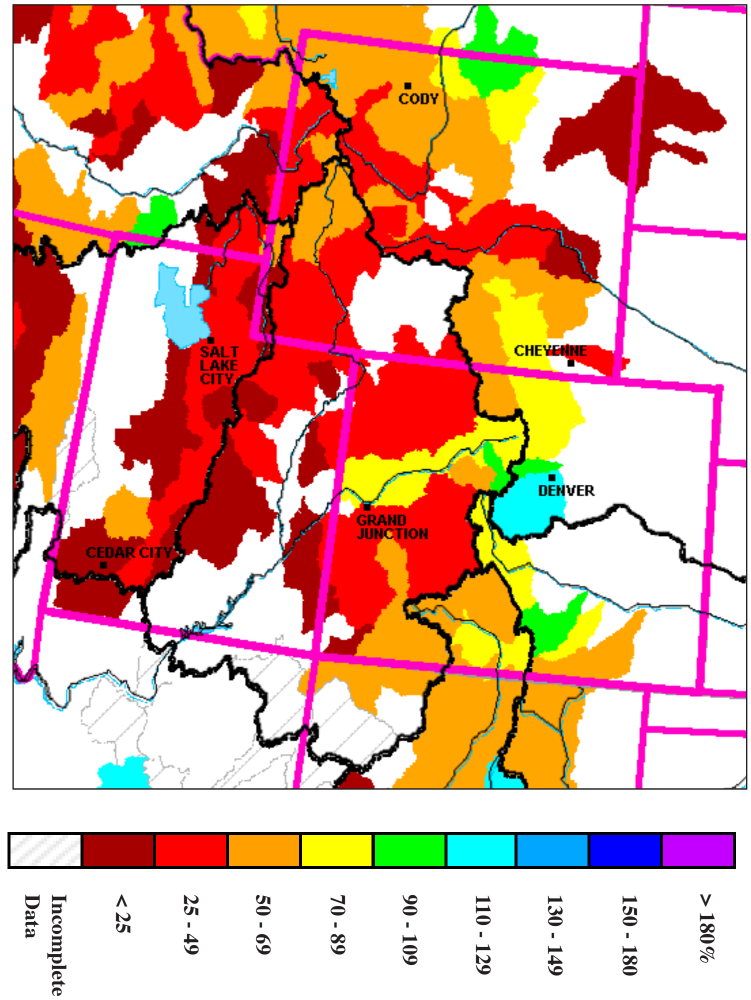


Figure 5. Snow water equivalent (SWE) as a percent of average for available monitoring sites in the Intermountain West as of May 1, 2007 courtesy of the Natural Resources Conservation Service.

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. 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. 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.

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. Basins with no SNOTEL sites or incomplete data are designated in white on the map. To see the locations of individual SNOTEL sites, see each state’s water availability page.

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.

Reservoir Supply Conditions

As water managers prepare for the 2007 runoff season, mid to low elevation snowpack has started to melt, and reservoirs are just starting to fill. Usually reservoir levels are at a low point during this time of year, however warm temperatures in April led to the early start of the runoff season and above average storage conditions for many reservoirs across the Intermountain West.

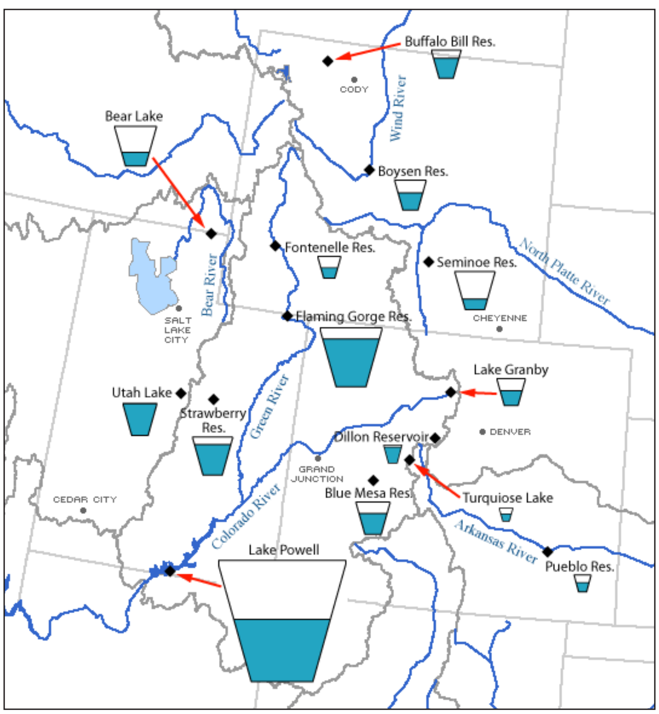
In **Colorado**, statewide reservoir storage is 106% of average, but varies between basins. All **Colorado** reservoirs listed in Figure 6 are near or above average. According to the NRCS, May 1 reservoir storage levels in the Gunnison basin are the highest in the state, reporting 126% of average. At 88% of average, the Rio Grande Basin has the lowest reservoir storage levels in the state. Based on a 62% of average April-July inflow forecast, the USBR does not anticipate Blue Mesa filling this season. Arkansas basin reservoir storage levels are 141% of last year's averages during this time of year.

Across **Utah**, reservoir storage levels vary, and statewide storage levels are 75% of average. With statewide streamflow forecasts down to 30-50% range, reservoirs will unlikely experience significant storage gains. Strawberry reservoir is 85% full and 142% of average, however April-July forecast inflow volumes put out by the CBRFC is projected at 23% of average. Lake Powell storage is 48% and projected April-July inflow is 4 million acre feet and 50% of average.

In **Wyoming**, reservoir storage levels vary, due to variance in statewide snowpack and forecasted streamflow volumes. Storage levels listed in Figure 6 vary with the lowest percent of average storage in Seminoe reservoir (31% full and 67% of average), and the highest storage in Buffalo Bill Reservoir (76% full and 166% of average). According to the USBR, unregulated inflow into Flaming Gorge for April was 72,000 acre feet. The USBR reports that Fontenelle reservoir will unlikely fill, due to 43% of average April-July inflow forecasts.

Notes

The size of each "tea-cup" in Figure 6 is proportional to the size of the reservoir, as is the amount the tea-cup is filled. The first percentage shown in the table is the current contents divided by the total capacity. The second percentage shown is the percent of average water in the reservoir for this time of year. Reservoir status is updated at different times for individual reservoirs, so see the websites below for the most recent information.



Reservoir	Current Water (KAF)	Total Capacity (KAF)	% Full	% of Average
Colorado				
Blue Mesa Res.	536.8	829.5	65%	133%
Lake Dillon	244.4	254.0	96%	115%
Lake Granby	290.9	539.7	54%	110%
Pueblo	190.1	354.0	54%	102%
Turquiose Lake	68.0	129.4	53%	115%
Utah				
Bear Lake	531.6	1,302.0	41%	56%
Lake Powell	11,790.2	24,322.0	48%	76%
Strawberry Res.	940.6	1,106.5	85%	142%
Utah Lake	905.6	870.9	104%	1104%
Wyoming				
Boysen Res.	462.3	741.6	62%	95%
Buffalo Bill Res.	490.2	644.1	76%	166%
Flaming Gorge Res.	3,187.2	3,749.0	85%	108%
Fontenelle Res.	130.3	344.8	38%	91%
Seminoe Res.	320.2	1,017.3	31%	67%

KAF = Thousands of Acre Feet

Figure 6. Tea-cup diagram of several large reservoirs in the Intermountain West Region. All reservoir content data is from May 1-5, 2007.

On the Web

- Dillon Reservoir, operated by Denver Water: http://www.water.denver.co.gov/indexmain.html.
- Turquoise Lake, Boysen Reservoir, Seminoe Reservoir, and Buffalo Bill Reservoir operated by the U.S. Bureau of Reclamation (USBR) Great Plains Region: http://www.usbr.gov/gp/hydromet/teacup_form.cfm.
- Lake Granby is part of the Colorado-Big Thompson project, operated by Northern Colorado Water Conservancy District and the USBR Great Plains Region: http://www.ncwcd.org/datareports/data_reports/cbt_wir.pdf.
- Blue Mesa Reservoir, Lake Powell, Flaming Gorge Reservoir, and Fontenelle Reservoir operated by the USBR – Upper Colorado Region: http://www.usbr.gov/uc/wcao/water/basin/tc_cr.html.
- Strawberry Reservoir, operated by the Central Utah Water Conservancy District: http://www.cuwcd.com/operations/currentdata.htm.
- Utah Lake, operated by the Utah Division of Water Rights, and Bear Lake, operated by Utah Power: http://www.wcc.nrcs.usda.gov/cgibin/resv_rpt.pl?state=utah.

Regional Standardized Precipitation Index data through 4/30/07

The Regional SPI this month varies across the region, as the southern part is generally wetter than the northern part (Figure 7). In **Colorado**, three out of the four climate divisions on the eastern side of the Continental Divide are in the moderately or very wet categories. Both the Arkansas and the Platte Drainage Basin climate divisions moved into wetter categories this month. The other two climate divisions are in the near normal category.

In **Utah**, most of the state is in the near normal category, and this is very similar to last month. The small Dixie climate division in southwestern **Utah** is the driest division in the state, in the very dry category. The North Central climate division moved into a dry category (moderately dry) from the near normal category of last month. The Southeast climate division is still the only on in a wet category (moderately wet).

Wyoming remains the driest state in the regions, with no climate divisions in any wet categories. The driest part of the state is central **Wyoming** (Wind River climate division), which is in the extremely dry category. Two climate divisions in north-central **Wyoming** (Big Horn and Powder/Little Missouri/Tongue) moved from the very dry category to the moderately dry category last month. The northeast (Cheyenne/Niobrara and Belle Fourche climate divisions) and northwest (Yellowstone climate division) parts of the state are in the near normal category.

Notes

The SPI is an index based on the probability of recording a given amount of precipitation, and the probabilities are standardized so that an index of zero indicates the median precipitation amount (half of the historical precipitation amounts are below the median, and half are above the median). The index is negative for drought, and positive for wet conditions. As the dry or wet conditions become more severe, the index becomes more negative or positive. The SPI is computed by the NOAA National Climatic Data Center (NCDC) for several time scales, ranging from one month to 24 months, to capture the various scales of both short-term and long-term drought. The Colorado Climate Center describes the SPI as valuable in monitoring both wet and dry periods, and it can be applied to other types of data (e.g. streamflow, reservoir levels, etc.). 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% would be expected to be drier. An index value of -2 means severe drought with only 2.5% of years expected to be drier.

A 12-month SPI is used for the Intermountain West region (Figure 7) and compares precipitation patterns for 12 consecutive months with the same 12 consecutive months during all the previous years of available data. The SPI at these time scales reflect long-term precipitation patterns. The graphic in Figure 7 comes from the Western Regional Climate Center, which uses data from the NCDC and the NOAA Climate Prediction Center.

+3.00 and above	Exceptionally Wet
+2.00 to +2.99	Extremely Wet
+1.25 to +1.99	Very Wet
+0.75 to +1.24	Moderately Wet
-0.74 to +0.74	Near Normal
-1.24 to -0.75	Moderately Dry
-1.99 to -1.25	Very Dry
-2.99 to -2.00	Extremely Dry
-3.00 and below	Exceptionally Dry

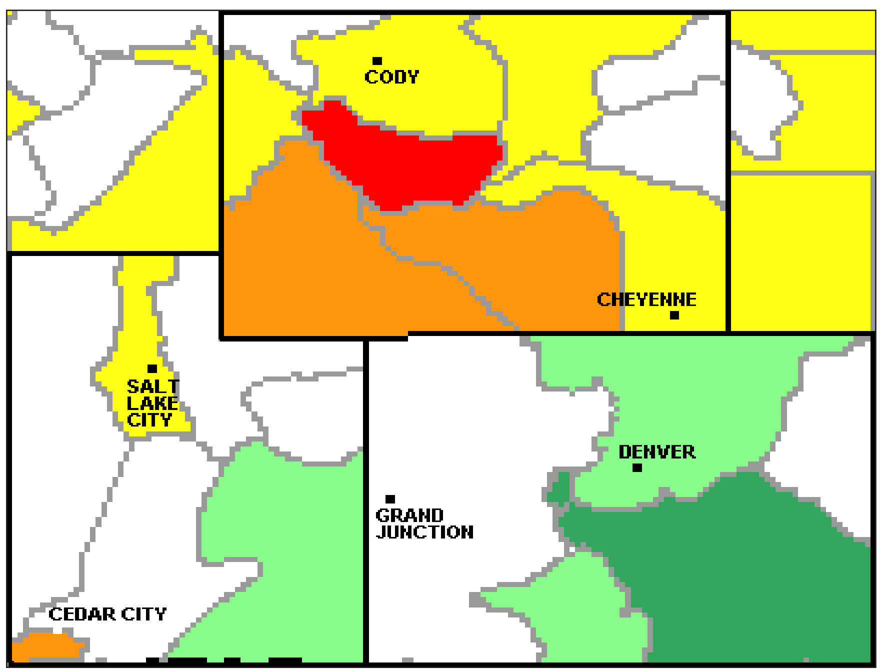


Figure 7. 12-month Intermountain West regional Standardized Precipitation Index (data through 4/30/07).

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.
- For SPI products directly form the NCDC, visit: http://lwf.ncdc.noaa.gov/oa/climate/research/prelim/drought/spi.html. These maps use the same data as Figure 7, but the categories are defined slightly differently.

Colorado Water Availability

Below average snowfall in April caused snowpack percent of averages to decline in all basins except the Upper South Platte, the Upper Rio Grande, and a tributary of the Arkansas River, leaving many basins with similar or worse water supply conditions. SWE percentages are highest along the northern Continental Divide, ranging from 100-160% of average (Figure 8a). At 88% of average snowpack on May 1, the Arkansas Basin is the only basin in the state to increase snowpack levels, up from 81% of average on April 1. However, many regions west of the Continental Divide have below or well below average SWE, ranging from 1-79% of average.

Statewide SWSI values range from a high of 1.1 in the South Platte Basin to a low of -3.0 in the White and Yampa Basins (Figure 8b). The Yampa, White, and North Platte basins also had the lowest precipitation in April, 66% of average. Aside from the South Platte basin, the Rio Grande basin is the only one with a positive SWSI value. Note that the SWSI is calculated a little differently from May – October than from November – April. SWSI takes reservoir storage into account in the spring and summer and takes snowpack into account in the fall and winter. Please see the Notes section for a more detailed explanation.

For more information on snowpack levels and streamflow forecasts across the Intermountain West, visit pages 10 and 20.

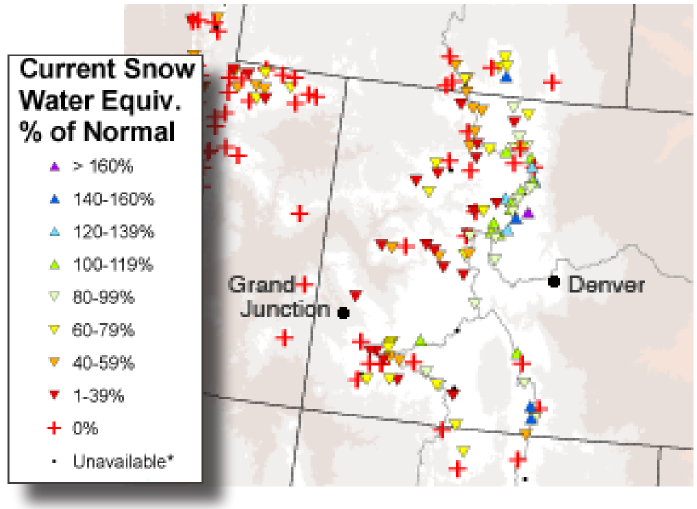


Figure 8a. Current snow water equivalent (SWE) as a percent of normal for SNOTEL sites in Colorado as of May 1, 2007, courtesy NRCS. Note: this is provisional information.

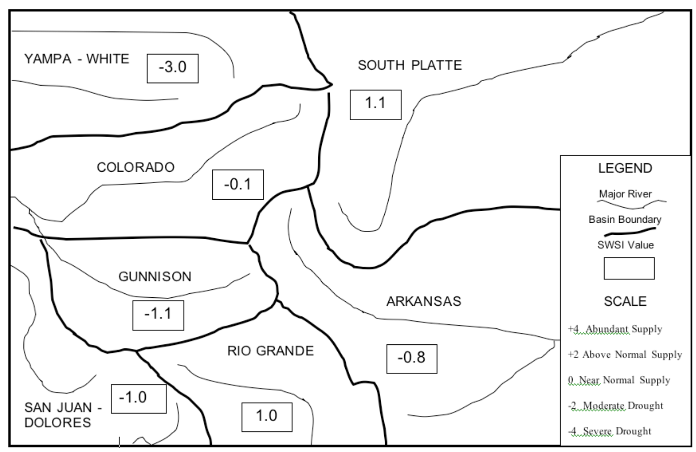


Figure 8b. Colorado Surface Water Supply Index. The map is an indicator of mountain-based water supply conditions in the major river basins of the state as of May 1, 2007.

Notes

Figure 8a is the SWE as a percent of normal (average) for SNOTEL sites from the NRCS. The Surface Water Supply Index (SWSI-Figure 8b), developed by the Colorado Office of the State Engineer and the USDA Natural Resources Conservation Service, 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 streamflow, reservoir storage, and precipitation for the summer period (May - October). This differs from winter calculations that use snowpack as well. During the summer period, streamflow is the primary component in all basins except the South Platte Basin, where reservoir storage is given the most weight. The SWSI values in Figure 8b were computed for each of the seven major basins in Colorado for May 1, 2006, and reflect conditions through the month of April 2006.

On the Web

- For current maps of SWE as a percent of normal as shown in Figure 8a, visit: http://www.wcc.nrcs.usda.gov/gis/snow.html and select the desired state using the embedded scroll bar.
- For current SNOTEL data and plots of specific sites, visit: http://www.wcc.nrcs.usda.gov/snotel/.
- For current graphs of SWE projections as a percent of normal as seen in Figure 8b, visit http://www.co.nrcs.usda.gov/snow/snow/watershed/current/daily/maps_graphs/swe_projections.html and click on desired basin or statewide graph.
- The Colorado SWSI, along with more data about current water supply conditions for the state can be found at: http://www.co.nrcs.usda.gov/snow/index.html.
- For monthly reports on water supply conditions & forecasts for major CO river basins, visit: http://www.wcc.nrcs.usda.gov/cgibin/bor.pl.
- Water Supply Outlook information for the Upper Colorado River Basin, produced by the Colorado Basin River Forecast Center, is available at: http://www.cbrfc.noaa.gov/wsup/wsup.cgi.
- For current streamflow information from USGS, visit: http://water.usgs.gov/waterwatch/.

Wyoming Water Availability

Precipitation for April was below average across most of Wyoming (see page 8), and Wyoming's SNOTEL data shows that as of May 1, 2007, the SWE is below average throughout most of the state (Figure 9a). In the western mountains, many SNOTEL sites are now at 40-59% of average with some in the Snake, Wind River basins at 1-39%. In the north central mountains, several SNOTEL sites are reporting closer to average, with a few sites in the 60-79% of average range. The only basin reporting above average is one site in the southern mountains, but this might be due to a mistake in the data. Other SWE reports in the southern mountains are generally in the 60-79% range.

Streamflow is expected to be below average across Wyoming. Most probable yield for the entire State of Wyoming is forecast to be at 61% (varying from 26-91% of average). According to the Drought Monitor, Wyoming is still facing drought conditions. Most of the state remains under drought status ranging from severe in the southwest to abnormally dry in the north-central region. (See page 9 for the Drought Monitor graphic.) The state's drought status is also evident in the current SWSI map from NRCS (Figure 9b). Almost all basins have negative SWSI values. The Big Sandy basin (-4.70) has the lowest numbers, and is in the extreme drought category. Lower North Platte (-3.28), Wind River (-3.21) and the Upper Green (-3.15) basins are in a severe drought category.

For more information on snowpack levels and streamflow forecasts across the Intermountain West, visit pages 10 and 20.

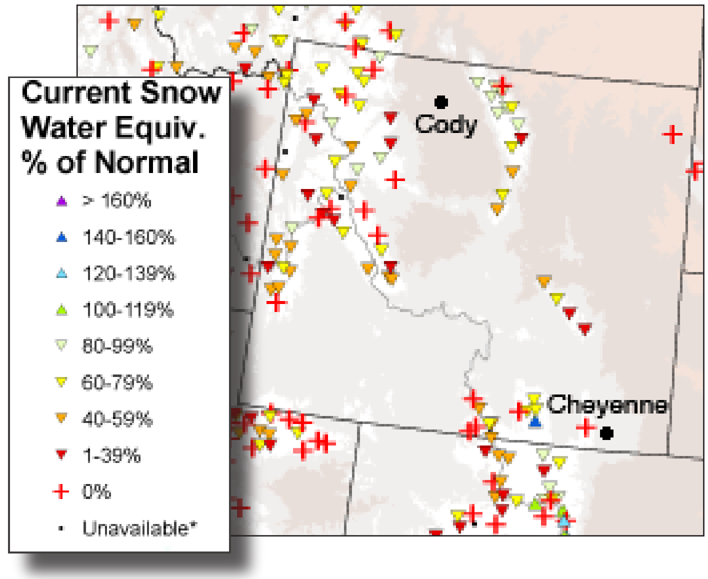


Figure 9a. Current snow water equivalent (SWE) as a percent of normal for SNOTEL sites in Wyoming as of May 1, 2007, courtesy of NRCS. Note: this is provisional data.

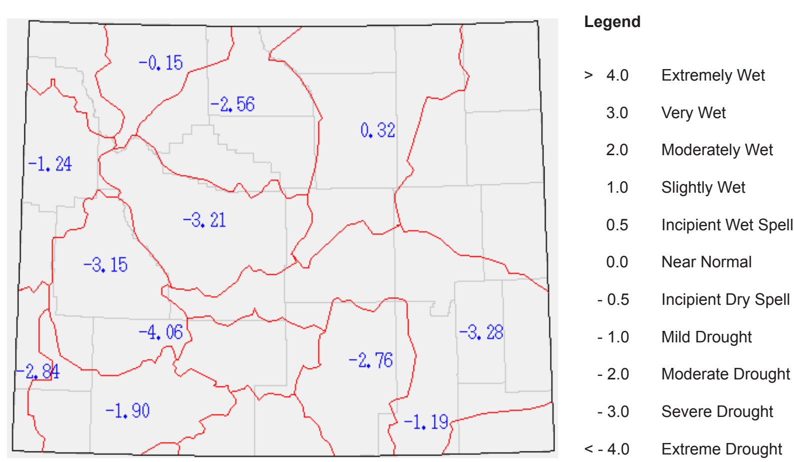


Figure 9b. Wyoming Surface Water Supply Index (data through 05/01/07) courtesy of NRCS and Water Resources Data System (WRDS) of Wyoming.

Notes

Figure 9a shows the SWE as a percent of normal (average) for SNOTEL sites in Wyoming, courtesy of the Natural Resources conservation Service (NRCS). According to the WY NRCS, "The Surface Water Supply Index (SWSI) (Figure 9b) 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."

On the Web

- For current maps of SWE as a percent of normal as shown in Figure 9a, visit: http://www.wcc.nrcs.usda.gov/gis/snow.html.
- For current SNOTEL data and plots of specific sites, visit: http://www.wcc.nrcs.usda.gov/snotel/.
- The Wyoming SWSI, along with more data about current water supply conditions for the state can be found at: http://www.wrds.uwyo.edu/wrds/nrcs/nrcs.html.
- For monthly State Basin Outlook Reports on water supply conditions and forecasts for WY river basins, visit: http://www.wcc.nrcs.usda.gov/cgibin/bor.pl.
- Wyoming Water Resource Data system's drought page is located at: http://www.wrds.uwyo.edu/wrds/wsc/dtf/drought.html.

Utah Water Availability

According to the NWS Salt Lake City, April 2007 was warmer and drier than average. As of May 1, 2007, all of Utah's SNOTEL sites report below average SWE (Figure 10a). The NRCS Utah Basin Outlook for May 1 reported that with record or near record low snowpacks in March, and accelerated melt in April, snowpack now ranges from 3% of average over southeast Utah to 33% of average on the Bear River, with many stations already melted out. Snowmelt streamflows are expected to have a wide range from much below average to near average across the state.

Below average snowfall in March and April contributed to the state having below average SWSI numbers (Figure 10b). The lowest values are in the San Rafael (-3.59) and Weber (-3.35) basins. The highest values are in the West Unitah Basin (0.83). Other values that are close to average, but still negative are the Provo (-0.67) and both Sevier (-0.16) (-0.43) basins. Despite low SWSI numbers, the NRCS reports that storage in 41 of Utah's key irrigation reservoirs is at 75 % of capacity up 1% from last month. This is an increase of 2% from last year.

For more information on snowpack levels and streamflow forecasts across the Intermountain West, visit pages 10 and 20.

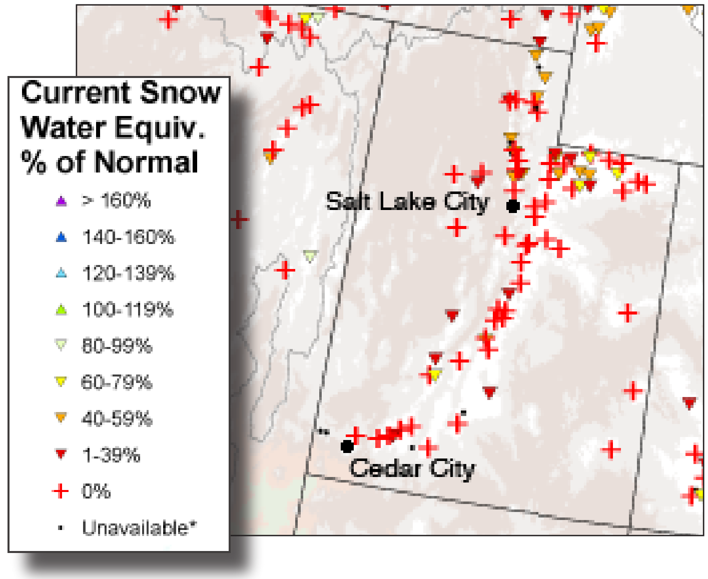


Figure 10a. Current snow water equivalent (SWE) as a percent of normal for SNOTEL sites in Utah as of May 1, 2007, courtesy of the NRCS. Note: this is provisional data.

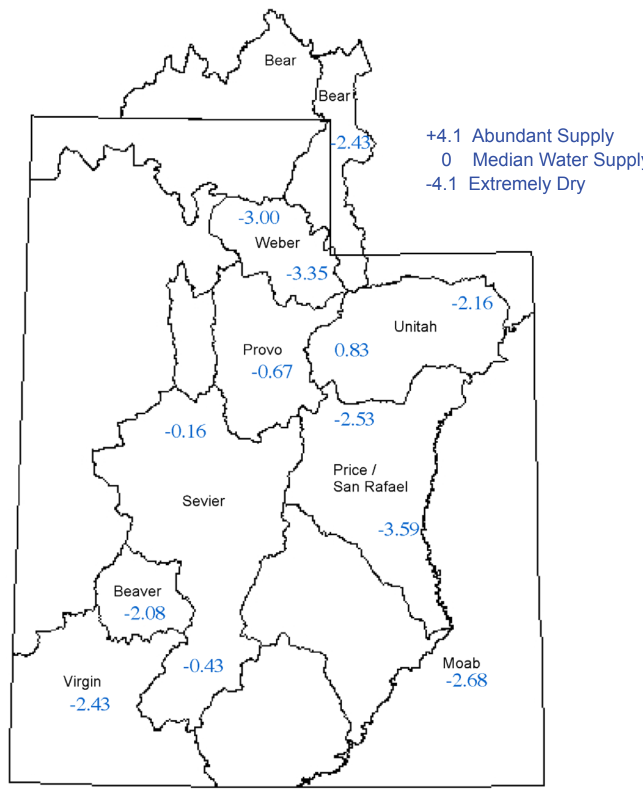


Figure 10b. Utah Surface Water Supply Index (data through 5/1/07). Maps are courtesy of Utah NRCS.

Notes

Figure 10a shows the SWE as a percent of normal (average) for SNOTEL sites in Utah, courtesy of the Natural Resources Conservation Service (NRCS). 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 11 for the SPI.

On the Web

- For current maps of SWE as a percent of normal as shown in Figure 10a, visit: http://www.wcc.nrcs.usda.gov/gis/snow.html.
- For current SNOTEL data and plots of specific sites, visit: http://www.wcc.nrcs.usda.gov/snotel/.
- The Utah SWSI, along with more data about current water supply conditions for the state can be found at: http://www.ut.nrcs.usda.gov/snow/watersupply/.
- For monthly reports on water supply conditions & forecasts for major CO river basins, visit: http://www.wcc.nrcs.usda.gov/cgibin/bor.pl.
- Water Supply Outlook information for the Upper Colorado River Basin, produced by the Colorado Basin River Forecast Center, is available at: http://www.cbrfc.noaa.gov/wsup/wsup.cgi.

Temperature Outlook June - October 2007

The NOAA/CPC temperature outlook for June 2007 indicates an increased risk of above average temperatures across **Utah**, western **Colorado** and **Wyoming**, and the Rio Grande Valley (Figure 11a). This forecast is based on climate models as well as long-term trends. In the June-August 2007 and subsequent forecast periods, areas with probabilities for above average temperatures include most or all of the Intermountain West and the Southwest (Figure 11b-d). The IRI multi-model world temperature forecast also indicates a slightly increased risk for above average temperatures across much of the region in its June-August 2007 forecast period (not shown, see On the Web box).

CPC does not expect any El Niño or La Niña impacts on the climate of the United States during the June-August 2007 season. La Niña may become a factor in fall forecasts for some regions of the U.S., but should not have a significant impact on the temperature of the Intermountain West. An updated June 2007 temperature forecast will be available on May 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 11a-d predict the likelihood (chance) of temperatures occurring in the above-average, near-average, and below-average categories. The numbers on the maps do not refer to actual temperature values, but to the probability in percent that temperatures will be in one of these three categories.

The NOAA-CPC outlooks are a 3-category forecast based largely on the status of ENSO and recent trends. As a starting point, the 1971-2000 climate record for each 1 or 3 month period is divided into 3 categories (terciles), indicating the probabilities that the temperature in the period will fall into the upper third of the years (upper tercile), the middle third of the years (middle tercile, or around average), or the lowest third of the years (lower tercile). The forecast indicates the likelihood of the temperature being in the above-average (A) or below-average (B) tercile--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, see notes on the precipitation outlook page.

Equal Chances (EC) indicates areas for which the models do not have sufficient skill to 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.

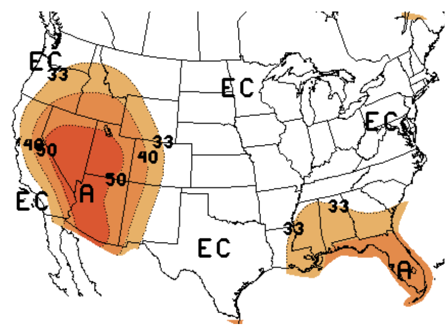


Figure 11a. Long-lead national temperature forecast for June 2007 (released May 17, 2007).

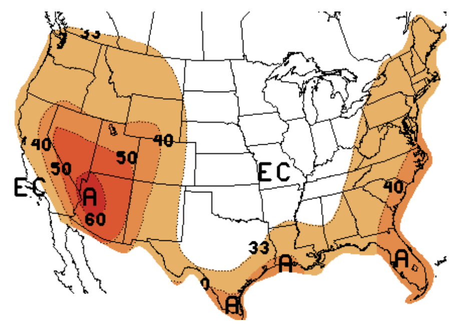


Figure 11b. Long-lead national temperature forecast for June – August 2007 (released May 17, 2007).

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

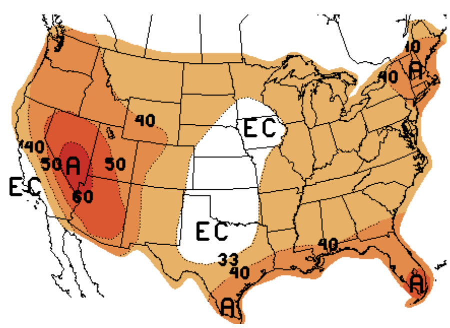


Figure 11c. Long-lead national temperature forecast for July – September 2007 (released May 17, 2007).

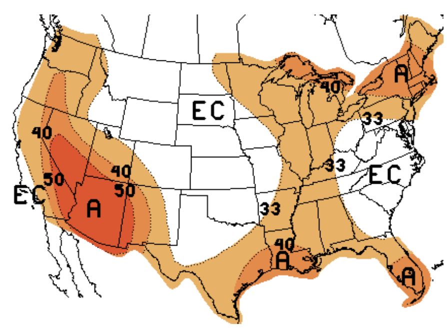


Figure 11d. Long-lead national temperature forecast for August – October 2007 (released May 17, 2007).

On the Web

- For more information and the most recent forecast images, visit: http://www.cpc.ncep.noaa.gov/products/predictions/90day/. 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 May - August 2007

The NOAA/CPC forecasts issued May 17th indicate "EC" or "equal chances" of above-average, near-normal or below-average precipitation for much of the region for the June 2007 and subsequent forecast periods through the summer and fall (Figures 12a-c). However, there is an increased chance of below average precipitation in the northern Great Basin, including all of **Utah** in June, which continues for parts of **Utah** in subsequent forecast periods. For June, the NOAA "Climate Forecast System" (CFS) model indicates dry conditions for the Great Basin and Pacific Northwest, and hints that cool SSTs in the eastern equatorial Pacific may play a role in favoring dry conditions in this region as well. Soil moisture conditions are somewhat drier than normal in parts of the northern Great Basin and this also favors increased chances of below median precipitation. However, CPC says their confidence is not very high, because most precipitation variability is associated with day-to-day weather events not predictable beyond a week or so in advance.

According to Klaus Wolter, who creates experimental forecast guidance for precipitation for the southwest (not shown, see On the Web box), the forecast for the July-Sep 2007 is "mild" for much of the interior southwestern U.S., with no significant tilts towards dry or wet conditions. He says, "most of New Mexico and the northern Front Range in **Colorado** are more likely to see a dry summer, while Arizona appears more likely to receive above-average moisture. If La Niña were to take hold soon, a dry and hot summer would be slightly more likely than not in much of **Colorado**, **Utah**, and New Mexico."

An updated June 2007 precipitation forecast will be issued May 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 12a-c predict the likelihood (chance) of precipitation corresponding to the above-average, near-average, and below-average categories. The numbers on the maps refer not to amount of precipitation, but rather to the probability in percent that precipitation will be in one of these three categories.

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 1 or 3 month period is divided into 3 categories (terciles), indicating the probabilities that the temperature in the period will fall into the upper third of the years (upper tercile), the middle third of the years (middle tercile, or around average), or the lowest third of the years (lower tercile), 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 occurring in the 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, areas with dark brown shading in the precipitation outlook indicate a 40.0-50.0% chance of below-average, a 33.3% chance of near-average, and a 16.7-26.6% chance of above-average precipitation. Light brown shading displays a 33.3-39.9% chance of below-average, a 33.3% chance of near-average, and a 26.7-33.3% chance of above-average precipitation and so on. Green shading indicate areas with a greater chance of above average precipitation.

Equal Chances (EC) indicates areas for which the models cannot predict the precipitation 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.

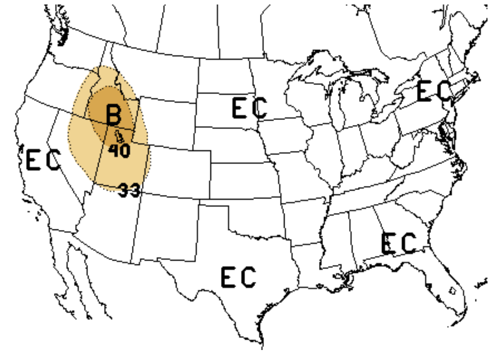


Figure 12a. Long-lead national precipitation forecast for June 2007 (released May 17, 2007).

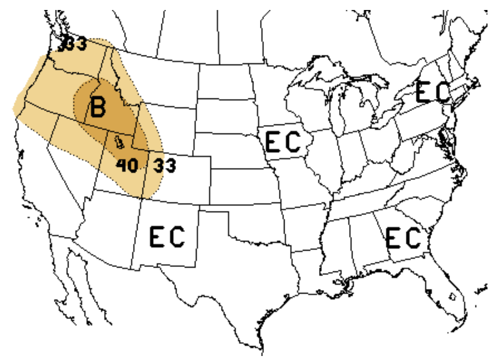


Figure 12b. Long-lead national precipitation forecast for June – August 2007 (released May 17, 2007).

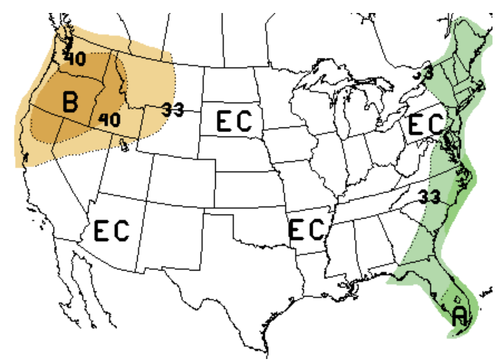


Figure 12c. Long-lead national precipitation forecast for July – September 2007 (released May 17, 2007).

A = Above
40.0–49.9%
33.3–39.9%

B = Below
40.0–49.9%
33.3–39.9%

EC = Equal Chances

On the Web

- For more information and the most recent CPC forecast images, visit: http://www.cpc.ncep.noaa.gov/products/predictions/90day/. 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.
- The Experimental Guidance Product, including a discussion and executive summary, is available at: http://www.cdc.noaa.gov/people/klaus.wolter/SWcasts/index.html.

Seasonal Drought Outlook through August 2007

In June, the Climate Prediction Center (CPC) will increase the frequency of scheduled issuances of the U.S. Drought Outlook (DO). Currently the DO is issued once a month on the 3rd Thursday of each month with a valid period of approximately 3 1/2 months after issuance. Beginning on June 7th, CPC will also issue the DO on the first Thursday of the month with a valid time covering the rest of the month plus the next two months (i.e. just under three months after issuance). This will provide an improved and more consistent level of service; more information on the change in service is available on the DO webpage.

The current DO depicts general, large-scale trends from that date through the end of August 2007 (3.5 months), and is developed by experts based on their subjective judgement of various forecasts (Figure 13). Forecasters predict that the area of drought that extends from California into the Great Basin (including **Utah**, western **Colorado**, and **Wyoming**) is going into the dry season, so little lasting relief is expected in this region. The summer thunderstorm season running from July into September should bring some relief to Arizona. Drought is expected to persist in **Wyoming**, and western Nebraska.

Notes

The delineated areas in the Seasonal Drought Outlook produced by the NOAA Climate Prediction Center (Figure 13) are defined subjectively and are based on expert assessment of numerous indicators, including outputs of short- and long-term forecasting models. Areas of continuing drought 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.

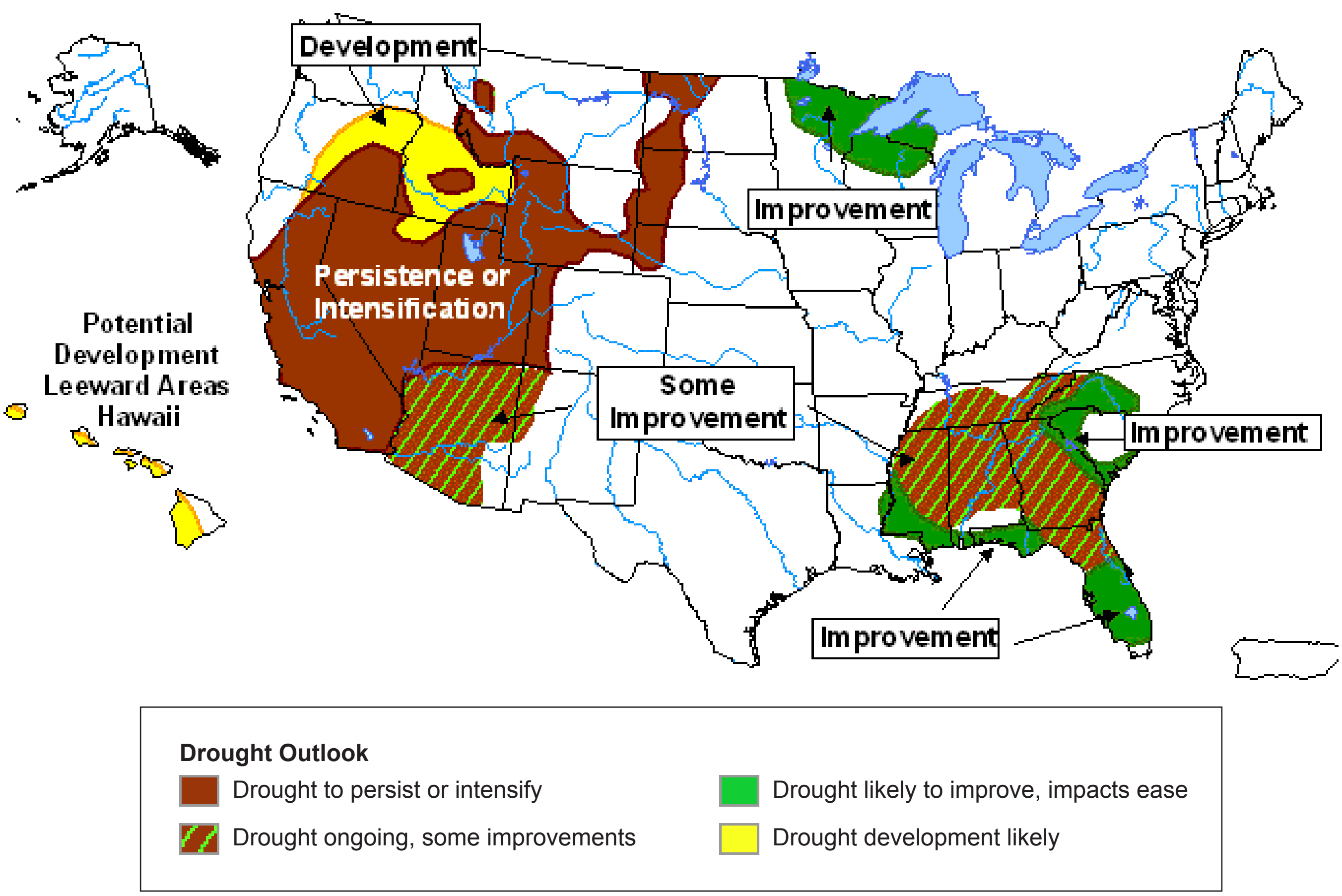


Figure 13. Seasonal Drought Outlook through August 2007 (release date May 17, 2007).

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 May 2007

Both the NOAA CPC and the International Center for Climate and Society (IRI) indicate that the pattern of sea surface temperatures (SSTs) during April 2007 was consistent with ENSO-neutral conditions in the tropical Pacific, with average to slightly below-average SSTs extending from the mid-pacific (180°W, the "date line") to the west coast of South America (Figure 14a).

As of mid-May, conditions in the tropical Pacific suggest that a La Niña – anomalously cool conditions in the eastern equatorial Pacific – may develop within the next 2-3 months (Figure 14b). Equatorial sea surface temperatures (SSTs) are much below average in the eastern Pacific and along the coast of Peru, and the upwelling currents – forced by anomalously strong easterly winds – in the eastern equatorial Pacific are bringing colder than average waters to the surface. However, the Southern Oscillation Index (SOI), an atmospheric pressure indicator of ENSO events, is still slightly negative and thus does not yet indicate development of La Niña conditions.

According to the IRI, model forecasts and current observations of the ocean surface and subsurface indicate the probability of a La Niña is 55% from the coming May-Jul season through Sep-Nov 2007. The probability of El Niño conditions re-emerging during the forecast period remains at or below 5%. The probability of maintaining ENSO-neutral conditions is below 50% probability, until late-2007. No significant ENSO impacts are anticipated on the climate of the U.S. during the June-August 2007 season. However, weak La Niña conditions are factored into the forecasts for the late fall and winter. The CPC ENSO Diagnostic Discussion will be updated on June 7th.

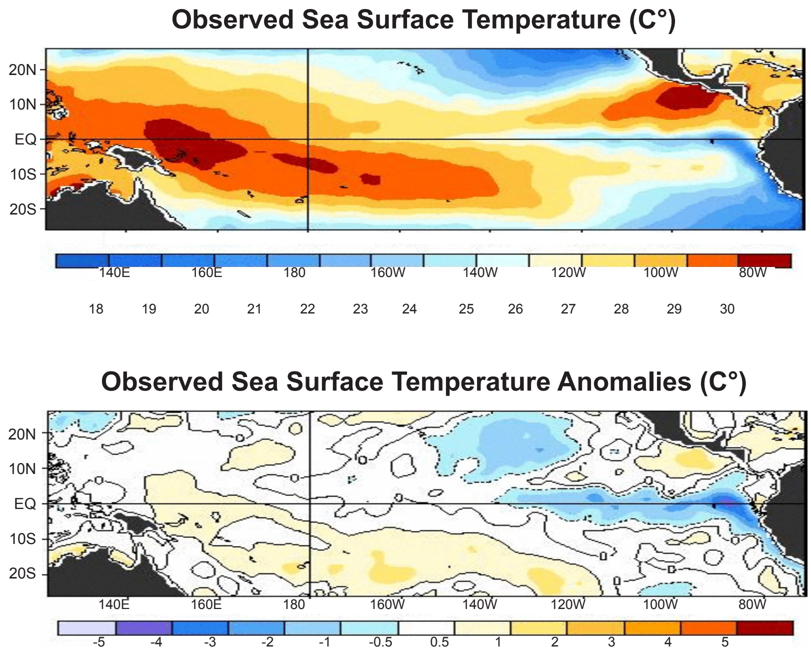


Figure 14a. Observed SST (upper) and the observed SST anomalies (lower) in the Pacific Ocean. The Niño 3.4 region encompasses the area between 120˚W-170˚W and 5˚N-5˚S. The graphics represent the 7-day average centered on May 9, 2007.

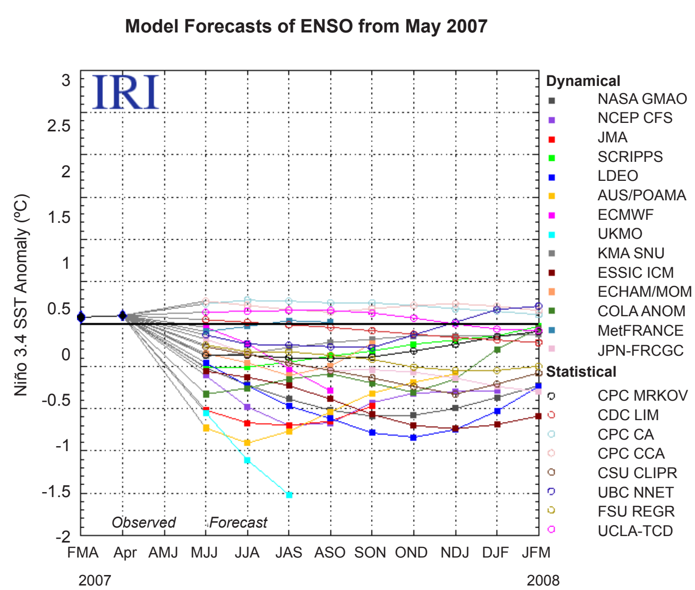


Figure 14b. Forecasts made by dynamical and statistical models for sea surface temperatures (SST) in the Niño 3.4 region for nine overlapping 3-month periods from May 2007 through March 2008 (released May 17, 2007). Forecast graphic is from the International Research Institute (IRI) for Climate and Society.

Notes

Two NOAA graphics in Figure 14a show the observed SST (upper) and the observed SST anomalies (lower) in the Pacific Ocean. Data are from the TOGA/TAO Array of 70 moored buoys spread out over the Pacific Ocean, centered on the equator. The buoys measure temperature, currents, and winds and transmit data in real-time. NOAA uses these observations to predict short-term (a few months to one year) climate variations.

Figure 14b shows forecasts for SST in the Niño 3.4 region for nine overlapping 3-month periods from May 2007 through March 2008. "Niño 3.4" refers to the region of the equatorial Pacific from 120°W to 170°W and 5°N to 5°S, which is used as an index for defining ENSO sea surface temperature anomalies. Abbreviations represent groups of three months (e.g. SON = Sept-Nov). Note that the expected skills of the models, based on historical performance, vary among the models, and skill generally decreases with lead-time. Forecasts skill also varies over the year because of seasonal differences in predictability of the system, for example, forecasts made between June and December are generally better than between February and May. Differences among forecasts 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 Niño 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 Niño, including the most recent forecasts, visit: http://iri.columbia.edu/climate/ENSO/.

Spring and Summer Streamflow Forecasts for the 2007 runoff Season

Due largely to below average snowpack conditions, spring and summer streamflow forecasts are below average for the Intermountain West Region (Figure 15). The highest streamflows (90-109% of average) are forecasted for parts of the South Platte, Arkansas, and Upper Colorado basins in **Colorado**. Elsewhere in **Colorado**, the NRCS forecasts below average streamflow volumes for nearly the entire state. The lowest forecasted volumes (50 - 60% of average) are in parts of the Yampa, Gunnison and Dolores basins.

Utah has some of the lowest forecasted streamflow volumes. Forecast streamflows range from 1% on North Creek near Monticello to 60% of average for Little Cottonwood Creek. Most basins have forecasts of 30 - 50% of average. The NRCS warns that reduced streamflows in **Utah** might contribute to an earlier and longer fire season, reduced forage production, agricultural and forest stress, and any number of other drought related impacts.

Wyoming streamflow forecasts are below average across most of the state, ranging from below 25% to 109% of average. The lowest forecasts as a percent of average are in the upper North Platte, the Green, and the Little Snake River basins (below 25% of average). The highest forecast is for the Tongue River basin (90-109% of average).

At this time of year, any significant improvements to these volumes are unlikely in the Intermountain West Region. Certainly a cool and wet spring will benefit water users and extend the melt into the later summer season.

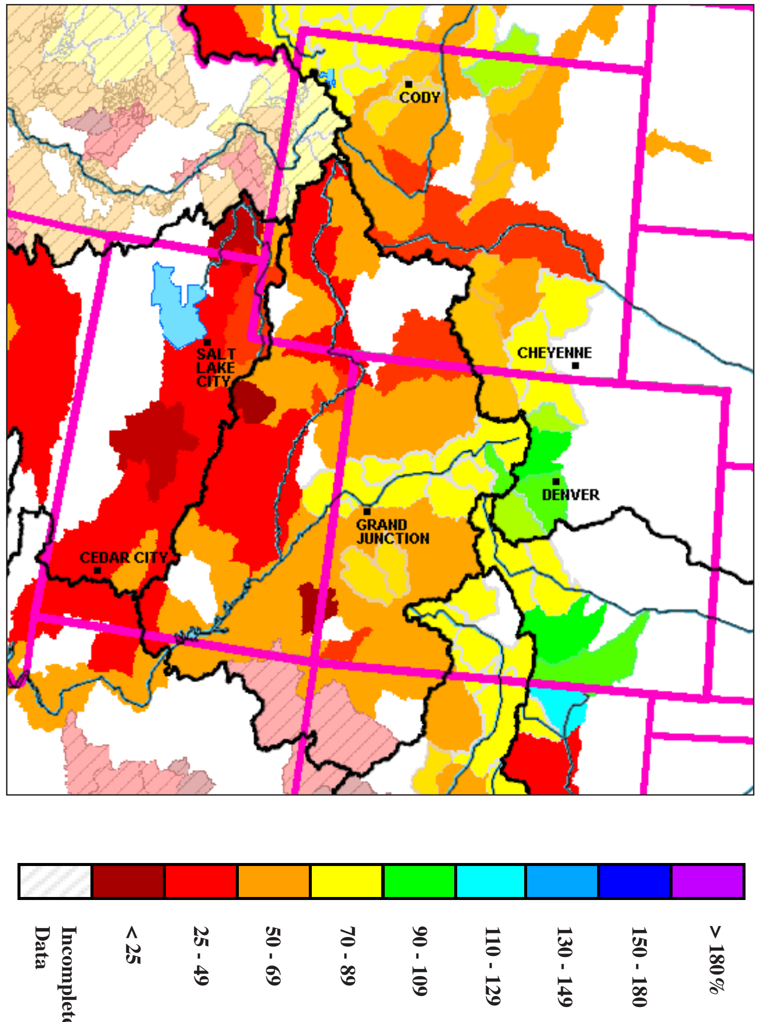


Figure 15. NRCS outlook for natural streamflows for spring and summer in the Intermountain West region as a percent of average streamflows (data through May 1, 2007 courtesy of Natural Resources Conservation Service).

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 15). 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/
- The NOAA CBRFC has a new interactive website that shows streamflow forecasts as inputs to reservoirs: http://www.cbrfc.noaa.gov/westernwater/.

New National Weather Service Western Water Supply Forecast Services

By Christina Alvord of Western Water Assessment and Kevin Werner of the NWS Water Resources Hydrology Science Program

Seasonal runoff volume forecasts are a coordinated effort between the NWS, the NRCS, US Bureau of Reclamation, USGS, and other state and local water agencies. These forecasts provide water managers, farmers, and outdoor enthusiasts with projections of natural streamflow volumes useful for water management, seasonal planning, and drought forecasting. NOAA/NWS recently debuted a website that consolidates all water supply forecasts onto a common map with site-specific forecast tools and information (See On the Web Box). This article gives an overview of the forecast methodology, various features on this website, and general tips on how to navigate through the website.

Forecasts of natural flows are made on the first of each month from January – June for the total runoff volume of the runoff season (usually April – July) for several hundred gauged points. Most stream gauges do not reflect natural flow because upstream diversions reduce the natural flow. Before they can forecast natural flows, forecasters must first reconstruct them by adjusting the observed regulated flows by all known upstream allocations to get a close approximation of streamflow volumes absent known water diversions. Forecasters model the relationship between the reconstructed natural runoff and observable hydrologic parameters (i.e. snowpack, precipitation and soil moisture) in order to forecast natural flows for the runoff season. Forecasts are adjusted as hydrologic and climate conditions change throughout the winter and spring. For example, as we move into the 2007 runoff season, temperatures and precipitation amounts will largely shape the rate and timing of snowmelt and the remainder of the seasonal runoff volume forecasts.

On the new NOAA/NWS website, users can zoom into a desired region, customize data input layers shown, and view site-specific runoff forecast information including individual forecast plot graphs. While this map displays the common forecasts of all agencies involved, different forecast points used by various forecast agencies account for the difference in shading extrapolation and percent of average range categories in this map. (In comparison to other streamflow forecast maps from the NRCS as shown on page 20.) The **map** of seasonal runoff volume forecasts (Figure 16a) shows color-coded percent of average seasonal runoff volume forecasts. Percent of average runoff volume projection categories range from below 70% to above 130%

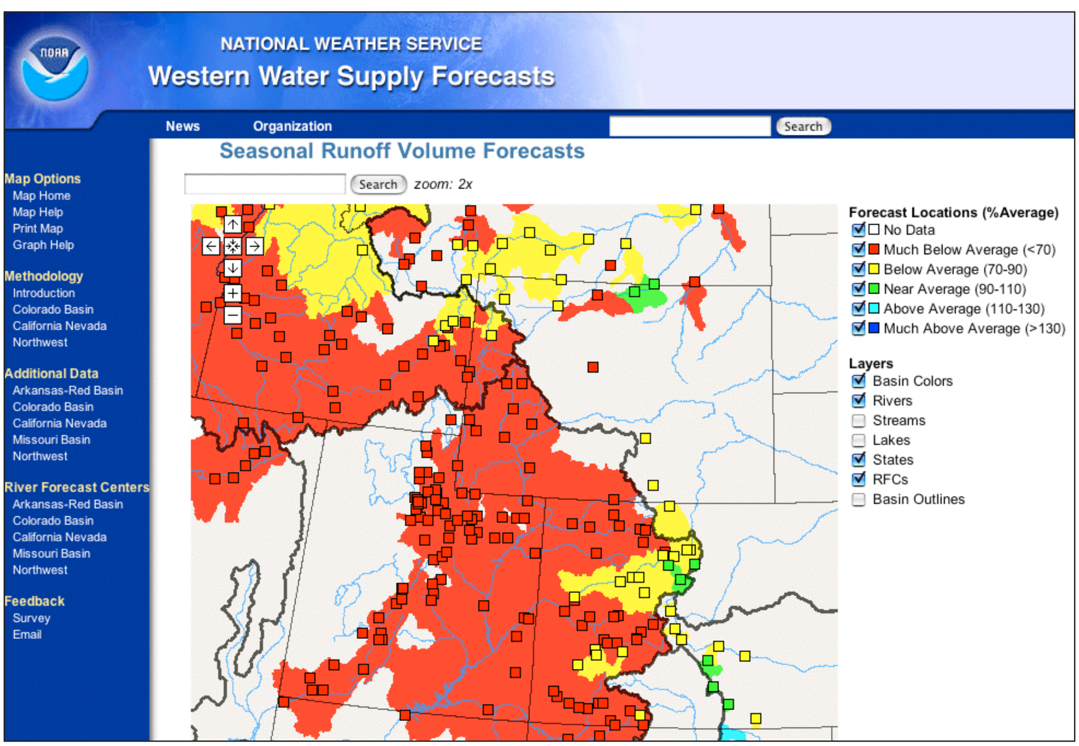
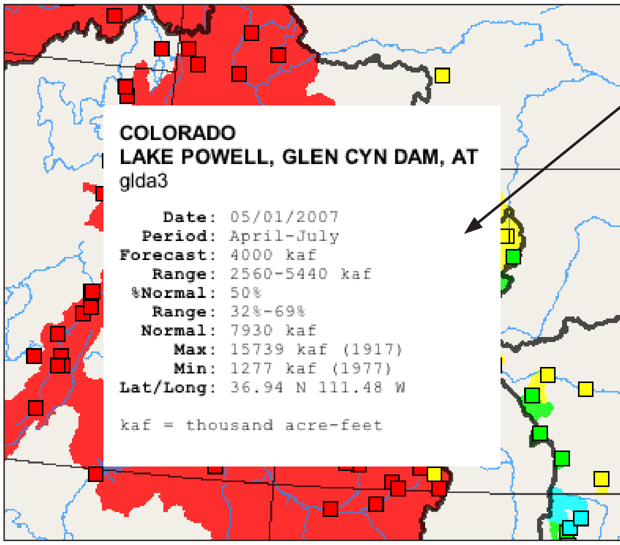


Figure 16a. New NOAA/NWS seasonal runoff volume forecast map for the western US as a percent of average. Zoomed in from map on homepage (www.cbrfc.noaa.gov/westernwater). (Data though May 1, 2007.)



Description of Box
Date: Forecast issue date
Period: Time period of forecasted total runoff volume.
Forecast: 50% exceedence projection of total runoff volume for the period.
Range: The range of runoff volume projections between the 90% and 10% exceedence probabilities.
%Normal: 50% exceedence projection expressed as a percent of normal (average).
Range: The range of runoff volume projections between the 90% and 10% exceedence probabilities expressed as percent of normal (average).
Normal: The historic average total runoff volume for the period.
Max: Based on historic data, maximum total runoff volume for the period, followed by the year it occurred.
Min: Based on historic data, minimum total runoff volume for the period, followed by the year it occurred.
Lat/Long: Location of the forecast point.

Figure 16b. Detailed forecast information provided by NOAA/NWS at Glen Canyon Dam. To see this from map in Figure 16a, place cursor over desired forecast location box to retrieve site-specific forecast information. (Data through May 1, 2007.)

of average with 20% increments between each category. Water supply forecasts are made only for gauged basins with potentially significant amounts of snow melt. Boxes on the right side of the graph under the "Layers" heading allow users to add or remove map content including lakes, streams, state lines, and smaller river basin outlines.

Specific forecasts can be obtained by clicking on the map or using the search button query to zoom into or locate desired region. Click on the map to zoom into desired region, and place the cursor over the **forecast location box** to show forecast information including forecast period, issuance date, and the range of forecasts between the 90 - 10% exceedence probabilities as a percent of average and in 1000 acre feet (kaf) (Figure 16b). Historical mean, maximum, and minimum flow periods are also included. Forecast periods depend on basin climatology and user requirements. In general, forecast periods are April – July, but may be April - September in more northerly basins.

The current **forecast evolution** is displayed in graphical format by clicking on a forecast location box (Figure 16c). These plot graphs allow users to compare observed and forecasted streamflow volumes for the current water year with normal (average) flows broken down monthly or as total volume accumulation. The most probable forecasts (50% exceedence probability) for the current water year are displayed on the forecast plot as red circles. They are positioned as a function of their issuance date, allowing the forecast user to easily see the evolution of the current forecast. The range of forecasts between the 90 - 10% exceedence probabilities is displayed by the red triangles and the red vertical lines above and below the red circles. Users can customize plots by adding or removing content to suit their needs.

Development continues on this website and in the coming months and years, several improvements are planned:

- **Forecast Evaluation Tool:** A forecast evaluation tool will be available on line later this year. This tool will access a large archive of forecasts and forecast tools and allow users to assess forecast skill through a variety of methods.

- **NWS Ensemble Streamflow Predictions:** Users will be able to access forecasts directly from the NWS ensemble streamflow prediction (ESP) system. ESP leverages the NWS continuous hydrologic model for forecasting capabilities. Initial plans will allow users access to ESP forecasts for the specified water supply forecast periods. However, in 2008, users will increasingly be able to customize forecast information from ESP for runoff volumes from a user definable forecast window, time to peak flows, and a wide variety of new information.

• **Water Resources Information:** Information beyond the traditional scope of water supply forecasts is being considered for addition to the website in future years. This information may include soil moisture, snow pack, and climate signals.

NOAA/NWS is looking for feedback. Please take a minute and take the survey located under the "Feedback" navigation bar located on the left side of the website.

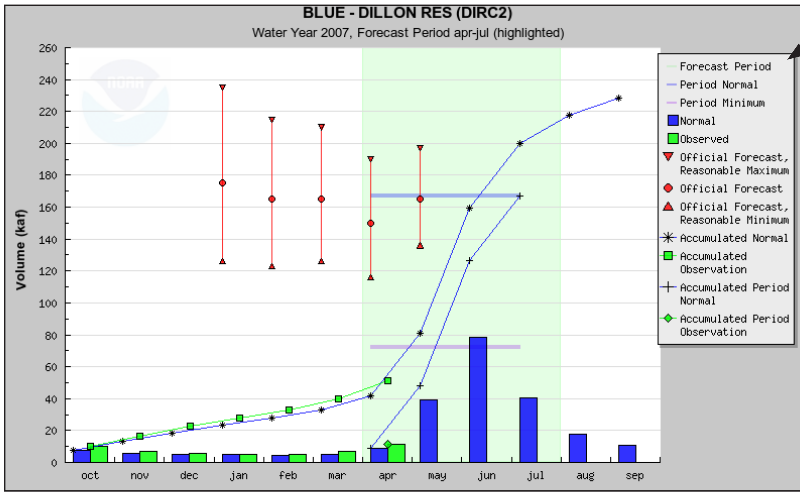


Figure 16c. Streamflow volume (kaf) forecast graph for inflow into Dillon Reservoir, generated by the NOAA/NWS. (Data through May 1, 2007.) The evolution of seasonal volume forecasts issued is shown in red vertical lines on the graphs. For inflow into Dillon Reservoir in northern Colorado, near average snowpack coupled with warm temperatures has resulted in a slight reduction of April-July streamflow volume forecasts since the first forecast was issued in January.

Description of Key

Forecast Period: Forecast is for the total runoff volume occurring in this time period. Highlighted in pale green.
Period Normal: Average total runoff volume in kaf for the forecast period on historic data. Highlighted as horizontal blue line within shaded forecast period.
Period Minimum: Minimum total runoff volume in kaf for the forecast period based on historic data. Highlighted as horizontal pink line within in the shaded forecast period.
Normal: Average total monthly runoff volumes in kaf. Shown as vertical blue bars.
Observed: Observed total monthly runoff volumes in kaf for current water year. Shown as vertical green bars.
Official Forecast, Reasonable Maximum: Official maximum forecast in kaf based on a 10% exceedence probability. Shown as downward-pointing red triangle in the month in which the forecast was made.
Official Forecast: Official most probable forecast in kaf based on a 50% exceedence probability. Shown as a red circle in the month in which the forecast was made.
Official Forecast, Reasonable Minimum: Official minimum forecast in kaf based on a 90% exceedence probability. Shown as upward-pointing red triangle in the month in which the forecast was made.
– Note that the progression of these red official forecast lines shows how the forecast evolves as the winter and spring progresses.
Accumulated Normal: Accumulated monthly average runoff volumes for each month starting at the beginning of the water year, October 1. Shown as a blue line with stars.
Accumulated Observation: Accumulated observed monthly runoff volumes starting at the beginning of the water year, October 1. Shown as a green line with green boxes.
Accumulated Period Normal: Accumulated monthly average runoff volumes for each month starting at the beginning of the forecast period. Shown as a blue line with plus signs.
Accumulated Period Observation: Accumulated observed monthly runoff volumes for the forecast period. Shown as a green line with green diamonds.

On the Web

- The new NOAA/NWS Seasonal Runoff Volume Forecast website is: http://www.cbrfc.noaa.gov/westernwater.
- For additional information about the NOAA/NWS forecast maps and graphs, including additional map and graph help tutorials, methodology used, and links to the RFC's, please visit the NWS Western Water Supply Forecast webpage or contact Kevin Werner at Kevin.werner@noaa.gov.