A History of
DROUGHT IN COLORADO

LESSONS LEARNED AND
WHAT LIES AHEAD

by
Thomas B. McKee, Nolan J. Doesken, John Kleist
Colorado Climate Center
Atmospheric Science Department
Colorado State University

and

Catherine J. Shrier
Colorado Water Resources
Research Institute

in collaboration with

William P. Stanton
Colorado Water Conservation Board

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"When drought returns to Colorado, as it surely will, it will be challenging to see just how far we can stretch our water."

Open Letter on Drought in Colorado

Dear Reader:

Over 20 years ago, the severe winter drought of 1976-77 sent shock waves through Colorado's economy and state government. Bare ski slopes, empty reservoirs, and drifts of topsoil left many of us in government feeling helpless and ill prepared. At that time, Governor Richard Lamm convened a special council of experts who assessed the crisis and proposed ideas for lessening the impacts on recreation-based industries and agriculture.

The greatest frustration expressed by decision makers then was the lack of timely and integrated information on which to make plans and base actions. How severe and how widespread were the drought conditions? Who was affected and what were the current and emerging impacts? The state needed better information.

The crisis motivated actions, but by 1978 heavy snows and spring rains were falling again. As is often the case, when the immediate crisis passed, proposed actions were tabled. Then came the winter of 1980-81 with another round of severe snow shortages. Governor Lamm, who was still in office, brought back many of the same experts. Within a matter of months the "Colorado Drought Response Plan" was approved and implemented. While it is arguable that this plan could immediately reduce drought impacts, what the plan did accomplish was to identify drought as a major natural hazard in Colorado and to establish clear mechanisms for monitoring drought conditions and impacts, and communicate water supply and drought impact information to decision makers. Colorado was one of the first states to institutionalize drought monitoring and response, and has been very active ever since in promoting research and encouraging drought mitigation efforts.

This report describes some of the new techniques for drought monitoring that have been developed in Colorado, and presents results of drought studies which have been supported by the Colorado Office of Emergency Management, the Colorado Water Resources Research Institute and the Colorado Agricultural Experiment Station.

Since the "Colorado Drought Response Plan" was implemented in 1981, Colorado has enjoyed the longest period free from widespread multi-year droughts since before the 1930s "Dustbowl." Yes, we now have better information about drought and improved data on the frequency and severity of droughts from the past. But with the very generous precipitation for the period 1982-1999, are we ready and able to deal with drought and its consequences?

Please take the time to read this report. At the very least, I hope this will remind us all how real the threat of drought is here in Colorado so that we can be better prepared when the next drought threatens.

Sincerely,

Tommy Grier, Director
Colorado Office of Emergency Management

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Colorado is a dry state.

Annual precipitation in Colorado averages only 17 inches statewide. The majority of the state is considerably drier with only 12-16 inches of precipitation annually. The San Luis Valley in south-central Colorado is the driest region, averaging only seven inches in the center of the valley. In comparison to the large majority of the area of the United States, these precipitation totals are meager — less than half of the precipitation that falls over the U.S. corn belt, for example. But Colorado benefits from much higher precipitation amounts on the ranges of the Rocky Mountains that cover the state from north to south. Most of the areas above 10,000 feet in elevation average more than 25 inches of moisture annually, with more than 50 inches in a few isolated high-mountain locations.

With great effort, some planning, and a history of diligence and creativity, Colorado has adapted to this dry climate such that the state successfully maintains a large agricultural industry, large and growing urban population centers, a vast and diverse recreational industry and a high quality of life for the citizens of the state, while still sending large volumes of water to downstream states on the major rivers.

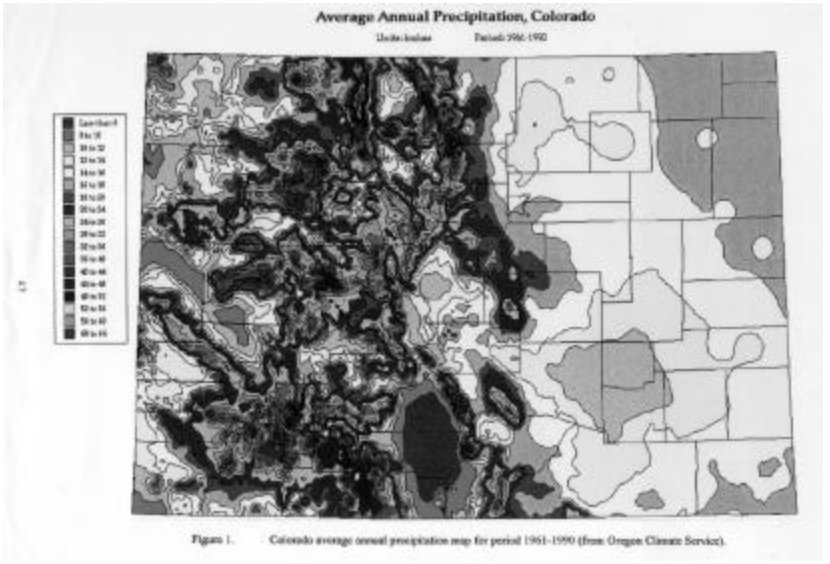
But a threat looms over Colorado and its vibrant economy. It is the threat that is with us nearly every year but which often goes unnoticed or ignored. It is the threat of drought -- and the social, economic, and environmental impacts that come with drought.

Colorado's population continues to grow rapidly. Much of this population growth has occured since the last major statewide drought in 1981. In recent decades, there has also been an introduction of several newer uses of water in the state. Water is now needed to support populations of endangered species, mountain snow making, and river and reservoir recreationists as well as more traditional uses for farmers, for hydropower generation, and for rapidly growing thirsty cities.

So far, we have done a fairly good job meeting these diverse demands while still delivering the water to downstream states as prescribed by interstate compacts. We have been able to meet these demands in part through changes in water management, but also (and perhaps most importantly) through the abundance of water availability that we have enjoyed. The last multi-year drought in Colorado ended in 1978. The last two decades have brought Colorado the most reliable precipitation since before the "dust bowl" drought of the 1930s. When drought returns to Colorado, as it surely will, it will be challenging to see just how far we can stretch our water.

A study of historical dry and wet periods in Colorado was recently completed by the Colorado Climate Center at Colorado State University. This study, which is summarized in this report, analyzed precipitation, snowpack, and streamflow data over the last 100 years or so, and provides some important insights into the nature of drought in Colorado.

Before we can understand dry, or "below normal", and wet, or "above normal" precipitation, we need to understand what is considered "normal" in Colorado, a state that experiences a wide range of climate patterns in different parts of the state and at different times of the year. We also discuss how and when water is used in Colorado, since this gives us an understanding of who will be impacted by "single season" droughts. We consider some implications of the new uses of water and new demands for water availability that have developed in Colorado. Finally, we look at Colorado's drought history and what that history can tell us about droughts in Colorado's future.



This map can be found at website
http://www.ocs.orst.edu/prism/images/co.gif

What is drought?

Drought is unique among natural hazards because it is not a clear event, like a flood, earthquake, hurricane or tornado. These events strike, leave their mark, and are gone. A drought, however, sneaks up on us quietly disguised as lovely, sunny weather. Unlike a hurricane, we cannot follow its course on a map. We are never sure when a drought began until after it is already well underway, and we are often unsure when it ends. Any day when it doesn't rain or snow (which describes the majority of days here in Colorado) could be the beginning of the next drought.

Which still does not answer our question: what is drought?

Drought is a concept that is both simple and complex. Drought is a shortage of water, usually associated with a deficiency of precipitation. Drought occurs when the demand for water exceeds the supply of water.

Simple, right?

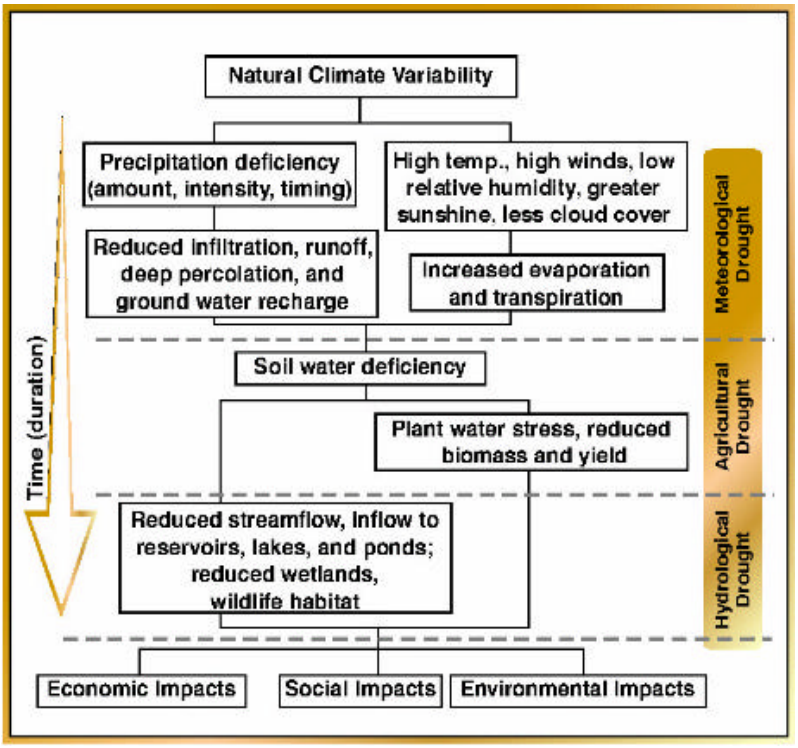
Yes, except that different types of demands require different amounts of water in different forms at different times of the year. Droughts are often defined by their impacts, e.g. on crops or on reservoir water levels and power availability. Thus, there is no universal definition of a drought. The more diverse the economy and the climate of a region are, the harder it is to define drought. Drought means different things to different people; one person's drought can be another person's "sunny day."

Drought is also "relative" and must be defined in terms of what is "normal" for a particular region or time of year. To someone who has lived in Nevada or Arizona, Colorado looks mighty green and lush. Folks who just moved here from the eastern half of the United States, however, may think that Colorado experiences perpetual drought. In fact, for most locations east of Omaha or Kansas City, the driest year on record may still be wetter than the wettest year on record for most of Colorado's lower elevations. Coloradoans have adapted to this dry regime.

One important measure of drought is the impacts of water shortage on nature and society. These impacts may change over time as new mitigation measures are developed. For example, many water users in Colorado are able to store water over time, or transport water from other parts of the state, or use groundwater recharge to re-regulate streamflows, or make artificial "snow" for ski areas. Since Colorado receives new water supplies only one way – as rain, snow, or other precipitation – some form of precipitation is necessary to provide water to Colorado's population and economy. That precipitation, however, does not necessarily fall on the populations that use the water most or at the times when it is most needed.

Understanding – and thus preparing for – a severe drought in Colorado requires an appreciation of how Colorado receives its water supply and how different water demands use that supply. This paper presents a discussion of Colorado's water supplies and demands, and an analysis of the history of wet and dry periods in Colorado.

Several definitions of drought have been proposed by various agencies. The figure, which is from a publication by the National Drought Mitigation Center (**http://enso.unl.edu/ndmc/**), illustrates a set of definitions that show both causes and impacts of drought over time, namely: meteorological drought, agricultural drought, hydrological drought, and socioeconomic (and environmental) drought. Another important definition of drought concerns wildfire risk. This paper deals primarily with meteorological drought and the history of wet and dry periods in Colorado. However, the impacts of droughts of different durations, levels of severity, and areal extent, are also discussed.



Measuring and Assessing Drought

Because drought can be defined in so many ways, based on both the causes (lack of supply) and the effects (adverse impacts to water users), several methods have evolved to measure and assess drought. A variety of monitoring and analytical tools are available to help track precipitation and current water supply anomalies, and to identify and describe droughts that have occurred in the past. In particular, several indices are used to help simplify complex data to provide information for planners and decision makers. Paleoclimatic techniques, such as measurement of tree rings, ice cores, pollens, and ancient lake levels, are also employed to study drought patterns and frequencies over the past several centuries.

Instrumental data are used extensively for monitoring precipitation, snowpack, streamflow, and reservoir levels. **Precipitation** is measured daily at several hundred locations across Colorado. Some National Weather Service stations have data collected for 100 years or more, and are used extensively by the Colorado Climate Center at Colorado State University for drought research. **Snowpack** data, critical for predicting runoff and surface water supplies, are collected at higher elevations by the Natural Resources Conservation Service, U.S. Department of Agriculture. A few of these sites date back more than 60 years. Precipitation and snowpack data have been analyzed in a recent study (summarized in this report) to determine the patterns of wet and dry periods and their hydroclimatic impacts in Colorado over the last 100 years. Monitoring this data is very important to predict near-future drought potential. **Streamflow** is the net result of precipitation, snowmelt, evapotranspiration, infiltration and groundwater recharge, as well as man-made influences such as irrigation diversions and reservoir storage and releases. The combination of streamflow readings and reservoir levels provides the best direct indication of available surface water supplies in each of our river basins.

These climate observation networks provide important data to analyze current and historic droughts and relate water availability to the observed impacts. Years of experience, along with common sense, have shown that the types and levels of drought impacts are directly related to the following drought characteristics:

- **Magnitude** (how large the water deficits are in comparison with historic averages)
- **Duration** (how long the drought lasts)
- **Areal Extent** (what area is impacted by the drought)

Severity, the most commonly used term for measuring drought, is a combination of the magnitude or "dryness" and the duration of the drought. This combination can be linked to actual impacts from a drought. Traditional maps and graphs of precipitation, snowpack, and streamflow patterns continue to be used extensively for identifying drought. The following set of indices are also used in Colorado:

The **Palmer Drought Severity Index** is a complex soil moisture calculation that is used by federal agricultural agencies to determine when to provide drought assistance. Since this index was developed for areas of the country with more homogeneous climates, Colorado adapted the index by separating the state into 25 climatically similar regions.

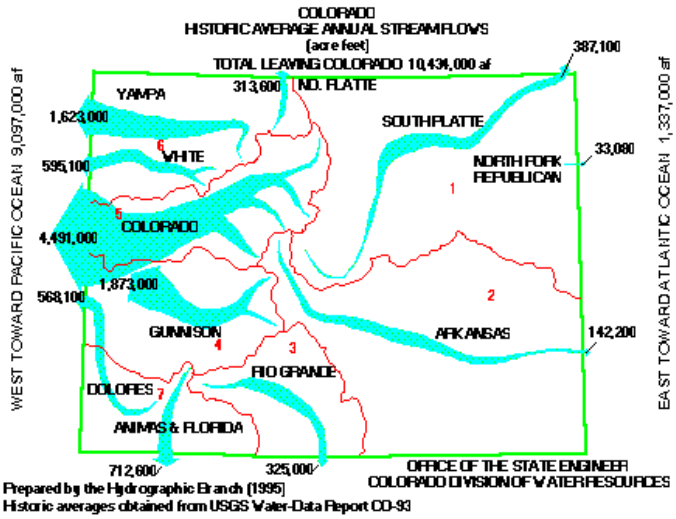
The **Crop Moisture Index** was developed from the Palmer Index, and was designed to evaluate short-term moisture conditions across major crop producing regions. It uses the average temperature and total precipitation for each week and compares the calculated index with the previous week. This is a better index to measure rapidly changing conditions and for comparing different locations.

The **Surface Water Supply Index** (SWSI, pronounced "swazee") was developed in Colorado, and is used in many Western states to provide a weighted index of snowpack, streamflow, precipitation, and reservoir storage. The SWSI is calculated independently for each basin due to differences in climate and reservoir capacities. The weighting factors for this index change from winter to summer.

The **Standardized Precipitation Index** (SPI), also developed in Colorado, appears to be the simplest yet most robust index for describing drought patterns. The SPI is based on current and historical precipitation data for a particular location. The SPI is proportional to precipitation deviation from the "average" (surplus or deficit) for that location, and has a unique probability that the deviation would occur at that location. The SPI can be computed for different time scales, can provide early warning of drought and help assess drought severity, and is less complex than the Palmer Index. The SPI identifies a beginning and end for each drought, as well as an intensity level for each month in which the drought occurs. The following table shows the values for the SPI index.

SPI Values	
2.0 +	extremely wet
1.5 to 1.99	very wet
1.0 to 1.49	moderately wet
-.99 to .99	near normal
-1.0 to -1.49	moderately dry
-1.5 to -1.99	severely dry
-2 and less	extremely dry

An excellent discussion of different drought indices is available on the National Drought Mitigation Center web site at http://enso.unl.edu/ndmc/enigma/indices.htm



This map can be found at the following website:

http://waterknowledge.colostate.edu/flow_map.htm/

How Colorado Gets its Water

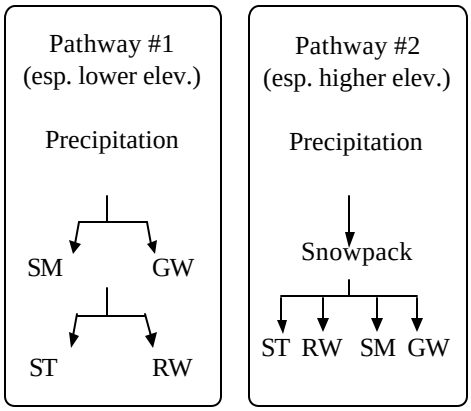
Colorado gets new water supplies[1] from only one source: precipitation, in the form of rain, hail, or snow. Colorado gets all of its water from precipitation because there are no major rivers that flow INTO Colorado.[2] There are several major river basins, originating in the Colorado Rockies, that flow OUT of the state, providing water to much of the southwestern United States, and contributing to the Missouri and Mississippi rivers as well. Thus, Colorado earns its title as "the Mother of Rivers."

Although the main source of Colorado's water supplies is precipitation, Coloradoans typically do not use water directly in the form of precipitation. Usually, water comes to Colorado as precipitation but is then stored in one of five forms of usable water:

- snowpack (SN), used directly for recreation, although it also serves as a storage of water supplies;
- streamflow (ST), used for recreation, habitat, irrigation and municipal water supplies, as well as to meet interstate compact obligations;
- reservoir water (RW), used similarly to streamflow;
- soil moisture (SM), used for natural vegetation and agriculture; and
- groundwater (GW), used for irrigation and municipal water supplies.

The amount of time it takes for precipitation to turn into a usable form of water can vary greatly. Precipitation can add to soil moisture or snowpack almost immediately. However, there can be delays of several days or weeks before precipitation adds to the water levels in streams, reservoirs, or groundwater aquifers. During those time delays, some precipitation can be lost to evaporation. Thus, some of the brief summer rains that fall in Colorado will add little or no water to the usable water supply. Water can also be stored as snowpack for months before melting to become streamflow, then reservoir water or groundwater.

There are two natural pathways by which water from precipitation become a usable source of water supply:



The first pathway is that precipitation falls on the ground and becomes soil moisture (SM) and groundwater (GW) to support vegetation and other uses locally where it occurs. A portion may also become streamflow (ST) and reservoir water (RW). This is the dominant pathway for all lower elevations of the state and for the higher elevations in the summer season.

The second pathway is that precipitation falls as snow at higher elevations in the winter season to become snow-pack (SN), and later becomes available as streamflow (ST), reservoir water (RW), soil moisture (SM) and groundwater (GW) during the following spring and summer. This is the primary pathway by which mountain snows provide surface water resources for the state, and results in peak streamflows occuring from April through July.

[1] Not including ancient aquifers, such as in the Denver basin, which receive little or no recharge and are being "mined."
[2] Well, OK, there's Little Snake River, which starts in Wyoming, enters Colorado briefly to join the Yampa before leaving for Utah. The Green River also starts in Wyoming, flows to Utah, then comes into Colorado briefly to join the Yampa before leaving the state again.

Precipitation: Colorado's Direct Source of Water

Of all the elements that make up our climate, precipitation – how it forms and when and where it falls — is perhaps the most interesting and significant. Here are a few important traits of precipitation.

1) Unlike temperature, humidity and wind, which are continuous variables, **precipitation comes in episodes.** Depending on where you are in Colorado, precipitation falls only two to six percent of the time, on average.

2) **Precipitation is highly variable both in time and space.** No two years are ever alike. Within the state boundaries, it is extremely rare to have all parts of the state experiencing above or below average precipitation at the same time, even for a month. There is always diversity with some areas wet while others are dry. At any given point, annual precipitation totals can vary from only about half of the long term average in a very dry year to close to double the average in a very wet year. In relative terms, the variability is even greater for seasons or single months.

3) **Rain versus snow** – the fraction of annual precipitation that falls as snow varies greatly across Colorado from less than 15% over southeast Colorado to more than 70% at high elevations in Colorado's northern mountains. This has a major bearing on our water balance and helps determines how much moisture evaporates, soaks into the ground, or runs off to become stream flow and reservoir supplies.

4) **A few big storms contribute the majority of the precipitation that falls each year.** More than half of the total annual precipitation falls in only 20% of the days when precipitaiton occurs. The other half of annual precipitation comes from the remaining 80% of days when it rains, snows, or hails. What this means is that the difference between a very wet and a very dry year may come down to the presence or absence of just a few major storm systems.

5) **Precipitation is highly seasonal.** Most areas have well defined times of year that are distinctly wetter than others. This is not unusual as is typical for many parts of the world to have pronounced and repeatable wet and dry seasons. For example, throughout all of California most precipitation falls during the winter with very little precipitation falling during the summer. What is unique about Colorado, however, is the amazing diversity of seasonality. Some parts of the state experience their annual wet season at the identical time that others are in their dry season. Depending on location in Colorado, any of the four seasons are "the wettest time of year" in some part of the state. Just the short distance from a mountain peak to a nearby valley bottom can result in wet and dry seasons being out of phase. For example, Denver's wettest period is in the spring, but just 30 miles to the west, Berthoud Pass has its maximum precipitation in mid winter. This complexity is very important for understanding drought development in Colorado.

6) **Long range prediction (weeks, months, or seasons in advance) is very difficult.** While considerable progress is being made in long-term climate prediction, it remains extremely difficult to accurately predict when and where precipitation will fall with confidence and reliability.

To help understand drought history and potential for future drought, a brief discussion of precipitation mechanisms and moisture sources is appropriate.

There are two essential ingredients for precipitation anywhere in the world:

- **Water vapor in the atmosphere**
- **Upward vertical motion, which cools the air so that the water vapor condenses.**

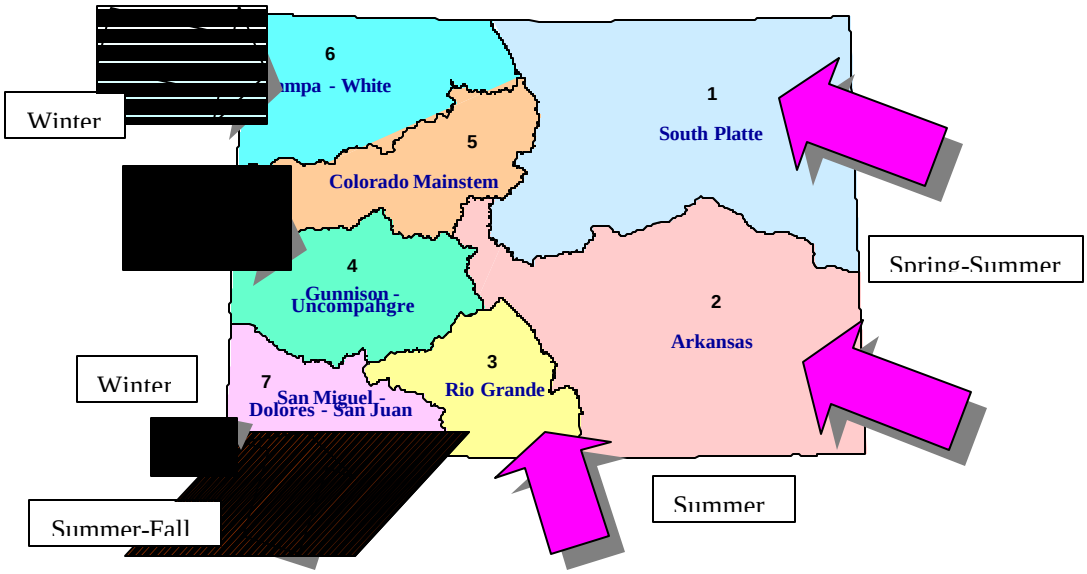
The complexities of precipitation patterns and seasonality in Colorado are largely a result of our interior continental location, far removed from primary oceanic moisture sources, in combination with Colorado's high elevation and rugged terrain. Three quarters of all land in the continental U.S. at elevations exceeding 10,000 feet is found here in Colorado. The Continental Divide that follows the crest of the Rockies through Colorado acts as an effective barrier to moisture transport, most of which occurs in the lower few thousand feet of the atmosphere.

In Colorado, the primary sources of water vapor in the atmosphere are:

- the Pacific Ocean
- Gulf of Mexico and recirculated Gulf moisture from evapotranspiration off of the land and vegetation throughout the Mississippi Valley
- Gulf of California and Gulf of Mexico moisture that reaches Colorado after first crossing Mexico

Mechanisms for producing rising air (upward vertical motion) in Colorado include convection (warm air rising), orographic (mountain-induced) lifting and large-scale storm systems that produce colliding air masses (storm-induced).

Figure: Sources of Atmospheric Moisture in Colorado



Although Colorado is far removed from oceanic moisture sources, moist air masses are carried to the state by global atmospheric circulations. These circulations migrate through the year, changing the sources of moisture that enter Colorado (as shown in the figure). The mechanisms to lift and cool air to saturation (when condensation and precipitation can occur) also change with the seasons.

During the late fall, winter, and early spring, the winds aloft are strongest over the mid latitudes of the northern hemisphere resulting from the very strong temperature gradients between the polar region and the equator. The great river of air known as "the jet stream" directs air masses and migrating storm systems approximately from west to east. During this time of year the Pacific Ocean is the primary source for moisture reaching Colorado. This is the time of year when storm systems are very strong and fast moving. This is also the time of year when orographic (mountain-related) air motions are most dramatic as rapidly moving air is lifted on the upwind side of each mountain barrier and then descends and warms on the leeward side of the mountains. Because of cold temperatures, however, total water vapor in the atmosphere is limited.

What this means for Colorado is that frequent snows near and immediately west of the each mountain range occur when enough Pacific moisture is present. Because of persisting cold temperatures in the mountains, most of the precipitation falls as snow and remains as snowpack that accumulates for several months until finally melting in the spring and summer. As the air moves east of the mountains, it descends, bringing very little winter moisture and periodic strong, dry winds. On occasion, a very strong winter storm will draw moisture northward from the Gulf of Mexico and for a matter of hours drop widespread "upslope" precipitation east of the Rockies. However, subsequent warmer days and sunshine will rapidly melt and evaporate much of this precipitation.

During the spring months, the westerly winds aloft begin to slow a bit and the air begins to warm. Storm systems are still present but move slower. This allows more moisture from the Gulf of Mexico to move northward and westward in advance of these storms. As a result, a few spring storms typically bring widespread precipitation along and east of the mountains. A single spring storm can deposit as much precipitation in eastern Colorado as most winter storms combined. This period of episodic widespread storms lasts from early March into early June. This is the wettest time of year for much of the Front Range and northeastern Colorado. At the same time, storms from the west diminish and contribute ever less Pacific moisture. June is the driest month of the year for much of western Colorado, while the last half of June is frequently hot, sunny and dry over most of the state.

During the summer months, winds aloft tend to be very light, and moist Pacific air masses no longer reach Colorado. The primary mechanism for lifting and cooling air to saturation becomes convective updrafts from the heating of air near the ground. Thunderheads (cumulonimbus clouds) become the primary cloud responsible for precipitation whenever sufficient moisture is present in the air. Occasionally, humid air from the Gulf of Mexico and the Mississippi Valley will drift into eastern Colorado. A few weak cold fronts will also drop southward from Canada to help trigger some local thunderstorms on the plains. Thunderstorms also become more frequent during July over the mountains and Western Slope of Colorado as air from the Gulf of California and/or Gulf of Mexico drifts slowly northward across Mexico and the Southwest U.S. This wind circulation associated with the "Southwest Monsoon" is responsible for an important wet season over portions of southern and western Colorado from July into September. July and August are the wettest months of the year for much of southern Colorado and many mountain valleys. When sufficient moisture is present, thunderstorms will develop every day in and near the mountains.

(continued on page 12)

Colorado's Typical Wet and Dry Seasons by Basin

It is common and necessary practice in watershed management to combine data from an entire basin including both high and low elevations. It is important to recognize, however, that the seasonality of precipitation may vary greatly within each basin, and that precipitation at different times of year across the basin may not be well correlated.

For many water management and planning applications, Colorado is divided into seven water divisions (see figure). Each of these basins originate in high mountain environments and descend through mountain valleys and eventually drop to much lower elevations. Thus, we can roughly divide each basin into an upper and lower basin based on approximate elevation and mountain proximity. The table below is not definitive, but is meant to give a general picture of the typical wet and dry periods experienced across Colorado.

Water Division I

South Platte, Upper: Wet Dec.-Apr., Dry June and again in Aug.-Oct.

South Platte, Lower: Dry Nov.-Feb., Wet Apr.-Jul.

Water Division II

Arkansas, Upper: Wet Dec.-Mar., Jul.-Aug., Dry (at the highest mountains) May-Jun.

Arkansas, Lower: Dry Nov.-Feb., Wet May-Aug.

Water Division III

Rio Grande, Upper: Wet Dec.-Mar. and mid-Jul.-early Oct., Dry May-mid-July.

Rio Grande, Lower: Dry Nov.-Apr., Wet mid-Jul-Sep. (NOTE: The San Luis Valley, which includes Great Sand Dunes National Monument, receives the least precipitation in the state, with an annual average of less than eight inches of precipitation.)

Water Division IV

Gunnison, Upper: Wet mid-Nov.-Mar., Dry mid-May-mid-Jun.

Gunnison, Lower: No significant wet season. Dry late May-Jun, slightly wet mid-Jul-Aug

Water Division V

Colorado, Upper: Wet late Nov.-Apr., Dry Jun-mid-Jul.

Colorado, Lower: On average, there is no clear wet or dry season in the lower portion of the Colorado River basin.

Water Division VI

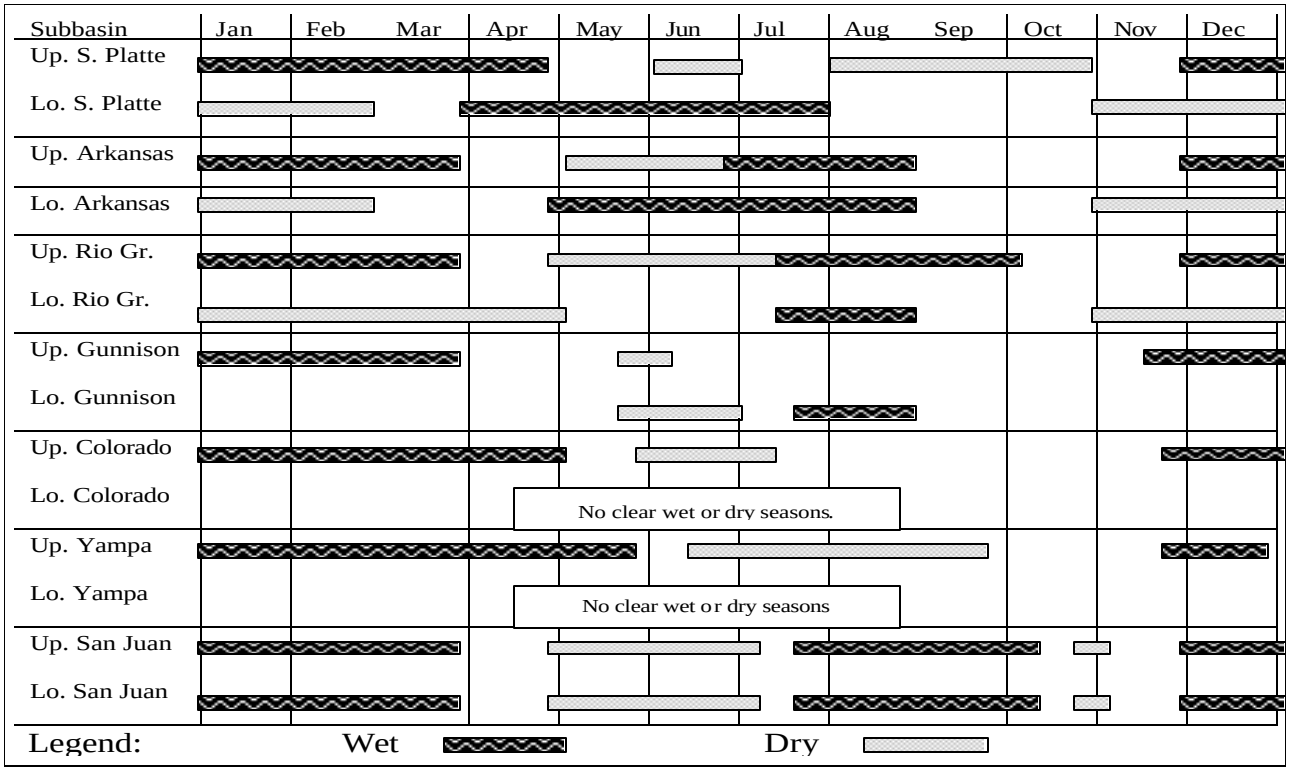
Yampa-White, Upper: Wet late Nov.-May, Dry mid-Jun.-Sep. (NOTE: The high mountains of this basin include some of the wettest areas of the state, receiving an average of more than 50 in/yr of precipitation.)

Yampa-White, Lower: Similar to the lower portion of the Colorado River Basin, with no clear seasons, and less likelihood of receiving rain from the summer monsoon.

Water Division VII

San Juan, Upper: Wet Dec.-Mar. and late Jul-early-Oct., Dry May-early Jul. and mid-Oct-mid-Nov. (NOTE: The high mountains of this basin are also among the wettest in the state, receiving more than 50 in/yr average annual precipitation.)

San Juan, Lower, Wet Dec.-Mar. and late Jul-early-Oct., Dry May-early Jul. and mid-Oct-mid-Nov. (NOTE: similar to the upper basin, but less wet in the wet seasons.)



Water Demands in Colorado: How and when we use our water

Before we continue our discussion of the history of wet and dry periods in Colorado, and considering drought and drought preparedness, we should remember that precipitation — our source of water supply — is only half of the drought picture. The impacts of a lack of precipitation on humans and nature depend on several factors including: how water is used; when water is needed; how much water is needed; and how long water can be stored before use.

Although this paper is based on research regarding the history of wet and dry periods in Colorado, some discussion is provided here of some of the major uses of water in Colorado to put these historic precipitation patterns in perspective. This is particularly important since the types and locations of water demands in Colorado have undergone some dramatic changes, particularly in the last 20 years. In many cases, important uses of water in Colorado are "non-consumptive", such as water in the form of snow for skiing or water in streams for recreation or habitat. Water is used multiple times between the time it enters Colorado as precipitation and the time it leaves the state as streamflow or evaporation. This discussion addresses the timing of water use and relative amount of water required for different demands in Colorado. As we have seen from the ski season of '76-'77 or any of several droughts that have impacted important crops in Colorado, major impacts to any of the economic sectors dependant upon these water uses have serious impacts on the economy of the **entire** state. In addition to these in-state uses of water, we also have several interstate compacts or agreements requiring water to flow from Colorado to other states.

Agricultural water supplies. This remains the number one water demand in Colorado. However, Colorado agriculture has undergone recent changes, including the introduction of new types of crops, new irrigation techniques, renewed interest in non-irrigated agriculture, and more drought resistant strains of traditional crops. Agricultural users have four sources of water: direct precipitation, streamflow diversions, reservoir storage and releases, and groundwater withdrawals. Storage of water in reservoirs is one form of drought mitigation. When more precipitation is available, however, farmers can rely less on their stored water supplies, and withdraw less water from streams and aquifers as well. Information on snowpack and precipitation that has fallen by early April is used to determine how the irrigation reservoirs are managed. Examples of **irrigated agriculture** in Colorado include corn, sorghum, dry beans, barley, potatoes, sugar beets, and vegetables. Water demands for most irrigated agriculture begin increasing in late April, peak in early July, and drop off into late October. **Non-irrigated or "dryland" crops** are more susceptible to damage by droughts, especially "single season" droughts. Major dryland crops, which include the largest acreage of crops in Colorado, include winter wheat and beans, as well as pastureland. Winter wheat crops are successful if they have some precipitation in the fall to start germination of the plants, and some precipitation in spring to develop the grains. Pastureland is particularly important for livestock. Newer non-irrigated crops include sorghum, corn, canola, and sunflowers, which are more drought resistant but still need adequate soil moisture and timely precipitation for a successful yield.

Municipal and industrial water supplies. Municipalities typically develop extensive storage facilities to ensure reliability of water supplies. For example, some cities have storage facilities in several different river basins, which allows them to use different sources of water in situations where one or more area has below normal precipitation. Water demands for industrial and many municipal uses are fairly constant throughout the year. However, about 50% of municipal water is used for watering of lawns and landscapes (e.g. parks and golf courses); these demands occur mainly in the summer.

Recreation. There are many uses of water in the state for recreation. Typically, recreational industries require that precipitation falls or has fallen by a certain time of year. For example, **ski resorts** must have water available for snow making in October and November, and snow direct from snow precipitation by November and continuing through April to ensure a successful season. The most profitable period, however, is during the December/January holiday season, so earlier snows are critical. **White-water rafting** is also dependant upon winter snows, although the timing of the snowfall is less important. Water for rafting comes from melted snow in the spring. Peak streamflows from snowmelt occur in May and June, and decreases later in the summer. **Summer recreation**, particularly in lakes (e.g. fishing and boating) requires water available in May through September.

Forests and Environmental Uses. National forests and parks are important for Colorado's economy both for timber resources and for tourism. Forest fire is also a major safety concern during droughts. In-stream uses of water to support animal and plant life and provide habitats is one of the more recent water demands of concern in Colorado. Water requirements to support critical habitat for different species vary throughout the year. Water planning and the management of water facilities now often include some consideration of these demands.

Hydropower A measurable amount of Colorado's power is generated in the form of hydroelectric energy, which can be provided when reservoir storage is high. If reservoir levels drop, the amount of energy that can be generated is reduced, and greater power demands by Colorado may impact "the Western Power Grid". Our peak power demands occur at the time when our water levels are falling, in the heat of the summer.

As summer comes to an end, the westerly winds aloft gradually increase again and low level moisture from the south and east retreat. The fall is often characterized by long periods of sunny, dry weather. Occasionally, however, Pacific moisture reaches western Colorado, sometimes in dramatic fashion as moisture from dissipated Pacific hurricanes sweeps northeastward. Infrequent but occasionally very heavy fall rains are an important part of the climate of western Colorado. A few storms will also harvest Gulf of Mexico moisture over eastern Colorado.

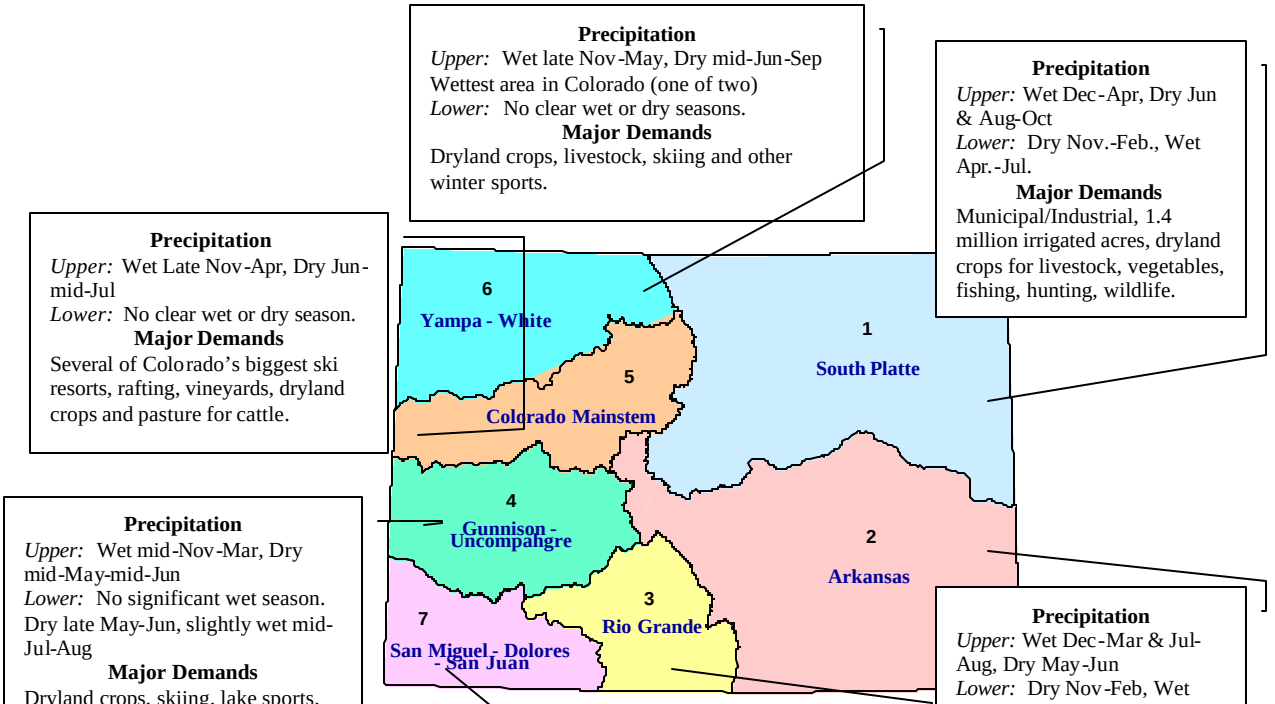
These seasonal weather patterns and the shifting of moisture sources through the year are a natural part of Colorado's variable climate. In combination with the topography of the state, the result is seasonal precipitation patterns that differ from north to south, from west to east and also locally as a function of elevation.

Drought can be initiated by either a lack of moisture from one or more of these predominant supplies, or a lack of upward vertical motion to harvest the water vapor from the atmosphere. Due to natural variations in our climate, single season droughts over some portion of the state are quite common. However, with so much climatic diversity and with such a variety of moisture sources and precipitation mechanisms, it is historically rare for all areas to be deficient at the same time. For example, in any given year, winter snowpack accumulation may be subpar in some portion of the mountains, but summer storms may compensate. Likewise, it is very common to have very dry winters east of the mountains, but a few spring storms can make up for winter deficits.

Multiple season and widespread droughts do happen, however, and we must be aware of their potential.

Major Water Demands in the Seven Colorado Water Divisions

The figure below shows the State of Colorado divided into the seven Water Divisions that are used for water right administration and management purposes by the Colorado Division of Water Resources. These Water Divisions correspond with the major river basins in the state, with some of the smaller river basins lumped together into a single division (e.g. the San Juan and Delores Rivers in the southwestern corner of the state, and the North Platte with the Yampe-White). Additional information on major water demands by basin available in *Water, Colorado's Precious Resource, 2nd Edition*.



Precipitation
Upper: Wet late Nov-May, Dry mid-Jun-Sep Wettest area in Colorado (one of two)
Lower: No clear wet or dry seasons.
Major Demands
Dryland crops, livestock, skiing and other winter sports.

Precipitation
Upper: Wet Dec-Apr, Dry Jun & Aug-Oct
Lower: Dry Nov.-Feb., Wet Apr.-Jul.
Major Demands
Municipal/Industrial, 1.4 million irrigated acres, dryland crops for livestock, vegetables, fishing, hunting, wildlife.

Precipitation
Upper: Wet Late Nov-Apr, Dry Jun-mid-Jul
Lower: No clear wet or dry season.
Major Demands
Several of Colorado's biggest ski resorts, rafting, vineyards, dryland crops and pasture for cattle.

Precipitation
Upper: Wet mid-Nov-Mar, Dry mid-May-mid-Jun
Lower: No significant wet season. Dry late May-Jun, slightly wet mid-Jul-Aug
Major Demands
Dryland crops, skiing, lake sports.

Precipitation
Upper: Wet Dec-Mar & Jul-Aug, Dry May-Jun
Lower: Dry Nov-Feb, Wet May-Aug
Major Demands
Some municipal/industrial, dryland crops including corn, alfalfa, and pasture, and vegetables and melons.

Precipitation
Upper: Wet Dec-Mar & late Jul-early-Oct, Dry May-early Jul & mid-Oct-mid-Nov Wettest area of Colorado (one of two).
Lower: Wet Dec-Mar & late Jul-early-Oct, Dry May-early Jul & mid-Oct-mid-Nov
Major Demands
Dryland crops, corn, apples, national parks, rafting, skiing.

Precipitation
Upper: Wet Dec-Mar & mid-Jul-early Oct, Dry May-mid-Jul.
Lower: Dry Nov-Apr, Wet mid-Jul-Sep (Driest area of Colorado)
Major Demands
Mostly crops irrigated with groundwater from San Luis Valley aquifer.

The Colorado Drought Response Plan

The State of Colorado has responded to and prepared for drought in several ways during this century. For example, state agencies have supported improvements in agricultural management, establishment of insurance programs, promotion of water conservation, and diversification of the regional economy. As the State responded to two short but intense droughts in 1976-1977 and again in 1980-1981, it became apparent that better coordination was required in the assessment of the development and impacts of drought, in the dissemination of information on developing droughts and on alternate responses available to decisions makers, and in the determination of when the State would act to request actions at the federal or local level. These concerns led to the development and implementation of Colorado's first Drought Response Plan in 1981. The purpose of the Plan is "**to provide an effective and systematic means for the State of Colorado to deal with emergency drought problems which may occur over the short or long term.**" The Plan was initially developed and implemented in 1981. It was revised in 1986 and again in 1990. As of December1999, the Plan is under review for a 2000 revision.

The Plan did not create a new government entity to deal with drought. Rather, the Plan provided a means for coordinating the efforts of those state agencies and related organizations (e.g. local government agencies, academic research centers and similar public and private organizations) that would be called upon to deal with drought, typically from the perspective of a particular economic sector (e.g. agriculture).

The Plan is organized into an **Assessment System** and a **Response System**. The Assessment System is organized into ten task forces: the Water Availability Task Force (TF#1), eight Impact Assessment Task Forces (TFs #2-9), and the Review and Reporting Task Force (TF #10). Of these task forces, only the Water Availability Task Force (WATF) meets continuously. The WATF has met at least quarterly since 1981, or more often if drought conditions are developing. The WATF consists of state, federal, local, and academic experts on drought analysis. This Task Force makes assessments and projections (in comparison with the historical norm) on:

- snowpack
- reservoir levels
- precipitant
- streamflows
- soil moisture
- ground water levels
- temperatures

If the WATF determines — based on their evaluations, experience, and common sense, and on whether certain "trigger levels" of drought indices (including the Palmer Drought Severity Index and the Surface Water Supply Index) have been reached — that drought conditions are developing, the WATF Chairman will notify the Governor and recommend activation of the Colorado Drought Response Plan. WATF notification will include information on which areas of the state will be most affected.

The Governor then activates the Review and Reporting Task Force, as well as the appropriate impact task forces. The Review and Reporting Task Force reviews and oversees the activities of the WATF and Impact Task Forces and prepares timely reports to leadership, the media, and key elements of the Response System. Local governments and state agencies are called upon to designate a drought coordinator. Each Impact Task Force assesses the potential drought impact for a particular economic sector or concern, and consists of representatives from agencies that would normally be responsible for issues related to that sector. The Impact Task Forces are:

TF #2: Municipal Water
TF #3: Wildfire Protection
TF #4: Agricultural Industry
TF #5: Tourism
TF #6: Wildlife
TF #7: Economic (aggregate economic loss)
TF #8: Energy Loss
TF #9: Health

The Response System consists of several lead agencies as well as an Interagency Coordinating Group (IACG). The IACG designates specific agencies as lead agencies for responses in appropriate areas, and ensures coordination of response activities by the various agencies. The Drought Response Plan states which of the emergency lead agencies are responsible for what responses. The IACG also handles media releases, coordination with the Executive Branch and state legislature, and makes recommendations regarding the need for a federal drought declaration.

The Office of Emergency Management and other agencies are currently reviewing the Colorado Drought Response Plan for a 2000 revision. Changes under consideration for the updated plan include increased guidance on drought impact mitigation for long term drought, and greater public access to and education on the Colorado Drought Response Plan and the state's current water availability status. Comments and suggestions on the Colorado Drought Response Plan would be welcomed by:

Jeff Brislawn
Colorado Office of Emergency Management
15075 South Golden Road
Golden, CO 80401
(303) 273-1790
jeff.brislawn@state.co.us

Analysis of Historical Dry and Wet Periods in Colorado

Now that we have an understanding of how we define and assess droughts, how precipitation falls in different parts of Colorado, and how Coloradoans use that precipitation to supply water for different sorts of demands, we can look at the historical dry and wet periods in Colorado with a better understanding of the significance of those periods, and how similar dry or wet periods would impact Colorado today.

The historical record of precipitation, snowpack, and streamflow data wereanalyzed for each river basin in Colorado. The periods of above or below average precipitation were identified both for individual basins and for a majority of the state as a whole. The table on the following page shows the periods during which at least 60% of Colorado was wet or dry, as determined by the Standardized Precipitation Index (SPI) values for 24-month periods.

The analysis performed in this study revealed several important facts about dry and wet periods in Colorado:

1) Drought is a very frequent visitor to Colorado

- Single season droughts with precipitation of 75% or less of average for one to three months in a row occur nearly every year in Colorado.

- Based on the Standardized Precipitation Index, 3-month droughts with an index value of –1 or lower (equivalent to a moderate precipitation deficit with a probability of occurrence of no more than 16% for any consecutive 3-month period), occur approximately 90 in 100 years at any given location (see graph below).

- 93% of time at least 5% of state (based on percent of long term weather stations) is experiencing drought at either a 3-, 6-, 12- or 24-month time scale.

What this means is that Colorado is almost always in drought or near drought somewhere in the state.

2) Drought rarely encompasses the entire state.

- Only about five percent of the time (or approximately one year in twenty) does moderate or greater drought encompass at least half of the state at the same time.

- During recorded history, moderate drought (as defined by a standardized precipitation index value of –1 or lower) has never covered the entire state at the same time.

- Short-term droughts (3-month duration) have covered as much as 80 percent of the state. Longer-duration droughts (2-4 years) have reached to about 70 percent of the state.

What this means is that precipitation shortages rarely occur in the entire state at the same time. Economic and social impacts tied to a more "local" drought, however, can in turn affect the economy of whole state.

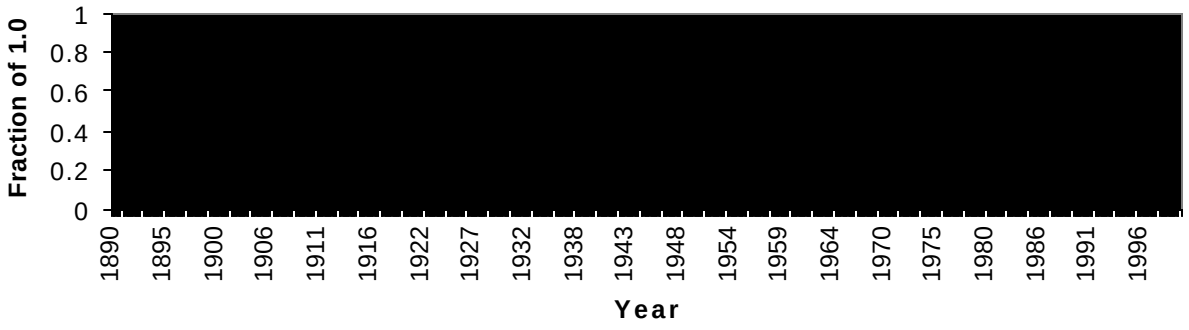
3) The most common droughts are short duration (6 months or less). They may be quite localized (especially during the growing season) or more widespread (especially during the fall, winter, and early spring). Depending on where and when they occur, they may have little or no impact on our lives. More widespread droughts do not necessarily have a tendency to become more long lasting.

4) Multi-year droughts occur infrequently.

- Precipitation time series for weather stations across Colorado show that periods of two or more consecutive years with much below average precipitation (less than 80% of average) have occurred a few times during the 20th Century at most Colorado stations. Below average precipitation lasting three years in a row, however, is quite rare. Many locations have never had three consecutive very dry years, particularly over the

(continued on page 16)

Fraction of Colorado in Drought
3-month SPI values



Summary of Colorado's droughts and prominent wet periods, 1890-1999.

NOTE: The dates in this summary are based on 12-month water year (Oct-Sept) precipitation totals from individual weather stations and thus are not identical to the dates in the table for 24-month periods, at the bottom of the page:

- 1890-1894 DRY Severe but brief drought in 1890, particularly east of mountains, followed by a very wet 1891. Dry 1893 with severe drought 1894, again most pronounced over eastern Colorado.
- 1898-1904 DRY Sustained and very severe drought over southwestern Colorado. Worst drought on record in Durango area. Some dry years elsewhere in Colorado, but not as severe or sustained. Very wet 1900 northeast Colorado.
- 1905-1929 WET Longest recorded wet period in Colorado history with greatest areal extent in 1905-1906, 1914-15, 1921, 1923 and 1927. Significant but brief droughts did occur during this period, most notably 1910-11, and 1924-25
- 1930-1940 DRY Most widespread and longest lasting (and most famous) drought in Colorado recorded history. Severe drought developed in 1931 and peaked in 1934 and early 1935. Interrupted by heavy spring rains in 1935 and more widespread heavy rains in 1938. Culminated with one more extremely dry year in 1939 when several stations along the Front Range recorded their driest year in history
- 1941-1949 WET Widespread wet weather, especially 1941-42, 1947 and 1949. Wet period interrupted with dry mountain winters – 1944-45 and 1945-46 with very low snowpack accumulation
- 1950-1956 DRY Extremely dry period statewide except for one very snowy mountain winter 1951-52. Most of state affected, and drought worse than the 1930s in some areas such as the Front Range.
- 1957-1958 WET 1957 brought persistent widespread drought-breaking precipitation across nearly all of Colorado – wettest year in recorded history.
- 1959-1973 DRY/WET Interesting roller coaster ride with alternating very wet and fairly dry periods and large spatial variations. Local drought was prevalent in 1959, 1960, 1962, 1963, 1964, 1966 and 1972. Very wet weather was reported in 1961, 1965, 1969, 1970 and 1973 with episodes of flooding.
- 1974-1978 DRY Colorado's most recent period of sustained multi-year drought culminating in the record-breaking winter drought of 1976-1977, the driest winter in recorded history for much Colorado's high country and Western Slope.
- 1979-1980 WET Brief but pronounced wet period with heavy winter snows helped replenish reservoirs.
- 1981 DRY An extreme but brief drought period from the fall of 1980 into the summer of 1981. This drought again took aim at the Colorado high country and ski industry and initiated a huge investment in snow making equipment. It also stimulated the writing of the "Colorado Drought Response Plan" and the formation of the "Water Availability Task Force" which has been meeting at least once a quarter each year since 1981.
- 1982-1999 WET Colorado's second longest sustained wet period in recorded history and the most drought free period since 1890. Extremely abundant snowpack and surface water supplies 1982-1987 – largest annual streamflow volumes this century on several rivers. Interesting period, 1987-1994 with only modest snow pack accumulation and consistently below average streamflows, but with low elevation precipitation above average reducing demand for surface water. Significant but brief drought in 1989 to early 1990 in southwest Colorado. A brief growing season drought in 1994 in northeast Colorado, and another localized drought over SW Colorado from late 1995 into 1996. Very wet state-wide in 1995, 1997 and 1999. The decade of the 1990s has been the wettest in recorded history over much of southeastern Colorado.

Table of Dry and Wet Periods for Colorado from the Fraction of Observing Sites. Precipitation for 24 month SPI.

Date	Dry	Duration	Date	Wet	Duration
1893-1905	X	12 years	1905-1931	X	26 years
1931-1941	X	10 years	1941-1951	X	10 years
1951-1957	X	6 years	1957-1959	X	2 years
1963-1965	X	2 years	1965-1975	X	10 years
1975-1978	X	3 years	1979-1996	X	17 years

northern half of Colorado. The only examples of four or more consecutive years with less than 80% of the long term average falling each year were found over southwestern Colorado near the turn of the last century (1899-1902), in southeastern Colorado during the dustbowl years (1933-1937), and over isolated areas of eastern Colorado 1952-1956.

- Based on SPI analyses, four droughts with a duration of at least four years (48 months) have occurred during the past century (see graph below).

- The significance and impacts of drought tend to increase with increasing duration (1930s, 1950s).

- Brief but extreme droughts can also have severe impacts. For example, extremely dry weather in eastern Colorado in April, May and June can ruin most of the winter wheat crop, even if the rest of the year is quite wet. Likewise, a very dry December, January and February can have very adverse financial impacts on Colorado's winter recreation industry, even if late season snows make up most of the precipitation deficit.

- Drought episodes have lasted as long as 10 years (1930s). However, these long-duration droughts are interspersed with periods of wet weather. For example, some of Colorado's wettest months on record (April 1900, May 1935, September 1938) were embedded in long-duration drought episodes.

5) Spatial patterns of drought.

- There appears to be no such thing as a "typical" drought pattern.

- Each of the largest and most severe droughts have had their own unique formation and spatial patterns.

- Each region of the state has its own drought history which may be similar or totally different from other regions of the state. Northern Colorado is sometimes wet when southern Colorado is dry and vice versa. The same is true for east versus west.

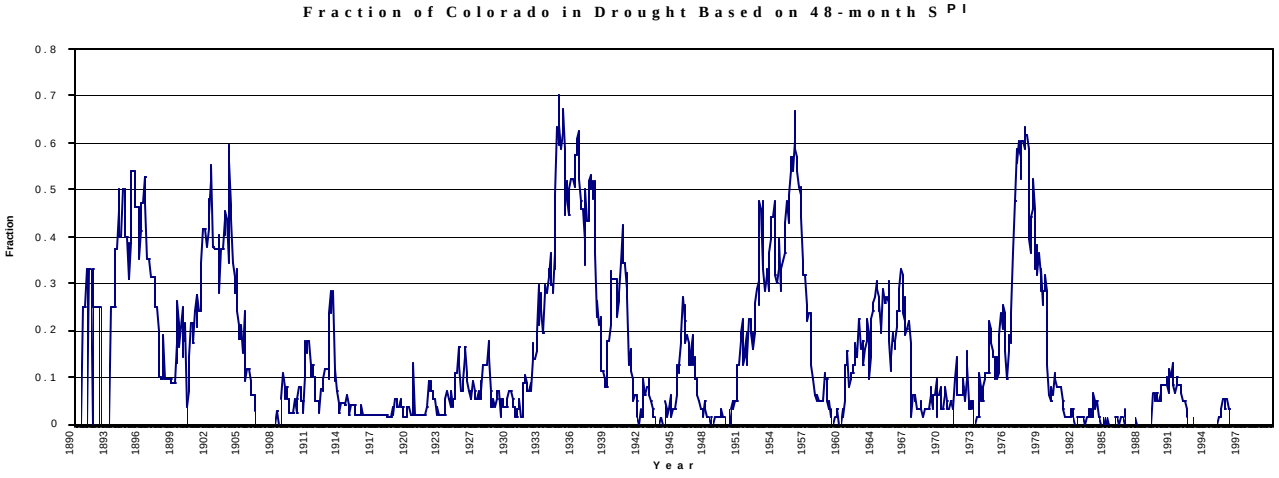
- It is rare for the entire state to exhibit similar precipitation patterns for more than a few months in a row.

6) Drought severity – how dry can it get?

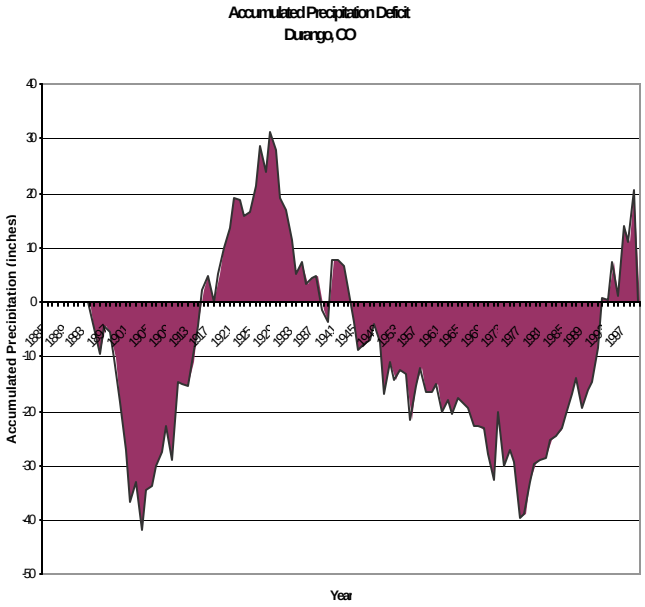
- Many areas of Colorado have gone without any measurable precipitation for up to 60 consecutive days. For a six-month winter season, 25-40% of the average accumulated precipitation represents an extremely dry winter (October-March). For an entire year, 50-60% of average represents an extreme drought year. Two to four months in a row with less precipitation than average is common. Five or more consecutive months with below average precipitation is very rare. Some weather stations have never had 6 or more consecutive dry months.

- Multiyear droughts of up to three consecutive years with less than 60% of average precipitation have occurred once or twice in the past 110 years at some locations in southeast and southwest Colorado. In Colorado's northern mountains, few sites have experienced two years in a row with less than 80% of average precipitation.

- Another way of looking at drought is by determining "accumulated deficits". For example, if your average annual precipitation is 16 inches, but you only received 12 inches, your accumulated deficit would be 4 inches for that year (see chart on the next page). When you accumulate deficits and surpluses year after year, you find that Colorado's worst droughts reach an equivalent deficit of about two full years of average precipitation. In Colorado's northern



mountains, and other areas with more reliable precipitation, accumulated deficits only reach about 1.2 years of average precipitation. For example, if Breckenridge averages 22 inches of precipitation per year, a very severe multi-year drought might result in an accumulated deficit of more than 22 inches over a few years time before above average precipitation reduces those deficits.



7) Timing of drought – When does it start? When does it end?

- Short duration droughts can begin and end in any season.

- Major droughts with durations of one year or longer tend to begin in and end in the season that is locally the wet season. This varies from place to place in the state. For example:

  Major droughts in the mountains tend to begin or end during the winter or spring months. In extreme southwestern Colorado, significant droughts have both begun and ended in the fall. The more dramatic the seasonal precipitation cycle is, the more difficult it is to end a major drought during the time of year that is the climatological dry season for that area. For example, over eastern Colorado, the months of December, January and February are typically dry. The three months combined produce, on average, less than 10% of the annual precipitation. Rarely does enough precipitation fall during this time of year to significantly alleviate longer-term moisture deficits. However, a week or two of very wet weather during late spring east of the mountains can bring a major drought to an end. For example, the spring of 1995 and the last few days of April 1999 delivered enough precipitation to compensate for large deficits.

- There are several examples of droughts ending abruptly with the appearance of widespread excess precipitation. For example, the severe 1950s drought was followed by the wettest year in Colorado's history in 1957. There are other examples of droughts that have ended more subtly, however.

8) Does a dry winter foretell a wet summer?

There is endless folklore concerning drought. Even before "El Nino" found its way into climatological jargon, people have talked ways to predict drought. Does the climate of one season foretell the next? Much folklore would suggest that. Our analyses, however, did not bear that out. We looked at a number of combinations. What happens after a very dry winter in the mountains? What happens after a very dry autumn at lower elevations (such as fall 1999 in Colorado)? Our analyses showed that sometimes dry winters in the mountains were followed by wet summers (like 1999), but other years they weren't. Sometimes dry springs along the Front Range were followed by hot dry summers (like 1954), but other years they weren't. Further analysis would be required to determine how and if preicpitation during one season helps foretell the next here in Colorado. Less than 10% of the variance in summer precipitation is explained anywhere in Colorado by the variations in winter precipitation.

9) Are there drought cycles?

People don't ask climatologists whether there are drought cycles in Colorado; most people are positive that there are. Some say there is a 3 year cycle, while others claim 7. The sunspot cycle of 11 years has caught some people's attention, while many strongly believe that a 22 year drought cycle (double sunspot cycle) controls Colorado's drought patterns.

We examined our rainfall records in Colorado in search of drought cycles. There is some evidence of a two to three year cycle over portions of southern and eastern Colorado. The dry periods in the 1890s, 1930s, 1950s and again in the 1970s have convinced some observers that the double sunspot cycle really does affect drought patterns in Colorado. That theory doesn't explain why the 1910s were so wet, why parts of the 1960s were very dry, and why we have been wet for the better part of 18 years in a row, but many still believe it. As for a seven or eleven-year cycle, there isn't much supporting evidence for that. It is true that dry periods are followed by wet, and wet followed by dry? That makes a cycle, doesn't it? The problem is that those cycles just aren't very reliable. As such, they don't help us much if at all in predicting what will happen next year or the year after that. Even throwing in the irregular cycle of the El Nino Southern Oscillation, we are still left with a great deal of unexplained variability in our precipitation.

Red Dawn II: What May Lie Ahead
(Colorado's "Worst Case Scenario" Drought)

Colorado has come a long way since the "dust bowl" years. We manage our crop and grasslands with soil and water conservation in mind. We store large volumes of water from wet years for use in dry years, and from wet seasons for use in dry seasons. We divert water from areas with lower demands to areas with higher demands. Still we know, history has a way of repeating itself.

Our study of past droughts has shown that the worst droughts are multi-year droughts. Vegetation dries up, soils blow, stored water reserves are gradually depleted, wells go dry. What begins as a minor inconvenience can, for many people, end in the loss of revenues, property, and livelihoods.

Sometime and somewhere in Colorado's future, a climatological scenario may unfold that goes something like this:

- *For two to four years, winter and spring precipitation in Colorado's mountains will fall far short of the average we have become accustomed to. Winter precipitation totals of 60 to 70 % of average in the high country will be followed by hot, dry summers on the Eastern Plains and Western Slope.*

- *The combination of diminished supplies along with heavy use of irrigation water will gradually deplete surface reserves and make ground water pumping more necessary. The Ogallala aquifer will again show signs of rapid depletion like it first did in the 1970s, and the cost of pumping groundwater will increase.*

- *Dryland vegetation will grow short and sparse. Bare patches will appear on sandy soils. Plant residue on unirrigated crop land will decrease each year. Despite efforts to retain soil moisture, crops will suffer and more topsoil will blow.*

- *Then along will come a winter like the winter of 1976-77 with snowpack accumulations less than 50% of average over most of the Colorado mountains, shutting down some ski areas.*

- *Spring will not bring its normal series of widespread rain and snow storms to the Front Range and Eastern Plains. A few storms will tease and appease us, but only a few. For the months of April through June, only about half of the average moisture will fall.*

- *Strong westerly and southwesterly winds will blow frequently, kicking up more and more dust as agriculture production falters. Giant dust clouds will blow through our cities and across fields.*

- *Water rights conflicts over municipal uses, agricultural uses, and instream flows will intensify, as will conflicts over interstate compacts and agreements.*

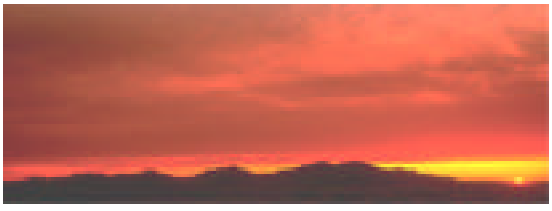
- *Finally, with reservoirs already very low, a long, hot summer will bring frequent temperatures near or above the 100 degree mark at lower elevations. Reservoirs will be too low to provide hydropower to meet demands for electricity to run air-conditioners and relieve us of the heat. Blackouts or brownouts will occur in some cities.*

- *Forest fires will race through thousands of acres of dry timber, and clouds of smoke will turn sunsets on the Front Range a deep blood red.*

Do you believe this? Will we be ready if it really does happen? Colorado's water planners think long and hard about drought. They know it is a part of life in the semiarid west. But most of us never give it a thought. Frankly, we haven't had to. The last multiyear Colorado drought ended in the late 1970s, and the last severe and widespread year-long drought Colorado ended in 1981. Yes, there have been local droughts since then, some quite severe, such as the drought southwestern Colorado experienced in 1989-1990 and again from the late summer of 1995 to early 1996. But droughts of that duration are not uncommon.

Overall, since 1982, Colorado has enjoyed the longest spell of wet (compared to historic averages) weather statewide since the favorably cool and wet period from 1905 through 1929 when so much of Colorado was settled and farmed. For portions of southeastern Colorado, the decade of the 1990s is the wettest decade since weather observations began in the late 19th century.

The heavy precipitation of the 1980s and 1990s does not guarantee that wet weather will continue into the 21st century. Neither does it assure us that drought is imminent. But one way or another, we know that drought will return. The longer we go without drought, the more likely we will be ill-prepared when drought makes its inevitable next visit to Colorado.



Are we ready?

Where to Learn More About Drought

This report in its entirety, with color graphics, can be found at the Colorado Water Resources Research Institute web site: http://cwrri.colostate.edu, click on Water in the Balance Archives.

There are numerous publications on drought assessment, impacts, and mitigation, and on droughts in Colorado and United States history. Below are just a few state agency contacts, publication references, and web sites that are available to provide more information about drought:

A Few Agency and Organization Contacts:

Office of the State Climatologist
Colorado Climate Center (CCC)
Department of Atmospheric Science
Colorado State University
Fort Collins, CO 80523-1371
Ph.: (970) 491-8545

Office of Emergency Management (OEM)
Water Availability Task Force
15075 S. Golden Road
Golden, Colorado 80401-3979
Ph.: (303) 273-1622

Colorado Water Resources Research Institute (CWRRI)
410 N University Services Center
Fort Collins, CO 80523
Ph: (970) 491-6308

Colorado Water Conservation Board (CWCB)
Office of Water Conservation
1313 Sherman Street, Room 721
Denver, Colorado 80203
Ph: (303) 866-3441

A Few Publications:

1999. McKee, Thomas B, Nolan J. Doesken, and John Kleist. Historical Dry and Wet Periods in Colorado, Climatology Report 99-1, Part A: Technical Report, Part B: Appendices, Dept of Atmos Sci, CSU. Available from CCC.

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Colorado Drought Response Plan, 1990 revision. Division of Disaster Emergency Services (now the Office of Emergency Management). Available from OEM.

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A complete list of publications available from CWRRI can be found at: *http://cwrri.colostate.edu/*
A complete list of publications available from CCC can be found at: *http://ccc.atmos.colostate.edu/*

A Few Good Web Sites:

- Colorado Climate Center
  http://ccc.atmos.colostate.edu/
- Colorado Office of Emergency Management
  http://www.state.co.us/data2/oem/oemindex.htm
- Colorado Water Resources Research Institute
  http://cwrri.colostate.edu/
- Colorado Water Conservation Board
  http://www.dnr.state.co.us/cwcb/index.asp
- Western Drought Coordination Council
  http://enso.unl.edu/wdcc
- Western Regional Climate Center
  (especially for climate data)
  http://ww.wrcc.sage.dri.edu
- USDA Drought Information Page
  http://drought.fsa.usda.gov/
- National Weather Service (especially for maps and regional monitoring data on precipitation, temperature, indices, and related information)
  http://www.cpc.ncep.noaa.gov/products/analysis_monitoring
- National Drought Mitigation Center (especially good educational materials on drought indices and definitions)
  http://enso.unl.edu/ndmc/
- Natural Resources Conservation Service
  http://www.co.nrcs.usda.gov/ssps.htm

About the Colorado Water Resources Research Institute and *WATER IN THE BALANCE*

The Colorado Water Resources Research Institute (CWRRI) exists for the express purpose of focusing the water expertise of higher education on the evolving water concerns and problems faced by Colorado citizens. CWRRI strives to constantly bring the most current and scientifically sound knowledge to Colorado's water users and managers.

For more information about CWRRI and/or the water expertise available in the higher eduction institutions in Colorado, please contact CWRRI at the address below or by phone, fax, or email as follows:

Phone: 970/491-6308

FAX: 970/491-2293

E-mail: **cwrri@colostate.edu**

CWRRI went on-line with its web page in December of 1994. The CWRRI home page is located at the following URL:

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