



# Colorado's Water: Climate, Supply And Drought

Colorado Water Resources Research Institute  
June 1990

**Colorado**  
**State**  
University



Water is very important to Colorado. Because of its fickle climate, the state is subject to drought. This brochure was prepared to explain why this subject is important, where Colorado's water comes from, how it is managed, and what Colorado is doing to best deal with drought.

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## Why is Water Important to Colorado?

Colorado is known as the "Mother of Rivers" because the headwaters of five major rivers flow from their birthplace on the continental divide to lower elevations. As these rivers increase in size and power, they sustain the heartbeat of Colorado's economy because water serves multiple uses throughout the state.

### Agriculture

About 80 percent of the water used in Colorado is for agricultural purposes. Irrigation practices have turned a once semi-arid desert into a multi-billion dollar industry that bolsters Colorado's economy and sustains rural lifestyles.

### Cities

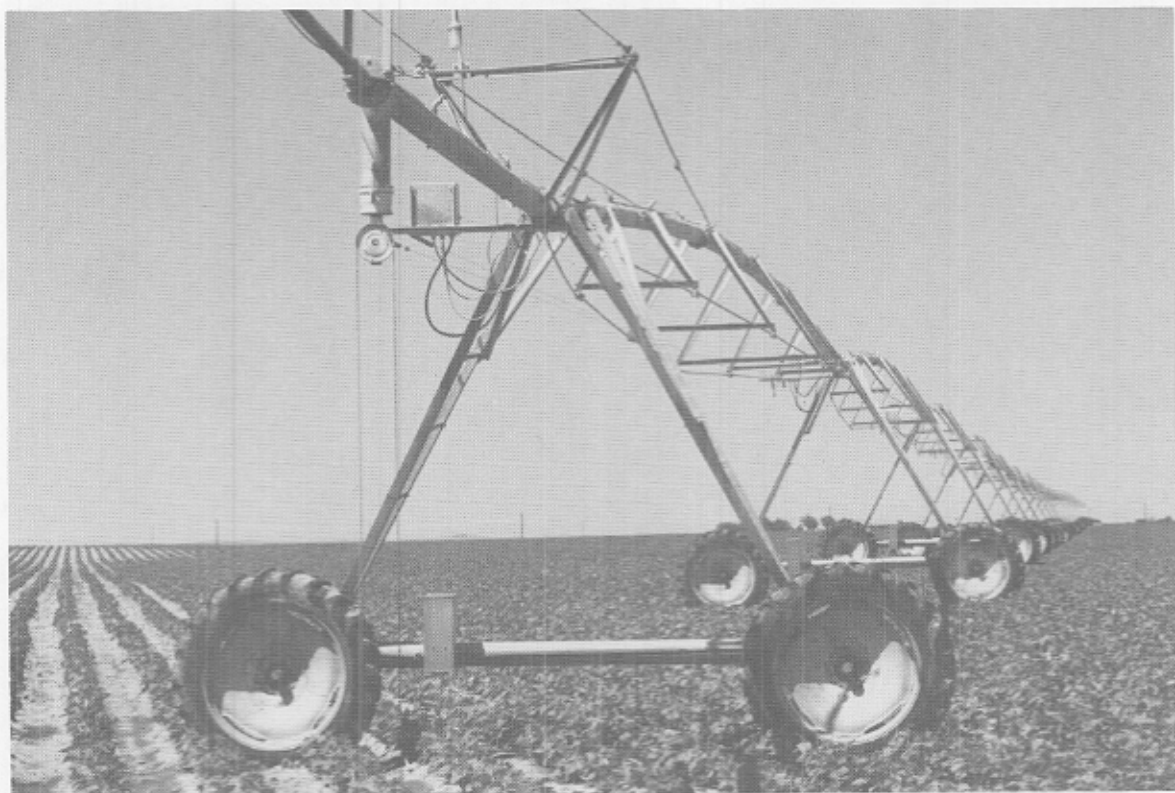
Burgeoning populations rely on water to support their domestic needs on a daily basis. In 1980, Colorado's population was 2.89 million people. In 1990, this number will have increased to 3.37 million. This 20 percent gain in just one decade means an enormous demand for water must be met. Without responsible development of new sources and proper management of existing sources, cities will fall short of supplying inhabitants with the water that is essential for urban life.

### Nature

Colorado provides more than just drinking and irrigation waters. Parks, wild and scenic rivers, and wilderness areas preserve native beauty that cannot be found anywhere else in the world. This natural beauty is worth a bundle to Coloradans — but how much? A 1985 study by Colorado State University's Department of Agricultural and Resource Economics attempted to generate a dollar value for the protection of eleven of Colorado's rivers.

Using the "willingness-to-pay" method, the researchers found the average Colorado household is willing to pay up to \$95 annually for both the recreational and preservation benefits of the eleven rivers. The statewide annual benefit (or worth of these rivers) is then \$112.6 million.

Although these numbers indicate the importance of natural waters to Colorado, they cannot capture the true beauty of a free-flowing river; nor can they indicate the importance of river water to wildlife and entire ecosystems, in Colorado and beyond. Those assets are priceless.



Agriculture is an invaluable part of the Colorado economy. About 88 percent of the water used in Colorado is for agricultural purposes.

## Recreation

"Recreation" and "Colorado" are often mentioned in the same sentence. The description is accurate: recreation is a hugely popular pastime as well as a major source of income for the state. Colorado skiing attracts visitors from many countries. The more than 1900 reservoirs throughout the state provide boaters, sailboarders, water skiers, and divers a haven for their activities and locals with a steady income. Furthermore, fishermen, rafting fans, and kayakers can encounter world-class waters on a variety of rivers.

It's difficult to pin numbers on to the economic value of these activities to Colorado, yet a few examples will help paint a picture: revenues from fishing licenses in 1989 topped \$8.5 million; direct and indirect expenses for the more than 200,000 people who paddle a kayak or row a raft down Colorado rivers are estimated at \$42 million a year.

Obviously, without water as a recreational resource, Colorado's popularity and economy would not be the same.

## Business

Without water, Colorado's commercial enterprises could not survive. Beer brewing, computer production, hydroelectric power generation, and other industries rely on water and are vital to the economy. As Colorado competes in the global economy, it needs reserves of pure water to help attract high-wage, non-polluting industries.

Although the question of why water is important to Colorado is easily answered, the question of what to do without it is not. We can begin by understanding its origins...



Colorado's water recreation is very popular and serves as a major revenue source for the state.



## Colorado's Weather and Climate

Colorado is a semi-arid state that receives an average of only 17 inches of precipitation per year. Winter snowstorms and summer showers are quickly followed by nice weather. Sunshine is plentiful, and humidity is low compared with much of the United States.

Winter precipitation in the Rocky Mountains accounts for about half the annual precipitation. Although some summer thunderstorms do increase stream flow, the winter snowpack provides the consistent run-off and ultimately determines how much water will be available for recreation, industry, farming, drinking and other uses. It does not matter when the snow falls, as long as there is enough to melt and fill the streams throughout the summer. In general, 15 inches of Colorado's powdery snow will equal one inch of water.

In Colorado, brief summer rains usually don't affect the water supply because evaporation is so high during the hot summer months. Only after .40 inches of precipitation have fallen is a runoff effect noticed. On average, this occurs less than a dozen days per year. However, those dozen storms contribute 30 to 60 percent of Colorado's annual precipitation.

Precipitation is Colorado's only true source of water. Therefore, a basic understanding of the weather mechanisms that cause precipitation is helpful. Any time air ascends there is cooling. If there is sufficient moisture in the air, the moisture will condense, clouds will form, and precipitation will occur. Air can be lifted by four different meteorological effects that can occur separately or in combination.

### Convective Lifting

Most of the precipitation Colorado receives between June and August is caused by convective lifting. This occurs when a body of air close to the ground is warmed by solar heating. As the air temperature increases, the body of air becomes less dense and rises. If there is moisture present, precipitation will occur. This phenomenon occurs usually in the spring and summer when solar heating is at its greatest and is characterized by full, billowing clouds such as the common summertime thunderheads.

### Synoptic Scale Lifting

Synoptic scale lifting is a big contributor to Colorado's precipitation. It refers to vertical motions caused by large storm systems in the atmosphere that generally occur from September into May. Synoptic scale lifting is produced by air converging toward a low pressure area. Normally, air flows around a low-pressure area, but close to the ground the air slows due to friction and moves in towards the center of the low in an attempt to fill the low. When air comes together under these circumstances, it rises. This phenomena is illustrated in **Figure 1**.

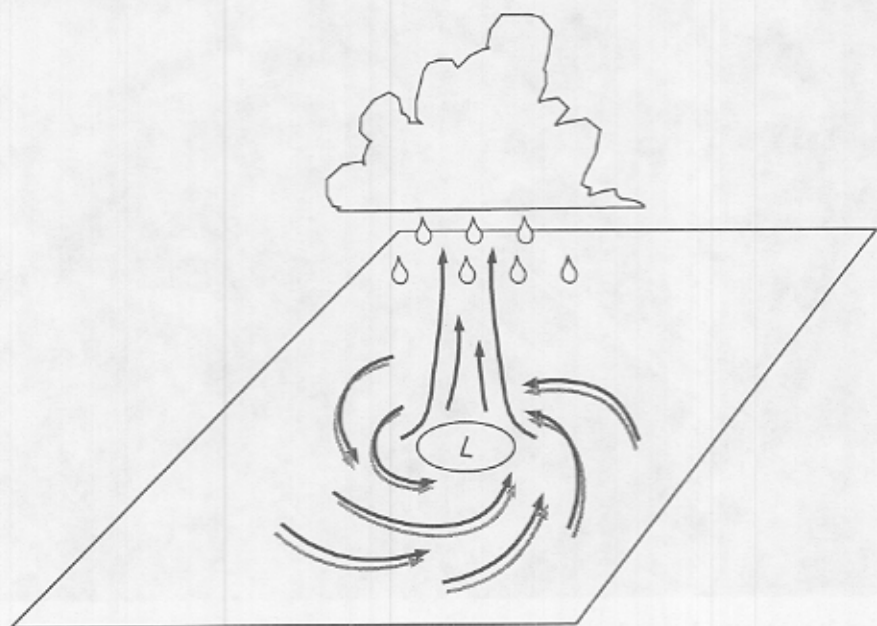


Figure 1. Synoptic Scale Lifting

## Frontal Lifting

The last meteorological effect that creates precipitation is frontal lifting. When cold air meets a warmer air mass, the more dense cold air plunges under the warm air and forces it upward. See Figure 2. Again, as the warm air rises, it cools and releases its moisture. There is not much frontal precipitation in Colorado since the Rockies tend to break up fronts.

These four meteorological effects explain how Colorado receives its limited precipitation. Because precipitation is so limited, there is no room for error in its use. When it declines in a period of drought, the State must be prepared to handle it.

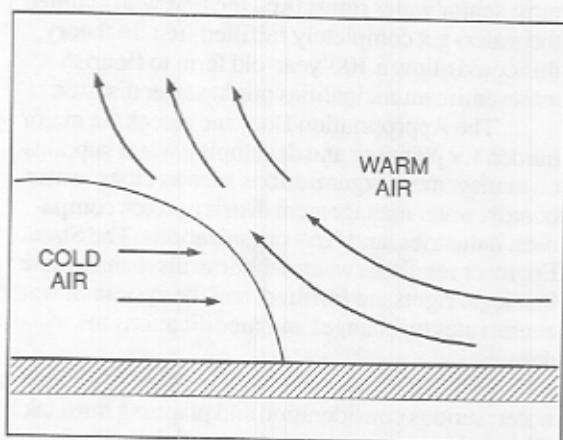


Figure 2. Frontal Lifting

## Orographic Lifting

Orographic lifting takes place when winds encounter a mountain barrier and are forced up and over that barrier. The Rocky Mountains serve as just such a barrier. As the air rises it cools, and if moisture is present, precipitation occurs. There are three basic wind patterns that Colorado encounters:

■ **Figure 3a** is the classic wind behavior that brings moisture in from the Pacific Northwest and creates precipitation in Colorado by the orographic lifting mechanism.

■ In **Figure 3b**, winds from Alaska sweep down through the Mid-West and don't encounter the Rocky Mountains to any large extent. Extended periods of this type of wind patterns leave Colorado short of precipitation and may cause the onset of drought conditions.

■ A sporadic situation occurs in **Figure 3c** when winds sweep in from middle or southern California. The air holds large amounts of moisture due to its warm-climate origin. This results in wet and stormy conditions that drop copious amounts of snow, usually accompanied by synoptic scale lifting.

Mountains affect precipitation year-round, but more so in the winter when orographic lifting greatly enhances snow accumulation in high-mountain areas.

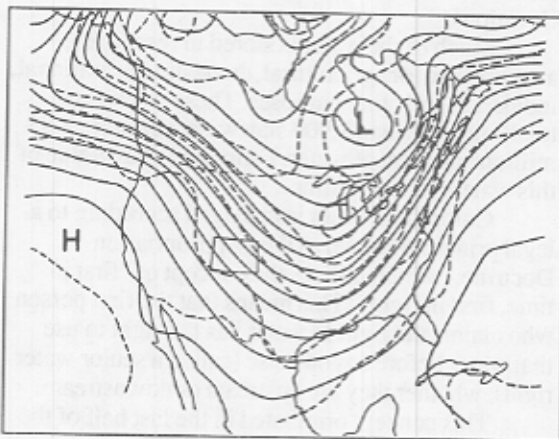


Figure 3a. Orographic Lifting

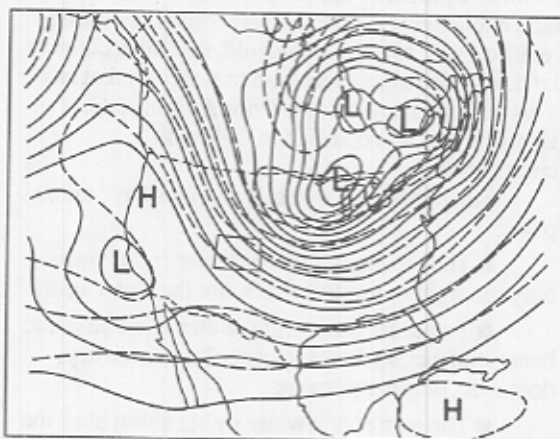


Figure 3b. Orographic Lifting

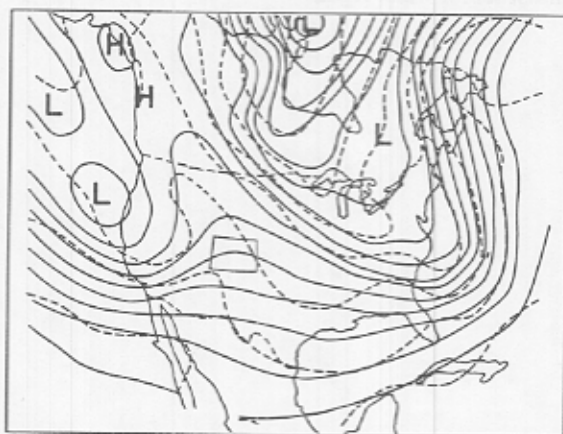


Figure 3c. Orographic Lifting

## Water Supply, Management, and Law

Colorado's water supply has its origins in the Rocky Mountains. During the winter season, snowfall accumulates and acts as a frozen reservoir. With spring, the snow melts and provides runoff for the rivers and streams that branch out to the lower elevations.

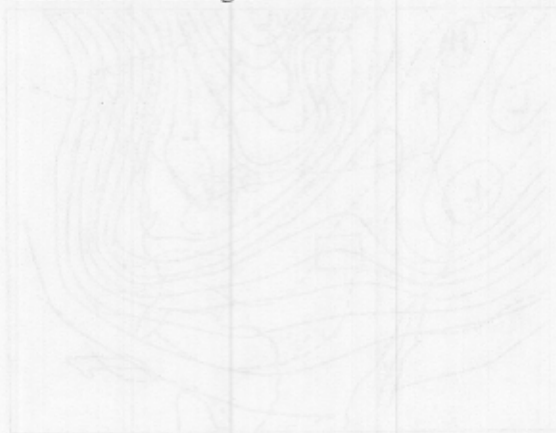
Much of the water is stored in reservoirs, awaiting use for agricultural, domestic, recreational, industrial, and other purposes. These reservoirs, totalling more than 1,900 statewide, can store 8.85 million acre-feet of water. Estimated retail value of this water is \$991 million.

Colorado's water is managed according to a legal principle known as the "Appropriation Doctrine," which utilizes the concept of "first in time, first in right." This means that the first person who claims the right to water has the right to use that water before anyone else (called a senior water right), whether they are upstream or downstream.

This concept originated in the last half of the 1800s when miners flocked from California to Colorado in search of gold. The first miner to stake a claim to a parcel of land had the right to mine that land exclusively. Since many methods of mining require water to expose the gold, staking a claim to land included staking a claim to water on that land. This became known as the Prior Appropriation Doctrine and was codified in Colorado's constitution.

Since then, a few subtle changes have taken place:

- The person who owns water rights owns only the right to use the water, not the water itself.
- To hold a water right, water must be put to beneficial use, such as for agriculture, industry, domestic, or other purposes.
- The owner of a water right cannot alter the diversion or use of the water if it will harm a current downstream user — regardless of who owns the most senior water right.



Until recently, the system has worked well. It allowed the arid eastern part of the state to be agriculturally developed through irrigation. This would not have been possible with the East Coast's doctrine of riparian water law which states that only owners of land adjoining water have the right to use it — making irrigation ditches a practical impossibility. The ability of Colorado's farmers to divert water from a stream to a farm miles away has become an important part of Colorado's economy.

As the state grows, more and more demands are put on water use. In water-abundant years, this is not a problem. In times of drought, however, when river flow is low, the Appropriation Doctrine doesn't require conservation and still holds that the most senior water rights (i.e., the first who claimed the water) get completely fulfilled first. In theory, this could allow a 100-year-old farm to flourish while entire municipalities might suffer disaster.

The Appropriation Doctrine places the major burden for planning and developing water supplies on management organizations such as cities, water boards, water management districts, ditch companies, industries, and farm organizations. The State Engineer regulates water withdrawals to make sure that legal rights are fulfilled, and the system of water courts rules on changes and modifications to decrees.

While the laws work well in times of abundant water, serious consideration and planning must take place as to appropriate procedures for times of drought.



## Drought is Inevitable

Understanding how Colorado receives its water (through precipitation) and how it is managed (through agencies working within the Appropriation Doctrine) is a basic first step in dealing with drought.

Yet what exactly is drought? Although a variety of definitions exist, the most general one seems to be "a prolonged and unusual period of dryness."

There are several important parts to this definition. A drought occurs only when water supply is consistently below normal. A drought is not necessarily alleviated by a single huge snowstorm such as the one in the photo below. Because a drought is a prolonged period of dryness, a short

period of moisture may put only a small dent into the actual drought condition. The actual impact of the drought is largely determined by water demand. Through careful reuse and conservation a drought may appear to be less severe than forecasted.

Times of drought, intervals of normal precipitation, and periods of excessive moisture follow one another randomly in an endless pattern. Climatic fluctuations determine the severity, duration, and order of each part of the cycle.

While Coloradans can do little to change the climate, they can focus their efforts on the ability to anticipate the onset of a drought and how to deal with it.



Many think a blizzard or heavy rain ends a drought; in fact, it may only make a minor addition to the overall water supply.

## Anticipating Drought

The principle behind anticipating a drought is to express a large amount of current climatic and water data simply so that trends can be determined. Much like weather forecasting, the future cannot positively be determined; yet good judgements can be made using current technology and accurate information. Three methods of foreseeing drought are used in Colorado.

### Palmer Drought Severity Index

The Palmer Drought Severity Index (PDSI) is published weekly by the United States Department of Agriculture. Originally developed as a tool for government decision makers, it is presently the most widely used drought index in the United States. Every year, it indicates each state's dryness or wetness with representative values. It is a simple soil moisture budget that uses basic calculations of what will evaporate, what will soak into the soil, how much will soak through the soil as deep percolation, and how much will run off. The index has coefficients and normalization processes whereby the current condition can be assessed as normal or abnormal. In wet conditions the index value has a positive value, and in dry conditions there will be negative index values.

The index is accurate only in a relative sense. For example, **Figure 4** is a graphic illustration of drought conditions in Colorado over the past one-hundred years. The droughts of the late 1800s, 1930s, 1950s and the 1970s are illustrated by their deficient appearance relative to other years.

In 1983, the Palmer Index was specifically tailored to Colorado's climate to give the numbers greater spatial definition. However, The biggest drawbacks to using the Palmer Index in Colorado

are that it doesn't include snowpack and doesn't consider irrigated land, two major factors in Colorado's water supply.

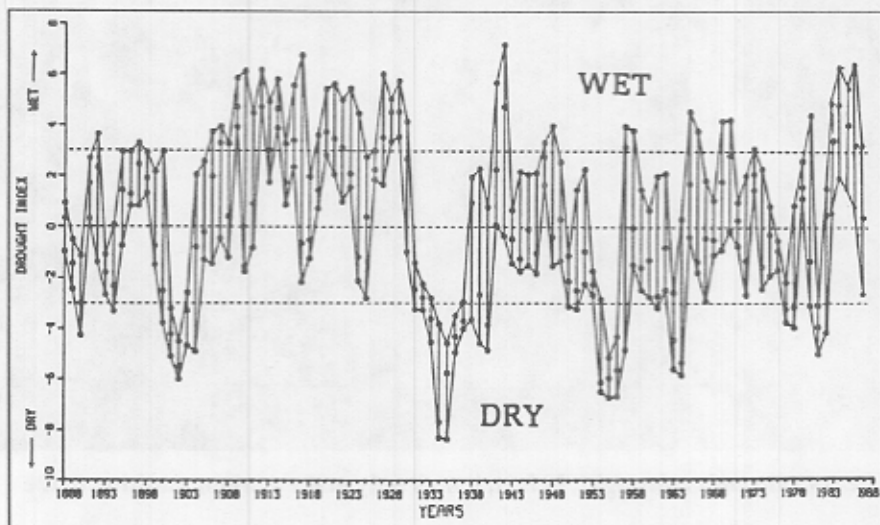
### Surface Water Supply Index

A special index was designed for Colorado in 1981 by the State Engineer's Office and the Soil Conservation Service. Named the Surface Water Supply Index (SWSI), it links the effects of snowpack, streamflow, precipitation, and reservoir storage using a weighted-probability formula. Values of the SWSI are published monthly by the State Engineer's Office in a map format. See **Figure 5**. The formula applies weighting coefficients to the various water sources to calculate the index value. The coefficients are determined on a basin-by-basin case over each of Colorado's seven major river basins: the South Platte, Arkansas, Rio Grande, Gunnison, Colorado, Yampa/White, and San Juan and Dolores/Animas. The SWSI, similar to the Palmer Index, utilizes a relative scale.

A drawback to the SWSI is the difficulty in determining the relative importance of each of the different sources (reservoir storage, precipitation, snowpack) accurately. Also, converse to the Palmer Index, the SWSI does not consider carry-over moisture in the soil profile.

Water resource authorities use the PDI and SWSI to assess water supply conditions throughout the state. Variations in index values are used to consider drought planning actions by various mitigating agencies.

Although indices provide a relative snapshot of the drought picture throughout the state, they are still just a single tool in the assessment of potential drought conditions. Another tool to predict droughts is measuring the snowpack in the mountains.



**Figure 4. Palmer Drought Severity Index (Colorado Climate Newsletter, June 1988)**



## Snow Measurements

Seventy-five percent of Colorado's total surface runoff is derived from snowmelt. The benefit of being able to predict spring runoff early in the year is enormous: municipalities can estimate water supply and prepare conservation measures; farmers can adjust their irrigation schedules based on how completely their water rights will be met; and the state can begin mitigation measures before the full impact of a water-short year takes its course.

The standard method of collecting snowpack data is to manually measure the depth and water content of snow along various snowcourses spread throughout the high-mountain regions. However, in 1979 an easier, more efficient way to collect snowpack data was begun in some regions with the installation of the SNOTEL system. The system, which uses pillows filled with anti-freeze that lie on

the ground, measures the pressure of the accumulated snowpack on top. This pressure is converted into an equivalent amount of water, and along with other data, such as temperature and precipitation, is electronically transmitted to the Soil Conservation Service. The data collected from all the sites are then sent to a central data collection facility where predictions are generated using statistical hydrologic models. Streamflow forecasts are then issued.

In Colorado, the Soil Conservation Service operates a network of approximately 120 manually measured snowcourses and 75 SNOTEL sites. SNOTEL is a boon since it can routinely collect data throughout the year.

The Palmer Index, the Surface Water Supply Index, and snow measuring give water authorities a chance to prepare for what is to come. With additional research to refine techniques, anticipating a drought will become increasingly accurate.

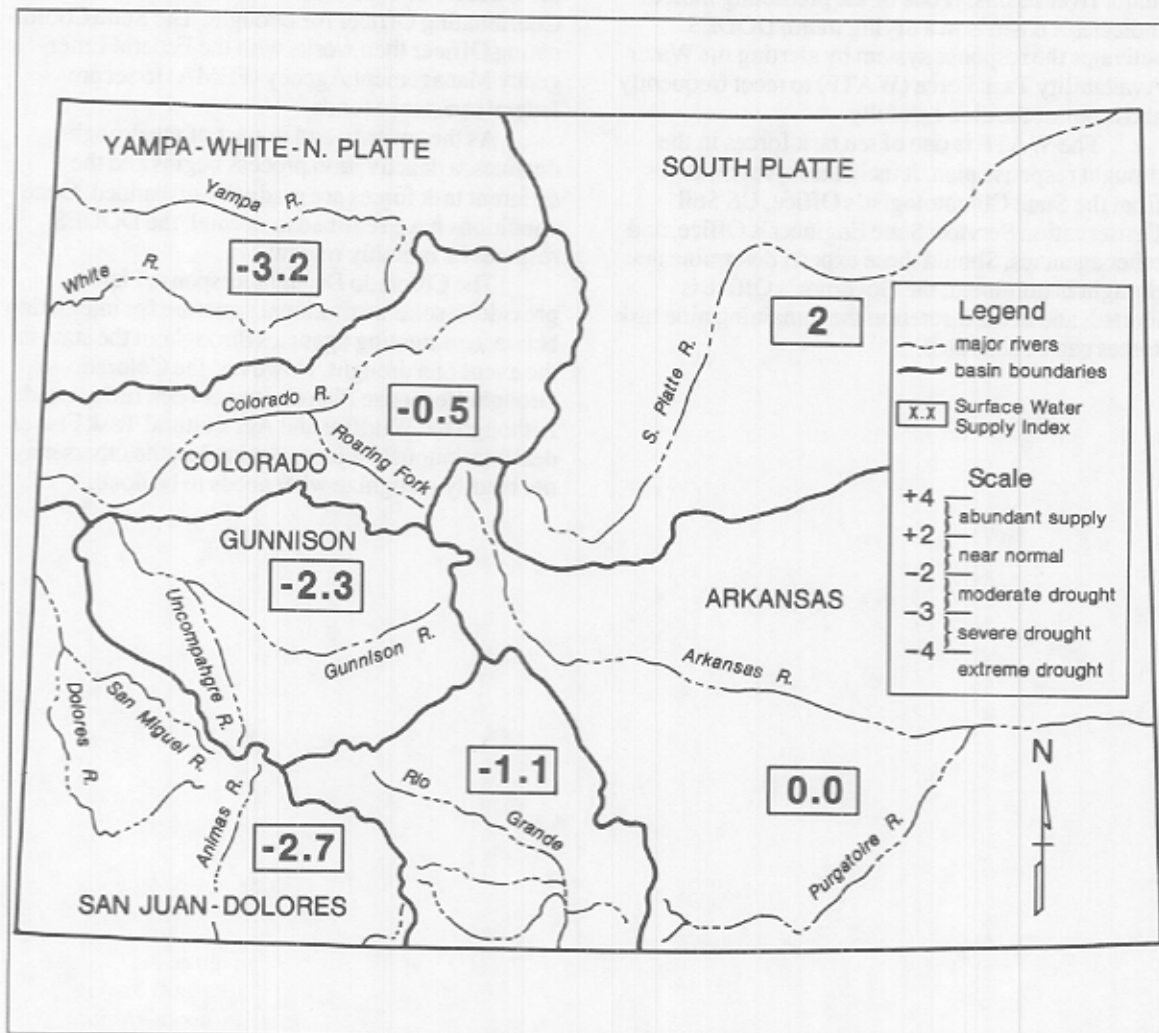


Figure 5. Surface Water Supply Index (Colorado Water Supply Conditions Update, Sept. 1987)

## Drought Response Arrangements

Once a drought is on its way, how does Colorado prepare for it and deal with it?

Colorado formulated a comprehensive drought response plan in 1981 "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 concept behind the plan is a system that includes both assessment and response. The assessment system monitors the conditions of regions in the State through various information sources and keeps the government informed. When drought conditions arise, the response system engages to meet the needs of whatever part of the State is impacted. When the impact is too great, state legislative or federal assistance is requested.

The assessment system begins with the Division of Disaster and Emergency Services (DODES). It evaluates the conditions in Colorado's major river basins. If one of the predicting indices indicates a basin is in a drying trend, DODES activates the response system by alerting the Water Availability Task Force (WATF) to meet frequently and monitor the area carefully.

The WATF is one of ten task forces in the drought response plan. It includes representatives from the State Climatologist's Office, US Soil Conservation Service, State Engineer's Office, and other agencies. Should these experts determine that drought is imminent, the Governor's Office is alerted, and at his discretion the remaining nine task forces can be activated.

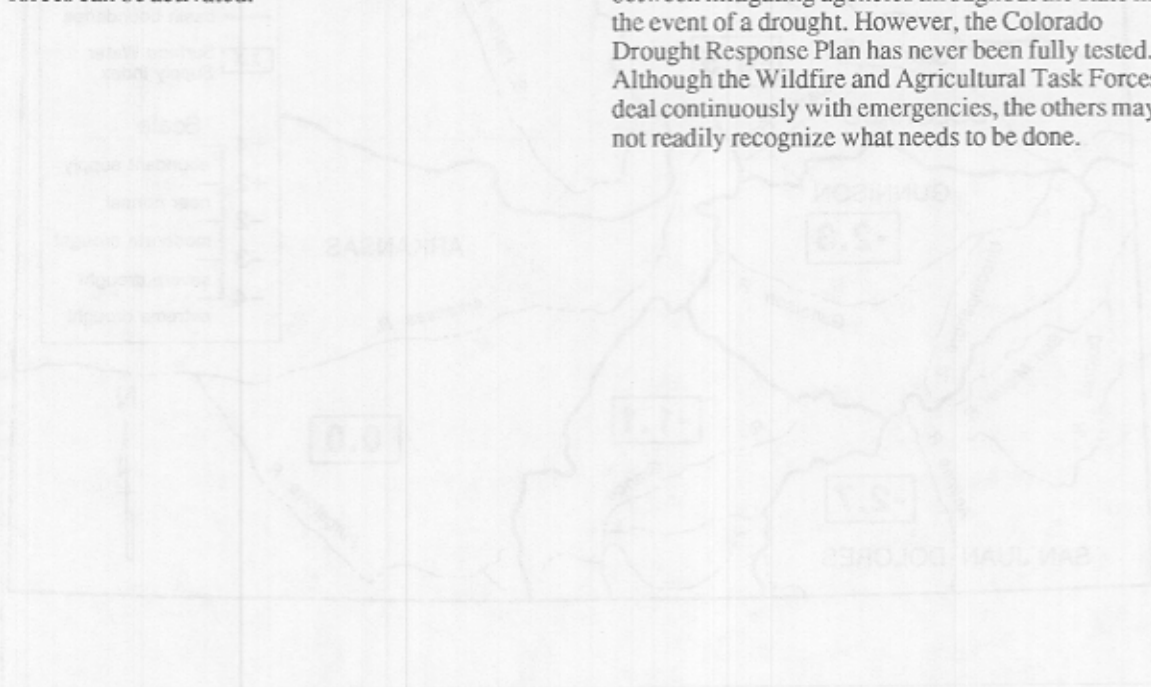
The task forces and their associated lead agencies are listed in the following table.

Each task force, comprised of professionals in their respective fields, assesses and responds to a different impact area of drought. The lead agencies provide specialized resources needed to determine a course of action.

When the individual task forces and their lead agencies cannot meet the needed response to drought conditions, Task Force X, the Review and Reporting Task Force, is activated. It acts as a liaison to the Governor by making recommendations for activation of the Inter-Agency Coordinating Group (IACG). Once activated, this group reallocates resources to areas of need and makes recommendations to the Governor on needs that cannot be met. The IACG provides support data to the Governor in the event that federal assistance is requested. If a federal disaster situation is declared, the Director of the DODES is designated as the State Coordinating Officer for Drought. The State Coordinating Officer then works with the Federal Emergency Management Agency (FEMA) to secure federal assistance funds.

As the severity and impact of the drought declines, a deactivation process begins and the different task forces are gradually disbanded. Once conditions have returned to normal, the DODES resumes its monthly review.

The Colorado Drought Response Plan provides a solid institutional structure for interaction between mitigating agencies throughout the state in the event of a drought. However, the Colorado Drought Response Plan has never been fully tested. Although the Wildfire and Agricultural Task Forces deal continuously with emergencies, the others may not readily recognize what needs to be done.





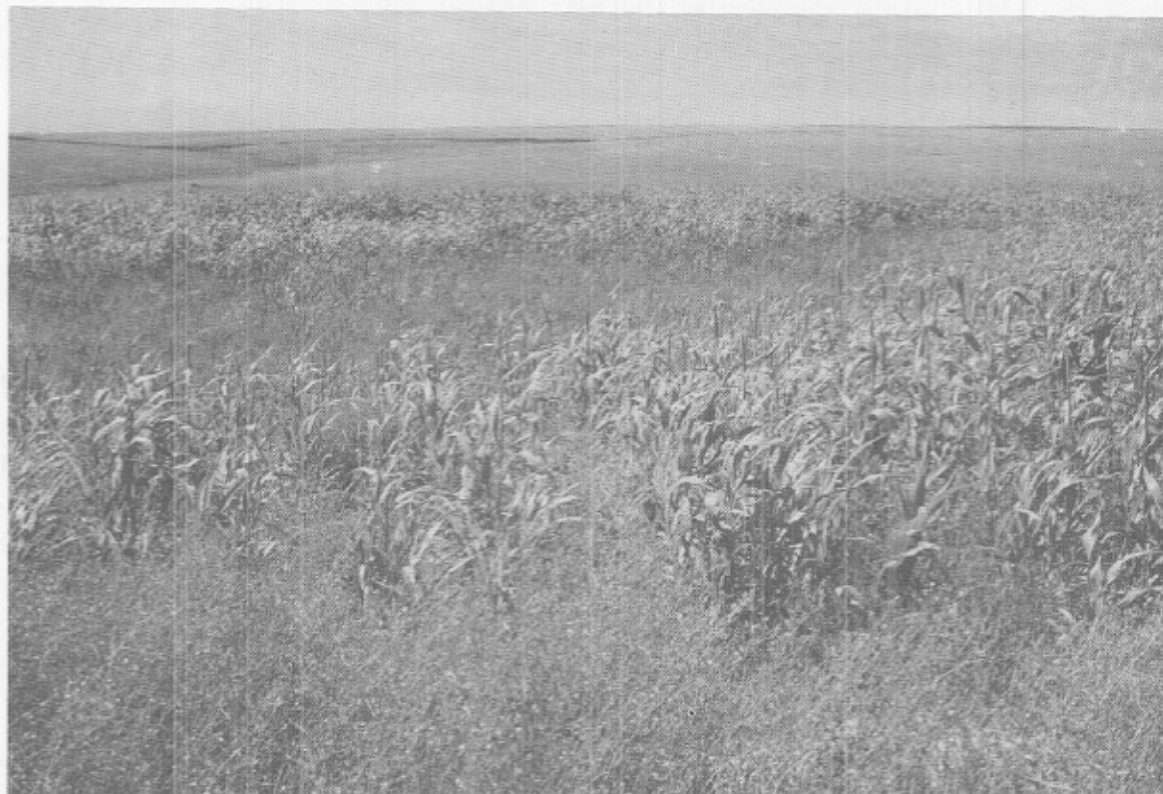
The plan has no internal funding; instead it relies on staffing from a number of state and federal agencies. Personnel can shift workloads to take on extra duties for a short period of time, but should a drought last four or five years, the overload may be too much.

As mentioned earlier in this brochure, to effectively deal with drought it is important to recognize the condition as early as possible. Continued research on predicting techniques and defining a drought condition will help mobilize government agencies quickly.

Lastly, one of the system's bigger problems is that it doesn't encourage conservation. This is the result of inflexible water laws that allow senior water rights holders to use their full amount and pass little or none on to those who hold junior water rights. The laws indicate no provisions for conservation in times of drought.

## Task Forces and Their Lead Agencies

Task Force	Lead Agency
1: Water Availability	DODES
2: Municipal Water	Department of Local Affairs
3: Wildfire Protection	State Forest Service
4: Agriculture Industry	Department of Agriculture
5: Commerce/Tourism	Department of Local Affairs
6: Wildlife	Division of Wildlife
7: Economic Impacts	Office of Planning and Budgeting
8: Energy Loss	Office of Energy Conservation
9: Health	Department of Health
X: Review/Reporting	DODES



In the mid-1970s, drought caused this cornfield near Lindon, Colorado, to grow slowly and become weed infested.

## Where Do We Go From Here?

Water to Colorado is like oil to Saudi Arabia: the State's economy relies heavily upon the use of water.

The type of use varies greatly from group to group and region to region. Farmers, municipalities, recreationists, industry, and nature itself all compete for water use. The battles cross the Continental Divide as the growing Front Range thirsts after Western Slope water; now these conflicts also affect Northern and Southern Colorado.

These worthy water uses all must be addressed. It's not a question of **who** will get the water, but **how** will water get to everyone. To accommodate everyone, we need to strive for the best use of the available water through efficiency of use and conservation, as well as to consider developing new supplies.

Colorado's Executive and Legislative branches must determine how to unravel the complex legal and political questions associated with water supply and use, both within Colorado and out-of-state.

These issues can best be addressed through a better understanding of the entire water issue. Extensive research (including climate, snow measurements, water management, and water use and reuse) is imperative to begin solving the water problems. Upgraded educational programs for students and adults will lead to a more water-conscious society. And lastly, new approaches developed through study commissions would aid in effectively dealing with water problems at a local, state, and national level.

The time to act is now — for tomorrow's Colorado relies upon it.



## State Drought Response Organiza- tions

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