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DROUGHT IMPACT ON THE COLORADO RIVER BASIN

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by

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ABSTRACT

The Colorado River Basin is marked with numerous dams, which make sufficient water reservation possible. The man-made reservoirs behind the dams provide water for households, businesses, and crop irrigation. Everything seems to work out nicely as long as climate remains constant and reservoirs are full. Based upon drought history, a prediction has been made on the severity and duration of the present drought, which suggests that the dry times will continue for at least several more years.

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1. INTRODUCTION

The purpose of this IQP was to provide information and the analysis of the seriousness of the current Colorado drought. The population of Colorado has swelled 50% since 1980, which marked the end of the 1978 drought. Agriculture will suffer the most, but households and businesses will also have limited water usage, if the drought continues.

The Colorado River Basin starts in lower Wyoming, flows down into Nevada, Utah, and Colorado, continues down into New Mexico, Arizona, and California, and then empties into the Pacific Ocean, in Baja. What happens to the river in Mexico? As it turns out, the construction of the Parker, Hoover, Glen Canyon, and other various dams has ensured that almost no water escapes from the U.S. into Mexico.

One needs to understand that without the man-made reservoirs, such as Lake Havasu, Lake Mead, and Lake Powell, most farms and cities within and even outside the Colorado River Basin could not exist as they do today. Las Vegas is one such example. Las Vegas was once never believed to have been possible, since it receives only 3 inches of rainfall per year, the same amount that Egypt receives. Nevertheless, it is estimated that 30 million Americans depend on Las Vegas, whether it be for housing, work, or something else. One hotel in Las Vegas can usually support as many as 10,000 jobs.[1]

The terrain along the Colorado River is rocky and is home to various mountain ranges of considerable size. It's true that many cities and states around the country are starting to become overcrowded, thus forcing citizens to move to the once unfavorable

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[1] Cadillac Desert: An American Nile, Part II, Produced and directed by Marc Reisner, 55 min, Trans Pacific Television, 1997, Videocassette.

west. Sure it was once a dry barren land, but building feats such as the Hoover Dam and complex aqueduct systems have inspired many to give it a chance to build a new life.

Fig 1.1 The Colorado River Basin is primarily located in the four corner states. (http://www.hooverdam.usbr.gov/workings/basinmap.htm)

2. USES FOR THE COLORADO RIVER

2.1 The Anasazi Indians

In the second half of the 13th century, as many as 100,000 Anasazi Indians flourished in the area known as the southwestern United States. A "Great Drought" lasting 20-30 years eventually caused the Anasazi, "to abandon their magnificent stone villages at Mesa Verde and elsewhere on the Colorado plateau, never to return again."[2]

Archaeologists have determined that the Anasazi suffered from malnutrition, and had a much higher infant mortality rate than in previous years. However, it is speculated that the drought alone did not eliminate the Anasazi. It has been said that "Social Strife," added even more fuel to the drought situation. Updated research suggests that a gruesome civil war erupted among the Anasazi.[3] Thus, it seemed as though the consequence of drought produced enough tension within the community to break it up with bloodshed.

Archeological evidence suggests that the Anasazi Indians began building primitive dams at Mesa Verde and Hovenweep, so that the Colorado River would flow into the farm areas. As the hypothesized drought progressed, lower elevations became much more dry than the higher elevations, which would have caused the Anasazi to relocate to higher grounds. This is because the moisture from the Pacific loses much of its precipitation in the Rocky Mountains, which leaves the lower terrains east of the mountains with less rainfall.

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[2] George Johnson, "Social Strife May Have Exiled Ancient Indians," The New York Times Company, 20 August 1996, http://www.santafe.edu/~johnson/articles.anasazi.html (18 November 2002), 1.
[3] Johnson, 1-2.

Dr. Van West spent much of his time investigating Tree-Ring research, and he believes that the Anasazi may have had to deal with several confrontations by others, when they sought higher terrains. West believes that a Little Ice Age occurred around 1250, roughly the same time as the drought. From these data, a prediction can be made on what caused the downfall of the Anasazi reign. First, the Anasazi began their habitation near the Colorado River. Second, the climate became much drier, forcing the Anasazi to move to higher elevations. Third, the climate began to get much colder, forcing the Anasazi to squeeze into a middle elevation, causing the Anasazi to dwell close to other Indian civilizations. Finally, turmoil arose between the different Indian groups because of territorial issues, and then a bloody war ensued upon the land.[4]

2.2 Agribusiness

In order to understand the current water situation in Colorado, one needs to understand the dependency that the Colorado residents have for the Colorado River. Less than 20 inches of rainfall per year is not enough to support various farms across Colorado. Fig. 2.1 illustrates where the Colorado agriculture is located. This figure shows that 12 counties in Colorado would experience economic difficulties, if water became an issue.

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[4] Johnson, 2.

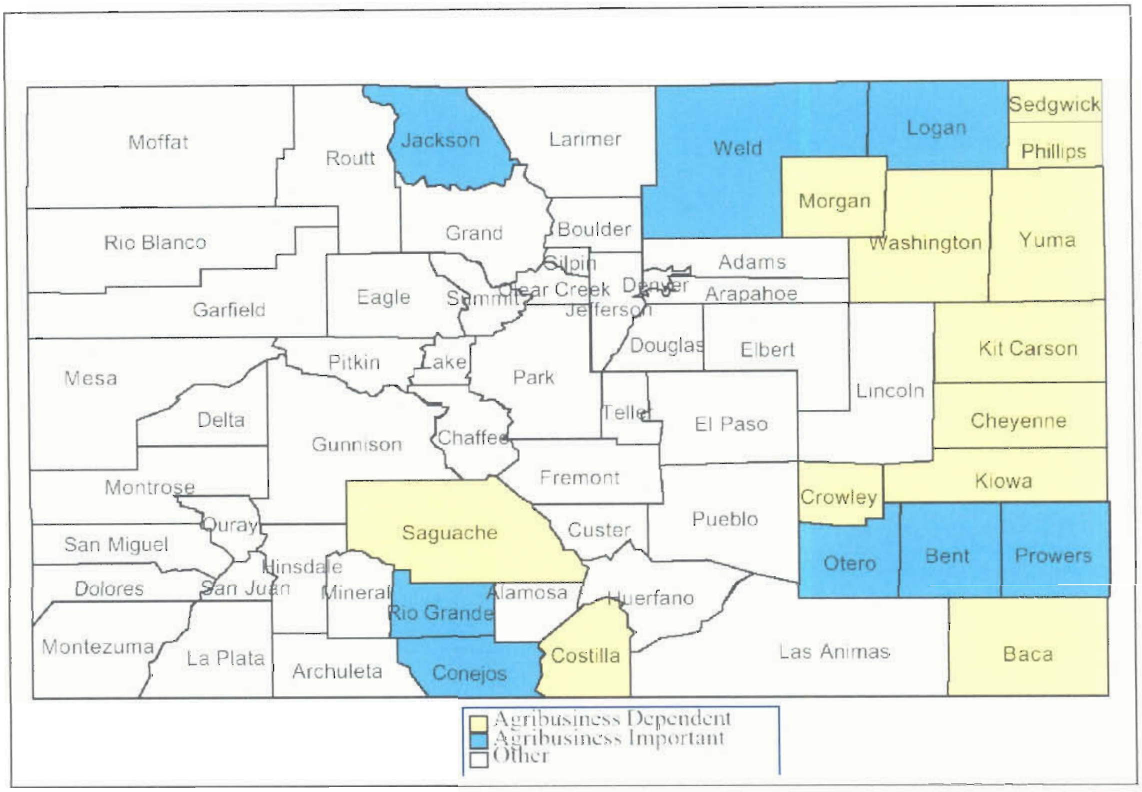
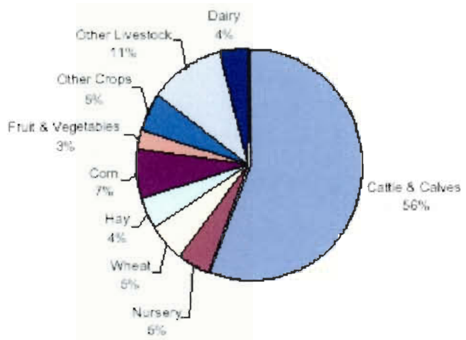


Fig. 2.1 Colorado counties that rely on agribusiness.
(http://dare.agsci.colostate.edu/extension/agbusrpt.pdf)

It is true that Colorado has a rather large commodity of cattle and calves. Perhaps cattle and calves are not crops. However, grass and hay are used to feed these animals, and if this food cannot be produced on Colorado's soil, farm owners will need to spend extra money to have it imported. Most farm owners know that farming is not always a lucrative business, and if a few animals die because of heat or thirst, it can be the difference between turning a profit and claiming a loss.

Table 2.1Colorado is the 4th ranked state in cattle/calves production and 10th in corn production. (http://dare.agsci.colostate.edu/extension/agbusrpt.pdf)



	Rank in the US in 1997	Value (Million $)
Total	17	4,534
Livestock	11	3,207
Crops	24	1,327
Leading Commodities		
Cattle/Calves	4	2,538
Corn	10	240

Source: Colorado Agricultural Statistics, 1997 and USDA-ERS State Financial Summary, 1996.

Fig. 2.2 The division of Colorado's agriculture. (http://dare.agsci.colostate.edu/extension/agbusrpt.pdf)

Chips Barry, manger of the water agency in Denver, argued, "Are we prepared to deal with a 20-year drought? My answer is, probably not." Barry also remarked, "Our system was designed to carry us through three years of drought, but we've never had to do that." Another important note made by Barry was that, "Too many people live in the wrong place."[5] Barry pointed out a few useful issues to consider, and these need to be investigated.

Agriculture is responsible for employing 3.9% of Colorado's population. Also, 1.2% of Colorado's population is involved in food product manufacturing, bringing the total agriculture related workforce to 5.1%.[6] This number isn't too impressive, but multiplying 5.1% with 4,000,000 people gives 204,000, which is the number of people involved in agriculture that would be adversely affected by a drought. This number is

[5] Joe Garner, "Drought in Colorado is Foreign to New Residents," Rocky Mountain News, 3 May 2002, http://www.rockymountainnews.com/drmn/state/article/0,1299,DRMN_21_1126058,00.html (28 October 2002),

[6] Owens, 4.

similar in other Colorado River Basin states such as Arizona, California, New Mexico, Nevada, and Utah.

Most people probably consider agribusiness to be the number one sector of Colorado's economy to suffer if drought strikes. However, tourism supplies 8% of Colorado's workforce and supplies Colorado's economy with $8.5 billion. Colorado tourism includes: skiing, hunting, fishing, rafting, camping, golfing, and hiking.[7] Each one of these activities requires water usage. Hunting, camping, and hiking all suffer if there is a forest fire threat. Fishing and rafting suffer if the water levels are low. Skiing requires a large amount of snowpack. Finally, golfing isn't as desirable if the greens and fairways are not green.

2.3 Hydropower

Hydroelectric energy is pollution free and renewable. In addition to creating jobs, preventing harmful floods, and storing water for later use, dams such as the Hoover (see Fig. 1.1) provide a great deal of energy. The Hoover Dam supplied the energy needed to operate the Southern California's Aircraft factories, which helped the U.S. to win World War II. The Hoover Dam also supplied 75% of the energy needed to fuel the growth of Las Vegas.[8]

Dams within the Colorado River Basin are not only useful, they are built strong enough to last 1,000's of years. On June 6, 1933, the first pail of concrete was placed at the foot of the Hoover Dam. This marked the start of taming the wild Colorado River.

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[7] Owens, 1-2.

[8] Ann Schrader, "Water Woes are Latest Issue in Growth Debate," Denver Post.com, 29 September 2002, http://www.denverpost.com/Stories/0,1413,36%7E11%7E890920,00.html?search=filter (30 September 2002), 1.

When the Dam was finished, the warm, silted water of the Colorado River transformed into the cool, transparent water of Lake Powell. Most species of fish that once thrived in the Colorado River were killed fairly quickly.[9] However, in almost every undertaking, one party will be benefited at the expense of another. In this case, humans, cattle, and Colorado vegetation across the land were benefited.

Hydropower is efficient, and relatively inexpensive. Nevertheless, the energy produced through hydropower is relatively proportional to the amount of water flowing past the dam. Now, at the lower end of the Colorado River Basin, it is said that for every one percent reduction in streamflow translates into a 3.6 percent reduction in total power generated by the dams. The upper Colorado River dams probably lose closer to a 3% reduction of total energy since many of the reservoirs up there are larger. When reservoirs become smaller, due to lack of precipitation, pressure decreases, as well, causing water to flow past the generators at slower speeds.[10]

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[9] Reisner.

[10] "Hydropower," Epa Global Warming, September 2002, http://www.epa.gov/globalwarming/impacts/water/hydropower.html (7 September 2002), 1.

3. DROUGHT

3.1 The 1978 Drought

One may ask: How can a drought adversely affect Colorado's economy? Certainly, if one lived or worked there, it would matter. Colorado has a population of roughly 4,000,000, and everyone depends on water for life, work, and recreations. First, One needs to understand which of Colorado's industries rely the most heavily on water. Generally, Colorado has only two distinct economic sectors. These two include tourism and recreation and agriculture.[11] One needs to investigate previous droughts, and how tourism and plant and animal agribusinesses were affected.

During the 1977 drought, Colorado experienced a 15% decrease in employment at ski resorts, and even a 40% reduction of the lift ticket sales by the consumers. For the agricultural sector, revenue from crops decreased by 2.8% even after financial help provided by the federal government. However, if the 1977-1978 drought had occurred for more than a couple of years, these figures would most likely increase with each recurring drought year.[12]

In 1977, Colorado's mountain snowpack level was at 46% of its average, and last year (2002) Colorado's deficit was around 50% of the snowpack level that was recorded in 2001.[13] So far, the 2003 winter season snowpack level is below average. These data can be found in section 4.

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[11] Julie Hart, "Economic Impact Task Force Report on the Impact of Drought," State of Colorado, 30 April 2002, http://cwcb.state.co.us/owc/Drought_Planning/Economy_ITF_report.pdf (October 2002), 1.

[12] Hart, 4.

[13] Dell Rae Mollenberg, "Q & A About Drought," Colorado State University Cooperative Extension, 29 April 2002, http://www.ext.colostate.edu/news/020429b.html (28 October 2002), 2.

3.2 Forest Fires

Table 3.1 From January 1, 2002 to September 27, 2002, Colorado had the 2nd greatest number of wild land fires among the four corner states. (http://www.nifc.gov/fireinfo/nfnmap.html)

State	Fires	Acres
AZ	2,759	649,729
CO	2,031	501,686
NM	1,767	325,436
UT	1,143	267,709

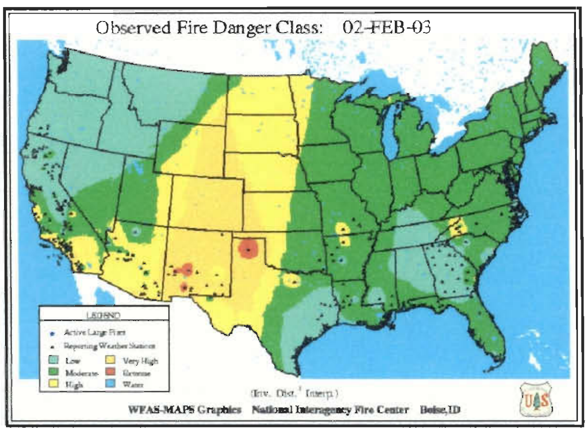

Fig. 3.1 On Feb. 2003, the Fire Danger areas were primarily located in the southwestern U.S. (http://www.fs.fed.us/land/wfas/fd_class.gif)

Fig. 3.1 shows just how severe the forest fire threat was back on Feb. 2, 2003. Clearly, the fire danger rating is still very high for Colorado and the area north and south of the state. Western Colorado usually receives significant snowfall in the winter months, implying that this is a particularly dry winter. Also, it is quite impressive to see that forest fire threats exist even with the cold temperatures and the snow on the ground, or lack of it. Table 3.1 indicates the number and area of the fires, which occurred in the Four Corner states, last year.

One obvious economic problem that could result from a potentially serious, long-term drought is Colorado residents considering fleeing from the drought. The Hayman fire engulfed parts of four different counties (Park, Jefferson, Douglas, and Teller) and burnt down 133 Colorado homes. This was the largest fire ever recorded, and remained alive for about 40 days, during the months of June and July. This fire provides evidence of how a prolonged drought can impact this area. Also, even a forest fire threat can cause many problems. Thousands of residents were forced to live in temporary housing during the Hayman fire, and some spent as many as 20 days away from home.[14]

Robert Villani was one such resident who spent 16 days in temporary housing. He was reported saying, "It's worth the risk," to reside in Colorado, which does not necessarily reflect the views of other Colorado residents. He also said, "The way I look at it, you could have a fire inside your house nothing to do with the forest."[15] Perhaps the current drought has not instilled much fear among Colorado residents, yet, no one said this drought is over.

Colorado State Forest Service entomologist, David Leatherman, said, "Drought-stressed trees are being lost all over the state." Also, in the Manitou Experimental Forest, 28 miles northwest of Colorado Springs, Wayne Sheppard reported that he had never seen so many trees dying directly from drought and not from disease or insects, and that he'd, "Been working for the Forest Service for 33 years."[16]

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[14] Mark P. Couchand and Kristi Arellano, "Siren Song of the Forest Stays Strong," Denver Post.com, 30 June 2002, http://www.denverpost.com/Stories/0,1413,36%7E23851%7E704678%7E,00.html (30 September 2002), 1.

[15] Couchand and Arellano, 1.

[16] Jim Erickson, "Colorado's Tree's Dying," Rocky Mountain News, 5 September 2002, http://www.rockymountainnews.com/drmn/state/article/0,1299,DRMN_21_1373545,00.html, (30 September 2002), 1.

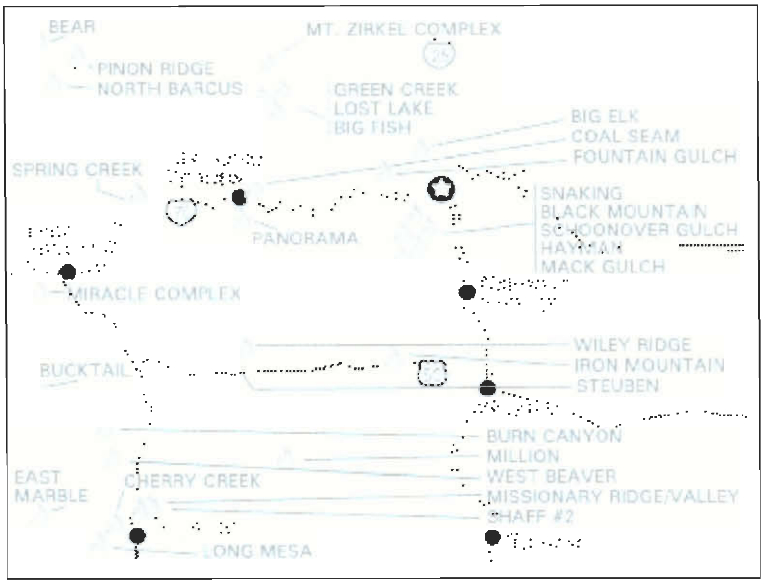

Fig. 3.2 The flames represent the locations of the forest fires for 2002, and routes 70, 50, and 25 are represented by the dotted by lines, respectively. (http://www.dola.state.co.us/oem/PublicInformation/firebans/CO_Fires1.pdf)

Fig. 3.2 is an interesting image of the 2002 wildfires, in Colorado. Fig. 3.2 should be compared with Fig. 2.1 in section 2. One should notice that most of the agribusiness areas did not have fires, because there aren't as many trees in these areas. Another note is that many of the fires occurred right along major highway routes, which emphasizes how dangerous these fires really were.

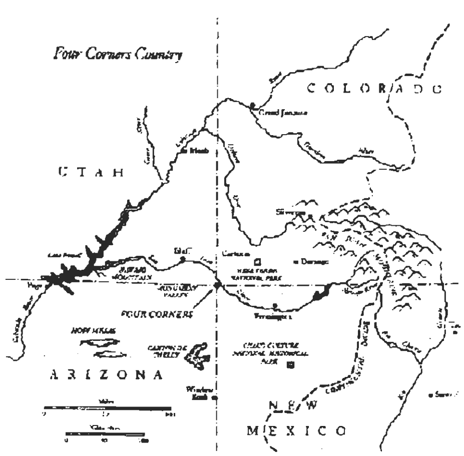

Fig. 3.3 The Four Corner states and the Colorado Mountains.

Also, an important point that needs to be brought up is that the area west of the Rocky Mountains receives a different climate than the area east of the mountains. In Western Colorado most precipitation falls in the winter months, and very little rain falls in June. In Eastern Colorado the reverse is true, and April, June, and July are rather wet months.[17] In fact, these areas should have different climates since most of the precipitation west of the continental divide comes from the Pacific. When this moisture reaches the Rocky Mountains, it is broken up, and turns into snowpack in the high terrains. This is because Colorado has various mountain peaks that reach altitudes of over 14,000 feet.

Eastern Colorado receives its moisture mostly from the Gulf of Mexico, and 70-80% of this precipitation falls between April and September. During the winter and spring months, the plains are subject to harsh winds, and during especially dry periods, hazardous dust storms frequently result from the parched soil.[18] Thus, if the weather becomes much more dry it will mean that the harsh winds and dust storms will be that much more severe.

3.3 Increasing Population

In 1980, Colorado had a population of 2.9 million. By 2000, Colorado's population had reached 4.3 million, and by 2020, Colorado's estimated population will be 6 million.[20] Perhaps the metropolitan areas throughout the U.S. are getting too crowded, or perhaps people miss the outdoors. Kevin Probst, president of the Land Use Coalition,

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[17] "Climate of Colorado," Western Regional Climate Center, 22 February 2002, http://www.wrcc.dri.edu/narratives/COLORADO.htm (3 February 2003), 1.
[18] "Climate of Colorado", 1.
[20] Schrader, 1.

and resident of Nederland, Colorado, had this to say, "There's a reason people live up here. It's more than pretty. It does something for a person."[21]

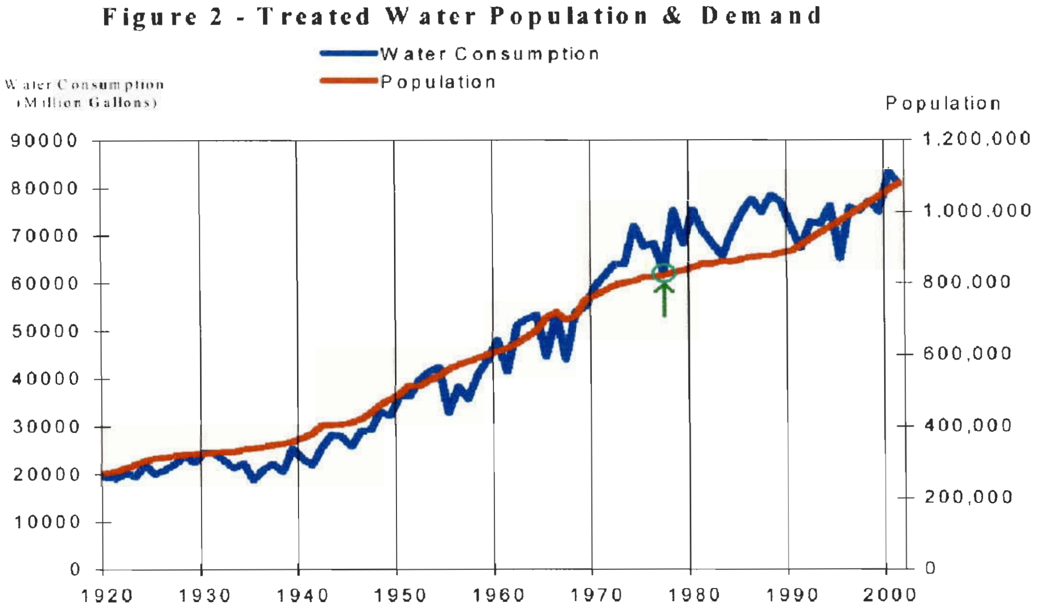

Fig. 3.4 The population and the demand for treated water for the Denver County and other users of Denver Water Service. (http://www.water.denver.co.gov/financialinfo/budget02/PDF/Pages33&35&37.pdf)

Fig. 3.4 shows that water consumption was quite low during the 1977-8 drought. However, it seemed to have taken about a decade for the Denver County and surrounding areas to recover from the drought. It wasn't until about 1990 that the population started growing at the rate it did from before the drought. Luckily the 1977-8 drought did not last much longer than it did, since the rate of the water consumption could have further reduced population growth.

This graph poses an interesting point. Can the water consumption line continue alongside the path of the population line? Surely, water limitations will result, which

[21] Couchand and Arellano, 3.

could cause a stifled population growth. Also, this could put stress on the agriculture industry in Colorado, since irrigation of crops consumes a substantially larger amount of the water than civilian use. If residents begin complaining about household water restrictions, they may argue that crops are receiving too much water.

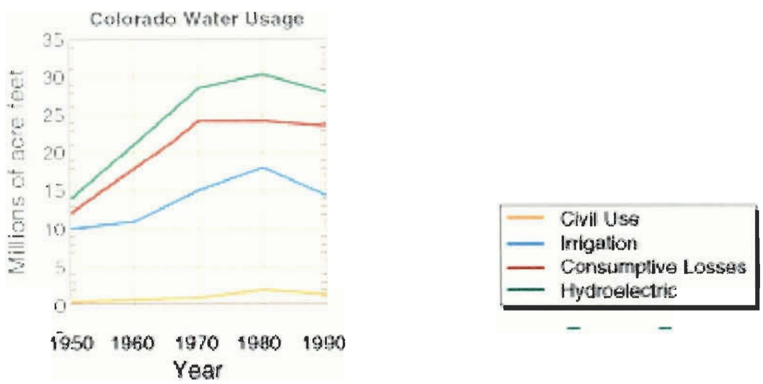

Fig. 3.5 The number of acre-feet of water consumed in Colorado from 1950-1990. (http://geochange.er.usgs.gov/sw/changes/natural/diaz/)

Fig. 8 shows that in 1990, irrigation consumed about 15 times more water than civilians consumed. Clearly, Fig. 3.5 indicates that the irrigation will see the biggest decline in water availably since it consumes such a large portion of Colorado's water supply. Colorado is the 10th largest producer of corn in the Unites States, which means that if a serious drought instills Colorado's lands, corn lovers may have to find alternative foods to relish during the warmer months. Perhaps this will not cause havoc across the Colorado, but it is still one more issue that could result. Although this is a small issue, it still needs to be mentioned.

As Colorado Governor, Bill Owens, put it, "What we're going to get instead of the big brown sprawl, are wide-open brown spaces." Owens was referring to the dying agriculture, and of his plans to increase water storage in reservoirs. Currently, it should take an estimated 10-12 years to build any new reservoirs, and Owens urges that this process be sped up. Owens also mentioned that there would be a lot of red tape, since businesses owners do not always see things the way state governments see them.[22]

It's clear that population and water consumption are increasing along side one another. However, population depends upon resources and land availability. On the other hand, water consumption depends upon water availability. Colorado has plenty of space for new human habitation, but water availability is much more limited. This means that water consumption will reach its maximum value before the population reaches its maximum value. Thus, Colorado's population growth will be limited to amount of water availability. This could mean that a serious drought could adversely affect Colorado's population growth. It is important to gather recent Colorado precipitation data in order to access the current water availability condition.

Fig. 3.6 The most recent precipitation data for Colorado.
(http://www.co.nrcs.usda.gov/snow/pcptimeseries.gif)

The most recent precipitation data is provided, in Fig. 3.6 Clearly, every data point from Sep. 2001 to Aug. 2002 is below the "percent of average" line, shown in red.

[22] Schrader, 2.

Sure September and October of 2002 were fairly wet months, but this could just be temporary relief from the drought. The recent average (from Oct. 2000 to Jan. 2003) is 75.4% for the last 28 months compared with Colorado's historical average. As one can see, December of 2002 and January of 2003 were noticeably dry. The addition of these two months yields 101% of average, which is only 1% higher than Colorado usually receives for a single month, which emphasizes the extend of the current drought the Colorado is experiencing.

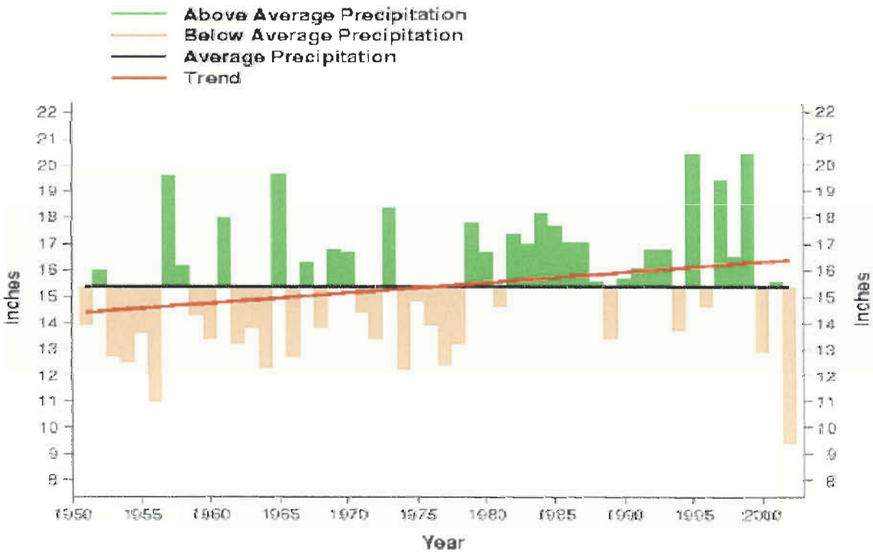

Fig. 3.7 This is a precipitation bar graph for Colorado, which dates back to 1950. (http://lwf.ncdc.noaa.gov/oa/climate/research/cag3/CO.html)

Joe Garner stated, "The people came when the rains came." However, according to meteorologist, John Henze, "Newcomers who have moved to Colorado in the last 20 years have developed a lifestyle based on above average moisture."[19] Henze is right; Fig. 3.7 indicates a gradual increasing trend of precipitation, which means that Colorado residents have come to expect an increased trend in precipitation for the last 50 or 60

[19] Garner, 1.

years. This means that a sustained drought could do even more serious damage since everyone has learned to depend on the "average" availability of water.

It's true that a severe drought would catch residents by surprise, since many have become accustomed to above average precipitation. Perhaps the precipitation trend will continue on its path. However, its more likely that the historical average (more than 50 years) will reestablish a horizontal trend, implying that the upcoming years will receive below average precipitation amounts.

4. PREDICTION

4.1 Likelihood of a Severe Drought

A "Severe Sustained Drought" is likely to occur every 400-700 years. By the observation of tree-ring series, it can be shown that the last severe sustained drought occurred in the southwest from 1579-1600.[23] Clearly, from 1600 to the present time, over 400 years have passed. This does not mean that Colorado and other surrounding states are doomed for a long, harsh drought; it simply means that there is the possibility of one.

During the 1579-1600 drought, it was estimated that the two driest 5-year intervals occurred from 1582-1587 and from 1589-1594. At Lees Ferry, in Colorado, about 60% of normal Colorado River flow occurred for each of these intervals. Also, during this 21-year period about 4 year's worth of water was lost.[24] However, one needs to understand that there are many tributaries and small rivers that feed into the Colorado River. This means that if only Colorado and the other four corner states experienced a severe drought, the land away from the river basin would be much more dry, which could cause even more severe forest fires than Colorado had last summer.

One way to predict how wet the soil will be in the summer, is by checking the snowpack level in the winter. Also, snowpack levels provide useful data in predicting the water level of the reservoirs since melting snow flows into the reservoirs. According to Fig. 4.1, most of Colorado and surrounding areas are between the 50-89% range of

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[23] Meko and Tarboton, "How Severe Would a "Really Bad" Drought in the Colorado River Basin Be?," Defining Sustained Colorado River Drought, 1995, http://geochange.er.usgs.gov/sw/changes/natural/codrought/define.shtml (15 September 2002), 5.

[24] Meko and Tarbotan, 5.

historical average snowpack. However, it is important to note that western Colorado receives most of its precipitation during the winter months, So if February and March are dry months, Colorado reservoirs will not be receiving much water runoff from the mountains, meaning less water will be available for civil consumption, hydropower, and irrigation of crops.

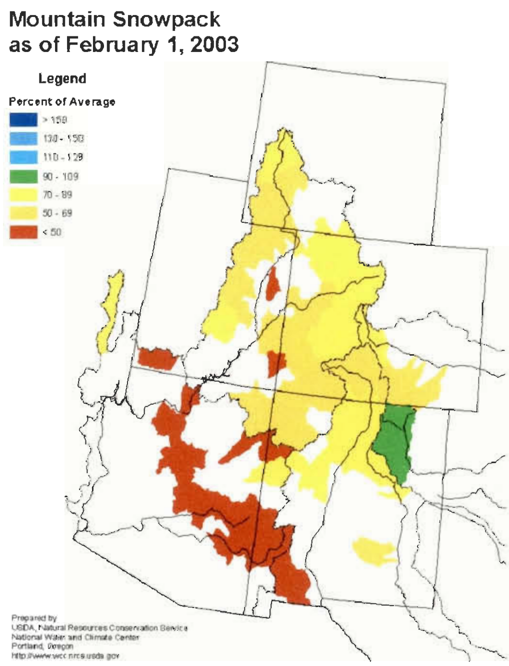

Fig. 4.1 Mountain snowpack data for February 1,2003.
(http://www.wcc.nrcs.usda.gov/water/snow/colosnow.pl?state=colorado_river)

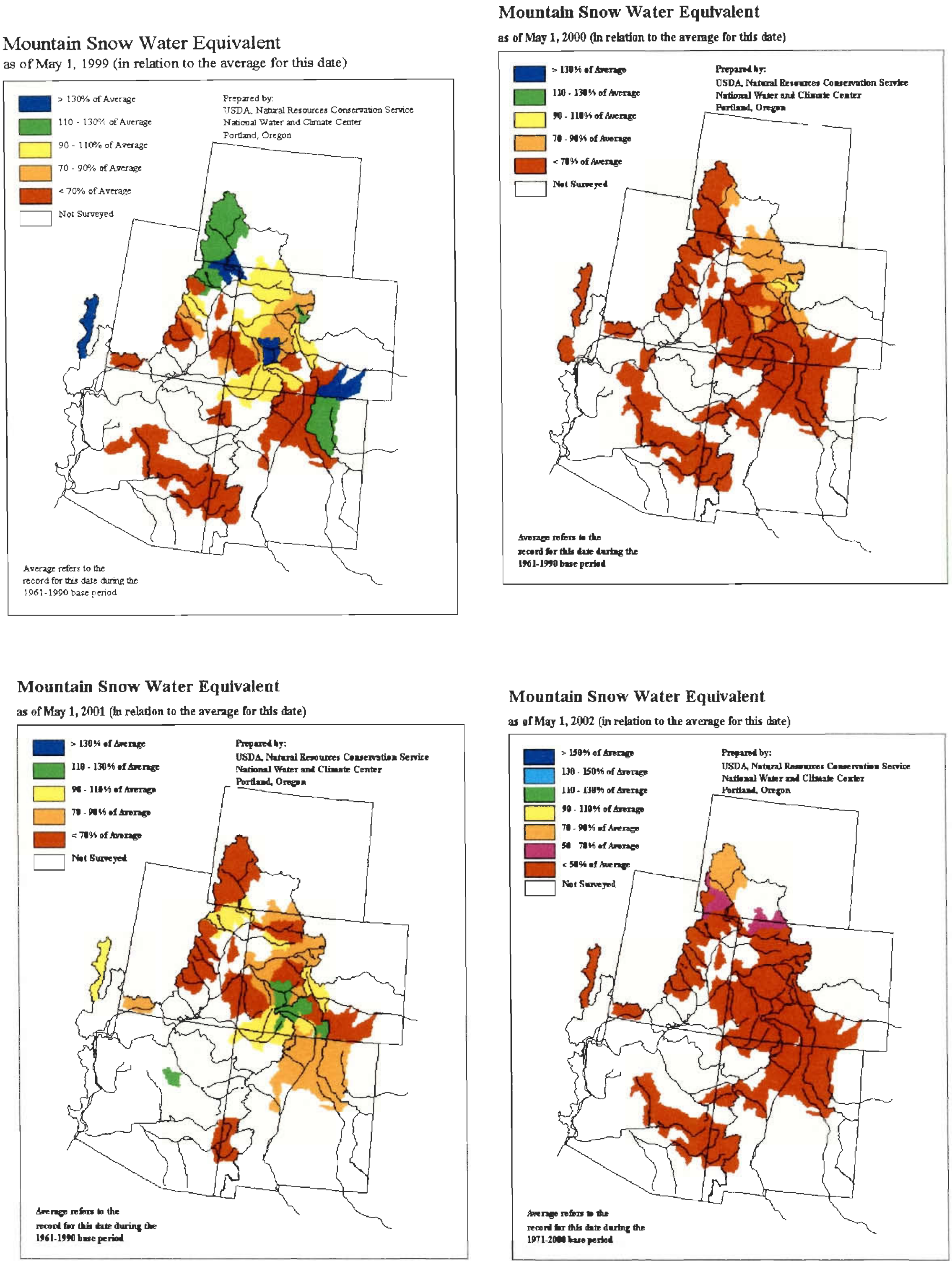

Fig. 4.2 Colorado mountain snowpack levels for May 1, 1999-2002.
(http://www.wcc.nrcs.usda.gov/water/snow/colosnow.pl?state=colorado_river)

Fig. 4.2 reveals that from 1999-2002 each May has been drier than the years before 1999-2002. Judging by this data, one would guess that the Colorado River Basin reservoirs have not been receiving much water runoff from the mountains, recently. If this continues, communities around the Basin will encounter severe water struggles. May 1st snowpack data is displayed for each year from 1999-2002, since a large amount the snowpack begins to melt after May 1st as temperatures get warmer.

4.2 Drought (and Sunspots?)

Table 4.1 The 4 most recent droughts in Fort Collins, CO seem to be spaced at 11 or 22 years apart. (http://www.wecsa.com/FCClimate/)

Year(s)	Drought
1930-1934	Dustbowl drought
1954	Drought: Hottest year ever in Fort Collins (most 100+ temps.)
1966	Fort Collins gets only 7.34" of rainfall
1972-1977	Drought: Horsetooth reservoir is nearly void of water

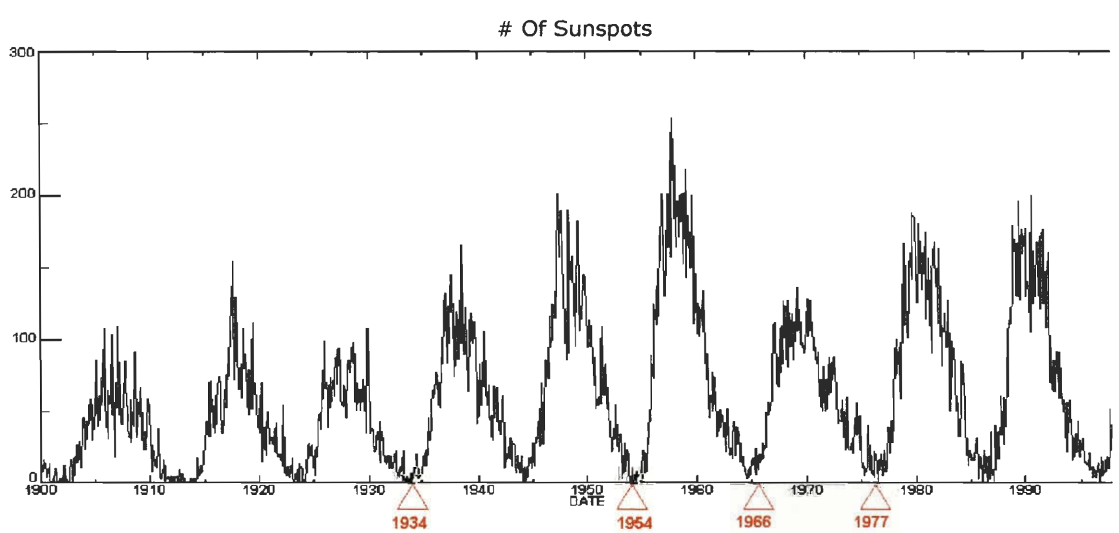

Fig. 4.3 Monthly sunspots averages (Δ's note CO droughts) show an obvious sunspot cycle. (http://spacescience.spaceref.com/ssl/pad/solar/images/zurich.gif) Arrowheads indicate drought periods.

"Sunspots are large magnetic storms on the sun's surface." Sunspots can be seen with a telescope and appear as dark spots on the surface of the sun. They last for only a couple of days. Scientists are sure that the number of sunspots reaches a maximum every 11 years, and they view the pattern as a 22-year cycle.[25] The drought that occurred from 1579-1600 was roughly a 21-22 year drought, which highly supports the evidence provided, above.

Many believe that the sunspot cycles are 11 years each. However, from 1902-1997 there have been 9 full cycles (regarding each full cycle as a mound). 1997 minus 1902 is equal to 95, and 95 divided by 9 is in fact 10.56. It seems more accurate to view this pattern as a 10.5-year sunspot cycle, meaning that two consecutive sunspot cycles add up to 21 years and not 22 years. Perhaps this is only true for the 20th century, but if predictions are to be made, it is important to keep calculations as precise as possible to ensure higher accuracy in judging the future.

"Some scientists believe that sunspots change the pressure and temperature conditions at the equator."[26] Now, changes in temperature and pressure can surely affect the weather patterns of the Earth, since precipitation patterns depend on atmospheric pressure and temperature fronts. The sun's corona (the outer atmosphere of the sun) reaches temperatures higher than 1,000,000° C. Also, the sun gives off a solar wind that strikes the Earth at speeds greater than 1 million miles per hour.[27] Perhaps, fluctuations

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[25] Lindsey Michaels, "It's a Drought," Chain Reaction, 5 September 2002, http://chainreaction.asu.edu/weather/digin/drought.htm (11 November 2002), 1.
[26] Michaels, 2.
[27] "Space Weather," Science @ Nasa, November 2002, http://science.msfc.nasa.gov/ssl/pad/solar/whysolar.htm (12 November 2002), 1.

in the solar wind could result in the 21-year rain and drought patterns, which in fact many have come to believe.

As Fig. 4.3 notes, during about half of the troughs a considerable drought is recorded. Another interesting note is that when the number of sunspots starts to increase again, the droughts appear to end. In 1930-1934 and in 1972-1977, the final years of the drought periods marked the start of new 10.5-year sunspot half-cycles. In other words, a drought could have started any time before a trough, but always had its final drought year just before the number of sunspots started to increase again. This could be why the 1579-1600 drought had two 5-year periods of extreme drought, since the drought lasted for two 10.5-year half-cycles.

Now, this is simply an observation, and no facts currently support this argument. Only more data and knowledge of this matter could back up the paragraph above.

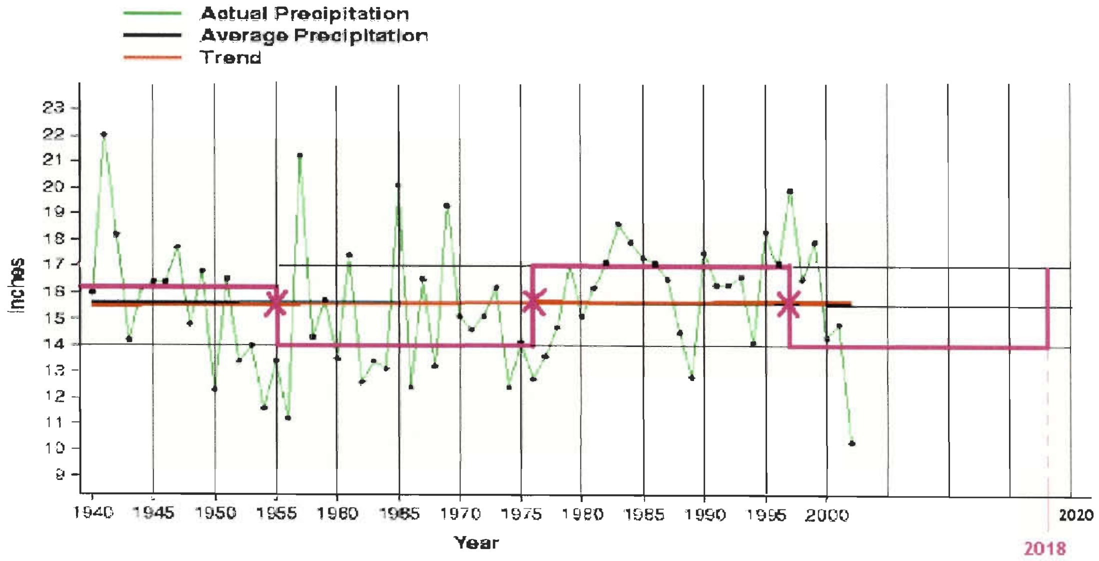

Fig. 4.4 An edited version of the precipitation data of Colorado from 1940-2002, along with a prediction from 2003-2018. (http://lwf.ncdc.noaa.gov/oa/climate/research/cag3/CO.html)

Fig. 4.4 is an interesting image. The purple lines indicate a rough estimate Colorado's precipitation. The purple lines divide these data values such that half of the points lie above the lines and the other half lie below the lines (within each interval). For example, between 1955-1976 12 points lie above the purple line, and 10 points lie below the purple line. The purple line is simply a horizontal line that extends from the 14-inch mark on the y-axis. A better approximation would be to draw a horizontal line at 14.1 inches in order to evenly distribute the points. However, 14 inches is an integer value, so it was the simpler approximation that was used. The purple lines located at 14 inches and 17 inches clearly emphasized that there exists disparity among the intervals.

Thus far, the 1997-2018 interval has had 5 years that have received more than 14 inches of precipitation, and only 1 year below 14 inches. If the trend continues, there will be many dry years after 2002, in order to achieve the proposed balance of point distribution. One may think that 14 inches and 17 inches of rainfall are almost the same. However, if one sunspot cycle produces 14 inches of precipitation per year, and the next cycle produces 17 inches of precipitation per year, inhabitants of Colorado will surely notice the difference. Three more inches of rainfall is a 21% increase in precipitation from 14 inches, which is a rather large increase.

Fig. 4.4 shows that from 1997-2018 it is going to be rather dry, compared with the previous 21-year period. Now, one may notice that the 1977-8 drought occurred during a wet 10.5 year period. However, Fig. 4.3 explains why this is so. Fig. 4.3 notes that at all the endpoints, and middles of each dry period are marked with a drier than normal period of precipitation. What this means is that the troughs are always dry (since the 1930's) around the dry cycles, and these dry periods may last for 1-5 years (This is also true for the wet periods). Thus, the 1977-8 drought was really a delayed reaction to the 1955-1977 dry cycle.

However, Fig. 4.4 reveals an interesting note. The 1997 trough appears at a year with more than average rainfall, which disproves the paragraph above. The year 1997 needs to be investigated further. As it turns out, there was a significant precipitation-altering factor. During 1997 a phenomenon know as El Niño occurred, which is known to bring increased precipitation in the southwest during the colder months. In 1997, Colorado received 3.02 inches of precipitation in the winter season when the average was 2.40 inches. Also, Colorado received 5.34 inches of precipitation in the fall season when the average for that period was 3.36 inches. Also, Fig. 4.3 shows that the local trough actually occurred in the middle of the years 1996 ad 1997, and the summer and fall of 1996 were rather dry.

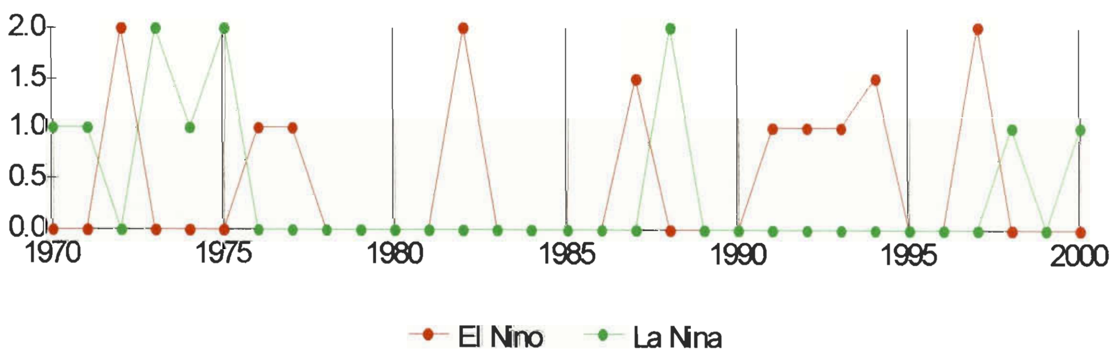

Fig. 4.5 El Nino and La Niña years since 1970. 1.0, 1.5, and 2.0 indicate mild, moderate, and strong El Nino or La Niña years. (http://ggweather.com/enso/years.htm)

Fig. 4.5 shows El Niño and La Niña years. The sunspot cycle seems to have a relation with the El Niño and La Niña years. Figure 4.4 shows that the 1976-1997 wet cycle only had 1 La Niña year, but 9 El Niño years. Since La Niña produces dry weather, and El Niño produces wet weather, Fig. 4.5 further supports the sunspot theory. Thus, one should expect that the 1997-2018 dry cycle will produce many La Niña years, and fewer El Niño years. Thus far, (1997-2000) there have been 1 El Niño year and 2 La Niña years.

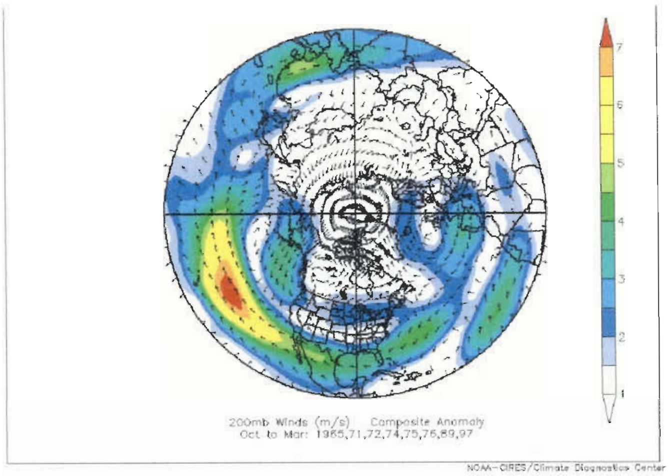

Fig. 4.6 Northern Hemisphere wind speed magnitudes and directions during the last 8 La Nina years. (http://www.wrcc.dri.edu/monitor/700mb/compomwind2dln8soi.gif)

Fig. 4.6 shows that during La Niña years wind speeds reach extremely high magnitudes over the eastern Pacific Ocean and are directed away from the United States. The high wind speeds could prevent precipitation air masses from reaching the United States, thus resulting in drought. Also, the El Niño year wind speeds (not presented) were mostly pointed in the opposite direction as the La Niña vectors. Also, the El Niño wind speed vectors had less magnitude than the La Niña wind speed vectors, implying that La Niña may have a larger impact in weather than El Niño.

Before any more predictions will be made, more evidence needs to be gathered on how sunspots can actually affect the weather. There is no sense in drawing conclusions without more proof that the sunspots truly have an impact on the determining the weather.

It is known that sunspots are actually eruptions on the suns surface, which are roughly 50,000 miles in diameter. From these eruptions electro-magnetic waves, ultra-violet radiation, electro-magnetic waves, and electrically charged particles are ejected into space. It is also known that these 3 factors increase the number of cyclones and thunderstorms. Therefore, at the troughs of the sunspot cycles, one can expect less cyclones and thunderstorms. Now, it needs to be shown that less cyclones and thunderstorms are related to drier weather.[28]

It's pretty clear that storms require energy to form. It also makes sense that sunspots heat up the Earth's upper atmosphere, because of the increased ultraviolet rays. Also, electro-magnetic waves are very energetic, and when energy strikes something (in this case the earth's surface) heat is produced. Backtracking a bit, when the earth was born, temperatures were extremely hot, and there was intense lightning. Also, it is known that water was evaporating and then precipitating at very high rates. To shorten up the story, when it's cooler and there is less lightning, it tends to rain less.

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[28] Carol Moore, "Sunspot Cycles and Activist Strategy," Carol Moore.net, 2000, http://www.carolmoore.net/sunspot-article.html (3 February 2003), 1.

4.3 Prediction

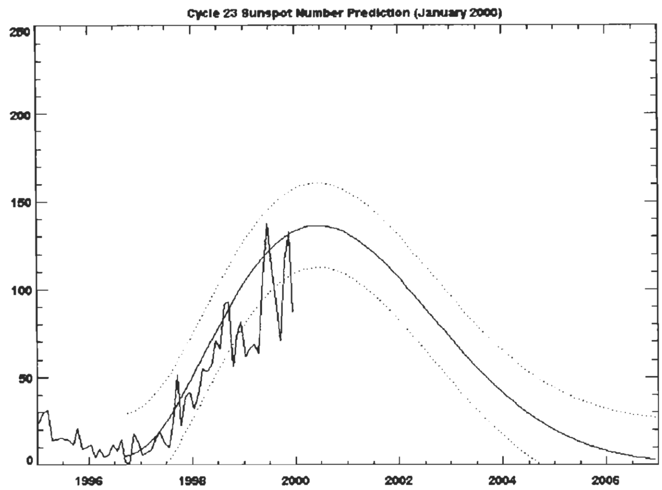

Fig 4.7 The sunspot cycle that exists today is very predictable.
(http://spacescience.spaceref.com/ssl/pad/solar/images/zurich.gif)

Fig. 4.7 is an interesting image of the 10.5-year half-cycle, which exists today. One should notice that the smooth bell shaped curve is quite an accurate fit for the actual "jagged" data. Now, it appears as though the 10.5-year half-cycle won't end until around 2007-8, which would result in the next 10.5-year cycle ending around 2018. This proposition is definitely in line with the prediction formed in Fig. 4.4.

In section III.A it was stated that a "Severe Sustained Drought" is likely to occur every 400-700 years. 800 years ago (13th century) the Anasazi experienced a "Severe Sustained Drought," and 400 years ago (1579-1600) there was one such drought as well. Perhaps Meko and Tarboton were mistaken, and a serious drought occurs approximately every 400 years. If this is true, the sequence for serious droughts occurs around the years of the sequence 1200, 1600, 2000, etc. Only time will tell if this will prove to be true.

A more detailed prediction needs to be made for the 1997-2018 dry period. Referring back to Fig. 4.3 and Fig. 4.4, and what was proved in section 4.2, a primary prediction needs to be made. From 2003-2005 and from 2010-2015 it will be fairly dry. From 2005-2010 and 2015-2019 it will be very dry. El Niño seriously affected this pattern, because 1996-1998 was supposed to be much drier than it was, since 1996-1998 occurred during a low-level of sunspot numbers. This means that the current dry cycle will most likely be drier than previous dry cycles, since the local precipitation line (over the last 50 years; refer to Fig. 3.7) will need to average out to attain stability.

The precipitation predictions presented represent average values for the years in each interval. This means that there will be variability within each interval and there will exist some years that seem like anomalies. Nevertheless, this is a generalized weather forecast for Colorado over the next 15 years. Also, other areas of the globe will most likely experience these drought conditions as well. Surely, the whole Southwest is experiencing similar drought conditions, as well as much of South America, and even Australia, too.

In a recent issue of the magazine "Science" Martin Hoerling and Arun Kumar (2003) introduce an interesting relation. Warm Indian and western Pacific Oceans combined with a cool eastern Pacific Ocean result in a sustained high pressure over the middle global latitudes. More specifically, from 1998-2002 there existed a sustained high pressure over the central United States, and a severe sustained high pressure over the northeastern Pacific. Hoerling and Kumar also found that the eastern Pacific Ocean received very seasonal sea surface temperatures, which were warmest during late fall and coolest during spring.[29]

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[29] Martin Hoerling and Arun Kumar, "The Perfect Ocean for Drought," Science, 31 January 2003, 691-693.

"It is plausible that human activities played a role to the extent that the unusually warm land temperatures . . . contributed to desiccation." Also, "It is considered likely that increased greenhouse gases intensified the global hydrologic cycle in the latter half of the 20th century."[30] Greenhouse gases are: Carbon Dioxide (produced by deforestation, and burning fossil fuels), Methane (produced by rice cultivation and cattle), Nitrous Oxide (produced by fertilizers and burning fossil fuels), Chlorofluorocarbons (produced by refrigerators and cleaning solvents), and Ozone (produced by photochemical smog production). Since 1750, Methane concentration increased by 143%. This was highest increase of all five-greenhouse gas contributors.[31]

Table 2.1 (section 2.) shows that the cattle / calves industry comprises 56% of Colorado's agribusiness system. Also, Methane is the biggest contributor to the greenhouse effect, which could be why Colorado and the other southwestern U.S. states were hit the hardest by the 1998-2002 drought. Perhaps the large amount of Methane in Colorado's atmosphere caused a more substantial drought in Colorado than in other U.S. states where there wasn't as much Methane in the air, during the 1998-2002 drought thus far.

Increased greenhouse gases could also explain why 1997 was wet when it was supposed to be dry. Perhaps there was a surplus of fossil fuel use and deforestation in 1997. As it turns out, there was a 28% increase in the amount of land burned in the Amazon forest, in 1997.[32] This increase from 1996 could have been one of the many factors that caused abundant precipitation in 1997 for Colorado and the rest of the world.

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[30] Hoerling and Kumar, 691.

[31] Tracy Gow and Michael Pidwirny, "Greenhouse Effect," Living Landscapes, 17 October 1996, http://royal.okanagan.bc.ca/mpidwirn/atmosphereandclimate/greenhouse.html (17 February 2003), 1.

[32] Marina Mirabella, "In the Amazon, deforestation is on the rise," Cnn.com, 24 November 1997, http://www.cnn.com/EARTH/9711/24/amazon.burning/ (19 February 2003), 1.

This piece of data seems to put all the pieces together, and makes a real good attempt at making a sunspot-precipitation relation for Colorado and the rest of the four corner states. Also, since sunspots alter weather in the southwestern states of the U.S. it is more than likely that sunspots affect the rest of world as well.

Possibly, a more accurate prediction could have been made if more precipitation history was available. The analysis of stalagmites in the Guadalupe Mountains of southeastern New Mexico could provide useful precipitation data for the lower Colorado River Basin. Stalagmites are calcite deposits that form from the evaporation of cave waters. They form on the roofs of caves, and can reveal annual evaporation of the cave waters through the use of optical microscopy. The Stalagmites were sampled from Hidden Cave, Carlsbad Cavern, and from the caves of Guadalupe Peak.[33]

More than 3000 years of stalagmite growths were sampled from the three locations. These data revealed that from 1,300-1,700 years ago there was little stalagmite growth, and from 460-670 years ago there was no stalagmite growth. Less stalagmite growth implies less cave water evaporation, which implies dryer conditions. The dryness of the 460-670 years B.P (before present) reveal a very interesting thought. Around 500 years B.P. the Little Ice Age began. This is very interesting since 500-670 years B.P. the climate of southeastern New Mexico was the driest it has been in more than 3,000 years B.P.[34] Perhaps, drier conditions can help to trigger the onset of an Ice Age.

Obviously, this proposition is simply a conjecture, but it could be true. Perhaps thorough analysis of the stalagmite growth could reveal a predictable trend in New Mexico precipitation. Furthermore, an assessment of the dryness of this area could

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[33] Victor J. Polyik and Yemane Asmerom, "Late Holocene Climate and Cultural Changes in the Southwestern United States," Science, 5 October 2001, 148.

[34] Polyak and Asmerom, 150.

foretell a future Ice Age. Clearly, a lot of propositions have been made about Colorado's future weather, as well as stalagmite growth. Although one may find some of the ideas presented in this work somewhat anecdotal, there are some scientific backings to many of them. If one enjoys reading these types of surmises, there are many publications in which in find them.

Unquestionably, there are many interesting and perhaps amusing material on unorthodox means of predicting the weather. One such example is the "Old Farmer's Almanac." At www.almanac.com, one can find information on how sunspots, and other solar activity are used to predict the weather. In the 1970's, an affiliate of the Army Corps of Engineers, in Sacramento, California, found that the Almanac's forecast for California was accurate to more than 75%. Now, an individual making an independent study did this research. However, perhaps other organizations should investigate some of these ideas, and possibly use any useful information that may be contained in the Almanac.[35]

[35] Richard Head, "More About Sunspots and How We Predict the Weather," The Old Farmer's Almanac, 2000, http://www.almanac.com/preview2000/predict.html (11 November 2002), 2-3.

5. CONCLUSION

In conclusion, it can be said that Colorado can be a great place to live. However, Colorado and other nearby states are highly dependent on the water stored behind the many dams, which have been built during the last century. Today, there exists a large amount of water behind the dams to supply much of the Colorado River Basin. Nevertheless, if the dry times continue, drastic measures will need to be taken to conserve as much of the river as possible. This will mean that many farms may have to reduce water use, productivity, and maybe even shut down, and homeowners and business owners may be forced to move elsewhere. Lawns would no longer be green, and more severe forest fires could blaze upon the land. Cities like Las Vegas would have to find other, probably more expensive water supplies, which would most likely fail, as well.

Based on the data presented in section 4, it appears as though the Colorado drought will ease up within the next year. However, judging by the severity of the 2000-2002 drought, from 2005-2010 another drought may repeat that is unreasonably dry as well. During the 2015-2019 period the dry cycle (1997-2018) will most likely see its final very dry period, and then a wet 21-year cycle will follow.

One may wonder why the year 2019 will be a dry year, since year 2019 is actually part of the 2018-2039 wet cycle. Judging by the data presented in section 4, the endpoints of each cycle are dry. This implies that the predicted 21-year dry cycles are not the same length as the 21-year wet cycles. More accurately, the dry cycles last about 23 years, and the wet cycles last around 19 years. This is because when the number of sunspots decreases less energy is available to produce heavy storms, thus less rainfall.

Typically, Colorado reservoirs can only hold a 3-year supply of water, which means that 4 or 5 consecutively dry years could leave water supplies desiccated.

One question has yet to answered though. Why do the both the dry and wet cycles last for two consecutive sunspot cycles, and not one, or not at all for that reason? It's clear that the troughs of the sunspot cycles should be dry, but this doesn't explain why general precipitation average is high for two consecutive cycles, and then dry for two consecutive cycles, and so on. In fact, this remains a mystery. However, in order to provide completeness for the sunspot-precipitation relation, an educated guess needs to be made on this topic.

It can be proved that during any period of time, and average level of precipitation can be computed. Since yearly rainfall is not the same every year, it can be said that each 10.5-year sunspot cycle receives different averages of precipitation than other 10.5-year sunspot cycles. Now, it's also true that the troughs of the sunspot cycles are drier than during the years when the sunspot cycles peak. Perhaps long ago, the troughs broke up averages into two distinct groups (dry and wet periods).

This means that if the first period happened to be wet, then the next would have to be dry (since an average would need to be reached for the combined periods). This explains why a wet period may be followed by a dry period. However, this doesn't explain why two consecutive wet periods precede two consecutive dry periods. Another educated guess needs to be made.

For practical purposes, let one say that a dry cycle was first to occur. This means that the premier dry cycle would be followed by a wet cycle. However, the first few years of the wet cycles are contradictory. This is because a wet cycle starts at a trough, which is dry (with exception to 1996-8, which will probably result in a much more serious drought in 2005-2010 and in 2015-2019). Perhaps this caused the "average system" to be disrupted, causing another dry cycle instead of a wet cycle. Now, by the third cycle it would absolutely have had to be wet, thus the next cycle was wet. Thus, in order to compensate for the two consecutive dry cycles, two consecutive wet cycles followed, causing the present day 21-year precipitation cycle, and not a 10.5-year precipitation cycle.

During the present dry cycle (1997-2018) things could get pretty stressful with new water conservation laws, and many residents may not stay around until things would get resolved. Hopefully, this particular drought will not follow the trend set by the previous droughts of this century. Only about a hundred years of solid data (not including stalagmite growth in New Mexico) is not enough to make a foolproof prediction, anyway. Perhaps in a few years new technology will develop to make water transportation more efficient, and no one will have to worry, and all will be well, or not…

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