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47th Annual New Mexico Water Conference

There's No Doubt, We're in a Drought!

October 9-11, 2002
Ruidoso Convention Center

New Mexico Water Resources Research Institute
New Mexico State University
Las Cruces, NM 88003

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There's No Doubt, We're in a Drought!

47th Annual New Mexico Water Conference
October 10-11, 2002

PROGRAM

Wednesday Afternoon, October 9, 2002

1:00 pm	Tour of Carrizo Valley Ranch *or* Alamogordo's Treatment Plant and Storage Reservoirs

Thursday Morning, October 10, 2002

8:30 am	Welcome **Karl Wood**, WRRI Director **Leon Eggleston**, Mayor, Ruidoso
9:00	*Relationships Between the Pacific Decadal Oscillation and New Mexico Precipitation* **Charlie Liles**, National Weather Service
9:40	*Drought Impacts on Water Supplies and Delivery in New Mexico* **Tom Turney**, New Mexico State Engineer
10:15	BREAK
10:45	*Meeting Compact Delivery Obligations During Times of Drought* **Norman Gaume**, Interstate Stream Commission
11:15	*The Need for a U.S.-Mexico Border Environment and Human Health Initiative* **Chip Groat**, Director, U.S. Geological Survey
12:00 - 1:30	Lunch - Award Winning High School Student Essays

Thursday Afternoon, October 10, 2002

1:30	*The Economic Impacts of Drought on Uses on the Rio Grande* **Frank Ward**, Department of Agricultural Economics, NMSU
2:00	*Desalination as a Supply for Drought Relief* **Eddie Livingston**, Livingston Associates, P.C.
2:30	*Strategies for Produced Water Handling in New Mexico*

Robert Lee, Petroleum Recovery Research Center, NM Tech

3:00 *Current Technology Related to Drought and Irrigation*
Phil King, Department of Civil and Geological Engineering, NMSU
Gary Esslinger, Elephant Butte Irrigation District

3:30 BREAK - Hosted by the U.S. Bureau of Reclamation - Centennial Celebration

4:00 Inside New Mexico (Moderated by **Sherry Tippett,** County of Grant Attorney)
How Does Water Law Affect Management of New Mexico's Water During Times of Drought?
David Benavides, Community and Indian Legal Services of Northern New Mexico
Fred Hennighausen, Pecos Valley Artesian Conservancy District
Steven L. Hernandez, Hubert and Hernandez
Derrick Lente, Sandia Pueblo
DL Sanders, Office of the State Engineer

6:00 - 8:00 Dinner Barbeque and Flying J Ranch Western Stage Show
Ruidoso Convention Center

Friday Morning, October 11, 2002

8:15 am *U.S. Bureau of Reclamation Drought Programs*
Michael Gabaldon, U.S. Bureau of Reclamation

9:00 *Water Banking: Panacea or Placebo?*
Bob Grant, New Mexico Interstate Stream Commission
Sue Wilson Beffort. New Mexico Senator

9:30 *How a Large Municipality Plans to Meet Its Future Water Supply Needs*
Ed Archuleta, El Paso Water Utilities

10:00 BREAK

10:30 *How a Small Town is Dealing with Drought Conditions*
Len Stokes, Consultant for Village of Ruidoso

11:00 *Water Requirements for Endangered Species in New Mexico*
David Cowley, Department of Fishery and Wildlife Sciences, NMSU
Letty Belin, Belin and Sugarman
Joy E. Nicholopoulos, U.S. Fish and Wildlife Service

12:00 Closing Remarks: **Karl Wood,** WRRI Director

__Charlie A. Liles__ is the Chief Meteorologist/Manager of the National Weather Service (NWS) Forecast Office in Albuquerque, New Mexico. He received his B.S. in meteorology from the University of Oklahoma in 1974, and M.S. in meteorology at Texas A&M University in 1976. While teaching in graduate school, Charlie researched severe thunderstorm cases. After working briefly with a private corporation as a forecaster and consultant, he joined the National Weather Service in 1977. He became a senior forecaster at the Jackson, Mississippi NWS office in 1981. He worked at the Environmental Research Laboratory in Boulder, Colorado in 1983 and 1984, publishing a book on the forecasting of thunder-storms. As a senior forecaster at the Jackson, Mississippi NWS office, he also taught meteorology at Jackson State University in 1986 and 1987. In 1988, Charlie became Deputy Meteorologist-in-Charge of the Albuquerque NWS office, and in 1990, Area Manager. He has written a number of research papers, published and unpublished, over his career, with his most recent work focusing on climate issues in New Mexico. Charlie has worked with the New Mexico Drought Task Force on drought-related climate issues since 1996.

DROUGHT, AND RELATIONSHIPS BETWEEN THE PACIFIC DECADAL OSCILLATION, THE EL NIÑO - SOUTHERN OSCILLATION, AND NEW MEXICO ANNUAL AND SEASONAL PRECIPITATION

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Introduction

In the summer of 1996, when New Mexico was in the midst of a drought, Governor Johnson's office began an initiative to develop a drought task force for the state. A number of federal agencies, the National Drought Mitigation Center and State of New Mexico worked together to develop a drought contingency plan for the state. This document is and always will be a work in progress.

The New Mexico Drought Contingency Plan states drought is a complex physical and social process of widespread significance. The plan further states that despite all the problems droughts have caused, drought has proven to be difficult to define and there is no universally accepted definition. There are a number of reasons for this. Drought, unlike floods, a winter storm, or a tornado, is not a distinct event with a well-defined beginning and ending. Indeed, it is often some time after a drought when we look back in history and can have a good idea of when a drought began and when it ended. Some droughts can end fairly quickly while others fade away. However, droughts never have abrupt beginnings. They tend to develop slowly, spread, and gradually infiltrate all facets of life.

By convention and tradition, the most commonly used definitions of drought have been based on **meteorological, agricultural, hydrological**, and **socioeconomic** effects. Droughts are usually first defined by recognizing a period of substantially diminished precipitation through one or more of various drought indices. It is usually after this first step when an agricultural drought becomes obvious when there is no longer adequate soil moisture to meet the needs of a particular crop at a particular time. An individual growing one particular crop may perceive or recognize a drought at a particular time while someone growing another crop does not experience a drought issue because their crop does not need more moisture at that time. Once a drought has been meteorologically recognized and has begun to affect the agricultural community, hydrological drought typically becomes more apparent. This refers to deficiencies in surface and subsurface water supplies. Here in New Mexico, we typically note reductions in stream flow, drops in reservoir levels, a lack of snow pack, and wells going dry.

As drought worsens or deepens, water shortages begin to affect the health, well-being, and quality of life of people. "Water wars" increase and people begin to behave differently.

Typically, in an effort to gauge the intensity of a drought, people want to compare a current drought with a drought in history to determine the recurrence interval for a specific condition. For example, many people want to know if a drought is a "25-year, or 100-year" drought. Unfortunately, droughts cannot be accurately assessed in this manner. The planet is anything but a static system. Populations change, demands change, laws change, and systems change. The following table illustrates an attempt to compare the drought of 2002 in New Mexico with the drought of the 1950s.

By the end of September, 2002, the Palmer Drought Severity Index (PDSI) had detected severe or extreme drought conditions (index of lower than -3.0) for six months in the present drought. During the period from 1949 through 1956, the PDSI was below -3.0 for 67 months. Temporally, the drought of the 1950s was far more significant than the drought of 2002. However, the PDSI in 2002 dropped to -6.9 in climate division 2 (the northern mountains), which equaled the lowest value of 1950s. This might suggest the *intensity* of the 2002 drought was similar to that of the 1950s, if one can use the PDSI as a gauge of drought intensity.

During the present drought, New Mexico's statewide precipitation deficit has averaged (as of September, 2002) about six inches over a three-year period. This has ranged from 10-12 inches in portions of the northern mountains to only a couple of inches in some other areas of the state. However, during the 1950s, the statewide deficit averaged 24 inches over a seven-year period. The fact that the stream flows in 2002 set many daily record lows coupled with these precipitation deficits may suggest that increased demand and other changes play a huge role in the drought impact in New Mexico. In other words, it takes a much smaller precipitation deficit now than those experienced during the 1950s to "get us into significant trouble."

It's very difficult to compare reservoir levels of the 1950s with present levels, because the reservoir system is not the same. Mankind has intervened throughout the years to change the system. What can we say about the subsurface water supply now compared to the 1950s? Does anyone really know how much "water is in the tank?"

In spite of 150 drought definitions, which could suggest to us we still don't know how to define

Table 1

INDICATOR	DROUGHT OF 2002	DROUGHT OF 1950s
Palmer Index in Severe/Extreme categories	6	67
PDSI lowest value	-6.9	-6.9
Statewide Precipitation deficit	6 inches	24 inches
Streamflow	Record low	
Reservoirs	??	??
Subsurface Water	??	??

drought, I've noticed increasing dialogue to attempt to create yet another definition. On the national drought monitor forum in which I participate, there has been recent dialogue that it may be time to look at drought more in terms of supply and demand than just by using indices. However, this approach also raises some big questions. If we gauge drought using a supply and demand approach, if water resources are not properly managed, or even if they are and demand exceeds supply, is it okay to say we are in a drought during times when precipitation has been "normal?" Indeed, the day is coming when there will be water-supply issues even when the atmosphere has produced "normal" precipitation. Also, the day is coming (or is already here) when "normal" doesn't mean acceptable. Consider Elephant Butte Reservoir, for example. For the period 1953-1979, the average storage at Elephant Butte was approximately 324,000 acre-feet. During the abundant rainfall periods of the 1980s and 1990s, storage topped 2 million acre-feet in the late 1990s. By late 2002, storage was back down to roughly 350,000 acre-feet. For an index that uses historical records (instead of 30 year normals), the present level of Elephant Butte is not too far from normal, but is 350,000 acre-feet acceptable? Considering the demands of the present day along with the wording of the Rio Grande Compact Commission documents, many would argue that 350,000 acre-feet is not an acceptable level for Elephant Butte Reservoir.

One could also argue that it is "normal" for New Mexico to be in a drought. For the period 1896 through 2002, severe to extreme drought (defined by -3.0 or less on the PDSI) has affected at least a portion of New Mexico during 59 of those 107 years, or 55 percent of those years. Each of the eight climate divisions in New Mexico has been in severe to extreme drought approximately 8 to 15 percent of the time (see Figure 1). Colorado's climate division 5, which should be considered near and dear to the hearts of New Mexicans, has been in severe to extreme drought at least 20 percent of the time during the period from 1895 through 1995. Colorado climate division 5 is responsible for a very significant contribution to the stream flow on the Rio Grande.

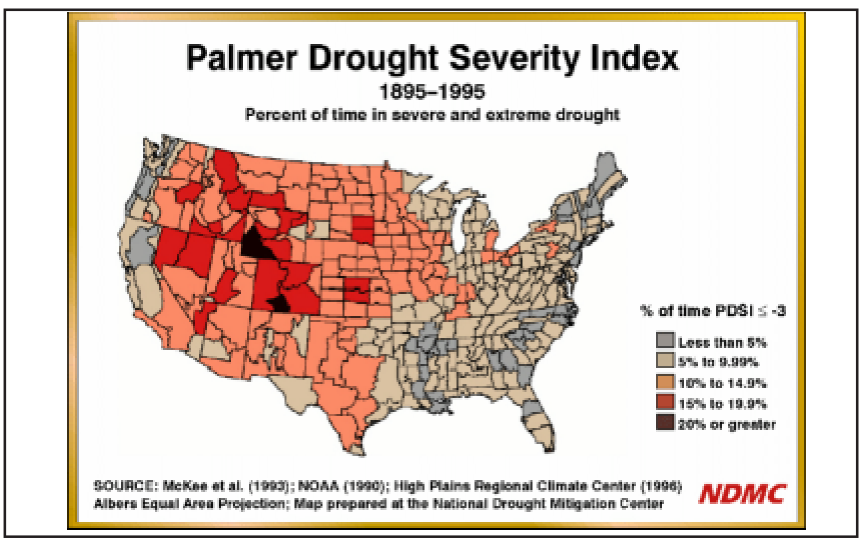

Figure 1

As you can see in Figure 1, drought affects virtually every part of the United States. However, the greatest frequency for drought is over the western U.S., especially along the Rocky Mountain chain where year to year and season to season variability can be great. It should be apparent that drought, no matter how we define it, has been a normal part of life in New Mexico's history. Tree rings show great variability and very significant droughts over the past couple of thousand years. Faced with significant drought, civilizations of the past likely had no choice but to get up and move during those times.

Just as tree rings show cycles of the past couple of thousand years, meteorological records show similar patterns over the past 100 years or so. The table below shows the significant droughts in New Mexico (as defined by PDSI values less than -3.0) since 1895.

The one thing we can say with great confidence is that, just as there have been droughts in our past, there will be droughts in the future. Drought in our future is a given. Our preparation and response is to be determined.

Table 2

Severe and Extreme Droughts in New Mexico

YEAR	#Months (SVR (SVR/Extreme)	Worst Area Affected	Lowest PDSI
1896	2	South	-3.2
1899-1905	64	Most of state	-6.6
1909-1911	20	Most of state	-5.2
1913	1	Southeast	-3.1
1917-1918	16	Eastern Plains	-4.2
1925	4	Nrn/Cntrl Mtns	-4.6
1928	1	Northwest	-3.2
1934-1935	18	Most of state	-5.5
1943	4	Northeast	-3.9
1946	5	Northeast	-3.5
1947-1948	12	Central Mountains	-5.2
1950-1957	67	Became statewide	-6.9
1959-1965	22	Mainly Northwest	-5.1
1967	5	Northern Mountains	-4.8
1971	5	Southwest	-4.3
1972	5	Northwest	-4.7
1974	4	Most of state	-4.2
1976-1977	12	Northwest	-4.3
1981	9	Northern Mountains	-4.3
1989-1990	10	Northwest	-4.0
1994-1996	15	Became statewide	-5.9
2000	5	Became statewide	-5.1
2001-2002	6*	Northern mountains	-6.9

* Current as of October, 2002.

WHAT DOES OUR FUTURE HOLD? WHAT IS THE FORECAST FOR THE NEXT 20 YEARS?

Meteorology, weather forecasting, and climate forecasting are all frontiers. There have been many discoveries in these fields over the past 100 years, and the future should bring more discoveries of cycles and trends where we presently have no clues. Recently, it has become apparent that at least two distinctive signals in the Pacific Ocean have a profound influence on New Mexico's precipitation. One of these signals has become familiar to many people since the early 1980s, and is referred to as the El Niño-Southern Oscillation (ENSO). This includes the extremes of a cycle, that is El Niño and La Niña. Many researchers have studied and identified weather patterns associated with ENSO.

Another signal that was first explored by Nate Mantua and co-authors in 1997 is the Pacific Decadal Oscillation (PDO). Presently, scientists do not understand the relationships between these two signals, and some scientists may even still doubt the existence of the PDO.

ENSO cycles range from about 2 to 7 years, with an average of around 4 years. The range shows considerable variability. PDO cycles are typically 50-60 years, but there aren't very many to study. Figure 2 shows typical sea surface temperature anomalies in the Pacific for the PDO and ENSO cycles.

Figure 2 can be used to demonstrate the Pacific temperature differences between the positive and negative phases. Someone familiar with ENSO will also note quite a bit of similarity between the positive PDO and El Niño, as well as the negative PDO and La Niña. However, calculations of the ENSO are performed using data along the equator, while calculations for the PDO are much farther north. For this discussion, when I am mentioning ENSO, I am referring to the patterns of sea surface temperatures and pressure patterns along the equator. For the PDO, I am referring to the area over the central and northern Pacific Ocean.

A typical El Niño during a neutral PDO phase will look similar to the positive PDO shown on the left side of Figure 2, but without the colder than normal temperatures over the northern portion of the Pacific. A typical La Niña will look like the equatorial region shown for a negative PDO, but without the anomalies over the northern Pacific.

It is certainly possible to have El Niño occurring during either the negative or positive PDO phase, or La Niña occurring during either the negative or positive PDO phase. That is, ENSO and PDO can be in conflict, or in harmony. When they are in conflict, our confidence in relationships between the signals and our expected weather is diminished, but when they are in harmony, our confidence in seasonal forecasts is enhanced.

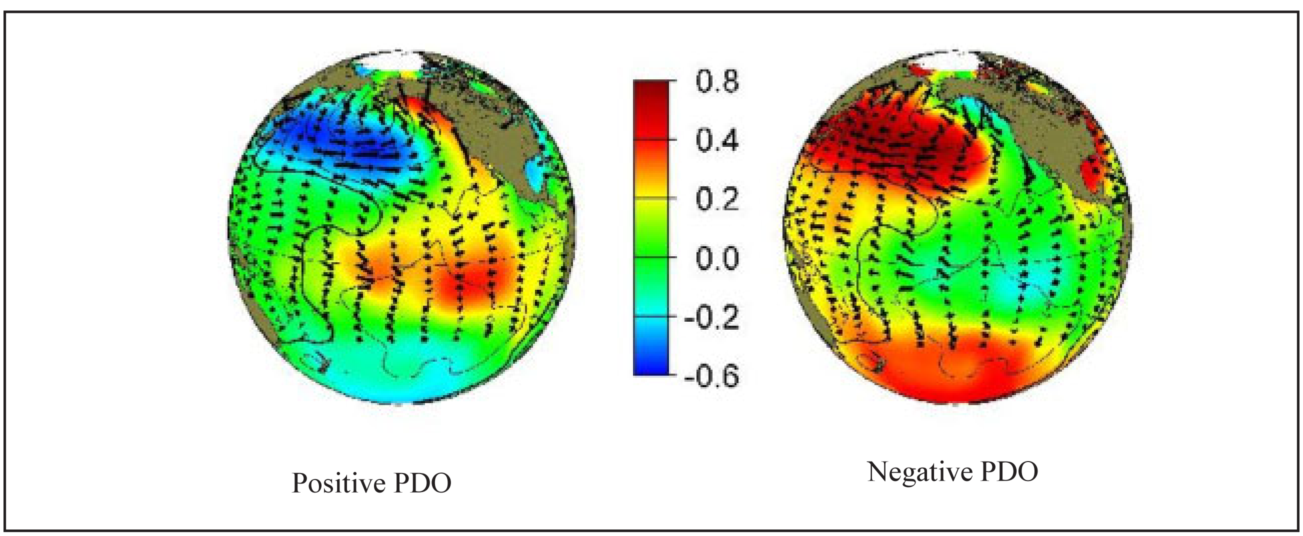

Figure 2

When an El Niño occurs during times when the PDO is significantly positive (positive by at least one standard deviation from the mean), the El Niño is likely to be enhanced. Such cases lead to super wet years such as 1941, when White Tail (near Cloudcroft) received 62.45 inches of precipitation. This remains the record for maximum annual precipitation for New Mexico.

On the other hand, when La Niña occurs during years in which the PDO is significantly negative, the La Niña tends to be enhanced. These two signals work in harmony to produce substantially diminished precipitation in New Mexico. They lead to super droughts such as the one experienced in the 1950s.

Meanwhile, a negative PDO coupled with El Niño or positive PDO coupled with La Niña produces conflicting signals. Confidence in seasonal forecasting is not especially high during these episodes. However, it appears to be quite difficult to get a strong El Niño/La Niña during significantly negative/positive PDO years. When the ENSO and PDO are in conflict and either an El Niño or La Niña occurs, the PDO is frequently only slightly negative/positive at that time, and usually responds to the ENSO signal by temporarily reversing signal for a time scale of months. Also, preliminary work suggests that the ENSO signal will typically be the more influential signal during the cooler times of the year for the areas of the state where the ENSO is typically strongest, that is, mainly southern New Mexico.

ENSO considered by itself exhibits a fairly confident relationship with precipitation in New Mexico from autumn through spring. Both the Climate Prediction Center graphics shown in figures 3-5 for 11 El Niño events and local research for 20 El Niño events (Figure 6) show New Mexico benefits during El Niño cool seasons. However, other factors must be introduced. Figures 3-5 (especially Figure 4, which shows winter) show that as one heads north, the benefits from El Niño diminish, and the pattern reverses. Wyoming, Montana, and Idaho typically have dry winters when El Niño is occurring. The northern edge of El Niño's benefit tends to be somewhere near the Colorado-New Mexico border, and during the last event in 1997-98, the northern benefit was even farther south, near the latitude of Santa Fe. Consequently, chances for a wet cool season are best in southern New Mexico, and diminish northward. The Rio Grande depends on the melting of snow over northern New Mexico and southern Colorado, so when the Rio Grande Basin is in drought, El Niño can't be counted on to alleviate drought in all cases.

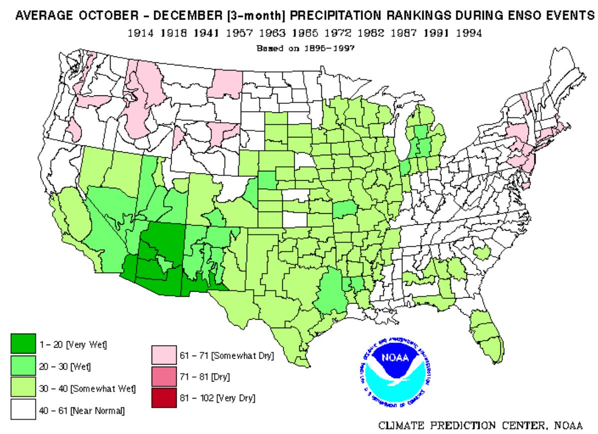

Figure 3

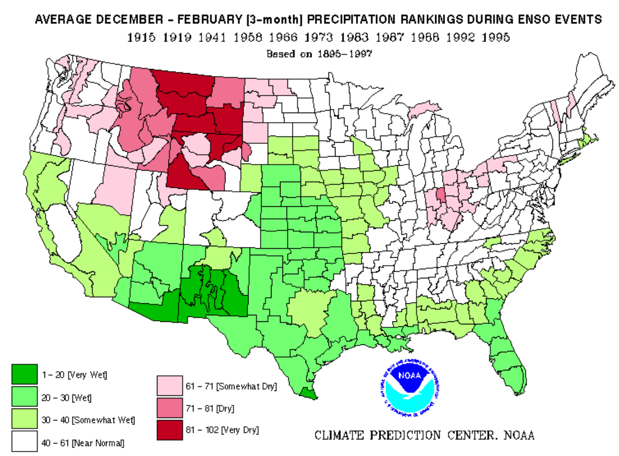

Figure 4

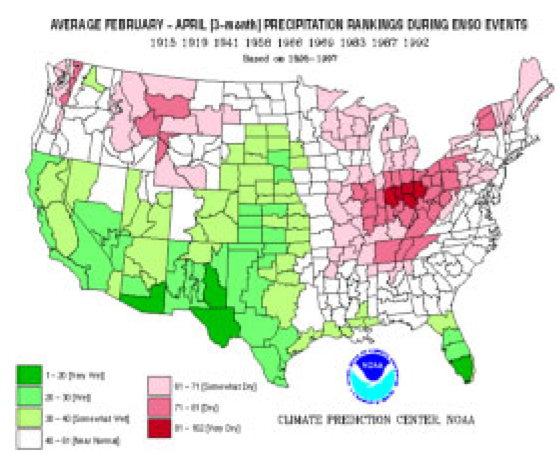

Figure 5

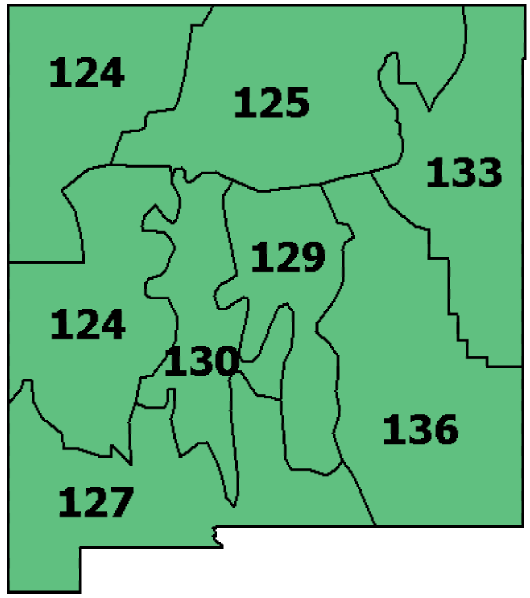

Figure 6

When looking ahead to the next 20 or 30 years, it seems the PDO is the main factor to consider because the PDO cycle is so much longer than the ENSO cycle. Figure 7 shows the PDO cycle since 1900.

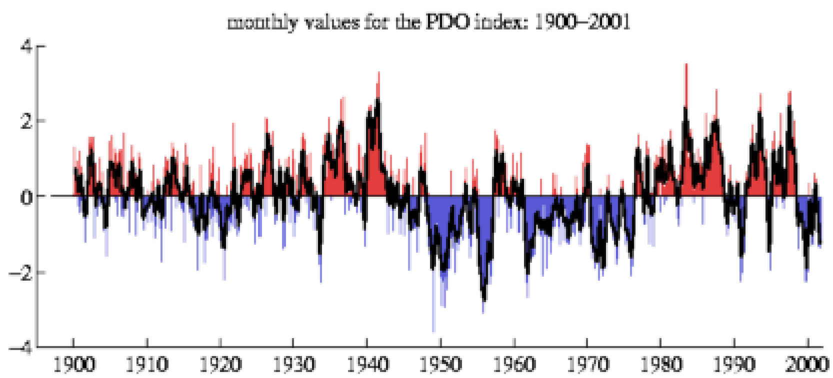

Figure 7

Although exactly when we've entered positive and negative PDO cycles is a matter for some debate, the generally-accepted time frames are given in the table below. The methodology and results of a study on the relationships between the PDO and New Mexico seasonal and annual precipitation are detailed below.

Table 3

Recent PDO Cycles

1923-1944	Positive Phase
1944-1977	Negative Phase
1977-1998	Positive Phase
1998-2030?	Negative Phase

Methodology

The relationship between the PDO and New Mexico precipitation was studied in several ways. Data sets for the PDO (as well as Figure 7) were obtained from the University of Washington web page. An annual PDO average was calculated for each year from 1900 through 1999. Average precipitation for each of eight climate divisions (Figure 8) was calculated, for each of those years, using data obtained from the National Climatic Data Center (NCDC). Precipitation was also calculated for each of the seasons. Years were determined for which the PDO varied substantially from zero. In this paper, one standard deviation of PDO values (1900-1999) was centered about the mean value (+0.04) to represent normal conditions. Outside of this range, the PDO was categorized as "significantly negative" or "significantly positive." "Significant Negative PDO years" were determined to be years in which the average PDO was less than -0.73. "Significant Positive PDO years" were determined to be years in which the average PDO was greater than +0.82. Years were determined for which the average PDO was outside of the range from -0.73 to +0.82. The positive and negative PDO years are shown in Table 4, along with the PDO average for those years:

Table 4

Negative PDO Years	Average PDO	Positive PDO Years	Average PDO
1920	-0.907	1926	+1.160
1948	-0.874	1934	+1.183
1949	-1.228	1936	+1.731
1950	-1.810	1940	+1.769
1951	-0.769	1941	+1.994
1952	-0.866	1981	+0.918
1955	-1.948	1983	+1.648
1956	-1.804	1984	+0.838
1961	-0.818	1986	+1.239
1962	-1.158	1987	+1.821
1964	-0.770	1992	+0.928
1967	-0.734	1993	+1.417
1971	-1.291	1997	+1.461
1972	-0.922		
1973	-0.804		
1975	-1.102		
1999	-1.063		

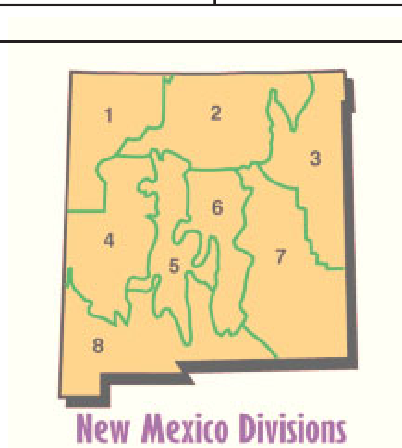

Figure 8

For the one hundred years included in the study, 30 years were determined to be either "significantly positive" or "significantly negative." Of those 30 years, 13 were determined to be "significantly positive," and 17 years were "significantly negative."

An average annual precipitation was computed for each climate division based on data obtained from the National Weather Service's cooperative observer network, and any aviation observation stations with long-term records. Approximately 175 stations were used in these calculations. Precipitation was considered to be normal for years in which the average for the division was within one half standard deviation of the long-term average. The remainder of the years were classified according to "above-normal" or "below-normal" status. This was also done for a "statewide" composite of all the climate divisions. The same methodology was employed for seasonal precipitation, with values plus or minus half a standard deviation designated "normal."

An attempt was also made to quantify precipitation during significantly positive or negative years. Average precipitation was calculated for each year and compared to long term averages. Ratios were also computed to compare the average precipitation during significantly negative and significantly positive years. The same methodology was employed to investigate seasonal precipitation for each of the eight climate divisions.

Results for Annual Precipitation

Tables 5 and 6 show the number of years with normal, above-normal, and below-normal precipitation for each climate division during the significantly positive and negative PDO years.

Table 5 (Significantly Negative PDO Years)

Precip.	Div 1	Div 2	Div 3	Div 4	Div 5	Div 6	Div 7	Div 8	ALL
Above	1	1	3	2	2	2	2	2	15
Below	6	8	7	5	6	9	8	9	58
Norm.	10	8	7	10	9	6	7	6	63

Table 6 (Significantly Positive PDO Years)

Precip.	Div 1	Div 2	Div 3	Div 4	Div 5	Div 6	Div 7	Div 8	ALL
Above	7	5	6	10	6	7	8	7	56
Below	0	1	4	0	1	1	2	1	10
Norm.	6	7	3	3	6	5	3	5	38

It's readily obvious that significantly positive PDO years favor above-normal precipitation, and significantly-negative PDO years favor below-normal precipitation. During negative PDO years, the dry years outnumbered the wet years nearly four to one, when all divisions were considered for those years in which precipitation varied from normal. During positive PDO years, wet years outnumbered dry years between five and six to one, when all divisions were considered for those years in which precipitation varied from normal.

Table 7 shows the average precipitation for each climate division during significantly positive and significantly negative PDO years, as well as long-term average precipitation for all years (1900-1999). The table also shows the ratio of precipitation between the negative and positive PDO years.

Table 7 (Precipitation averages and percentage of normal during positive/negative PDO years)

Precip.	Div 1	Div 2	Div 3	Div 4	Div 5	Div 6	Div 7	Div 8	ALL
+ PDO	13.78	18.07	18.31	16.17	11.45	19.50	17.19	13.18	15.96
%Normal	122.7	110.7	115.5	124.7	122.7	116.3	127.8	122.2	119.6
- PDO	9.90	14.92	14.77	11.88	8.34	15.18	11.80	8.95	11.97
%Normal	88.1	91.4	93.1	91.6	89.3	90.6	87.7	83.0	89.7
Norm.	11.23	16.32	15.86	12.97	9.33	16.76	13.45	10.78	13.34
-/+ Ratio	71.8%	82.5%	80.7%	73.5%	72.8%	77.8%	68.6%	67.9%	75.0%

It's readily apparent every climate division received more precipitation than normal during the positive PDO years, and less precipitation during the negative PDO years. Climate divisions 1, 4, 5, 7, and 8 all averaged more than 120 percent of the normal precipitation during the positive PDO years. Least affected was climate division 2, the north-central mountains bordering Colorado. The statewide average for positive PDO years was 119.6 percent of normal.

During negative PDO years, the state has averaged 89.7 percent of normal precipitation. It appears that climate division 8 (southwest desert) suffered greatest, with precipitation averaging only 83 percent of normal.

By looking at the ratio of negative PDO years to positive PDO years, one might be able to get a sense of the magnitude of change that can be expected when the cycle reverses. Looking at the ratio, it's apparent the amount of change increases southward in New Mexico. Ratios of slightly more than 80 percent along the Colorado border from north-central through northeast New Mexico (divisions 2 and 3) show less dramatic effects of the PDO cycle compared to climate divisions farther south. In divisions 7 and 8 (the southeast and southwest), precipitation during negative PDO years averages less than 70 percent of the average during positive PDO years. The statewide average ratio of precipitation between the negative and positive PDO years is 75 percent.

Results for Seasonal Precipitation

Seasonal precipitation was investigated for each climate division and determined to be normal, above-normal, or below-normal. The long-term average centered about one standard deviation provided the range of normal precipitation. For each climate division, the number of years for each season was determined for each category. For winter, two calculations were made for each climate division. One calculation was for those winters that were in progress at the beginning of a year determined to be a positive or negative PDO year. Another calculation was made for those winters that were determined to begin at the end of a year determined to be a positive or negative PDO year. For purposes of this paper, the seasons were determined in the following manner: Spring was March through May; Summer was June through August; Autumn was September through November; and Winter was December through February. Tables 8-17 show the results of the seasonal analyses.

Table 8 (Spring Season - Negative PDO Years)

Precip.	Div 1	Div 2	Div 3	Div 4	Div 5	Div 6	Div 7	Div 8	ALL
Above	3	3	3	2	3	1	1	3	19
Below	8	7	8	9	8	7	8	8	63
Norm.	6	7	6	6	6	9	8	6	54

Table 9 (Spring Season - Positive PDO Years)

Precip.	Div 1	Div 2	Div 3	Div 4	Div 5	Div 6	Div 7	Div 8	ALL
Above	7	2	3	5	6	6	6	6	41
Below	0	2	1	0	2	1	0	1	7
Norm.	6	9	9	8	5	6	7	6	56

Table 10 (Summer Season - Negative PDO Years)

Precip.	Div 1	Div 2	Div 3	Div 4	Div 5	Div 6	Div 7	Div 8	ALL
Above	4	4	6	4	3	5	5	4	35
Below	7	6	7	9	8	7	7	8	59
Norm.	6	7	4	4	6	5	5	5	42

Table 11 (Summer Season - Positive PDO Years)

Precip.	Div 1	Div 2	Div 3	Div 4	Div 5	Div 6	Div 7	Div 8	ALL
Above	4	2	7	7	4	3	4	4	35
Below	2	5	4	3	4	5	3	5	31
Norm.	7	6	2	3	5	5	6	4	38

Table 12 (Autumn Season - Negative PDO Years)

Precip.	Div 1	Div 2	Div 3	Div 4	Div 5	Div 6	Div 7	Div 8	ALL
Above	3	2	3	5	4	3	2	4	26
Below	8	11	9	6	9	9	8	9	69
Norm.	6	4	5	6	4	5	7	4	41

Table 13 (Autumn Season - Positive PDO Years)

Precip.	Div 1	Div 2	Div 3	Div 4	Div 5	Div 6	Div 7	Div 8	ALL
Above	6	6	4	6	5	6	5	5	43
Below	2	3	4	2	4	2	4	3	24
Norm.	5	4	5	5	4	5	4	5	37

Table 14 (Winter Season (a) - Negative PDO Years)

Precip.	Div 1	Div 2	Div 3	Div 4	Div 5	Div 6	Div 7	Div 8	ALL
Above	2	4	4	3	2	5	5	2	27
Below	8	9	4	8	8	7	6	9	59
Norm.	7	4	9	6	7	5	6	6	50

Table 15 (Winter Season (b) Negative PDO Years)

Precip.	Div 1	Div 2	Div 3	Div 4	Div 5	Div 6	Div 7	Div 8	ALL
Above	3	3	2	4	2	5	3	4	26
Below	6	8	4	8	7	6	9	7	55
Norm.	8	6	11	5	8	6	5	6	55

Table 16 (Winter Season (a) Positive PDO Years)

Precip.	Div 1	Div 2	Div 3	Div 4	Div 5	Div 6	Div 7	Div 8	ALL
Above	5	6	5	7	6	5	5	5	44
Below	4	3	2	3	3	5	3	4	27
Norm.	4	4	6	3	4	3	5	4	33

Table 17 (Winter Season (b) Positive PDO Years)

Precip.	Div 1	Div 2	Div 3	Div 4	Div 5	Div 6	Div 7	Div 8	ALL
Above	9	7	3	8	7	6	5	6	51
Below	1	2	5	2	3	3	5	2	23
Norm.	3	4	5	3	3	4	3	5	30

Table 18 (All Seasons for Negative PDO Years)

Precip.	Div 1	Div 2	Div 3	Div 4	Div 5	Div 6	Div 7	Div 8	ALL
Above	15	16	18	18	14	19	16	17	133
Below	37	41	32	40	40	36	38	41	305
Norm.	33	28	35	27	31	30	31	27	242

Table 19 (All Seasons for Positive PDO Years)

Precip.	Div 1	Div 2	Div 3	Div 4	Div 5	Div 6	Div 7	Div 8	ALL
Above	31	23	22	33	28	26	25	26	214
Below	9	15	16	10	16	16	15	15	112
Norm.	25	27	27	22	21	23	25	24	194

Discussion of Seasonal Results

Spring

When looking at the amount of time precipitation falls into categories of normal, above, and below normal, it's apparent that the spring weather during positive PDO years was significant. When the precipitation was outside of the normal range, wet springs outnumbered the dry years 41 to 7 for all divisions. Precipitation fell in the normal range 56 seasons, or 54 percent of the time. Divisions 1, 4, and 7 experienced no (zero) dry years during positive PDO years. Division 2 (north-central mountains near the Colorado border) was the only division to show no effect, with 2 wet springs, 2 dry ones, and 9 in the normal category.

Negative PDO years produced dry springs more often than not by a ratio of over three to one. For all climate divisions combined, dry springs outnumbered wet ones 63 to 19. Fifty-four seasons were considered normal, which was approximately 40 percent of the time. Divisions 6 and 7, constituting roughly the southeast quarter of the state, exhibited the greatest effect from negative PDO years, with dry springs outnumbering wet springs 15 to 2 in those divisions combined.

Summer

Of all the seasons, summer was least affected by whether the PDO was positive or negative for the year. Positive PDO years favored above-normal precipitation, but by a small margin. Wet summers outnumbered dry ones 35 to 31, with 38 falling into the normal range. Divisions 2, 6 and 8 (the mountains and southwest desert) actually had more dry summers than wet ones during positive PDO years, while division 5 (central valley) broke even.

The tendency for dry summers during negative PDO years was a bit more apparent, with dry summers outnumbering the wet ones 59 to 35 for all divisions combined. Forty-two summers fell into the normal range.

Autumn

Tables12 and 13 show the effect of positive and negative PDO years on autumn precipitation. For all climate divisions, dry years outnumber wet ones 69 to 26, with 41 seasons falling in the normal range. The effect of negative PDO years on autumn precipitation was especially apparent in division 2 (north-central mountains), where dry years outnumbered wet ones 11 to 2. Meanwhile, division 4 (west-central mountains) was relatively balanced between the wet and dry years.

During positive PDO years, wet autumns outnumbered dry ones nearly two to one. However, there appeared to be little effect in the Eastern Plains (divisions 3 and 7), as well as the Central Valley (division 5).

Winter

Recall winter precipitation was determined for those winters which were already in progress at the beginning of the negative/positive PDO year, as well as those winters that began at the end of a negative/ positive PDO year. These two winters are referred to, respectively, as winter (a) and winter (b) in tables 14 through 17.

For negative PDO years, winters (a) and (b) exhibited little difference. For both winters (tables 14 and 15), dry seasons outnumbered wet ones slightly more than two to one. For winter (a), the least difference was noted in divisions 3, 6, and 7. This area comprises the Eastern Plains and central mountain chain, or roughly the eastern half of New Mexico. This pattern wasn't noted for winter (b), although division 6 (central mountains) exhibited more balance than the other divisions.

Tables 16 and 17 show that positive PDO years favored above-normal precipitation, especially in the winters (b) that began at the end of a positive PDO year. Winter (b) was especially interesting in that wet winters that began at the end of positive PDOs almost exclusively favored western and central New Mexico. Division 1 (northwest) only experienced one dry winter in 13 years. In divisions 1, 2, 4, 5, 6, and 8 (all of west and central New Mexico), wet winters outnumbered dry ones 43 to 13 for winter (b), with 22 falling into the normal range. This was in marked contrast to the Eastern Plains (divisions 3 and 7), where dry winters (b) actually outnumbered wet ones 10 to 8, with 8 falling in the normal range.

All Seasons Combined

Tables 18 and 19 show the results of all seasons combined. For negative PDO years (table 18), dry seasons outnumbered wet seasons approximately 2.3 to 1. The greatest ratio was in division 5 (central valley), where dry seasons outnumbered wet ones nearly three to one.

For positive PDO years, divisions 1 (northwest) and 4 (west-central mountains) stood out, with wet seasons outnumbering dry ones over three to one. Effects of a positive PDO were least in divisions 2 (north-central mountains) and 3 (northeast plains). For all divisions combined, wet seasons outnumbered dry ones nearly two to one.

Seasonal Precipitation Quantified

Monthly and seasonal precipitation in the Southwest U.S. exhibits great variability. During any "normal" year it's not unusual to have some months in which less than 20 percent of normal precipitation falls, and others with precipitation that exceeds 200 percent of normal. Consequently, besides examining the number of seasons with above-normal, below-normal, or normal precipitation, average precipitation was calculated for each climate division during positive and negative PDO years, and compared to the long-term averages.

Tables 20-24 show the percentage of normal precipitation for each climate division and each season, along with a ratio of averages during negative PDO years to averages during positive PDO years.

Table 20 (Spring Season) (%)

	Div 1	Div 2	Div 3	Div 4	Div 5	Div 6	Div 7	Div 8	ALL
– PDO	78.7	85.5	88.7	71.0	72.0	75.1	69.2	73.1	78.7
+ PDO	142.9	115.7	130.7	160.4	141.6	142.8	163.4	175.0	142.2
Ratio	55.0	73.9	67.9	44.3	50.9	52.5	40.6	41.8	55.4

Table 21 (Summer Season) (%)

	Div 1	Div 2	Div 3	Div 4	Div 5	Div 6	Div 7	Div 8	ALL
– PDO	94.1	97.0	98.7	91.8	95.9	96.5	97.9	93.5	96.0
+ PDO	106.2	98.5	101.0	104.8	103.8	95.6	107.6	101.9	101.8
Ratio	88.6	98.5	97.8	87.6	92.4	101	91	91.7	94.2

Table 22 (Autumn Season) (%)

	Div 1	Div 2	Div 3	Div 4	Div 5	Div 6	Div 7	Div 8	ALL
– PDO	90.2	82.7	85.0	97.9	87.5	85.6	80.8	93.0	87.5
+ PDO	122.7	116.1	124.8	127.8	130.1	127.9	122.6	125.0	124.4
Ratio	73.7	71.2	68.1	76.6	67.4	67.0	65.9	74.4	70.4

Table 23 (Winter (a)) (%)

	Div 1	Div 2	Div 3	Div 4	Div 5	Div 6	Div 7	Div 8	ALL
– PDO	86.4	92.2	97.0	88.8	86.0	93.3	97.1	87.2	90.7
+ PDO	124.3	117.3	133.1	130.4	134.9	112.7	137.7	136.7	126.5
Ratio	69.5	78.6	72.8	68.1	63.8	82.8	70.5	63.4	71.7

Table 24 (Winter (b)) (%)

	Div 1	Div 2	Div 3	Div 4	Div 5	Div 6	Div 7	Div 8	ALL
– PDO	80.2	91.9	86.3	90.2	82.9	92.3	82.6	93.2	88.1
+ PDO	139.6	123.7	105.6	145.1	130.2	121.9	116.9	137.1	127.5
Ratio	57.5	74.3	81.8	62.1	63.4	75.7	70.7	68.0	69.1

Discussion of Seasonal Precipitation Quantities

The effect of the PDO cycle is profound when one studies the quantity of precipitation New Mexico receives during the positive and negative phases of the cycle that lie outside one standard deviation of the mean value. Tables 20 through 24 show that this effect was most pronounced during the spring, and least noticeable during the summer.

Table 20 shows that the state received only 78.7% of the normal spring precipitation during the negative PDO years, but a whopping 142.2 percent of the normal spring precipitation during the positive PDO years. The ratio of precipitation between negative and positive PDO years was 55.4 percent for the state. This ratio is especially noteworthy in divisions 7 and 8. Spring rains are extremely important in these two divisions, because of the agriculture (ranching and farming) operations. The ratio between positive and negative PDO years in these divisions was, respectively, only 40.6 and 41.8 percent. Spring precipitation in these two divisions exemplify the “feast” and “famine” cycle. Meanwhile, there was less difference farther north between the dry and wet springs. The highest ratios between the dry and wet springs were in divisions 2 (north-central mountains) and 3 (northeast plains), where there are also agricultural activities at that time of year.

Divisions 4 (west-central mountains), 5 (central valley), 7 (southeast plains) and 8 (southwest desert) suffered most during negative PDO years. Precipitation averaged less than 75 percent of normal in those divisions. Divisions 2 and 3, in the north-central and northeast, suffered the least, with precipitation between 85.5 and 88.7 percent of normal. Those same two divisions (2 and 3) were also least affected during positive PDO years, especially division 2, which averaged 115.7 percent of normal precipitation. Meanwhile, some of the divisions that suffered the most during negative PDO years benefitted the most during positive PDO years. Divisions 4, 7, and 8 all averaged greater than 150 percent of normal spring precipitation during the positive PDO years. Division 8 averaged 175 percent of normal. Of course, one thing to keep in mind with the drier climate divisions in New Mexico is that normal precipitation is a small amount. Consequently, the range that division 8 exhibited between negative PDO and positive PDO years (73 to 175 percent of normal) translates into a difference of about one inch of precipitation. However, one inch of precipitation in the southwest desert is 10 to 15 percent of the average annual precipitation.

One effect of positive PDO years on spring precipitation in the mountainous climate divisions (primarily 2, 4, 6) would certainly be to increase the amount of spring snow melt for numerous applications. A complete study of this issue related to the PDO would need to include the climate divisions of southern Colorado. A good portion of the spring precipitation in division 2 (north-central mountains) is in the form of snow, although divisions 4 (west-central mountains) and 6 (central mountains) tend to see a change from snow to rain during the second half of the spring.

Summer exhibited less of a ratio between negative and positive PDO years than the other seasons. Most affected by the negative PDO years were the climate divisions in western New Mexico. Divisions 1 (northwest), 4 (west-central mountains), and 8 (southwest desert) all received less than 95 percent of the normal summer precipitation during negative PDO years. All divisions farther east received between 95 and 99 percent of the normal summer precipitation during negative PDO years. Divisions 1 (northwest), 4 (west-central mountains), and 7 (southeast plains) were most favored during positive PDO years. Even so, division 7, the most favored, received only 107.6 percent of normal precipitation during positive PDO years. Consequently, the only division with a ratio of less than 90 percent between negative and positive PDO years was division 1, with a ratio of 88.6 percent. One division (6) was actually slightly wetter during the negative PDO years. Divisions 2 (north-central mountains) and 6 (central mountains) actually have better (wetter) summers when the PDO is neither significantly negative or positive.

Table 22 shows the results of significant negative and positive PDO years on New Mexico autumn precipitation. Autumn precipitation differences between negative and positive PDO years was not as pronounced as spring, but far more noticeable than summer. It's apparent all divisions suffered less precipitation during negative PDO years and received more during positive PDO years. The ratios between the negative and positive PDO years averaged 70.4 percent, with a range from 65.9 percent in division 7 (southeast) to 76.6 percent in division 4 (west-central mountains). This was the smallest range of ratios of all the seasons.

The overall effect on the state of significantly negative and positive PDO years on winter precipitation was similar to autumn, regardless of looking at winters that were ending early in a PDO year or winters that had just begun at the end of a PDO year. Table 23 shows the results for winter (a), that is, those winters that were ending early in a significant PDO year. It's interesting to note the western portion of New Mexico suffered most during negative PDO years, with winter precipitation averaging less than 90 percent of normal. Meanwhile, the Eastern Plains faired best (divisions 3 and 7), averaging 97 percent of normal. During positive PDO years, all divisions received greater than 110 percent of normal precipitation, but divisions 3 (northeast), 4 (west-central mountains), 5 (central valley), 7 (southeast), and 8 (southwest desert) all exceeded 130 percent of normal. The greatest differences between the good and bad years were in divisions 5 (central valley) and 8 (southwest desert), where the ratios between negative and positive PDO years was between 63 and 64 percent.

Winter precipitation at the end of a significant PDO year (Table 24) showed a similar statewide average for the negative PDO years (88.1 percent versus 90.7 percent), but the pattern from east (wetter) to west (drier) did not hold true. Divisions 1 (northwest), 5 (central valley), and 7 (southeast) all averaged between 80.2 and 82.9 percent of normal precipitation during the negative PDO years. Divisions 6 and 8 (central mountains and southwest desert) faired a little better, with averages of 92.3 and 93.2 percent.

Winter precipitation averaged 126.5 percent (statewide) for winter (a), and 127.5 percent for winter (b), showing no appreciable difference.

Summary/Conclusions

There is a strong relationship between the Pacific Decadal Oscillation and precipitation in New Mexico. From Table 5, it can be seen that dry years outnumbered wet years nearly four to one for significantly negative PDO years whenever precipitation was either above or below normal. For all divisions combined, dry division-years outnumbered wet ones 58 to 15, with 63 falling in the normal range (plus or minus one-half standard deviation from the mean precipitation). During significantly positive PDO years (Table 6), wet years outnumbered dry years between five and six to one. For all divisions combined, wet division-years outnumbered wet ones 56 to 10, while 38 fell into the normal range.

The effect of the PDO cycle increases generally from north to south in New Mexico. Ratios of negative to positive PDO precipitation averages shows this quite well. Table 7 shows that this ratio ranges from just above 80 percent in divisions 2 and 3 (north-central mountains and northeast plains) to less than 70 percent in divisions 7 and 8 (southeast plains and southwest desert). The statewide average is 75 percent.

Seasonal precipitation during significant PDO years is especially affected during the spring and least affected during the summer. Spring seasons during positive PDO years are especially noteworthy, with wet springs outnumbering the dry ones nearly six to one (table 9). The ratio between spring precipitation during negative and positive PDO years (Table 20) is very significant, with a statewide average of only 55 percent. This affect is especially noteworthy in the south and southwest, where divisions 4, 7, and 8 all had ratios of less than 45 percent. This has profound ramifications for the agricultural regions in those divisions.

If historical data from the 20th century can be used to forecast conditions in the 21st century, one might conclude the following: Precipitation totals during the next negative phase of the PDO will likely be approximately 75 percent of those during the most recent positive PDO cycle. If it is true that a negative phase of the PDO cycle began in the late 1990s, then it is likely precipitation totals for New Mexico between the late 1990s and the 2020s may only average 75 percent of those totals from the middle 1970s through the middle 1990s. If this forecast is accurate, it will have profound effects on New Mexico. Water issues in New Mexico have been significant throughout recent history, and the importance of these issues will increase dramatically as the population continues to grow. These figures are especially important during periods of rapid growth or great changes in the state. New Mexico experienced rapid changes and substantial population growth during the positive PDO phase that began in the middle 1970s. Anyone who judges the period from the middle 1970s through the middle 1990s to be “normal” may find the negative phase of the PDO cycle to be especially harsh in terms of water yield.

Water demands related to increased population along with changes in laws would alone suggest New Mexico will experience an escalation of water issues in the future. When the possible water budget cut of 25 percent is factored into the equation, problems are exacerbated.

There are certainly some caveats in this entire process of extrapolating history forward. The planet is not a static place. The atmosphere of 2002 is not the same as the one of 1950. One big issue of concern is certainly global warming. Some global warming models suggest New Mexico will continue to get wetter as the globe heats up. However, since we rely substantially on snow pack to produce water supply, global warming, even if it did produce more precipitation, would overall diminish the water supply by raising snow levels and decreasing the percentage of total precipitation that falls as snow. However, it is also possible that global warming is creating the increase in amplitude we are seeing in the PDO cycle. If this is true, it could lead to worse droughts during the negative phase and even wetter periods during the positive phase. In any case, considering the ramifications and huge impacts a drought similar to the 1950s (or worse) would have on the Southwest United States, it seems only prudent to plan for significant droughts in our future. We know they will occur. We’re just not sure exactly when or how bad they will be. This study of the relationships between the PDO phase and New Mexico precipitation suggests the likelihood of a very significant drought that will be much higher during the next 20-30 years than it was over the past 20 years when we reaped the benefits of a positive PDO phase. If we are going to meet demands for water in our future, it will take a combination of excellent management, conservation, and the development of new, affordable technologies.

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Thomas C. Turney's *New Mexican roots go back to Jornado del Muerto northeast of Las Cruces, where his grandfather settled in the 1880s. As a New Mexico professional engineer for over 20 years, Tom is licensed in a multitude of fields, including civil, electrical and sanitary engineering. He received his bachelor's and master's degrees from New Mexico State University. As state engineer, Tom assumes a position where he has general supervision of the water of the State as well as the measurement, apportionment, and distribution of those waters. Tom comes to the post of state engineer at a time when the role of state government in the protection of the state's water resources is critical. His goal is to develop a water resource strategy that protects existing water right holders, while at the same time addressing the numerous internal and external pressures on the state's limited water supply.*

DROUGHT IMPACTS ON WATER SUPPLIES AND DELIVERY IN NEW MEXICO

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The current drought has taught us one thing this summer. It fully demonstrates the importance of managing our state's finite water supply. Daily I am inundated with phone calls from people running low on water and wanting me to solve their supply problems.

One thing I believe a lot of people have forgotten is a basic principle of New Mexico water law. Our constitution says this state is a "prior appropriation" state. A priority in time gives a better right. We administer water by priorities. In times of a drought or diminished water supply, this results in junior appropriators being curtailed first. This is the system our founding fathers set up.

I think a lot of people have forgotten that we have this priority system. They think they can simply go out and get well permits, pump forever – never even envisioning that a "priority administration" system exists. Maybe somebody in the future will come up with a different way to administer water, but right now our constitution says that we are to administer water by priorities of time. As we move into a drought, our constitution dictates that this is the way administration is to occur. There simply won't be enough water for everyone to have all the water they want. Someone is going to get their water use curtailed.

Figure 1 is a graph that we have plotted showing precipitation for New Mexico over the past 100 years. If you look at the early part of the century–1905, 1910, and 1915–you can see a series of droughts. If you move on along to the 1920s and 30s, you can see other droughts occur. Then, it got wet. Then again, in the 1950s, there was another major drought period. After the 1950s, we moved into a period of generally wet years, though you can see that there have been some isolated years that certainly can be called drought years. These drought periods, though, were never continuous, occurring year after year after year like we

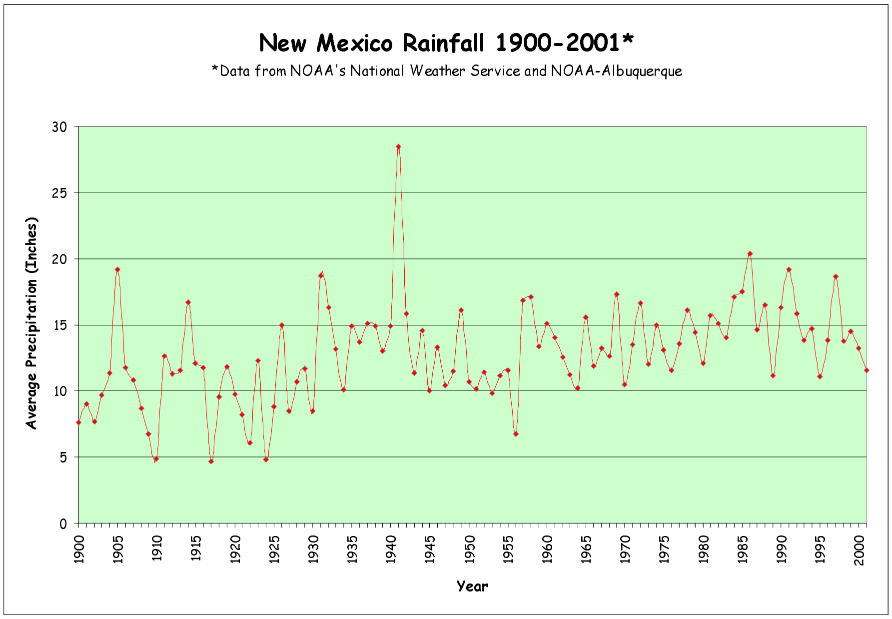

Figure 1. New Mexico Rainfall for years 1900-2001, Office of the State Engineer, April 2002.

saw in the early part of the century. In fact, you can say for the last 20 years we have had abnormally high amounts of precipitation in the state. Again though, there have been some isolated periods of drought.

Now I want to talk about managing the waters of New Mexico. As an example, let's consider Costilla Creek. Costilla Creek is in the northern part of New Mexico–above Taos. It begins in New Mexico, flows into the state of Colorado, and then turns and flows back down into the state of New Mexico. We administer this creek by priorities. It has not been a piece of cake by any means–but we do it.

The first thing we did was prepare a draft manual for administration of the creek. We received a lot of comments on the draft manual–that it was not fair, that we should change this, we should change that. And yes, we did make some changes that people suggested. We adopted this manual two summers ago. This past summer, the drought brought on the driest summer I have ever seen up there. Interestingly though, even with the drought I didn't receive any complaints at all concerning administration of the river. Prior to adopting the manual, every summer I received numerous complaints—many being brought to the level of the Governor's office.

One thing we did to assist in administration was to provide everyone with a measuring device at their point of diversion. That just by itself was controversial. But it also made people aware of the importance of water management. Many times in the past, neighbors had commented to me that sometimes they felt their fellow neighbors might be taking a bit too much water. The measuring devices controlled how much water everyone received. Next, using permits and a court decree, we set up priorities and rates of diversion for all the different points of diversion. On top of all that, because the creek swings into Colorado, we have had to deal with an interstate compact with Colorado. Working with Colorado, we hired a full time water master and assistant. Water administration now not only occurs among New Mexico users, it also complies with our compact. Prior to the adoption of the manual, we were often at odds with our sister state. But this summer, I personally have not received any complaints from Colorado. I hope that continues.

So how bad is the drought? I can tell you that the Rio Grande is looking right now like it's at the lowest level on record. The San Juan River is running about 6 to 8 percent of normal and I'd say even though the year is not yet over, it looks like the year is pushing close to record lows.

Figure 2 shows spring runoff at the Rio Grande Embudo Station for March through July. This graph goes back a hundred years with just a few years of missing data. Looking at 2002, it sure looks like the Rio Grande at Embudo has had the lowest runoff in a hundred years!

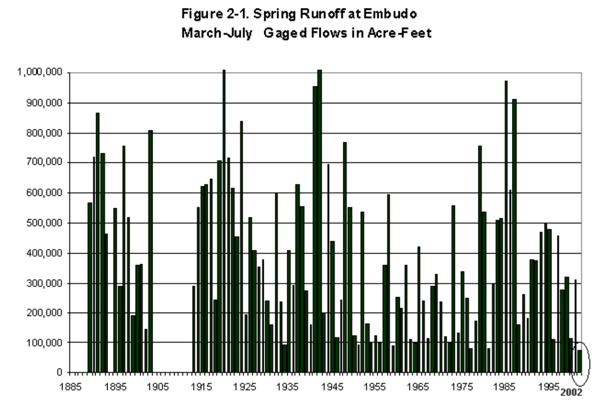

Figure 2. Spring runoff at Embudo March-July; gaged flows in acre-feet.

Figure 3 illustrates reservoir storage at different reservoirs around the state. On the Canadian, we are running at 20 percent of normal. On the Pecos, 15 percent of normal, the Rio Grande–again, these are reservoir storage levels–running about 50 percent of normal, and on the San Juan at 75 percent of normal.

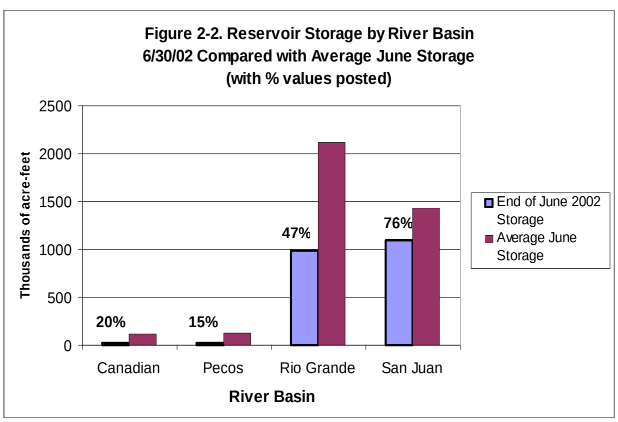

Figure 3. Reservoir storage by river basin on June 30, 2002 compared with average June storage.

Elephant Butte Reservoir is depicted in Figure 4. The photo was taken about two weeks ago. The water level at Elephant Butte Reservoir is dropping. We flew down the river channel this past week and in this area called the Narrows, we could see the water has significantly receded.

Figure 4. Elephant Butte Reservoir in late September 2002.

Something interesting happens when Elephant Butte Reservoir begins to drop–and that has to do with the Rio Grande Compact. The Rio Grande Compact is a compact signed by three states: Colorado, New Mexico, and Texas. Certain provisions kick in based on the water storage level of Elephant Butte Reservoir referred to as “useable water supply.” We look at Elephant Butte Reservoir and Caballo Reservoir, and then at New Mexico credits and Colorado credits. The arithmetic is not terribly important, but what is important is that when Elephant Butte starts dropping, we must abide by Compact provisions.

The Rio Grande Compact says that New Mexico should not increase the amount of storage in reservoirs constructed after 1929 whenever there is less than 400,000 acre-feet of usable storage.

What does this provision mean? We have not seen Elephant Butte Reservoir drop to its current level for a long, long time. Reservoirs constructed after 1929 in New Mexico include El Vado Reservoir, constructed in the late 1930s; and the Santa Fe Canyon reservoirs, also constructed after 1929.

Let’s suppose we have a wonderful winter this year with lots of snow in the Colorado mountains and runoff begins coming down the Chama River next March or April. Normally this flow is captured in the El Vado Reservoir. Figure 5 shows El Vado when it is full. I can tell you that today, though, for all practical purposes, it’s dry. Next year El Vado can’t increase its storage or hold any water. They must let the water flow through to fill up Elephant Butte Reservoir. That’s the way the Compact works.

Figure 5. El Vado Reservoir.

This has major impacts on anyone wanting to use storage from El Vado Reservoir. Water isn't needed during April or May. Instead, it is needed for the hot summer months of July and August. And that is when we have a problem due to Compact delivery obligations because there won't be any water in storage to release when it's needed by the farmers along the middle Rio Grande.

The City of Santa Fe is in a unique position. If it does snow in the Santa Fe mountains this winter, Santa Fe will be able to store water in McClure Reservoir provided an equal amount of water is released out of Heron Reservoir or wherever their San Juan/Chama water was being stored. That will keep the Rio Grande whole. I hope we can continue to do that, but I am worried that if we take the water out of Heron and release it for the silvery minnow, we won't be able to do this kind of exchange accounting next year or in subsequent years.

The next reservoir I want to talk about is Navajo Dam located in the northwest part of New Mexico. Ordinarily, Navajo Dam holds 1.7 million acre-feet. As I recall, it is down about 40 percent and sits at about 1 million acre-feet today. As the water level in Navajo Dam drops, there is pipe that comes out of the side of the reservoir that will begin to be exposed. This happens at about the 700,000 acre-foot level. The pipe supplies water to the Navajo Indian Irrigation Project (NIIP). The pipe sits up high from the reservoir bottom in order to provide water to NIIP by gravity flow. Thus, because of authorizing legislation, there could be a problem between the Navajo supply and the water we are releasing out of Navajo Dam today.

The inflow into Navajo Reservoir is about 50 cfs with a dam release of about 500 cfs. We are taking water out at a much higher rate than is coming in. There are a couple of reasons this is happening. We are trying to keep the flows in the San Juan River high in the Four-Corners's area because it is a critical habitat for the Colorado pike minnow there–and they need the high flows. The second is for the fly-fishermen. They enjoy fishing just below the dam and want the 500-plus cfs flow; it has given them a highly rated trout fishery just below the dam.

About two weeks ago we received a letter from the Navajo Nation. It was a copy of a letter they had sent to the Secretary of Interior in which implementing shortage sharing was discussed. They are very serious about shortage sharing because of that pipe I mentioned earlier that comes out of the side of Navajo Dam. There are other contract users–people who take water out of this reservoir–and everybody is going to have to share equally. That includes the San Juan/Chama diversion project.

Last week, I received a letter from the Bureau of Reclamation requesting that New Mexico assume responsibility for administration of the San Juan River. This would require us to go into priority administration. I previously mentioned the 500 cfs coming out in Navajo dam. There are irrigation ditches below the dam that have senior rights on the river–in the neighborhood of 150-160 cfs. They like to take 250 cfs. But when we move into priority administration and you only have 50 cfs of direct flow–that is all the senior water right holder is entitled to receive. So when we talk about going into administration next summer on the river, it is going to be an interesting situation.

On the Pecos River, Ft. Sumner and Santa Rosa reservoirs are essentially dry. There may be a couple thousand acre-feet, but for all practical purposes, they are dry today. This means that there is a possibility of under-delivery on our obligations to the state of Texas. Last year I made some predictions concerning under-delivery and this year I'm not even going to venture a guess. I was not too far off last year, but sometimes these things come back to haunt you. But I will say there is always a possibility of under-deliveries.

This year the state legislature authorized $30 million from the Tax Stabilization Fund for certain water projects. The Tax Stabilization Fund was to be spent for water improvements that were necessary around the state, with a specific amount of money to go to the Pecos River for water issues. But there is a problem. Even though we have need for the money now, there is a little caveat that came with the law that discussed “state reserves” and how “state reserves” must be above five percent before any money can be accessed. Unfortunately, the last reserve projection came in at slightly below five percent so we cannot access the $30 million. However, I think there is a strong desire among both the executive and the legislative branches to free up at least a portion of this money. The chairman of the Legislative Finance Committee, Representative Varela, suggested a method for doing so to the Department of Finance and Administration. We met with the Governor’s Chief of Staff yesterday and I think they are trying to find a way to release some of the money.

In addition to the Pecos River, we have other important water conveyance projects that are desperately needed. You will recall the picture showing the low level of water in Elephant Butte Reservoir. We need to get water into that reservoir. Right now, at the head waters of Elephant Butte, there is a big delta that has formed and the river just spreads itself when it enters the delta. Flying over the delta you can see the thin sheet of water glistening for miles. Walking through the area, you can see thousands of new shoots of willow trees as well as salt cedars begin to take root. I’m sure substantial evaporation is taking place here. To bring the water back up into Elephant Butte Reservoir, we need to cut a pilot channel through the delta so that the river connects directly into the reservoir. Not only will it provide water for the farmers in the Las Cruces area, it will also help to relieve the Rio Grande Compact pressures. About $3 million for this pilot channel project has been earmarked and I am hoping this special money will get released soon as we need to get the channel dug this winter.

The legislature also set up a bond issue; I think it will be “Bond Issue Number E” on the ballot this year. The total of the bond is around $13 million, $10 million of which is for addressing Pecos River issues. The rest is to address issues on the San Juan River, endangered species issues, and some small dams around the state. These small dams were constructed nearly 50 years ago by the Soil Conservation Service and are beginning to deteriorate and need renovation. A portion of the bond issue will help pay for partial renovation of these dams; there are literally dozens of them around the state. We also have Ute Reservoir on the Canadian River that needs some work done on the spillway.

Now let’s move onto the Pecos River. We have been working diligently toward the development of priority administration rules. We are also developing water banking rules and regulations. These two sets of rules are intertwined. You will probably hear more about this today. I would hope that if we must go into priority administration, water banking may be a method to relieve the pressures created by the priority administration.

Next summer, we will have many dilemmas facing us. We can learn valuable lessons from Costilla Creek: it’s expensive, it’s tough, there are a lot of tempers–but it is possible to administer by priority.

I think there has been complacency slowly developing in this state since the droughts of the 1950s–especially in the last 20 years. People continually come in and expect me to be able to give them unlimited permits for wells or for diversions off rivers. They are not happy that I won’t approve their requests. I wish I could, but it is simply not possible to do so. The state’s rivers are fully appropriated. We have a finite amount of water here and it is my job, as charged by statute, to measure and distribute the state’s water.

A decade ago, conjunctive management–where management occurs for interconnected rivers and groundwater wells–was not envisioned. But it is now squarely before us. It presents complex challenges to this state, but I know it can be done. It simply must be done. I also believe that if we fail, the courts will make these decisions for us and this will result in hurting individual users significantly.

I am going to ask everybody in this room who is a water manager to work constructively with our office with moving toward actively managing our water resources. I do not believe it is in our best interests for the federal government to assert control over our rivers. On the Pecos River, we have under-delivered in the past and I believe that if we don’t manage our waters by ourselves, there is every chance in the world the United States Supreme Court will become the water master on this river. I think it would be much easier for a New Mexican to deal with me, see me face-to-face, than to deal with some anonymous person back in Washington.

On the Pecos River, if I can get the money released, we will work toward acquiring farmland. I believe there are 18,000 acres of irrigated lands which are needed to be acquired along the Pecos River–6,000 below Carlsbad Irrigation District’s Avalon Dam and 12,000 above. I understand that in the last week, thousands of acres of salt cedars have been sprayed with an herbicide. The spraying has been done through the Department of Agriculture in cooperation with the soil conservation districts. Again, on the Pecos River, if we fail to make our compact deliveries, we need to emphasize that priority administration is a part of the state's tool box. And we will do so if necessary.

Concerning Pecos River priority administration, we have circulated preliminary drafts of our rules and regulations to people who sit on what we call the Pecos River ad hoc committee. I am sure the Interstate Stream Commission also will review the drafts and they then will finally be promulgated as per the formal role making process.

On to the San Juan River–this winter we will put together a very aggressive program. We will start installing measuring devices on dozens of ditches. This must be done because our preliminary measurements indicate that some ditches may be taking two, three, or four times as much water as perhaps they are entitled. If the drought continues, the San Juan Basin available water supply will only become tighter and tighter.

We have budgeted for a San Juan River water master to administer direct flow users. This means irrigators, and some cities as well, will be cut back to an appropriate amount. I include fly-fishermen here, although they are more of a reservoir user. They have filed suit against us because they like the high flows out of the river. They most certainly would not like to see these high flow releases restricted in any way. Cutting back releases from Navajo Dam could impact their fly fishing experience–especially if the flows going out of Navajo Dam were restricted or tied to inflow into the dam.

The reservoir users–and this includes the Navajo Indian Irrigation Project, the San Juan/Chama Project, some contract holders, and the Public Service Company of New Mexico–will all be going into shortage sharing. This is the first time we have gone to shortage sharing and there is a distinct possibility that it will have a major impact on users of the San Juan River.

We do not have a complete general stream adjudication in this area; we have one only on non-Indian uses. We can not use this partial adjudication to administer the waters of the Navajo Nation, as they were not a party to the decree. We need to define the rights of the Navajos.

In the coming months, we intend to invite many San Juan stakeholders to the table. I do not want to make this a big group–I want problem solvers. We will invite people from industries in the area, from the region's municipalities, and from the agricultural sector as well as the Navajos. We will discuss what we are going to do next summer and how we are going to administer the river. I met with representatives of the Navajo Nation people last Thursday and they are willing to participate. What is going to happen on the San Juan River will not be popular, but again, we must deal with the Basin's limited water supply .

Concerning the Rio Grande, I want to touch briefly on supplemental wells. My staff and I have extensively reviewed the current policy on supplemental wells. It is a very, very complex issue and certainly something that must be addressed. I did issue a supplemental well permit two weeks ago; an emergency permit to Dixon Apple Farms near Costilla, so we do occasionally issue supplemental well permits.

We have wells supplemental to primary wells–but we also have supplemental groundwater wells which are supplemental to surface water. Supplemental groundwater to surface water is an issue that we must carefully examine. I would like to see if we could approve these types of wells, but first we need to determine how to supervise the combined diversion of the surface and groundwater. We must do this if we are going to have the ability to replace any over-diversions or any excess depletions in subsequent years. We also want to make this an equitable system everywhere so that no particular party either gets hurt or benefits exclusively.

As you know, the silvery minnow decision is out. One thing I think holds a lot of hope on the silvery minnow is something called the "Middle Rio Grande Collaborative Program." This program brings together different groups–from federal and state agencies to environmental groups–all come to the table to discuss ways to recover the silvery minnow.

Next summer we must work with the Indian Pueblos and their primary and paramount rights. These "P and P" rights mean the Indians are the senior water rights holders on the river. We have El Vado Reservoir where Indians will be able to store their "P and P" water, as has been done historically during dry years. The water will be stored for the Indians and released to the Indians. This means that non-Indians cannot use that water. This is going to be of great controversy up and down the Rio Chama. If the water is in the river, the Rio Chama acequias will probably want to use this water.

We already ran into this problem this past summer on the Rio Chama. Someone used a backhoe and dug up a measuring device. They then threw the device out into a nearby field. We tried to work with the offender but finally had to take the case to court. The court ruled that the offender had to pay back his over-diversion. The court also said that if he took more water than he was supposed to, the OSE was to chain off the head gate. Next summer, we are going to take this over-diversion very, very seriously. If past history is any indicator, I predict there will be another legislative hearing on the banks of the Rio Chama when users see water running down the river and they start asking why the State Engineer refuses to let them take the water. It is not that I'm being a bad guy. The law says we must administer by priority. And the Rio Chama is not the senior water rights holder on the river, at least not in comparison to the Pueblos, nor do the acequias have any storage rights in El Vado. Of course, if acequias use water released from storage which they have leased or temporarily acquired, this is another story.

I want to talk a bit about the administration of Middle Rio Grande Conservancy District diversions– it is an issue that must be addressed in the coming months. It was very clear in Judge Parker's decision that this issue must be confronted. First, I'd like to compliment the MRGCD. In the last few months, perhaps with my encouragement, they have gone to ditch rotation. That means the ditches have not been kept full all the time and it has allowed them to stretch their water supply further. Ditch rotation is practiced by most if not all large irrigation districts. This is a practice that must continue even after our current drought passes. We are now working with the conservancy district on an efficiency study. The preliminary draft has been distributed to them and we are hopeful we will soon be receiving comments back. We hope to have the final study completed by the end of the year. It will be available on our web site when it is finalized.

Figure 6 takes us back to the collaborative program I mentioned earlier. It is a fish rearing and breeding facility under construction in the city of Albuquerque's Botanical Gardens. The state has provided $1 million to $1.5 million for the project with the intention of raising about 50,000 silvery minnows a year–putting 25,000 of those minnows back into the river. In yesterday's Albuquerque Journal, an article appeared about similar facilities and ponds being constructed on the San Juan River for the razor-back sucker. Six ponds are being constructed there. It is not the total answer to the recovery of the species–it is simply a part of many actions that must be taken in the future to recover an endangered species.

Thank you.

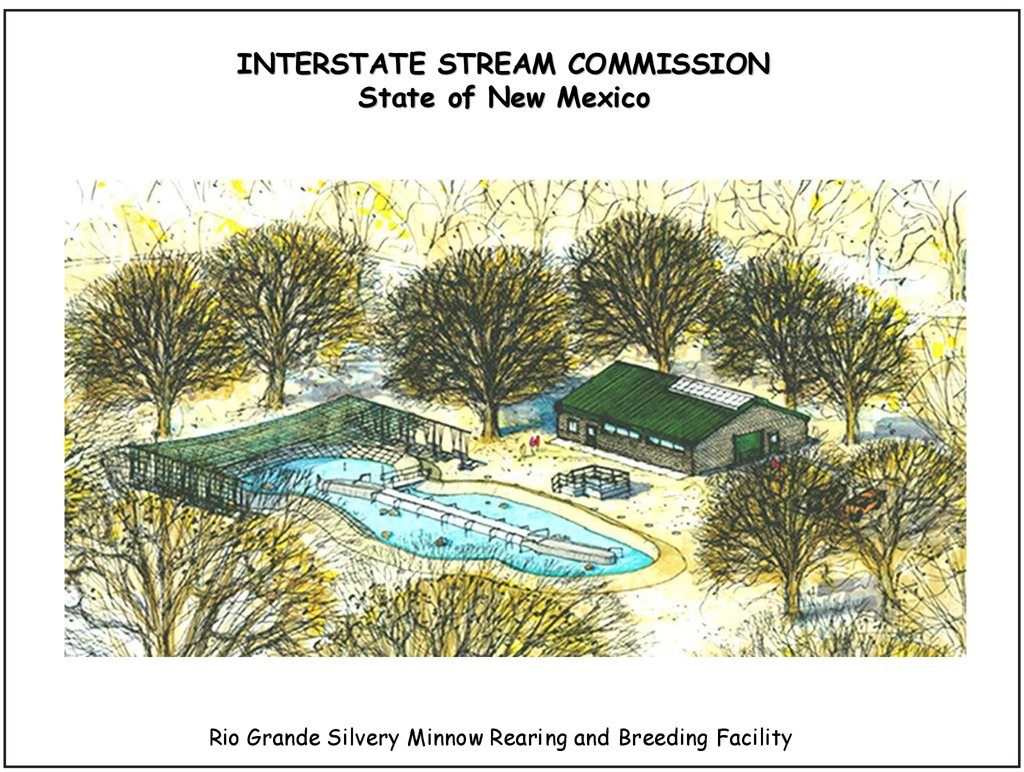

Figure 6. Rio Grande silvery minnow rearing and breeding facility. Albuquerque.

***Norman Gaume** has served five years as Director of the New Mexico Interstate Stream Commission (NMISC). By statute, the NMISC responsibilities include investigation, conservation, protection, and development of New Mexico's water resources and stream systems, administration of eight interstate stream compacts, state participation in federal water resources programs, and management of New Mexico's regional water planning program. Previously, Norman was Director of the Water Resources Division, City of Albuquerque. Norman's grandparents were ranchers and farmers in the Lower Rio Grande area of New Mexico. He was raised in Anthony and Deming, graduated from Hobbs High School, earned B.S. and M.S. degrees in electrical and civil engineering from NMSU, and has worked in Austin, Texas, Albuquerque and Santa Fe. Norman is a registered professional engineer and an avid whitewater canoeist.*

MEETING COMPACT DELIVERY OBLIGATIONS DURING TIMES OF DROUGHT

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Editor's Note: The author was unable to edit the following transcription of his remarks. Our apologies for any errors.

My topic today concerns meeting compact obligations in times of drought. I would like to begin by commenting on Charlie Liles' concept that we may need to change the definition of drought. We can get by without an active administration of our water resources priority administration when times are really wet, as they generally have been for the last 20 or so years. However, that period broke in 1996, 2000 was bad, and 2002 was terrible. Under normal water supply conditions, not dry conditions, we are going to have significant challenges in administering New Mexico's waters.

My topic overlaps with the material presented earlier by the state engineer. There will be some duplication and I hope to complement some of the things the state engineer said. I, too, want to point to Costilla Creek as an example of how things can work in New Mexico. A couple of concepts are basic and applicable to most systems in New Mexico where reservoirs exist: one of the duties of administration is to separate the direct flow, that is, the flow that would have come through the system before the reservoir was constructed for which there is no storage value, from the water that is coming out of the reservoir. Costilla Creek is a good example of that. There are direct flow users with seniority rights that go way back two centuries. There also are storage water users who are generally different and have different rights. The water that is actually in the stream and that has to be administered at the point of diversion is two different kinds of water. You must be able to separate the direct flow water from the storage water. That, I think, has been accomplished very successfully on Costilla Creek, but the effort and costs were significant.

Steve Vandiver, the state engineer advisor from the state of Colorado, is here today. I am the engineer advisor for New Mexico. The states of Colorado and New Mexico contribute hard cash of $98,000 a year to administer the water for 8,500 acres of land, about $12 an acre for administration. Watermasters need to be on duty seven days a week. It is not a 24-7 job, but it is much more than an eight hour a day job. In fact, our watermaster works very, very long days during irrigation season and we give him significant amounts of compensatory time at night duty. He also has to work at night during the off-season and one of the reasons is to keep people from stealing water. It is amazing how head-gates can creep open at night and it is the job of the watermaster to keep that from happening.

Costilla Creek is particularly sensitive because we have interstate delivery obligations. The Costilla Creek system has four separate points from which interstate deliveries must be made. In order to make those deliveries, uses and depletions in New Mexico (actually, uses in the case of Costilla Creek) must be administered. That means limiting and cutting back when water users want more water than they are entitled to, particularly in a system that has not been as tightly administered as it should have been historically. As I said, head-gates tend to open in the middle of the night or sledge hammers can get applied to stems. Security requires a very significant effort. But what this illustrates, and the main introductory point I want to make here, is that there are a number of necessary ingredients for meeting interstate obligations in times of drought. These are ingredients to distributing water: distribution of water to those who have rights to it and curtailment of uses by those who are out of priority or who are too junior for the amount of supply at that particular time.

Distribution is one of the state engineer's and the Interstate Stream Commission's objectives in our strategic plan. In order to distribute water there are a number of things that must be done. You must have a quantification of the water rights. We very much prefer that the quantification be done by a judge through an adjudicatory process that is complete. In a few places in New Mexico that is the case, but in many, many places where water will have to be administered in order to meet New Mexico's obligations, adjudications are not complete. In those cases, it means that administration will have to be based on the state engineer's assessment of the permits rather than the judge's final determination of the water right. Of course, when you consider Native American water rights areas where permits are not allowed, that creates another element of complexity. But the number one ingredient is to quantify the water right.

The second ingredient is water measurement. When we talk about water measurement, there are actually two big jobs to do. We have to measure supply as well as uses. The Interstate Stream Commission and the state engineer cooperate in providing a lot of money to the U.S. Geological Survey (USGS) to operate the stream-gaging system in New Mexico. We depend on stream-gaging measurements and investigations of interconnected aquifers to obtain a measurement of the supply. In terms of administration, which must take place daily, we have serious questions concerning stream-flow measurements and about improving stream gaging so that we have adequate results for administration of flows. We have conducted some studies and the results will be published soon in what we call the "framework state water plan." The USGS has participated in those studies. Frankly, I think much more needs to be done and I am concerned about whether or not the gaging that is in place can actually get the job done. Gaging in New Mexico has declined rather than increased as we have added demands to the system from a whole variety of sources including increased population and the environmental demands now being forced on us through litigation.

With those two basic ingredients–quantification of rights and measurement of the supply and the uses–we have the ability to administer water. However, we need manpower to be able to provide people in the field and they need political support to get the job done. Political will is a huge ingredient and I believe you will hear a very interesting panel discussion later in today's program on that topic. Political will, I believe, needs to be thought of in several different categories. First, you must have funding for the necessary manpower to do the water rights quantification, the water supply and water use measurements, and for the manpower in the field to actually administer the supply. That means, in some cases, cutting people off. A side element of political will concerns security; security for the people in the field who are dealing with the very emotional and contentious issue of telling people they are out of priority and they can not use water. We need improvement in these areas and we are going to have to bring the political will to bear on these issues.

Now I will discuss a number of other compacts to which New Mexico is a party. I want to talk about compact issues and meeting New Mexico's obligations as well as the management actions being taken or needing to be taken so that New Mexico is in compliance.

On the La Plata River Compact, New Mexico is the down-stream state. The issue there is that Colorado is not delivering water to New Mexico in accordance with the requirements of the compact. It has been a contentious and controversial issue for a number of years. We are not in agreement with the state of Colorado. The management actions needing to be taken by the state of New Mexico include doing what is necessary to see that Colorado complies with its delivery obligations to New Mexico on the La Plata. That becomes particularly difficult for Colorado in times of drought. The La Plata River, in the vernacular that we use, develops a hole before the river gets to the state line and it gets hard to push water through. We do not believe Colorado is meeting the intent of the compact or undertaking the actions required.

Herman Settemeyer is the engineer advisor for Texas on the Canadian River Compact where there has been interstate litigation. The issue there in drought times is actually no different than the issue in wet times. That compact does not provide for a delivery obligation to Texas; rather it limits New Mexico's storage. Thus in times of drought, it is actually quite simple, we can not store water that is not available and thus it is not a drought issue for New Mexico.

Now I want to address the Colorado River Compact and the Upper Colorado River Basin Compact. As you may know, seven states are a party to the Colorado River Compact and four states–Utah, Wyoming, Colorado, and New Mexico–are parties to the Upper Colorado River Basin Compact. The obligation of the four upper basin states to deliver water to the lower basin at Lee's Ferry, just below Lake Powell, is that the upper basin states must deliver 75 million acre-feet of water in a ten-year period. And every year from Lake Powell, the Bureau of Reclamation has released, not 10 percent of that ten-year average, which would be 7.5 million acre-feet, but 8.3 million acre-feet, which includes one-half of the United State's obligation to Mexico. Because of the drought, storage in Lake Powell is diminishing. Let me add another side of this issue. The upper basin states have not fully developed their entitlements to use water under those compacts. New Mexico is, I believe, significantly farther ahead in developing its approximately 11 percent share than the other states. Any water that is apportioned to upper basin states that is not used obviously ends up in Lake Powell. During dry times, if Lake Powell's storage drops to the point where it can not supply the 7.5 million acre-feet per year plus the United States' actions to take 50 percent of the United States' obligations to Mexico, then compact obligations for the upper basin states come into play. Let me tell you what the current situation is: the current useable storage in Lake Powell is low, significantly lower as a result of the drought and stands at 11 million acre-feet. In-flow this year minus Lake Powell evaporation was less than one million acre-feet, but 8.3 million acre-feet per year was released by the United States. What that means is that there is one year of firm supply left in Lake Powell. If we were to have, God forbid, two more years like the last year, the upper basin states would not make their delivery obligations completely in the second year, and that would require the four upper basin states to reduce proportionately their depletions of water. Again, New Mexico has an 11percent share of the upper basin states. If that scenario were to occur, there would be a disagreement that would probably move to litigation regarding whether or not the upper basin states are obligated to provide half of the United States' obligation to Mexico. New Mexico receives 1.5 million acre-feet per year and the situation can get, as I am sure you know, very contentious.

Another issue on the San Juan River part of the Colorado River system that the state engineer mentioned is the demand by Reclamation of the state of New Mexico for administration of the San Juan. I have their letter before me and I'm just going to read the next to the last sentence of that letter. The letter talks about the need for administration to protect releases for endangered species from diversions by water users that do not have a right to the storage water. They have direct flow rights and the state engineer said that the current in-flows are about 50 cubic feet per second but we have water users that have consistently taken many times that amount. This letter says "in order for all on the system to make the best use of their water now and in future years we formally request that the state of New Mexico through the state engineer's office do begin administration of adjudicated water rights on the San Juan River." And, of course, the Indian rights are not adjudicated and that leaves a big question.

The state engineer mentioned the situation in the Navajo Reservoir and let me provide a little bit of additional detail in that area. The current storage in Navajo Reservoir is about one million acre feet out of about a 1.7 million acre-foot reservoir. There's approximately 300,000 acre-feet of water available before the level of the reservoir drops below the point that the Navajo Indian Irrigation Project can receive its supply. At the point that the Navajo Indian Irrigation Project does not receive their supply. The legislation, and it was one bill passed in 1962 that authorized the San Juan Project and the Navajo Irrigation Project, requires that shortages be shared. Well, things were pretty bad for the San Juan/Chama Project this year. The in-flows to Heron were 6,300 acre-feet, out flows were 96,000 acre-feet. As a result of litigation brought by environmental advocacy groups, Judge Parker has said the United States has an obligation to use this imported water coming from the Colorado River Basin, where we have endangered fish problems, to maintain river flows in the Rio Grande. What that will do is hasten the time, I believe, of a really significant crash on the system should this dry weather continue.

And it almost certainly will trigger arguments about whether or not imported water taken from one side of the continental divide where there's an endangered species, is appropriately used on the other. It also imperils New Mexico's ability to see that senior water right users on the Rio Grande are not shorted in priority administration. Let me explain that. The state engineer declared the Rio Grande groundwater basins in 1956. That means from that point forward, any groundwater development has to replace its depletions of Rio Grande flows in order to pump. Many of the large pumpers, including the city of Albuquerque, rely on San Juan/Chama water to replace the depletions of water associated with the pumping. In the event that the San Juan/Chama project ends up without a supply, those demands associated with the historic groundwater pumping will continue to be exerted on the river, but there will be no supply to release from upstream reservoirs to run down the river to replace those depletions. If that happens, that will short the senior water rights holders in the Rio Grande basin, and will make it difficult for New Mexico to comply with its compact obligations.

As the state engineer mentioned, actions will be taken. We will create a small advisory committee of water users to help put plans in place and to get some concurrence about the necessity for administration on the San Juan this year. We will be moving forward aggressively to implement metering. The Bureau of Reclamation has offered their assistance in implementing measurements of all of the uses on the San Juan, and the agency will be undertaking a significant effort to come to the bottom line of what the diversion rights are. There is an old adjudication and a lot of transactions that have occurred since that time, of what the water right is for purposes of administration. Again, direct flow diverters that don't have a right to waters in the reservoirs will have to be limited in priority to the amount of natural flow on the river, which basically would be the inflow of pre-native inflow above the Navajo reservoir.

I am now going to move to the Rio Grande. There are three sets of entitlements and obligations that New Mexico has on the Rio Grande under the Rio Grande Compact. The first is above Otowi. New Mexico is entitled to deplete as much water above Otowi, drought or no drought, as it did at the time of the compact. Irrigated agriculture, mostly by acequias in northern New Mexico has diminished since the time of the compact and I don't believe that that is an issue. There is an obligation to limit depletions and to make deliveries in the Middle Rio Grande. The limitations and depletions must occur between the Otowi gauge and Elephant Butte Dam; that is a quantified obligation specified by a compact schedule. Many of you know that New Mexico, at low flows at Otowi (on an annual flow basis), is entitled to deplete a maximum of 43 percent of the water that flows past the Otowi gauge. Once the annual flows at Otowi get up to about 1.1 million acre-feet, New Mexico's marginal entitlement to deplete water is zero. The maximum depletions of Rio Grande flows is about 405,000 acre-feet. Part of the issue here is control of natural depletions of water. Extensive water budget investigations completed by the State of New Mexico, both historically and recently, indicate that only about one-third of the depletions in the Middle Rio Grande are caused by human uses of water. The other two-thirds are associated with evaporation from the river and from Elephant Butte Reservoir, which, of course, is there to serve the users below Elephant Butte Dam in New Mexico and Texas, and from the bosque. The water supply investigation published by the Interstate

Stream Commission and produced by Papadopulos and Associates is available on our webpage, The study indicates that depletions by the river itself in the Middle Rio Grande and the bosque are equivalent to the depletions of irrigated agriculture.

New Mexico's historic strategies for compliance with the Rio Grande Compact centered around control of natural depletions, but that strategy has been turned on its ear by the Endangered Species Act. The Bureau of Reclamation, which channelized the Rio Grande and has worked diligently on drainage and salvage efforts in cooperation with the Interstate Stream Commission, is not nearly as effective as it once was. And it appears that New Mexico will have to deal with the administration of the one-third of uses upon which all New Mexicans who reside in the Middle Valley depend.

Let me get a little more specific now about the forecast for our state. As of the end of last year's accounting, New Mexico has an accumulated credit in Elephant Butte Reservoir of a little over 155,000 acre-feet. The maximum debit that can be charged against New Mexico in any year is 150,000 acre-feet, partially because water that is put into storage above Otowi is accounted for in the year that it is put into storage, as occurred in 2001. That storage was empty from El Vado this year; there has been extra water in the system for which the accounting hits occurred the year before. New Mexico anticipates increasing its credit, possibly very significantly, and that creates some other issues downstream.

Let me elaborate about some of those issues. Elephant Butte storage is quite low. I believe that the vast majority of water that is left in Elephant Butte Reservoir today is credit water belonging to New Mexico and Colorado. The compact provides that New Mexico can relinquish credits and store an equivalent amount of water upstream. This is certainly an issue that will be discussed heavily in the winter months as we prepare for the upcoming season.

On the lower Rio Grande portion of the compact, we believe the compact apportions the water that is available in Elephant Butte and Caballo, the usable supply, to users in New Mexico and Texas on the basis of the Project supply that includes return flows and ultimately on the proportion of irrigated acreage. I am sure you are aware that Texas has threatened litigation. They actually have an appropriation of $6.2 million to sue New Mexico. New Mexico also has a large appropriation. Texas' public position is that they are due 43 percent of the water straight from the reservoir rather than the water that arrives at the state line being part of the supply and sufficient reservoir water added together to make up their 43% share. We are in settlement negotiations with the Elephant Butte Irrigation District about how to manage operations next year and we are in discussions with the State of Texas regarding these issues.

I want to briefly address the situation concerning prior and paramount water storage above Otowi for Native American rights. The United States has historically, despite the objections of the Rio Grande Compact Commission, stored water for the tribes. This year the engineer advisors of Colorado, New Mexico and Texas have met with the Bureau of Reclamation and we anticipate additional meetings regarding this storage. One of the issues for New Mexico, and one of the actions that we will have to take is to see that water stored for the tribes is not used by the acequias and other users on the Rio Chama who only have direct flow rights and some available amount of water in storage in Elephant Butte that is San Juan/Chama water that they can use to supplement their direct flow.

Finally, I want to address the Pecos River Compact and I think I will jump right to the bottom line. New Mexico currently is teetering on the edge of under-delivery to Texas. Our cumulative compact delivery credit is 9,900 acre-feet. Our calculations indicate that we will have to deliver somewhere between an additional 3,000 and 19, 000 acre-feet of water across the state line this year in order to avoid a debit. We are taking steps to deliver, although we will not be able to reach that upper limit additional water as we did last year by the end of the year.

The Interstate Stream Commission will be meeting in Carlsbad on October 23, and I have requested that the commission take action on two sets of regulations that have been developed. One set of regulations is for priority administration and those, I believe, the Interstate Stream Commission would recommend to the State Engineer for adoption. The same situation exists with water banking regulations. You are all aware that there is a consensus solution, that I believe is a permanent solution, to the Pecos River Compact problems that New Mexico has. It involves retirement of a significant amount of farmland, if Pecos Valley Artesian Conservancy District and Carlsbad Irrigation District can settle their long-standing differences over their respective rights.

We are in settlement negotiations with them and I am optimistic that those negotiations will be successful. If those negotiations are successful and if the money is received to purchase or retire all this land, then the priority administration regulations will have an effective date that will be very recent, perhaps 1988. In other words, the regulations will be in place, and we are prepared with quantification of water rights through the review of files to administer. In the event the consensus solution is not put in place, then the priority date would be much earlier–much, much earlier–and likely before the effective date of the compact.

Last year we requested special appropriations from the legislature to provide manpower to administer water right on the Pecos River and the legislature provided that appropriation. We are now hiring staff and are prepared to proceed, if that is required.

Thank you.

Chip Groat *was sworn in as the 13th Director of the U.S. Geological Survey in November 1998. He came to this position from the University of Texas at El Paso where he was Associate Vice President for Research and Sponsored Projects following a term as Director of the Center for Environmental Resource Management. His previous experience includes Associate Director and Acting Director of the University of Texas at Austin Bureau of Economic Geology, Chairman of the Department of Geological Sciences at the UTEP, State Geologist and Director of the Louisiana Geological Survey, Executive Director of the American Geological Institute, and Executive Director of the LSU Center for Coastal, Energy and Environmental Resources. He has been a member of the National Research Council Board on Earth Sciences and Resources and the Outer Continental Shelf Policy Board. Chip is a past President of the Association of American State Geologists and the Energy Minerals Division of AAPG. He holds a Ph.D. in geology from the University of Texas at Austin.*

USGS U.S.-MEXICO BORDER ENVIRONMENT AND HUMAN HEALTH INITIATIVE

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I'm going to talk about our border health initiative, but before I start on that issue, I can't resist the temptation to say a few things about some topics that were addressed earlier. One in particular is the critical importance of streamgaging–maintaining the network across this country that provides the information needed to manage critical water resources.

When people thought that water resource issues were principally found in the West and particularly the Southwest, there was less national visibility for water supply issues. But look today at the web page that shows our streamflow information, and you'll see real-time information from across the country plotted on what we call a "drought map," a map on which red and orange and yellow indicate bad-news areas and green and blue show the good news. You'll find that the Nation is endowed–or cursed, I should say–with lots of red and yellow dots on the map, indicating low, and in some cases record low, streamflow.

Many parts of the country share your dilemma, though not to the degree or perhaps with the gut-wrenching importance that it has here. But this ongoing drought has increased the visibility of the water supply situation across the country, not only in the West and in the Southwest, but in the East, where a drought has brought many people who never worried about water to a stark realization that their shallow wells and fractured-rock aquifers are going dry by the hundreds. They now realize that even Easterners need to worry about water.

That can't help but improve the national understanding of the water resource situation—a situation that is critical even in times of normal supply, because of our booming population, but that becomes particularly stressed in times of drought. So the need for an adequate, federally supported streamgaging system that meets the needs of this country has never been higher.

At the time of my confirmation hearing with the Senate, I made the rounds to the people on the Energy and Natural Resources Committee. When I met Senator Domenici, his first question was, "Is the fact that you're from Texas going to be a factor in your administration of this job, and do you have any prejudice in favor of Texas and against New Mexico in water issues?" I assured him that it wouldn't and I didn't. Even if I did, the fact is that we at USGS don't regulate anything, we don't manage anything, we don't set policy. We're a science organization, and personal preferences don't affect the outcomes of our research.

I will close with a few comments about water resources, particularly groundwater resources. But first let me focus on my main topic today: the U.S.-Mexico border health initiative. This may lead people to wonder whether the USGS has run out of things to do in dealing with environment and natural resources issues. But that's not the case. The fact is that the health initiative is really built on the traditional expertise and the core capabilities that the USGS has in water issues, in geochemistry, in surface and bedrock geology.

This expertise, and the information that we've been developing over decades, is relevant to many issues including animal and human health, not only to the health of the environment and the health of our natural resources. For example, in Fallon, Nevada, water-quality information that we've been gathering for a long time recently came into play as health officials started correlating leukemia clusters to the quality of water and particularly to levels of some of the radioactive elements in the water.

The arsenic in New England's groundwater has been linked to bladder cancer occurrences, so USGS is working with the Maine, New Hampshire, and Vermont departments of health and with the National Cancer Institute to develop an understanding of the distribution of groundwater and fractured rocks that contain arsenic and the correlation with occurrences of bladder cancer—a topic that is of great interest to the National Institutes for Health. The West Nile virus, which is now spreading across the country, was largely charted in its early stages by the USGS through our National Wildlife Health Center in Madison, Wisconsin.

In 1996, a biology unit joined our geology, mapping, and water units. The biology role within the USGS relates not only to wildlife health issues but also to human health issues. As more and more wildlife come into contact with humans and as we spread into their habitats, their diseases have a tendency to become our diseases—or at least our concern. Chronic wasting disease (CWD), for example, which is affecting deer and elk in many states in the West and Midwest, is something in which we have a significant role. CWD, though not known to infect livestock or people, is related to mad cow disease, the sheep disease scrapie, and Creutzfeldt-Jakob disease in humans.

USGS scientists played a large role in the aftermath of the World Trade Center collapse, looking at the dust that was developed there and what it might have carried into the lungs of firefighters and residents as they worked and lived in the area. The large clouds of dust that cross the Atlantic Ocean from Africa and get into the Caribbean and South Florida are significant factors in asthma and air pollution in the region, and we are making strong contributions to understanding how and where the dust travels.

We do a lot of things that relate to human health, and we're really trying to find a way to make our work both better known and of greater value to the biomedical and public health fields. We're not changing what we do, but we're finding more applications for our traditional science.

Clearly water and health issues are interwoven to a large degree. Water plays a key role in transporting health threats, especially in areas where shallow alluvial groundwater is the drinking-water supply, as it is for many disadvantaged populations. This also happens to be where these populations dispose of their waste, either through septic tanks in good areas, or through less efficient methods in others. So the interaction between health threats and water supply is a very strong one.

It's especially pronounced in the U.S.-Mexico border region. This is an area where population growth is exploding. In 2000, the population of the ten U.S. and Mexican states in the region was 11.8 million, and it's expected to reach 20 million by the year 2020. So the area's natural resources—water, energy, land—are all under stress, which will affect the region's ability to meet the health challenges.

There is a long list of challenges along the border that are related to health. The sprawling population is a significant factor because it affects the demand for water as well as for land and energy. Motor vehicles are increasing, and their exhaust pollutes the air but also gets into the water. The growing population is generating increasing amounts of waste, both industrial and domestic, in an area that doesn't have all the resources it needs to treat those wastes. Raw sewage and untreated wastewater still, in parts of the border region, get into the surface channels and in some cases intermix with the water supply, carrying viruses and bacteria and hazardous wastes that can affect human health. Water is often an important transporter of contaminants. In the most fundamental sense, the region lacks adequate supplies of clean drinking water, which forces people to use water that is of lower quality, leading to more threats from water-borne diseases.

These health threats are motivating many of us in the science business and the business of gathering information about the environment, to portray this information in ways that might have some value in understanding the relationship of these factors to health. We ought to be making that information available, and that's the goal of this initiative.

In addition, it is a bi-national area, so this is not a United States border issue, it is a Mexico-U.S. border issue. We face the challenge and the opportunity to find ways to link this initiative across the border, not only with the science agencies, but with the cooperating public health agencies that make use of this information. The border area is drained by two international river basins, most notably the surface waters of the Rio Grande/Rio Bravo system. River waters are seriously challenged–not only the Rio Grande but the Colorado River as well. Regional aquifers also cross the border and are seriously overdrawn in many places. And when you add the fact that the consumptive use is close to or even greater than the renewable water supply in these basins, the result is a very complex setting of health-related problems and critical water supply challenges.

In this new initiative, we're building on core capabilities, in both the earth and the biological sciences, and we are partnering with people who are in the health business. We're not a health organization, and we don't plan to change to become one, but we have much health-related information to contribute. The National Institute for Environmental Health Sciences (NIEHS) expressed great interest in our work, as they looked at the populations at risk in areas where the environmental issues were not clearly understood. What is the distribution of pathogens in the environment? What is the distribution of pesticides and herbicides in soils and in waters? What is the distribution of geologic elements, those metals and those anions that affect health? How can we understand their distribution in relation to the patterns of occurrences of health problems and of health threats? We have a wonderful technology to do that. Geographic Information Systems (GIS) let us portray geologic, hydrologic, geochemical, and medical information and relate it to populations that are threatened by or are presently suffering disease.

The NIEHS and its partners, principally universities and health organizations discovered that the information we collected, using our scientific capabilities and working with our partners, was extremely useful to them. They can be the translator into their field, and we can be the developer in our field. So we're going to develop environmental information from the USGS, and also from other sources, in formats useful to the health community. It's critically important that the communication lines stay open, that the customer and the partner keep talking with the developer, to make sure we develop products that they can use because we are providing these products and this information to a non-traditional audience. During the first year, we're going to spend a lot of time analyzing existing data sets, compiling those data sets, assessing the gaps in information, and then working with our partners to better understand what they need.

Let me wrap up by pointing out specifically what we're going to do and what the next steps might be as they affect not only New Mexico but other parts of the border region. When we start all this we'll be affected by the '03 budget. The FY2003 appropriations process is stalled. We are operating under continuing resolution that will run through early January 2003, which delays any new starts that were planned for '03.

When we do begin, we will prepare health-focus summaries of toxic substances using GIS technology, including data on their distribution in the environment and the natural concentrations in rocks and soils. We have to remember that the earth does things in its own way that humans have no influence over. So knowing where the rocks and soils are, the natural waters that provide these materials, is of great importance. We've been in that business for a long time. We want to characterize the natural processes that actually control the occurrence and the mobility and the distribution of these elements in the border region. We want to produce environmental geologic maps that relate environmental factors to the geology, that relate environmental factors to the hydrology, that show the distribution of elements, including such things as selenium and arsenic and uranium, that have health implications.

And we want to work with the health sciences to determine where these elements are exposed to populations who either have health problems or who are most at risk for problems. Last September, the group that is developing a plan for this initiative decided that the first effort would be in the Brownsville-Matamoras region—not just in the city, but extending into the lower valley of Texas. And one reason for choosing this area is that clearly our largest information system is there among the major urban areas along the border. We're going to review all the information that's available, we're going to combine it into a single database, we're going to look at additional source of data and download them, and then we're going to do the spatial analysis of these data.

We have to be thinking for the long-term, though. After we put this product together, if it's useful to the health community and if it's useful to others, what are the next steps? There may be data gaps in the original work done by us and by our partners that need to be filled. We need to conduct focused research with the health community as to what these relationships really mean, because relationships themselves don't necessarily mean causality. We need to determine whether there is a link. Or rather, in this case, they—our partners at NIEHS and elsewhere–need to determine it, because they are the health professionals. And we need to look at other areas along the border where we're going to expand this work on the basis of need.

This effort need not be limited to the border area. There are other parts of this country where human health is affected significantly by environmental factors related to the distribution of elements in the environment, a few of which I described briefly earlier in this talk. We also need to be sure that we're very strong in the partnership aspects. As I said earlier, we're not a health bureau, we're an environmental and natural resource organization. We develop reliable, unbiased information that can be used by others, in the health field and beyond.

We're really looking forward to working with our partners–the health centers, NIEHS, other government agencies–to provide this valuable information that will promote public health. Seen in a new light, our information can be applied to new uses that will be good for the border, be good for this state, and be good for the economic as well as the environmental health of the Nation.

Let me close then with just a couple of comments about groundwater supply, particularly on the border. As I said earlier, and as you all know, clean water and health are related. The importance of water supplies as a critical element in the economy and well-being of this region, New Mexico and the border, has been clearly demonstrated this morning. In fact it's hard for a talk on prospective health problems to be good news in light of all the challenging situations that have been described this morning and that are likely to be faced in the future.

But one of the best hopes we have, though it maybe a marginal one in the projected water situation, is looking at what we can do to develop new supplies. It's been clear that the surface supplies are already over-extended, even in good times, and in difficult times even more so. The likelihood that we're going to find new surface water is not very great, unless we have some significant climate change that brings us more water to work with. But an area where we don't know enough–and that's not just true in New Mexico, it's not just true on the border, it's true across the country–is our groundwater supplies. In many places we've done a fairly thorough job of developing groundwater for municipal, agricultural, and industrial use. But in many other places we haven't, because we haven't had to.

In areas now subject to drought, groundwater supplies are increasingly being looked to as an important resource for the future. I'm sure you've all read about the conflicts over water supply, endangered species, and irrigation issues over the past few years in the Northern Klamath Basin. We're doing significant work with the Oregon Water Resources department to characterize and model the groundwater system there. One hope is that perhaps unappreciated or inadequately understood groundwater supplies could contribute to the water needs in that area. Groundwater may be the only hope for additions to the water supply there.

Are there other parts of the country where if we better characterize our groundwater supplies, we might open the door to some new supplies to meet our increasing needs? I think the answer is yes.

Fresh water is obviously the most desirable source of water, and if we can find new supplies that are immediately useable that's the best and quickest solution. But what's less obvious is that we have huge resources of saline waters in this country. We talk about the Pecos, we talk about the Canadian in this area, with saline water issues, but there are large amounts of surface flow across the country that are not used to the degree they could be because of their salinity. The same is true in the groundwater system. We haven't paid a lot of attention to characterizing, to inventorying, to understanding the chemical composition of the waters in the subsurface and their distribution, or to understanding the characteristics of the aquifers they occur in, because there aren't many people pumping salt water out of the ground on purpose, for practical use.

Now they're pumping it out in oil fields to get rid of it, but they're not pumping it out for practical use. As desalination technology has advanced, and as we increasingly are faced with critical water-supply needs, can we afford to ignore not only those groundwater resources that we don't understand that are fresh, but also the far larger quantities of saline water resources? We must study and characterize and understand them to enable advances in brackish-water conversion and saline-water conversion that will, in the long run, significantly increase our water supplies.

The Bureau of Reclamation, assisted by Sandia National Laboratories, has been developing a blueprint for advances in desalination technology across the West. We've been making the argument, which has received positive attention from Commissioner John Keys and others in Reclamation, that there needs to be a characterization of the saline water resources, particularly the groundwater resources, but including a good understanding of our saline or brackish surface-water resources. So that parallel with our engineering accomplishments in desalination technology and the economics that are moving toward making it a more favorable technology, we also develop a solid understanding of the water we're going to desalinate. No one wants to find out they've designed systems that are incompatible with the characteristics of the feed-water supply.

This characterization of the resource base is the job of those of us in the earth science business, in the hydrology business. It's the job of our water resources discipline within the USGS. It's the job of our partners in the state water agencies and the state geological surveys and water resources research institutes in the universities, particularly in New Mexico and the southwestern states, but in the West in general. The job is to put together an understanding of those saline and freshwater resources and to create better models of the resources that can be used by decision makers, like the Stream Control Commission and the state engineer, in understanding those resources and making decisions with appropriate input from streamgaging, from inventory assessment, and from modeling.

That's a challenge. So a parallel effort to the border health initiative is an initiative to fully characterize the water resources of the region, working with the partners I've just described, to lead to a better understanding of the surface-water resources and even more importantly, the groundwater resources in the border area, in the Southwest, and in the West.

In closing, let me reiterate that we look forward to working with you and all our partners to provide the essential scientific information on border environmental issues and water supply issues that will enable decision makers at all levels to ensure public health, public safety, and public prosperity.

__Frank A. Ward__ has been a professor in the Agricultural Economics and Agricultural Business Department at NMSU since 1978. He received bachelor's, master's, and Ph.D. degrees in economics from Colorado State University. Frank received the Distinguished Research Award from NMSU's College of Agriculture and Home Economics in 1996. He has been working on a textbook, Environmental Economics, which will be published by Prentice-Hall soon. Frank was associate editor for Water Resources Research from 1991-2001. His areas of special interest include water resources management, minerals management, and mineral taxation.

ECONOMIC IMPACTS OF DROUGHT ON USES ON THE RIO GRANDE

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I would like to begin by repeating a story I heard Tom Bahr tell at a New Mexico water conference in 1982. It summarizes the difficulties of understanding, explaining, administering, and legislating New Mexico's water problems. According to Tom's story, sometime back in the 1930s, the famous British statesman Winston Churchill looked flushed after he gave a rousing and entertaining after-dinner speech. A critic alleged that Winston had consumed enough whiskey in his life to fill the room a foot deep. Winston calmly surveyed the room, mentally worked out that quantity of whiskey, and replied. "Yes, you can see I have accomplished much, but I have so much more to go." When Tom Bahr told that story, New Mexico had accomplished much in dealing with its water problems but we have so much more to go.

I would like to talk about the economic impact of the drought on water uses of the Rio Grande.

We begin today's slide show by showing the headwaters of the Rio Grande Basin starting in Southern Colorado at elevations over 14,000 feet (Fig. 1). Lower in the basin, the next slide shows the river as it approaches the Colorado/New Mexico border (Fig. 2). Here supplies from the Rio Grande Basin delivered to New Mexico are about 660,000 acre-feet in a normal year. The next slide shows New Mexico's beautiful Rio Puerco, which produces about 32,000 acre-feet in an average year (Fig. 3).

Figure 1. Rio Grande headwaters, Colorado

Figure 2. Rio Grande, Colorado supplies 660,000 ac-ft/yr (average)

Figure 3. Rio Puerco, New Mexico: supplies 32,000 ac-ft/yr (average)

In southern New Mexico, agriculture uses about 495,000 acre-feet per year. Elephant Butte Irrigation District (EBID) had a full allotment in 2002, but unless we have a very wet winter, it will ration in 2003. El Paso uses about 140,000 acre-feet per year in a full year. Mexico receives 60,000 acre-feet per year.

In the Rio Grande Basin, we have a pervasive problem of scarce and random surface supplies that is made worse during drought periods. The three states and two nations competing for this scarce supply are dealing with growing populations and growing water demands combined with the needs of endangered species as well as a lack of any comprehensive analysis of coping measures for major drought.

The map (Fig. 4) shows how the Rio Grande Compact and "Law of the River" divide the Rio Grande. Under the Compact, Colorado has to deliver a certain percent of its runoff every year to the Lobatos gauge at about the Colorado state line. New Mexico's delivery obligation to Texas is defined by the annual flows at the Otowi Bridge. Based on that flow, New Mexico must deliver a certain percentage to Texas.

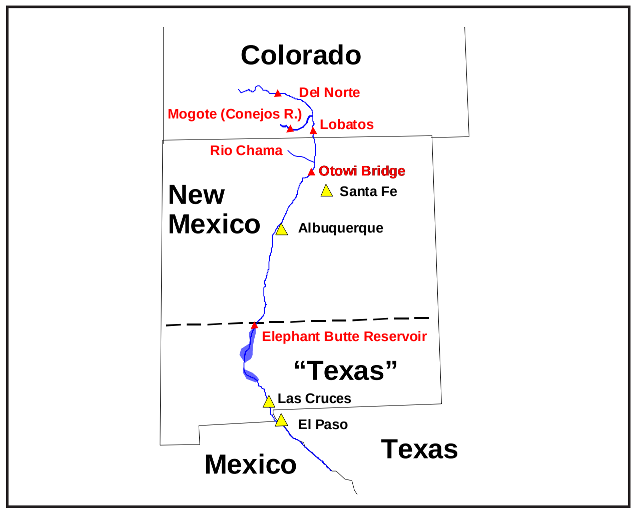

Figure 4. Rio Grande Compact and "Law of the River" divide the water of the Rio Grande

Elephant Butte Lake is where Texas starts for Rio Grande Compact purposes. The Compact mathematically splits up the flows according to how much runoff comes from the mountains. With that in mind, we are interested in the economic impacts of drought.

The approach we took in this study was to identify rules (institutions) for moving water around the system, the most important of which is the Rio Grande Compact. We wanted to estimate the economic damages for selective various drought scenarios under what we call "Law of the River," which means the current rules for sharing shortfalls in drought.

We estimated the economic impact of various ways of coping with this drought by setting up revised rules for moving the water around the system. An important part of the study was to describe the uses, supply, demands, and economic losses produced by various droughts. We did this by building a mathematical model that kept track of the supplies and demands of water as well as total economic benefits produced by the various uses.

The hydrology model kept track of some very simple surface and groundwater interactions. We assembled the model at two levels, including some on site detail and some on a broad regional analysis. For the detailed model, we attempted to replicate the decision processes on irrigated farms for the four major districts in the three states located on the Rio Grande. We also looked at municipal and industrial (M&I) values in benefits associated with water, and we looked at recreational benefits. We did not examine economic values of endangered species.

At the broader regional level, we summed up model results at the detailed farm level as well as accounting for the upstream-downstream interactions.

The next slide (Fig. 5) shows the major characteristics of consumptive uses at various locations in the Basin, starting from Southern Colorado Agricultural down to Albuquerque M&I, down to MRGCD, to EBID, to El Paso, and finally to El Paso Agriculture. The pluses indicated that a particular characteristic is active and a blank means the characteristic is inactive. Thus, this slide summarizes and simplifies what is going on in the Basin.

	Surface Diversion	Ground Water Pumping	Crop Use	M&I Use	Surface Returns	Aquifer Returns
Southern CO Ag	+	+	+	–	+	+
Albuquerque M&I	–	+	–	+	+	–
MRGCD Ag	+	–	+	–	+	+
EBID Ag	+	+	+	–	+	+
El Paso M&I	+	+	–	+	+	+
El Paso Ag	+	–	+	–	+	+

Figure 5. Consumptive uses by location

If we were to look at a normal year, we might see a water budget that looks something like the following slide (Fig. 6). The red lines are the state lines for Colorado/New Mexico, New Mexico/Texas, and Texas/Mexico. On the right-hand side, we have depletions: the numbers are in thousands of acre-feet, which balance as long as New Mexico and Colorado meet their delivery requirements.

Supply		Demand (Depletion)	
Rio Grande Headwaters	660		
Conejos River (3 gages)	346	339	Colorado Ag
Northern NM Mts	139		
Rio Chama	346		
Jemez River	45		
Albuquerque M&I	60	60	Evaporation
Rio Puerco	32	100	Central NM Ag (MRG)
Rio Salado	41	135	Riparian Vegetation
Ungaged tributary inflow		180	Elephant Butte Evap
		495	Southern NM Ag (EBID)
		140	El Paso M&I
		236	Texas Ag
		60	Mexico

Figure 6. Rio Grande Basin Water Budget, normal year

Let's discuss drought scenarios. What if over the next three years the same water inflows to the basin that we've had for the last three years? If we had those inflows for the next three years, what would they look like?

We projected future head-water inflows for the next three years based on head-water flows for the last three years (Fig. 7). Of course, nobody expects exactly the same flows in the next three years as in the last three, but it is a place to begin.

Then based on those inflows, we projected basin-wide sources and uses for the next three years at various places on the river, dividing demands and supplies according to past use patterns and according to the Rio Grande Compact.

- Headwater inflows for 2000-2002
- Reservoir contents for 2000-2002
- 'Project' future headwater inflows for 2003-2005 based on 2000-02 means
- Project basin-wide flows and uses, based on headwater inflows, RG Compact, and minimum reservoir contents for 2005.
  - Chama > 150 K
  - Cochiti > 50 K
  - Elephant Butte + Caballo > 250 K

Figure 7. Drought Scenarios

We built and ran a model that included minimum reservoir contents that are up to 10 percent lower than what we currently have. For example, we assume that the three Rio Chama reservoirs taken together must have no less than 150,000 acre-feet at the end of three years from now. Cochiti Reservoir must have 50,000 acre-feet, about what it had on October 1, 2002. Elephant Butte plus Caballo has to exceed 250,000 acre-feet.

The hydrology model (Fig. 8) is based on water budgets: additions from head-water flows, return flows, and the like.

Hydrology Model

Water budgets

- Additions
  - Headwater inflows (rainfall, snowmelt)
  - Return flows
  - Seepage to aquifer/stream
- Depletions
  - Surface diversions
  - Pumping
  - Reservoir evaporation
- 'Conveyance' functions
  - Unmeasured inflows, outflows
  - Allows water gain, loss from future mgmt

Figure 8. Hydrology Model

The economic sectors we analyzed were agriculture, M&I, and recreation. Detailed farm budgets (Fig. 9) were constructed for Colorado agriculture, based on a Ph.D. dissertation completed at Colorado State University. The M&I analysis (Fig. 10) is based on demand and supply and price elasticities of demand. Recreation (Fig. 11) is based on a reservoir contents and how much recreational use falls off when reservoir contents fall. We analyzed recreation for the six mainstem reservoirs.

Drought-Coping Institutions

One major drought coping institution I'd like to discuss today is adding 5,000 acre-feet of water supply by removing salt cedars north of Socorro.

We found that the drought costs about $127 per acre-foot lost. The Middle Rio Grande Conservancy District (MRGCD) will lose about $19 million per year if this drought continues for the next three years (Fig. 12). EBID loses about $32 million per year, Texas agriculture loses about $13 million, and El Paso water ratepayers lose about $44 million.

Agricultural Analysis

- Based on:
  - NMSU Cost and return budgets
  - Surface and groundwater supply
  - Irrigated acreage
  - Historical cropping patterns
- Developed for: San Luis Valley, CO
- Simplified for: MRGCD, EBID, EP#2
- Used to explain:
  - Adjustment to current/future drought
  - Economic damages from drought
  - Economic benefits from drought-coping institutions

Figure 9. Agricultural Analysis

M&I Analysis

- Based on demand/supply
- Current ground and surface water use
  - Current household use and price
  - Historical household response to price
  - Current and projected population
  - Planned surface water development
- Developed for: Albuquerque and El Paso
- Used to explain
  - Adjustment to drought
  - Economic damages from drought
  - Economic benefits from drought-coping institutions

Figure 10. M&I Analysis

Recreation Analysis

- Based on recreation visitor use
  - Historical use fluctuations with
    - lake level changes
    - on-site facilities
    - population growth
    - demographic factors
    - travel costs
- Developed for 6 major basin reservoirs
- Used to Explain
  - Adjustment to drought (1942-1985 flows)
  - Economic damages from drought
  - Economic benefits from drought-coping institutions

Figure 11. Recreation Analysis

Damages:	By State, Location, User ($1000s/yr)				
Institution:	*Law of the River*				
State	NM		TX		
User	MRGCD Ag	Alb M&I	EBID Ag	EP M&I	EP Ag
	18,900	0	32,000	44,000	13,000
$/AF lost	127				

Figure 12. Annual Average Drought Damages: 0.81 v. 1.57 maf inflow/yr

If we could reduce evaporation at Elephant Butte Reservoir by 25,000 acre-feet per year, New Mexico's MRGCD agriculture saves about $9 million in damages because it can deplete that much more water (Fig. 13). Texas receives no direct benefit from this scenario under the current Rio Grande Compact.

Damages Saved: By State, Location, User ($1000s for yrs 2000-05)					
Institution:	- 25 KAF evap/yr, Elephant Butte Reservoir				
State	NM		TX		
User	MRGCD Ag	Alb M&I	EBID Ag	EP M&I	EP Ag
	9,000	0	0	0	0
$ / AF	$60				

Figure 13. Drought Damages Saved Compared to Law of the River (25,000 ac-ft evaporation reduction at Elephant Butte Reservoir)

If we could produce 5,000 more acre-feet of water by reduced evaporation or other measures that add water back into the three mainstem Chama reservoirs, New Mexico gains about $301,000 per year, while Texas gains about $329,000 per year, for an overall average of about $33 per acre-foot of added water (Fig. 14).

Damages Saved:By State, Location, User ($1000s for yrs 2000-05)					
Institution:	- 5 KAF evap/yr, Chama Reservoirs				
State	NM		TX		
User	MRGCD Ag	Alb M&I	EBID Ag	EP M&I	EP Ag
	301	0	382	0	329
$ / AF	$33				

Figure 14. Drought Damages Saved Compared to Law of the River (5,000 ac-ft evaporation reduction at Chama reservoirs)

If we could produce 20,000 acre-feet more water at the San Acacia gauge through salt cedar control, MRGCD gets about $6.4 million per year in reduced losses. Because of the Rio Grande Compact, Texas receives no direct benefit (Fig. 15).

If we could reduce evaporation by 5,000 acre-feet per year at Cochiti Reservoir, MRGCD gains $1.7 million per year in reduced drought damages, or about $59 per acre-foot of new water (Fig. 16).

If we could produce 20,000 acre-feet more flow at the San Marcial gauge per year through salt cedar control, MRGCD agriculture saves drought damages of about $7 million or about $58 per acre-foot (Fig. 17).

Damages Saved: By State, Location, User ($1000s for yrs 2000-05)					
Institution:	+20 KAF/yr at San Acacia gage (salt cedar)				
State	NM		TX		
User	MRGCD Ag	Alb M&I	EBID Ag	EP M&I	EP Ag
	6,400	0	0	0	0
$ / AF	$52				

Figure 15. Drought Damages Saved Compared to Law of the River (adding 20,000 ac-ft at San Acacia)

Damages Saved:By State, Location, User ($1000s for yrs 2000-05)					
Institution:	- 5 KAF evap/yr, Cochiti Reservoir				
State	NM		TX		
User	MRGCD Ag	Alb M&I	EBID Ag	EP M&I	EP Ag
	1,709	0	0	0	0
$ / AF	$59				

Figure 16. Drought Damages Saved Compared to Law of the River (5,000 ac-ft evaporation reduction at Cochiti Reservoir)

Damages Saved: By State, Location, User ($1000s for yrs 2000-05)					
Institution:	+20 KAF/yr at San Marcial (salt cedar)				
State	NM		TX		
User	MRGCD Ag	Alb M&I	EBID Ag	EP M&I	EP Ag
	7,000	0	0	0	0
$ / AF	$58				

Figure 17. Drought Damages Saved Compared to Law of the River (adding 20,000 ac-ft at San Marcial)

For more details, we have a report on the NMWRRI's web page at: http://wrri.nmsu.edu/publish/techrpt/tr317/downl.html.

Conclusions

Models are a nice way to organize information. They help you identify knowledge gaps. They can be expensive to build, but they are usually cheap to run and tell you something about effects of a wide range of possible policies. One of the limits of the current drought study model is that its groundwater-surface water interaction is still weak, so policy analyses that rely on that interaction will be incomplete.

The current Law of the River is a widely understood and accepted institution for dividing the waters of the Rio Grande. In particular, the Rio Grande Compact provides structure as well as possessing good drought-coping flexibility. If the Compact were augmented with measures like water leasing and water banking, it may be an economically effective way to reduce drought damages.

Here are a few future researchable questions with major policy implications: What are the impacts of changing system operation? What is the economic cost of protecting endangered species and how can those costs be minimized while being compatible with the species' needs? What is the sensitivity of our modeled results to changes in the assumptions?

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DESALINATION AS A SUPPLY FOR DROUGHT RELIEF

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ABSTRACT

The majority of the groundwater within the state of New Mexico is considered brackish, with a total dissolved solids concentration of more than 1,000 mg/L. In general, municipalities do not usually consider using brackish waters for domestic supply, because although the water is potable, to most people it is not palatable. However, during extended drought periods, this brackish groundwater reserve can provide municipalities with an entirely new supply. Through the use of desalination technologies, the total dissolved solids are reduced to less than 500 mg/L, and a potable, palatable resource is created from an otherwise unusable reserve.

Desalination of saline water has been around for more than 40 years. Currently, more than 12,000 desalination plants exist worldwide, consisting of small hotel/resort brackish water systems to large seawater desalination plants. The economics of desalination has also improved over the recent years, to a point where many municipal and industrial entities are relying on desalination for their future water supply.

Various methods for desalinating brackish and saline waters are currently being used, and include reverse osmosis (RO), electrodialysis reversal (EDR), nanofiltration (NF), ion exchange (IX) and variations of distillation processes. New technologies are under research and development, including forward osmosis, bentonite clay-based membranes and others. New concentrate stream disposal alternatives are also under development.

Regionally, desalination for municipal water supply is currently being used by White Sands Missile Range (Stallion Site), New Mexico; Fort Stockton, Texas; and Horizon City, Texas; and is proposed for El Paso/Ft. Bliss, Texas and Alamogordo, New Mexico.

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STRATEGIES FOR PRODUCED WATER HANDLING IN NEW MEXICO

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Abstract

New Mexico produces about 454 million barrels of brine annually as a byproduct of oil and gas operations. As a result of the state's diminishing water resources, there is much attention focused on the possibilities of economically utilizing this brine for beneficial uses. The New Mexico Petroleum Recovery Research Center (PRRC) at New Mexico Tech (NM Tech) is the research arm of the petroleum industry in New Mexico. The four focus areas of produced water studies at the PRRC/NM Tech to be discussed are (1) *Water shutoff and conformance improvement:* We develop strategies for diagnosing and solving excess water production problems.

Particular emphasis is on strategically placed gels to reduce water production and channeling through fractures and other high-permeability features; (2) *Inventory mapping:* In this project, produced water data, including chemistry information, are being collected from various oil and gas companies to establish a summary dataset of produced water. We will make the data available to the public via a website with GIS capability; this is a joint effort with the New Mexico Oil Conservation Division (NMOCD); (3) *Optimal process identification:* Five existing water treatment processes have been proposed to the Industrial Advisory Board for this project. Two of the five processes will be chosen and pilot plants will be constructed in Lea County, New Mexico as a joint effort with the Sandia National Laboratories. In another arm of this project, together with industrial partners, we are examining optimal pretreatment methods of coalbed methane (CBM) produced water in the San Juan area; (4) *Brine treatment innovations:* This long-term study includes testing various brine treatment concepts in the laboratory. We are currently evaluating different clay membranes for their ability to reject salt. This is a joint effort with University of Missouri-Rolla.

Introduction

Four focus areas of produced water studies at the PRRC/NM Tech are to be discussed. They are (1) *Water shutoff and conformance improvement:* We develop strategies for diagnosing and solving excess water production problems. Particular emphasis is on strategically placed gels to reduce water production and channeling through fractures and other high-permeability features. (2) *Inventory mapping:* In this project, produced water data, including chemistry information, are being collected from various oil and gas companies to establish a summary dataset of produced water. We will make the data available to the public via a website with GIS capability; this is a joint effort with the New Mexico Oil Conservation Division (NMOCD). (3) *Optimal process identification:* Five existing water treatment processes have been proposed to the Industrial Advisory Board for this project. Two of the five processes will be chosen and pilot plants will be constructed in Lea County, New Mexico as a joint effort with the Sandia National Laboratories. In another arm of this project, together with industrial partners, we are examining optimal pretreatment methods of coalbed methane (CBM) produced water in the San Juan area. (4) *Brine treatment innovations:* This long-term study includes testing various brine treatment concepts in the laboratory. We are currently evaluating different clay membranes for their ability to reject salt. This is a joint effort with University of Missouri-Rolla.

Water Shutoff and Conformance Improvement

On average in the United States, more than seven barrels of water are produced for each barrel of oil. Worldwide, an average of three barrels of water is produced for each barrel of oil. The annual cost of disposing of this water is estimated to be 5-10 billion dollars in the US and around 40 billion dollars worldwide.

Many different causes of excess water production exist (see Fig. 1). Each of these problems requires a different approach to find the optimum solution. Therefore, to achieve a high success rate when treating water production problems, the nature of the problem must first be correctly identified. Many different materials and methods can be used to attack excess water production problems. Generally, these methods can be categorized as chemical or mechanical (see Table 1). Each of these methods may work very well for certain types of problems but are usually ineffective for other types of problems. Again, for effective treatment, the nature of the problem must first be correctly identified.

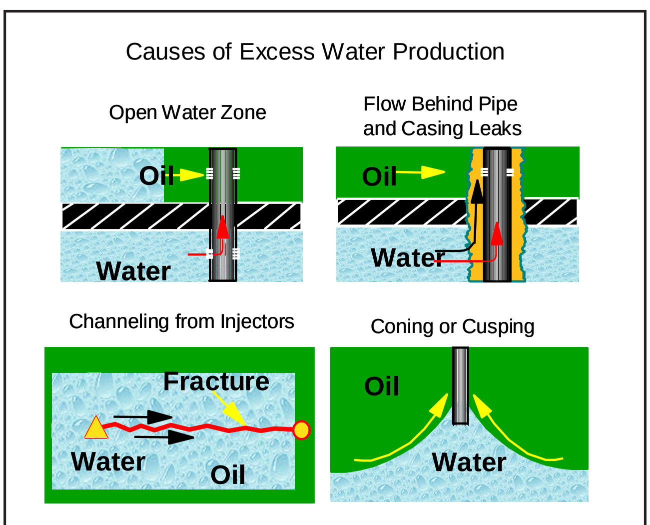

Figure 1. Causes of Excess Water Production

Table 1. Water Shutoff Materials and Methods

CHEMICAL	MECHANICAL
cement, sand, calcium carbonate	packers, bridge plugs
gels, resins	well abandonment, infill drilling
foams, emulsions, particulates, precipitates, microorganisms	pattern flow control
polymer/mobility-control floods	horizontal wells

Logically, identification of the excess water production problem should be performed before attempting a water shutoff treatment. Unfortunately, many (perhaps most) oil and gas producers do not properly diagnose their water production problems. Consequently, attempted water shutoff treatments frequently have low success rates. Several reasons exist for the inadequate diagnosis of excess water production problems. First, operators often do not feel that they have the time or money to perform the diagnosis, especially on marginal wells with high water cuts. Second, uncertainty exists about which diagnostic methods should be applied first, where perhaps 30 different diagnostic methods could be used. In the absence of a cost-effective methodology for diagnosing water production problems, many operators opt to perform no diagnosis. Third, many engineers incorrectly believe that one method (e.g., cement) will solve all water production problems or that only one type of water production problem (e.g., three-dimensional coning) exists. Finally, some service companies incorrectly encourage a belief that a "magic-bullet" method exists that will solve many or all types of water production problems.

We propose a straightforward strategy for diagnosing and solving excess water production problems. The strategy advocates that the easiest problems should be attacked first and diagnosis of water production problems should begin with information already at hand.

Conventional methods (e.g., cement, mechanical devices) normally should be applied first to treat the easiest problems—that is, casing leaks and flow behind pipe where cement can be placed effectively and for unfractured wells where impermeable barriers separate water and hydrocarbon zones. Gelant treatments normally are the best option for casing leaks and flow behind-pipe with flow restrictions that prevent effective cement placement. Both gelants and preformed gels have been successfully applied to treat hydraulic or natural fractures that connect to an aquifer. Treatments with preformed gels normally are the best option for faults or fractures crossing a deviated or horizontal well, for a single fracture causing channeling between wells, or for a natural fracture system that allows channeling between wells. Gel treatments should not be used to treat the most difficult problems—that is, three-dimensional coning, cusping, or channeling through strata with crossflow.

A key element of the proposed strategy is to look for and solve the easiest problems before attempting to attack the more difficult problems. In many cases, engineers initially assumed that three-dimensional coning caused the problem, whereas a small amount of subsequent diagnosis and analysis revealed the true source of water production was either flow behind pipe or "two-dimensional coning" through a fracture. This knowledge could have substantially reduced the cost of solving the problem. Also, by correctly identifying the problem first, the most appropriate method can be identified and the probability of successfully treating the problem increases significantly.

To help implement the proposed strategy, the following questions should be addressed in the order listed:

1) Is there a problem?
2) Is the problem caused by leaks or flow behind pipe?
3) Is the problem caused by fractures or fracture-like features?
4) Is the matrix-flow problem compounded by crossflow?

Further information of the study can be obtained at http://baervan.nmt.edu/randy/ or contact Randy Seright at (randy@prrc.nmt.edu or 505-835-5571).

Inventory mapping

At present, New Mexico produces about 454 million barrels of water annually as a byproduct of oil and gas production. Some of this water is reinjected at the site, but much of it goes through flowlines to handling or separating facilities. As a result, produced water is almost always present in oil pipelines and handling facilities, and can cause a number of problems. Although produced water in itself is not necessarily corrosive, in the presence of other gases and chemicals, it can become highly corrosive. This corrosivity is one of the major causes of leaks and spills in the oilfield. Obtaining data on the produced water quality to make decisions on a variety of issues from corrosion management to treatment decisions is very difficult. Produced water can also have high concentrations of undesirable substances such as salts and organic chemicals. Spills of produced water may cause surface and groundwater damage, and a spill of produced water requires reports to be filed with regulatory agencies. The necessary data for these reports, things like nearby wells or water bodies, depth to groundwater, and others, can be difficult and time-consuming to find for both the reporting operator and the regulatory agency in charge of verification. Information on location of water handling facilities, wellhead protection areas, surface water resources, or other vulnerable resources is often scattered among various offices and locations, yet this information is becoming increasingly important.

This NETL/DOE–funded project, "New Mexico Water and Infrastructure Data System (NM WAIDS)," seeks to alleviate a number of produced water-related issues in southeast New Mexico. The project is for the design and implementation of a Geographic Information System (GIS) and integral tools that will provide operators and regulators with necessary data and useful information to help them make management and regulatory decisions.

The major components of this system are: 1) databases on produced water quality, cultural data, and groundwater data, oil pipeline and infrastructure data, and corrosion information; 2) a web site capable of displaying produced water and infrastructure data in a Geographic Information System or accessing some of the data by text-based queries; 3) a fuzzy logic-based site risk assessment tool that can be used to help assess the relative seriousness of a spill of produced water based on proximity to water sources and other parameters deemed essential by the NM OCD; and 4) a corrosion management toolkit that will provide operators with data and information on produced waters that will aid them in deciding how to address corrosion issues.

The various parts of NM WAIDS will be integrated into a website with a user-friendly interface that will provide access to previously difficult-to-attain data and information. The benefits of this project will be multiple. Savings in time and labor needed to look up data for regulatory purposes will be significant. An even greater benefit will be realized by operators who implement best practices corrosion management plans based on information provided by the program.

Work on the project to date includes:

1. Creation of a water quality database with a web-based data entry system,
2. Acquisition of groundwater data from the New Mexico Office of the State Engineer, including chloride content and TDS,
3. Creation of a scale prediction tool that uses two common scaling indices (Stiff-Davis and Otto-Thomson) to predict the likelihood of scaling, again with a web-based interface,
4. Creation of a map-based fuzzy logic tool that enables the user to select a location and assess the relative level of spill response based on current OCD criteria,
5. Compilation of corrosion information from operators in the southeast New Mexico area,
6. Qualitative assessment of produced water from various formations regarding corrosivity,
7. Efforts at corrosion education in both the northwest and southeast parts of New Mexico through workshops and operator visits.

Future work on this project will include the development of a web and GIS interface for the information collected in this effort, improvement of the fuzzy logic risk assessment tool, mapping of produced and groundwater quality where sufficient data is available, improvements to the produced water quality data entry and querying system, and compilation of an online corrosion toolkit. The preliminary results are shown in Figure 2. This study is a joint effort between PRRC/NM Tech and OCD. Further information can be obtained from Martha Cather at (martha@prrc.nmt.edu, 505-835-5685).

Optimal Process Identification

A consortium of New Mexico oil and gas producers is partnering with New Mexico Tech, New Mexico State University and Sandia National Laboratories to examine, compare, and optimize several produced oilfield brine pretreatment processes. One project is being undertaken in northwestern New Mexico, targeting coalbed methane produced water, and one in the southeast for the oilfields of Lea County. Ultimately, commercial implementation

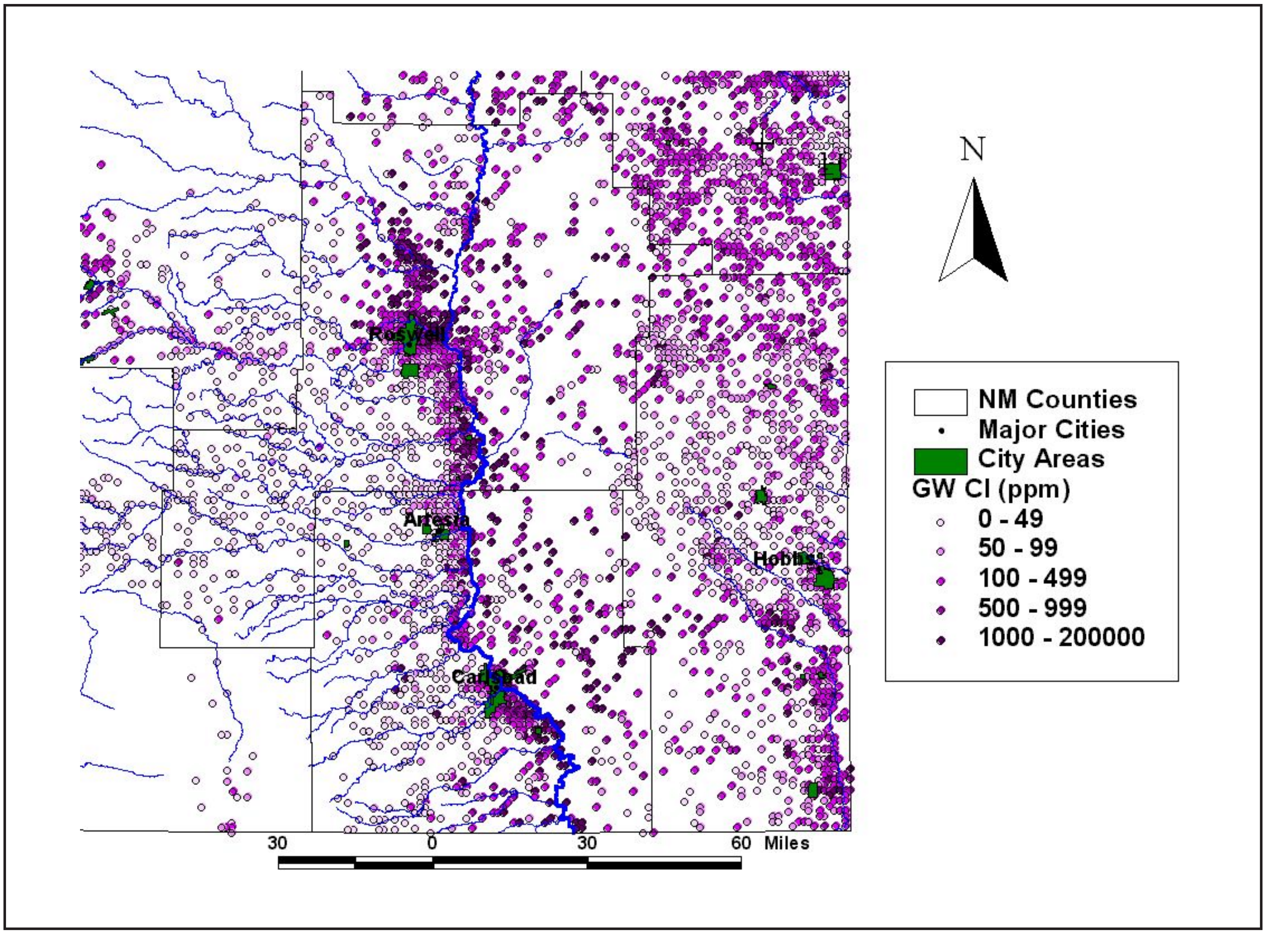

Figure 2. Chlorides distribution data in New Mexico.

pathways will be established for application of the best of these processes worldwide in the oil and gas industry.

As drinking water supplies diminish, produced water from oil and gas operations is increasingly being seen as a potential asset instead of an environmental liability. If cheap, high-volume desalination of oil-field brines and coalbed methane produced waters could provide water for industrial and agricultural use, an environmental liability would turn into a marketable asset. Equally important, the burden on freshwater aquifers could be relieved.

Coalbed methane production is especially problematic. Since water is usually not reinjected into CBM producing formations, unprecedented volumes of produced water, resulting from the rapid growth of CBM production in northwestern New Mexico, will be generated requiring treatment, surface discharge, or deep subsurface disposal. In basins where fresh water aquifers, springs, or wells are hydraulically connected to producing coal bed zones, CBM production could seriously deplete valuable groundwater resources. In other basins, where CBM produced water quality can range from 10,000 to 100,000 mg/l total dissolved solids, inappropriate water treatment and disposal could contaminate soil and surface and groundwater. CBM operators are facing increasing environmental problems and expense in disposing of produced water: these problems potentially could result in inhibiting the flow of natural gas production.

New Mexico, Texas, Oklahoma, and parts of the Rocky Mountain region, are all arid oil-producing areas. In the second arm of this project, southeast New Mexico is being used as a model to identify the cost/benefit ratios of oilfield brine reclamation; first on a pilot scale, then on a large scale.

Reclaiming oilfield brine for beneficial use could prove economical worldwide, if relevant performance factors can be worked out first at the pilot scale. For New Mexico, benefits could include lower oilfield operating costs and an exportable technology for regions where similar operations exist. A new industry would be brought to the state. Most importantly, drawdown of useable groundwater could drop significantly, conserving our shrinking water supplies.

Most reclamation methods for oilfield produced water require pretreatment of water to remove hydrocarbons, solids, and gases. These pretreated brines then undergo reverse osmosis, involving passage through a membrane (or other newer desalination processes) to be converted for beneficial reuse.

Biofouling of membranes by organic material has historically been responsible for the largest number of failures in reverse osmosis desalination processes. Thus, effective pretreatment of oilfield-produced brines is necessary to prevent biofouling and scaling of reverse osmosis membranes.

New Mexico's industry experts and researchers from three of the state's research institutes will join in a bilateral approach in the north and south, in a) an integral approach to CBM produced water management focused on the San Juan and Raton Basins and b) in seeking out the best means of pretreating produced waters before these undergo desalination, with a pilot area in Lea County.

In the San Juan and Raton Basins project, the team's capabilities in water modeling and surface and subsurface contaminant and transport will be used to assess CBM produced water generation impacts on water in connected aquifers or surface water systems and surface and subsurface disposal options. Several different pretreatment techniques will be evaluated for removing the organic content of the CBM water, which can range to 100 ppm or higher. Newly developed water treatment techniques for anionic and cationic contaminants such as salts and metals may also be applied, depending on the contents of the CBM produced water.

In the Lea County project, several different methods for pretreating oilfield-produced brine will first be examined and evaluated by past field performance, further laboratory work, and/or actual field trials. The most promising pretreatment protocols will be tested in a producing oilfield under varying conditions of brine salinities and residual oil. Each pretreatment process will be evaluated for its economics, effectiveness, and environmental impact. When this work is completed, a pilot test, from pretreatment through desalination for two separate pretreatment processes, will be developed and performed.

Factors used in evaluating pretreatment protocols will include:

- Cost
- Hydrocarbon and solids removal percentage as a function of particle size
- Hydrocarbon recovery
- Collection of methane
- Hydrogen sulfide stripping and disposal

- Throughput potential
- Projected/actual down time to change filters and replenish chemicals, etc.
- Inhibition of scale buildup such as calcium carbonate and calcium sulfate
- Control of silica deposition, if appropriate
- Boron removal, if appropriate
- Disposal of by-product streams/solids
- Nature of by-product solids, such as naturally occurring materials (NORM)
- Success in various field trials

It is realized that not all processes as presented are self-contained enough to meet all these criteria. One or more components of a given process could be combined with components from other processes if the combination looks promising. The five pretreatment processes are called Processes 1, 2, 3, 4 and 5 respectively for simplicity. Three processes are not self-contained (Processes 3, 4 and 5). However, these processes appear promising enough to merit further consideration and augmentation if appropriate. Three of the pretreatments below (1, 2, and 4) have already been tested in the field for their effectiveness in addressing the issues of oilfield produced water or closely related issues and objectives. One pretreatment process emphasizes chemical process primarily and filters secondarily; one primarily emphasizes filters and secondarily focuses on chemical treatment; one utilizes bacteria; one is a new product, which must be examined more thoroughly; and the other two employ hydrocarbon extraction technology. The methods to be investigated include, but will not be limited to, those listed below.

Pretreatment Process 1 emphasizes chemical processes supplemented by filtration and has undergone some field trials with oilfield brine, including a trial in southeast New Mexico. The order of the stages was varied to optimize the protocol and, in this case, a minimization of residual hydrocarbons was achieved and simultaneously water with very low total dissolved solids was produced. With this protocol, the input brine stream passes through a settling tank into a micro air flotation system. After the settling tank, the brine enters an advanced oxidation system where it undergoes aeration, centrifuging, and oil-water separation. The input brine stream then passes through an additional advanced oxidation stage into a pair of filter banks. After the filter banks, the oilfield brine enters the reverse osmosis process. This approach lowers the TDS of the oilfield brine in the New Mexico to well below expectations and merits additional evaluation. However, the TDS of the brines treated in the previous field trial were less than 25,000 TDS, which is considerably lower than the brines that are the focus of the proposed project, which are of major interest to area producers.

Pretreatment Process 2 has undergone field trials with oilfield brine in California. Parts of the pretreatment protocol have undergone field trials elsewhere. This system can be briefly described as a filter-based system utilizing cartridge filters, ultra filters, and nano filtration. The pH of the oilfield brine entering the initial brine feed tank is adjusted with sulfuric acid, and CO_2, with H_2S being “scrubbed.” The brine is then fed through prefilter cartridges to an ultra filter system (with recirculation). Antiscalent is added after this process. The brine stream is run through a nano filtration system prior to the reverse osmosis process. In this case, further CO_2 removal and boron removal are made in conjunction with the reverse osmosis system. An ion exchange system is available for even more boron removal, which may be necessary in some cases. Adjustments of the protocol can be (and have been) made to suit particular conditions of the input brine. This process appears to have some proven degree of flexibility. The cartridge filters, which are relatively inexpensive, bear much of the burden of the pretreatment. The team that used this approach has encountered many of the common and uncommon problems in pretreatment of oilfield brines and has experience in dealing successfully with the inevitable contingencies. An initial concern with the application of this process in high salinity oilfield produced water is the amount of acid that will be required to adjust pH of these highly buffered brines.

Pretreatment Process 3 differs from the other schemes in that it utilizes biological reactions to pretreat the brine. This novel approach is still under development and could ultimately include other steps to meet some of the criteria above. With this protocol, the input oilfield brine stream enters an anaerobic reactor where most of the organic material is removed along with the majority of the H_2S. Off-gas methane is collected. The brine next undergoes aerobic polishing for removal of the remaining organic material prior to entering the reverse osmosis process.

This process is under consideration because it is expected to result in a simple, inexpensive pre-treatment process. This process may require additional laboratory and bench scale study and possibly augmentation. Specific questions that must be resolved include:

- •Quantification of the extent of aerobic and anaerobic biodegradation, and
- •Measurement of such process issues as culture acclimation under high salt conditions and sulfide stripping efficiencies.

Pretreatment Process 4 utilizes a proprietary absorbent that can reduce inlet hydrocarbon solutions with a hydrocarbon concentration as high as the 10,000 ppm range to a concentration of 5 ppm. This product has been field tested for cleanup of oily water. It is made of a polymeric material backbone and is advertised as chemically neutral, non-toxic, and reusable. Its advertised features also include but are not limited to:

- •100% hydrocarbon recovery in unaltered state by oil recovery system
- •Reusable
- •No waste sludge generated
- •Can handle shock loads of oil in the thousands of ppm
- •Low energy consumption
- •Additional chemicals (for oil removal) not needed
- •Advertised applications include seawater protecting an actual seawater desalination plant

This product has produced exceptional field results; thus, it is felt that a direct application to pretreating oilfield brines should be considered along with the other pretreatment processes. There is also a possibility of combining this product with other processes.

Pretreatment Process 5 uses a macroporous polymer extraction (MPPE) technology, which has been used for removing hydrocarbons from offshore produced waters. In the MPPE process, water containing hydrocarbons is passed through a column containing porous polymer beads with pore sizes of 0.1 to 10 microns that contain a specific extraction liquid. The immobilized extraction liquid removes hydrocarbon components (dispersed aliphatic compounds and polycyclic aromatic compounds) from the water. In situ generation of the extraction liquid is accomplished periodically by stripping the hydrocarbons with low pressure steam. After the hydrocarbons are removed by the extraction liquid, the purified water can be reclaimed for beneficial use. Literature results cite the use of this process for the treatment of water produced with natural gas and condensate. These results merit the evaluation of this process in combination with other processes, especially in applications where the presence of aromatics (such as benzene, toluene, and xylene) and polycyclic aromatic hydrocarbons are of concern in the treated effluent.

The large potential market for membranes needed to reclaim CBM and oilfield produced brines is attracting the attention of the membrane industry. These projects will culminate in developing solid institutional and economic bases for the beneficial uses of desalinated brine. This study is a join effort between SNL and PRRC/NM Tech. More information can be obtained from Mike Hightower at (mmhight@sandia.gov, 505-844-5499).

Brine treatment innovations

Some visions cannot be quickly realized. Long-term research is the key with a painstaking evaluation of possibilities, testing of theories, and end results that can be translated into practical solutions. The question of how to develop a cost-effective, portable desalination unit that can be easily applied in the oilfield has been occupying scientists for years, and promises to intrigue them for some time to come.

Reverse osmosis is a process of water purification during which the salt water, under pressure, sweeps along one side of a semi-permeable membrane (fabricated from expensive synthetic materials), causing fresh water to diffuse through the membrane, leaving behind a concentrated solution. Conventional reverse osmosis has been used since the 1950s on a large scale, but at this time, it is too capital-intensive to be used at the wellhead. The need for chemical pretreatment of the water contributes further to this high operating cost. To make reverse osmosis cost-effective for the oilfield, it is necessary to find a way to economically remove solids from produced water and make it suitable for surface disposal, fresh water aquifer recharge, drinking water, irrigation, or release to streams. Further needed is a system to precipitate the dissolved salts in produced waters from solution, without added chemicals, so that the salts can easily be removed from the system.

Conventional reverse osmosis desalination applied to the produced water from the oilfield is problematic, for the following reasons:

- •Various agents in the produce water may damage the membrane or affect the reverse osmosis process. Pretreatment of the water is frequently needed, but pretreatment adds significantly to the cost.
- •Conventional water treatment methods are seldom applied economically to waters more saturated than seawater. Produced water, as we have seen, can be up to six times more saturated than seawater.
- •Reverse osmosis desalination of seawater often requires pressures from 800 psi to 1200 psi. Conventional reverse osmosis treatment with more concentrated brines would require much greater pressures, potentially greater than the membrane could withstand.
- •The resulting waste stream from conventional reverse osmosis methods can be between 50 and 80% of the total volume treated. These waste brines are still expensive to dispose.

The principal needs in a reverse osmosis system that can be used at the wellhead are for a suitable low-cost, easily available membrane, and for an inexpensive, environmentally friendly system of solute disposal. Such a system is the target of research being undertaken jointly at PRRC and the University of Missouri-Rolla. This project aims to take current reverse osmosis techniques beyond the state-of-the-art. More information can be obtained from Robert Lee at (lee@prrc.nmt.edu, 505-835-5408).

Bentonite clay—readily available, cheap, and extensively used commercially—has been identified as a material potentially suitable for RO membranes. Clay membrane efficiency can be controlled by compaction, increasing with increasing compaction or decreasing porosity. Thus, membranes could be constructed that would allow separation of solutes from very highly saturated water without requiring unreasonable fluid pressures. The project currently underway has been working on the fabrication of clay membranes compressed enough to allow such separation, but sturdy enough to withstand the process. Progress is being made with the fabrication of membranes in various configurations and degrees of compression. In addition, data on actual water chemistry from oilfields in New Mexico have been collected in order to target the fabrication of these membranes to specific problems.

The dissolved organics present in produced water may damage polymer membranes used in the conventional reverse osmosis process. It is believed that clay membranes should overcome this drawback. In this project, a clay membrane made of bentonite is compacted inside a specially made cross-flow experimental cell with an integral piston. Both synthetic NaCl solution and produced water are used to test the clay membrane and determine various membrane properties from the bench experiments. For produced water, the rejection rates of the ions decrease when TDS (Total Dissolved Solids) increases (Fig. 3).

It is our opinion that if a reverse osmosis waste reduction system is to be widely applicable to treatment of produced waters, the system must be able to precipitate highly soluble dissolved minerals, such as sodium chloride, as well as other less soluble dissolved minerals. Figure 4 shows the NaCl crystal distribution across the surface of the clay membrane under a microprobe scan. Efforts to increase the quantity and speed of this crystallization process are ongoing.

It is not anticipated that research results will culminate in the desired outcome—a prototype RO unit for use in the oilfield—for some time to come. This valuable research is advancing steadily with the support of statewide producers, but development of an effective prototype will require careful planning and bench testing. When such a system is realized, its applications may well extend beyond the oilfield.

Acknowledgements

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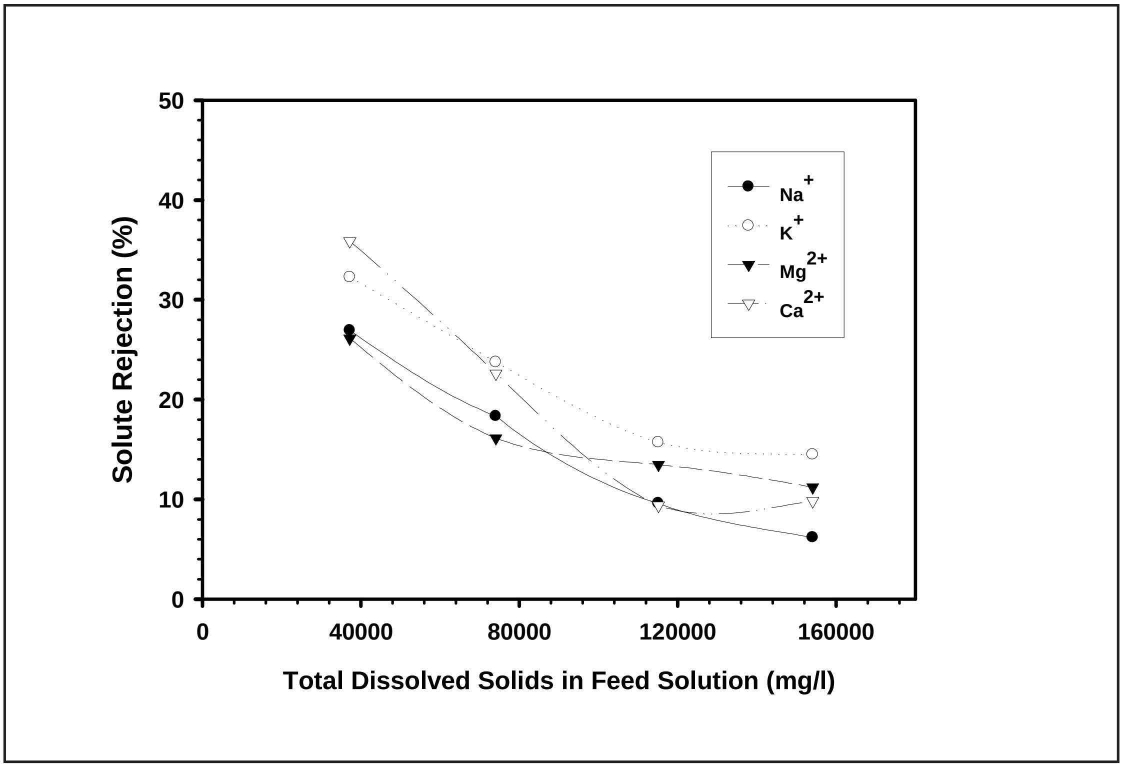

Figure 3. Solute rejection of cat ion as a function of TDS (membrane compacted to 36.1 Mpa) for produced water.

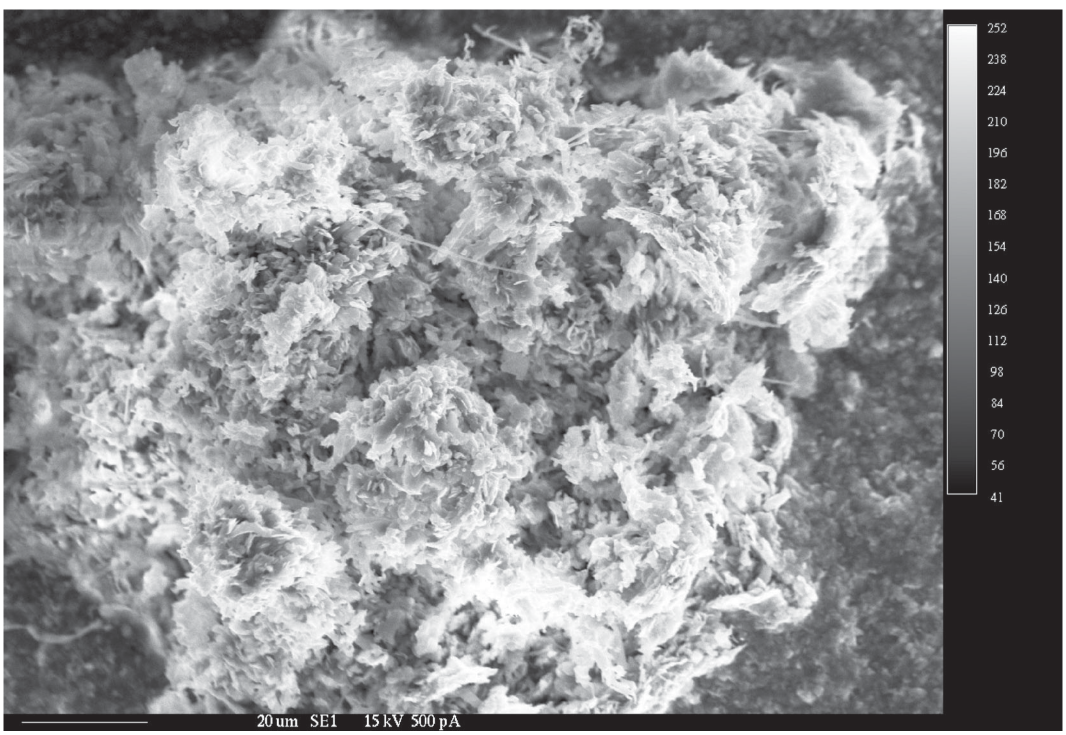

Figure 4. Microprobe scan showing distribution of NaCl crystals.

Gary L. Esslinger *is the Treasurer-Manager of the Elephant Butte Irrigation District. Gary is a third generation member of a pioneer farming family living in the Mesilla Valley. He has kept his roots in farming as well as other agricultural based industry. After receiving a bachelor's degree in business administration from Northern Arizona University in 1973, he worked six years in Los Angeles for a large west coast flour milling corporation as office manager. After becoming tired of the city life, Gary returned to the Mesilla Valley and began working for EBID in 1978 where he has been for the past 24 years. Gary began his District career as Purchasing Agent and has held other organizational positions such as Maintenance Chief and Assistant Manager. Gary is, and has been for the past 15 years, the District's Manager and has been the District's Records Manager for the past 2 years. Gary lives in La Mesa on the family farm with his wife, Tina, and three daughters.*

J. Phillip King*, P.E., is an Associate Professor and Associate Department Head in the Civil and Geological Engineering Department at New Mexico State University. He specializes in water resources engineering, and his research has included hydrology and water quality studies of the Rio Grande. Phil has worked with Elephant Butte Irrigation District since 1991 in the development of flow monitoring systems and organizational infrastructure to allow the District to monitor and control its water supply more effectively, and he provides technical support for mediation on area water issues. His B.S. in civil engineering is from Berkeley, and his Ph.D. and master's degrees are in agricultural engineering from Colorado State. Phil served as a Peace Corps volunteer in Malawi.*

CURRENT TECHNOLOGY RELATED TO DROUGHT AND IRRIGATION

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ABSTRACT

The Rio Grande Project in Southern New Mexico and West Texas, for the first time in nearly a quarter of a century, is facing a water supply reduced by drought. As the inflow to Elephant Butte Reservoir fails to meet even pessimistic forecasts, Elephant Butte Irrigation District (EBID) is implementing its drought response with the objective of minimizing adverse effects of drought on farmers and the District's hydrologic health.

While the District has been blessed with a plentiful supply of water in recent years, EBID's farmers and the employees remember the severe drought period of 1951-1978, when allocations to farms dropped below one acre-foot per acre a number of times. Even with the severely curtailed allocation, EBID managed to maintain its cropped area and yield by conjunctively managing the available surface water and groundwater. The District also made very effective use of local storm flows during the drought.

EBID farmers will likely respond to a short water supply by extensive pumping of groundwater. However, with the City of El Paso relying on surface water for over half of its municipal and industrial (M&I) supply, and U.S. treaty obligations to Mexico, there is much more pressure for accountability on the part of irrigators now than during previous droughts, and the District is developing a System Control and Data Acquisition (SCADA) system to facilitate conjunctive use of surface and groundwater.

One important aspect of the District's drought response is its coordination with downstream users to maximize the utility of releases from Project storage. El Paso County Water Improvement District No. 1 (EPCWID) and the Republic of Mexico both take water from the Rio Grande downstream of EBID, and it is in the interest of all three parties to plan releases to allow one user's water to "ride" on the water of other users. Prompt reaction to capture and use storm runoff will also make more water available to all users.

The District is developing individual turnout measurements for surface water deliveries to farms. Based on the hydraulic control of the existing turnout gate, the District Engineer has developed a rating equation for Armco gates that uses the differential head across the turnout and the gate opening area. Electronic sensors for these state variables transmit data through a radio telemetry system to EBID headquarters, where they are stored in a database and are accessible through the web.

A low-cost instrument for measuring groundwater withdrawals, dubbed the Mag Tube, is under development by EBID. The instrument is a type of Pitot tube monitored with pressure transducers. The calibration of the instrument is under way, and it promises to be affordable and sufficiently accurate, and will produce real-time data that can be integrated with EBID's existing flow and water quality databases.

From left: Derrick Lente, David Benavides, Fred Hennighausen.

From left: DL Sanders, Steven L. Hernandez, Sherry Tippett (moderator).

PANEL DISCUSSION
HOW DOES WATER LAW AFFECT MANAGEMENT OF NEW MEXICO'S WATER DURING TIMES OF DROUGHT?

David Benavides *is director of the water rights project for Community and Indian Legal Services of Northern New Mexico, a position he has held for ten years. Prior to attending law school, he worked in a number of positions in public interest organizations, including the Southwest Research and Information Center, the Montana Public Interest Research Group, and four years as the Director of the New Mexico Public Interest Research Group. David received both his B.S. and J.D. from the University of New Mexico in Albuquerque, and upon graduating from law school in 1990, was awarded a Skadden, Arps Public Interest Law Fellowship to begin his work on land and water rights in northern New Mexico. His work involves representing low-income persons and communities in gaining legal recognition for their water rights and their historic water-use customs. Working primarily with acequias, David also advocates for the rights of acequias in various judicial and administrative proceedings, and to have a greater voice in local water planning and water management decisions. He lives in Santa Fe, New Mexico.*

Fred H. Hennighausen *received B.S. degrees in general engineering and mechanical engineering from Duke University in Durham, North Carolina. He graduated from the University of Tulsa College of Law in 1983, and was admitted to the practice of law in New Mexico in September 1983. From 1948 to 1980, Fred was an engineer with the New Mexico Office of* *the State Engineer, including 24 years as District Supervisor, with responsibility for water resource investigations and water right administration in southeastern New Mexico. Fred currently is a partner in Hennighausen and Olsen, attorneys for the Pecos Valley Artesian Conservancy District. He is a certified legal specialist in water law and a registered professional engineer.*

***Steven L. Hernandez**, Esq. earned a B.S. in business administration in 1974 and his law degree in 1977 from the University of Arizona. In 1979, he was a water attorney for the City of Tucson dealing with Central Arizona Project issues and the implementation of the new Arizona Groundwater Act. From 1980-1981 Steven served in the Solicitor's Office, Department of Interior in Washington, D.C. dealing with water issues. In 1982, he moved to Las Cruces, NM to represent Elephant Butte Irrigation District in the El Paso groundwater export litigation. He is the senior board member of the New Mexico State Bar Section of Natural Resources, Energy and Environmental Law and the attorney for the New Mexico Section of the National Water Resource Association. He also serves as the legal representative on the governor's Blue Ribbon Water Task Force. He has testified before the New Mexico and Arizona legislatures on water issues. Steven has lectured and written on topics including the Endangered Species Act, Federal Facility Transfers, Water Right Ownership in Reclamation Projects, Subsection I Revenues from Reclamation Projects and State Stream Adjudications.*

***Derrick Lente** is a Native American from the Pueblos of Sandia and Isleta, located in central New Mexico. He works for the Pueblo of Sandia as their water resources manager, and serves in another capacity as the Chairman of the Six Middle Rio Grande Pueblos Water Coalition, (Coalition). The Coalition comprises six Pueblos including Pueblo de Cochiti, Pueblo of Santo Domingo, Pueblo of San Felipe, Pueblo of Santa Ana, Pueblo of Sandia, and the Pueblo of Isleta. Mr. Lente is a huge advocate of Indian water rights, and has given many talks regarding Pueblo water rights. Mr. Lente truly believes that education is the key to understanding and respecting the premise of Pueblo Indian water rights.*

D*L Sanders* *is General Counsel to the New Mexico State Engineer and Director of the Litigation and Adjudication Program as well being commissioned as a Special Assistant Attorney General. He manages all New Mexico water rights adjudications and provides legal counsel to the state engineer on water rights matters. DL is a product of the New Mexico public education system, including the UNM School of Law. As always, after 12 years, he still only knows three things about adjudications, they: 1) last a long time, 2) cost lots of money, and 3) create few friendships. New to his understanding are the added complexities that a drought can create in keeping anyone satisfied.*

***Sherry Tippett** holds a B.S. from George Washington University and a J.D. from the University of South Dakota. She served as Special Assistant Attorney General for the New Mexico Office of the State Engineer for seven years, working primarily on water adjudications in Northern New Mexico. She was also the City of Sante Fe's Water Attorney for seven years (A VERY LONG TIME TO SURVIVE THE SANTA FE POLITICAL SCENE), where she was originally hired to work on the purchase of the water company from PNM. For the past two years she has served as County Attorney for the County of Grant where she has been very active in the southwestern regional water plan.*

Editor's Note: The following abstracts were prepared by panelists prior to the conference. A videotape of the discussion is available from the WRRI.

How Does Water Law Affect Management of New Mexico's Water During Times of Drought?

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Many entities have long-established internal systems for dealing with drought conditions that should continue to be affirmed by state officials and state law. In the absence of such established systems, the most obvious feature of New Mexico water law in drought management is priority administration. However, the state's reluctance to implement that process, forcing senior water right holders into costlier forums, poses problems of equity and justice in a state like New Mexico where many senior water right holders are poor. Some observers see promise in utilizing various statutory forms of water right transfer, but those mechanisms may also disproportionately impact poor communities to the extent individuals are permitted, over the objection of the local community, to sever water rights needed for the local area's long-term resource base. Some combination of more aggressive state involvement in priority enforcement and assertion of district regulatory authority over transfers would probably create a favorable climate for inter-community partnering in water transactions. This would most likely simultaneously address the issues of water supply, protection for rural communities, access to justice, poverty, and underdevelopment.

Drought and New Mexico Water Law

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New Mexico water law can be effective in management of its water in several ways. Three significant ways are as follows:

1. **Enforcement of existing water law -** water laws need to be enforced to prevent illegal diversions, use of water, and waste of water.

2. **Conservation -** existing laws can be utilized to enforce conservation measures to prevent misuse, conserve and reuse existing supplies, and increase efficiency; included in such procedures should be metering of all water use and maintaining favorable conditions for water flow in the national forests.

3. **Priority administration -** while the concept is set out in the New Mexico Constitution and Statutes, application of the policy, particularly in groundwater and interrelated stream systems, can be difficult, if not impossible, to implement to achieve the desired result.

THE PECOS RIVER EXPERIENCE

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I. Implementation of House Bills 417 and 225 and its effect on the Pecos River adjudication of CID Senior Water Rights and the Pecos River Compact.

A. Purpose of the legislation.
   1. Achieve compliance with the Pecos River Compact.
   2. Establish a base flow of the Pecos River of 50 cfs at the Artesia Bridge.
   3. Provide a reliable annual irrigation supply of 90,000 acre-feet of water for delivery to Carlsbad Irrigation District.
   4. Provide adequate water to fulfill delivery requirements to the Texas state line pursuant to the Pecos River Compact.

B. Stay of the Proceedings of the Carlsbad Section of the Pecos River Stream Adjudication.
   1. Six-month stay in the ongoing litigation of Carlsbad Irrigation District Project Offer granted until mid January 2003.
   2. Four major parties are conducting settlement negotiations regarding the priorities of the Carlsbad Project Offer.
   3. Junior users are litigating priority dates and quantities of the Carlsbad Project.

C. Water Banking Regulations.
   1. Water Banking is really targeted at giving junior users a way to acquire senior water rights that will allow them to continue to pump water even though they may be shut down by a priority call.
   2. ISC developing regulations on water banking in the Pecos Stream system.

D. OSE is drafting regulations on how the state will manage a priority call.

II. Carlsbad Irrigation District leasing program with the Interstate Stream Commission.

A. Purpose of the lease program was to ensure Pecos Compact River deliveries were made to Texas.

B. If there is a short fall, then the state is instructed to comply with prior appropriation to make the necessary water deliveries to Texas.

III. Other Upstream Issues affecting Senior rights.

A. Dispute between the Fort Sumner Irrigation District and Carlsbad Irrigation District over stored water.

B. Release of stored water by the United States as by-pass flow.

C. Filing of suit by Forest Guardians regarding “discretion” of the United States in managing Carlsbad Project water in reservoirs for the Pecos Bluntnose Shiner.

Why New Mexico Fails to Administer Water Rights in Times of Drought

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Parker's ruling [in the Silvery Minnow case] could force New Mexico to face the realities of administrating a limited water supply in an arid state. Em Hall, *Albuquerque Journal* (Sept. 20, 2002)

The Problem

As evidenced by the handling of shortages in the Pecos River and the Rio Grande, apparently New Mexico water law is not an effective tool in administrating water rights during a drought. New Mexico water law is founded upon the prior appropriation doctrine: "first in use, first in right." However, if there is no administration or enforcement of priorities, the water code merely masks an underlying chaos.

One must ask whether it is beneficial to continue the enormous expense of adjudicating water rights in New Mexico if the political, appointed officials, or the courts do not have the desire or backbone to ensure the allocation of water to the rightful owners during times of shortage. At a time when New Mexico is at the bottom of the barrel in every category, from child health to per capita income, we should consider whether the millions of dollars spent annually by the New Mexico Legislature in adjudicating water rights is a waste of money.

Below are several examples of how New Mexico has failed in the administration of water and the protection of senior priority water rights.

Pecos River. The Carlsbad Irrigation District made a priority call against upstream junior water rights in 1972. The State Engineer determined that the effective administration of a priority call would require the adjudication of all water rights in the stream system. Surface water rights in the mainstream of the river had been adjudicated by a federal court decree in 1933. The ground-water rights in the Roswell Basin had been adjudicated in a state court decree in 1966. The State Engineer determined, however, that the priority call would require the adjudication of all water rights in a single suit. Thirty years later that suit is still pending. In the meantime, the state has been purchasing the water rights from junior Pecos River surface water pumpers upstream from the Carlsbad District to ensure Pecos River Compact compliance.

Rio Grande. The silvery minnow litigation clearly demonstrates the underlying chaos in New Mexico's water rights administration. The demands for water within the Middle Rio Grande Valley are great – not just that for the minnow, but also for future Pueblo, and municipal uses. This is the most critical area in the state requiring the administration of water rights. The Middle Rio Grande Water Budget estimates an existing deficit of 65,000 acre-feet/year. And yet there has been no effort to try to administer or apportion water in the middle valley.

Efforts to adjudicate water rights in the *Upper Rio Grande* have also failed to produce enforceable decrees. In the Taos Valley adjudication suit, the rights of two community acequias in Arroyo Hondo appear to be the oldest rights, but they are at the bottom of the stream system. They have not been able to obtain water even in the past year of severe drought and even though some of the upstream rights have very junior priorities. Their claims have been pending for over twenty years without relief from the judicial system.

Mimbres River. A final decree adjudicating water rights has been entered in the Mimbres Valley adjudication suit. It is the only state court adjudication in which a final decree has been entered in the past thirty years. The court has appointed a watermaster to enforce and administer the decree. On several occasions in the past few years, a community acequia with the oldest priority water right has requested the curtailment of upstream junior rights. It appears that prior rights cannot be enforced because few irrigation ditches have headgates and no ditches have measuring devices. Isn't the state's responsibility to ensure that priorities can be enforced in adjudicated stream systems?

Possible Solutions

If water right adjudication suits are not providing a means for the priority administration of water rights, what other methods might work?

- Can the permitting system be used to administer priorities?
- Can the Water District Act in Article 3 of the water code be used?
- Can State Engineer administration of water banking by districts and acequias protect prior rights in conjunction with strict limits on new domestic well rights?

Michael R. Gabaldon *currently is the Director of Policy, Management, and Technical Services for the Bureau of Reclamation and is responsible for the management of Reclamation-wide programs. Under his auspices are the Office of Policy; the Technical Service Center; the Management Services Office; the Research and Natural Resources Office; the Human Resources Office; and the International Affairs Group. He is also responsible for the management of Reclamation's Alternate Dispute Resolution Program. Mike has a long and distinguished career with Reclamation. In 2001, he was appointed Deputy Director of Operations with the responsibility of program coordination among regional and area offices in the 17 Western States. In 1998, Mike was selected as the Area Manager for the Albuquerque Area Office where he led the effort to establish the Middle Rio Grande Endangered Species Act Working Group. Prior to 1998, he served as Liaison Officer of the Pacific Northwest Regional Office. While working at the Bend Construction Office as the Supervisory Civil Engineer in 1991, Mike was promoted to Chief, Office of Engineering Division. In 1989, he performed design and contract administration work on the Animas-La Plata Project while working in the Durango Projects Office. A native of Belen, New Mexico, Mike received a B.S. from UNM and is a registered Professional Engineer. He also earned a 2-year degree in water technology from NMSU. Mike resides in Arlington, Virginia with his wife, Bonnie.*

U.S. BUREAU OF RECLAMATION DROUGHT PROGRAMS

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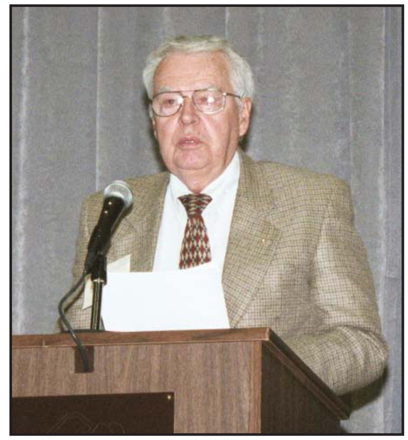
2002 Drought
- Drought Monitor - map
- Extreme to Exceptional Drought Conditions in much of the West

Reclamation Drought Assistance
- Reclamation States Emergency Drought Relief Act of 1991 (P.L. 102-250, amended by 106-566)
- Title I Authorities
  - o Technical and financial assistance to Federal, State, and tribal entities with 17 Reclamation States and Hawaii
  - o Construction of temporary facilities
  - o Construction of wells
  - o Purchase (lease) water
  - o Participate in water banking (Columbia River, Pecos River, Klamath)
  - o Loans to water users
  - o Operational changes (Reclamation wide)

- Water for instream flows (Idaho, New Mexico, Oregon)

- Other Reclamation Drought Assistance
  - Forbearance agreements
  - Water Conservation Activities (lining canals, education and training, demonstration projects)

- Title II - Drought Contingency Planning Assistance
  - Technical assistance to 50 states and U.S. territories
  - Financial assistance to Reclamation States and Hawaii
  - Precipitation management Technology Transfer Program (50/50 cost share)



P.R. (Bob) Grant, Jr. *is a consulting geologist with an office in Albuquerque specializing in the evaluation of New Mexico's water and energy resources. He has addressed these subjects for numerous clients, in professional publications, and in many appearances before professional organizations, state legislative bodies, civic groups, legal hearings, White House Forums, and U.S. Senate Committees. A graduate of the University of New Mexico, he has served in the New Mexico Legislature, was Chair of the state's Energy Research and Development Committee in the early 1980s, and was a member of the New Mexico State Investment Council in the early 1990s. He is a Fellow of the Geological Society of America, a member of the American Association of Petroleum Geologists, state and local geological societies, and serves on a number of boards and commissions. His biographical sketch has appeared in Who's Who in the West, Who's Who in Frontiers of Science and Technology, Who's Who in Finance and Industry, Who's Who in Science and Engineering, and Who's Who in the World. In 1999 Bob was appointed to a six-year term on the New Mexico Interstate Stream Commission.*

Sue Wilson Beffort *is serving her second term in the New Mexico Legislature. She currently is a member of the Senate Finance Committee as well as the interim Legislative Finance, Water and Natural Resources, and Tax and Revenue Stabilization committees. Sue is most noted for her initiatives in the areas of tax and water reform. In the 2002 legislative session, she was the Senate sponsor (Representative Pauline Gubbels was the House sponsor) of water banking legislation, which is limited to the Lower Pecos River only. However, this may serve as an exciting model for statewide adaptation. She has been a proponent of attaching tax credits to upgrading irrigation technology to encourage best practice techniques, such as drip farming, to conserve water and expand the reach of agricultural production. As a major proponent of watershed management and riparian restoration, she is demonstrating that forest thinning is not only an important tool to protect against catastrophic forest fires, but also a valuable technique to retain additional water in our state. Sue was a small business owner for 25 years and still maintains her Outplacement Division for the service of downsizing companies and assisting dislocated workers.*

WATER BANKING: PANACEA OR PLACEBO?

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In speaking of the futility of certain actions, Winston Churchill once said: "It's like a man standing in a bucket and trying to lift himself up by the handle." That's somewhat the position we find ourselves in today with regard to our water dilemmas. We're standing in that bucket, grasping its handle and pulling. But there's little hope of lifting ourselves up and resolving our water problems without stepping outside of that confining bucket. Trying to balance all the assaults on our state's water against a prosperous future that **must** include enough of this precious resource for all of us may be futile as well as very expensive if we don't take a serious look at changing some of the ways we do our water business.

Who would have given serious consideration a few years ago that rough fish and minnows, many of which state and federal agencies spent a great deal of time, money and effort to eradicate, would now control New Mexico's economic fate?

Who would have thought that meeting river compact requirements that were agreed to many decades ago, when New Mexico's financial destiny relied almost wholly on farming and ranching, would seriously impact our ability to grow in the sophisticated technology based economy of today?

Couple these with an all-encompassing, devastating and potentially extended drought, the desire of others outside our borders to stick their straw in our glass, and looming calls on our rivers, and there's little doubt that there's trouble–not only in river cities, but throughout the state.

Nostalgia is a wistful longing for the past, which is something we sometimes wish for. We often think of earlier times being easier, simpler and less complicated. But would any of us admit that we'd really love to turn back the clock and do things now the way we did things a hundred years ago? I doubt it.

And yet, that's almost precisely how we currently manage our water. Virtually all of New Mexico's water laws were promulgated in territorial days and ratified for the most part in the state's constitution in 1912. Water laws have changed little since then, but society certainly has. The 1920 census, the first after statehood, had 327,301 persons living here. We're approaching 2,000,000 now. Bernalillo county's 23,606 people then made it the state's largest, but by less than 700 more than San Miguel county. The state was a rural community then, folks, and most of the ways we do our water business haven't changed since then.

Don't misunderstand. No responsible person, and certainly not me, is suggesting wholesale dramatic changes in our water laws, especially as they pertain to the private property elements of a water right. But, I can't overemphasize that to meet future needs of our citizens and sustaining or improving the economic vitality of the state, **providing new uses from New Mexico's fully appropriated water supplies will require transfer of water from existing uses.**

And that primarily means agriculture. Secondarily it includes new and effective controls on and management of reservoir evaporation, phreatophytes and watersheds.

Our most recent and reliable data on water consumption in New Mexico says that in 1995 we depleted, consumed and removed from the hydrologic system some 2,762,000 acre-feet of water, about equally divided between surface and groundwater. If you live in the High Plains of eastern New Mexico, your source of water is virtually 100 percent from the underground Ogallala aquifer. On the other hand, if you live in the San Juan Basin, your water supply is almost entirely from surface streams. The rest of New Mexico uses more equal proportions of surface and groundwater.

Of this more or less considerable volume of water, irrigated agriculture's share is 68 percent or 1,880,000 acre-feet. Next on the scale of major consumers of New Mexico water is reservoir evaporation, accounting for the loss of 521,500 acre-feet annually, or 19 percent of the total, almost half of which is from Elephant Butte lake. Municipal, urban and public water supplies use a little more than 7 percent of our water, or about 198,400 acre-feet. The remaining 6 percent, in order of declining consumption, is divided among commercial uses, power plants, mining, livestock, domestic wells and industrial applications.

This is a preamble to the subject of this presentation, water banking, and why this subject should be given serious consideration as a mitigating factor in the dynamics of New Mexico water management.

Generally, the concept of water banking is analogous to financial banks. Those with water that is surplus to their needs deposit it in an approved bank where it is lent to others for a fee which is returned to the depositor after administrative costs are recovered. Although many western states, including New Mexico, have statutory provisions to lease, sell and transfer water, the process is usually lengthy, complicated, expensive and the results are uncertain.

With the availability of water and access to it becoming the most critical element in New Mexico's economic future, a more sophisticated and speedy process to "move" water from where it is to where it's needed is imperative.

Achieving a sustainable supply of water that meets the current and future needs of all our citizens relies on making the best use of all the water that is available to us. It will require the development and application of innovative technologies for water storage and conservation, managing use and demand, and increased reliance on water marketing. All within the framework of the least disruption to existing institutional water-related privileges and rights. Legally constituted water banks administered under rules and regulations promulgated by the State Engineer would:

- Provide a legal mechanism for conserving and salvaging water that is otherwise surplus to customary agricultural and other beneficial uses, creating "new water" for other uses while preserving the ownership of the water right.
- Make "new water" available for reallocation and application to expanded conventional needs as well as to higher, better, more economical and financially rewarding uses through facilitated voluntary transactions and sharing profits from these arrangements with the water rights owner/ depositor.
- Provide incentives to conserve water as well as economic benefits and reassurance to those holding valid water rights and permits that their conserved water will not be forfeited for non use.
- Ensure that banked water is "wet water" and that non-impairment of the water rights of others is a prerequisite to depositing and withdrawing banked water.
- Avoid expensive, drawn-out, confrontational and contentious processes that would accompany efforts to dramatically change existing water laws and rights.

Water for a bank is derived from conserving it or giving up its use. Deposits could include adjudicated or licensed water rights, irrigation project water, water conserved through improvements in irrigation practices, water temporarily out of use because of system upgrades or lack of demand, water salvaged from evaporation and, perhaps, portions of Indian water rights. The bank not only provides a safe harbor for deposited water, protecting it from forfeiture for non-use, it also provides users and lenders with a convenient central clearing house for information on water availabilities, costs, origin, destination, and bookkeeping.

Many would say that New Mexico already has effective water markets. Certainly, the buying, selling, leasing and transferring of water rights has been an ongoing process in the state's water world literally for centuries. In more recent times, the transfer of a water right, or a change in its use or to a new point of diversion requires approval by the State Engineer. In granting his approval, the State Engineer must determine that no other water right will be impaired and the change must not be detrimental to the conservation of water or the public welfare of the state. Each request must be evaluated individually and even applications on relatively non controversial transfers may take months to move through the system. Pending requests in the Office of the State Engineer have been in the thousands until recently when the legislature made additional funds available to the State Engineer to reduce the backlog.

One of the primary missions of a water bank is to speed up the approval process. In order to do that, the State Engineer, who is responsible for promulgating the rules under which a bank will operate, will have to establish presumptive factors that will serve as the basis for approval of transaction agreements and the administration of transfers. Some of these presumptive factors would include return flows and consumptive use; transit losses and gains; evaporation losses; and effects of groundwater diversions on surface flows. Implicit is that there will be no impairment of other water rights, no depletion of the stream system beyond that which has historically occurred, compliance with state law and, perhaps, restrictions to operating within the same stream system, watershed or underground water basin.

Looked at another way, establishing water banks achieves a process to allow legally determined water to be transferred from senior to junior users on a streamlined basis without extended hearings, and provides a market mechanism to easily move water from less valuable to more valuable economic uses. Ancillary benefits include greater opportunities to meet compact requirements and endangered species demands from banked water, as well as mitigating drought conditions.

Where will banked water come from? Most of it will come from those who have the water: the irrigation and conservancy districts. Recent decisions in state courts have determined that, at least in the Carlsbad Irrigation District, the farmers themselves own the water right appurtenant to their irrigated land. I wouldn't be surprised that this precedent won't hold for other irrigation districts. In the Middle Rio Grande Conservancy District, those farmers with pre-1907 water rights own them and can pretty well do what they want with them, independent of the district. The district itself, that manages all the irrigation water within its boundaries, does not own water rights. It obtains its water through permits with the Office of the State Engineer.

In any event, individual farmers or the districts themselves could elect to place water in a bank authorized by the district in compliance with a water banking law. Both Elephant Butte Irrigation District and the Middle Rio Grande Conservancy District have established pro-forma water banks for the purpose of leasing water to other entities that are not farmers. Although they have an undisputed right to transfer water within their boundaries from one irrigation purpose to another, it is not clear that this right extends to making water available to non irrigation users without approval from the state engineer and, perhaps, the federal government.

Further, most of the banked water will de derived through conserving water or fallowing land. Today, most of the rules regulating conserved irrigation water deprive the conserving farmer from an opportunity to benefit from it. His option is to place it in a state engineer approved conservation pool, which basically does nothing more than protect the farmer from the onerous "use it or lose it" forfeiture rule, or redirect it to another irrigation use. Conservation pools would be a good place to establish water banks by giving them the authority to move water to other places and uses and be paid for it.

Let's talk about conservation for a minute. About nine years ago my city of Albuquerque suddenly and dramatically became aware that it was mining its aquifer beneath the city. Conservation became a byword in 1995 when the city withdrew 135,000 acre-feet from the ground to serve its citizens. This year we'll produce about 110,500 acre-feet, a reduction or conservation of 24,500 acre-feet or 18 percent less than 8 years ago while population increased about 5 percent. Albuquerque isn't doing this to apply the saved water elsewhere, it's simply to extend the life of the aquifer while the city prepares to begin withdrawing most of its supply from the Rio Grande, using its San Juan/Chama contract water and certain pre-1907 water rights it has purchased.

By the way, half of the water Albuquerque produces or diverts from the aquifer is consumed and the other half, discharged from the city's wastewater treatment plant, becomes one of the largest return flows in the Rio Grande, all of which is "new" water available for downstream irrigators and compact compliance, that wasn't in the river in historical times.

If Albuquerque can conserve 18 percent of its water, would this be an unreasonable goal for irrigated agriculture? Conserving 18 percent of the 1,880,000 acre-feet consumed by irrigation annually would hypothetically make available 338,400 acre-feet of water to use elsewhere with water banks. Under current laws, virtually all of that water, about 6 times the demand of an urban center like Albuquerque, would be redistributed to additional irrigated land.

One more example of the benefits of conserved, banked water. How often have we heard it said by those who should know better that Intel is a huge water hog on the Rio Grande? Folks, if we only had more animals like them! In the six years from 1996 when their water wells began production, through 2001, Intel has produced 23,867 acre-feet of water from its wells, consumed 3,920 acre-feet, and has returned to the Rio Grande through Albuquerque's water treatment plant 19,948 acre-feet. That's an average diversion of 3,978 acre-feet, consumption of 654 acre-feet, and a return flow of 3,325 acre-feet each year.

With 654 acre-feet of water, Intel directly provides jobs for 5,200 New Mexicans with a payroll of $332,000,000, averaging $46,000 per year. They are New Mexico's largest corporate income tax payer. They are currently constructing a $2 billion expansion that will provide 500 to 1,000 new jobs and, they state on their web site, the additional water required will be negligible. Tell me where else we can get more economic bang for such a small amount of water. Water banks have the potential to alleviate the fears of business entities considering our state that immediately usable start up water is not available.

Another element of water banks that has been suggested as a limiting factor is storage of banked water. Not all bank water uses require storage, but those that do may find it in reservoirs such as Abiquiu where, as Albuquerque drains its San Juan/Chama water stored there to meet the requirements of its new

Rio Grande diversion facilities, space might be available.

Further, it is likely that groundwater storage will become a significant water supply augmentation strategy which may be a strategic element of successful water banking. A major consideration in this regard is that recharge and water storage in depleted aquifers in, for instance, the Middle Rio Grande region, that were full before river compacts were ratified may avoid compact prohibitions against new on-stream reservoirs, since replenishment simply restores them to pre-compact conditions.

Thank you for the opportunity to present what appears to be a workable plan to derive additional benefits from a limited water supply. Water banking may not be the panacea that resolves all our water problems, but it is far from a placebo that does nothing.

11/07/02 DRAFT

LOWER PECOS RIVER BASIN WATER BANKING REGULATIONS

RULE 1 ISSUING AGENCY: Office of the State Engineer

RULE 2 PREFACE: These regulations are adopted by the State Engineer upon the recommendation of the Interstate Stream Commission, pursuant to the authorities in NMSA §72-1-2.3 (Supp. 2002) and other authorities for the administration of water. These regulations are adopted in furtherance of the efforts of the State of New Mexico to achieve long-term compliance with its obligations under the Pecos River Compact, NMSA §§72-15-19 *et. seq.*, and the Decree and Amended Decree in *Texas v. New Mexico*, 485 U.S. 388 (1987, 1988). These regulations are adopted in order to facilitate water right transactions between water users for the purposes of Replacement of Stream Depletions which transactions will enhance the ability of the State of New Mexico to comply with the Compact and Decree.

RULE 3 SCOPE: These regulations shall apply to the establishment and operation of water banks established for purposes of compliance with the Pecos River Compact by irrigation districts, conservancy districts, artesian conservancy districts, community ditches, acequias, or water users' associations located in the Lower Pecos river basin below Fort Sumner Dam. These regulations are adopted solely for the purpose of facilitating temporary sources of water (Replacement Water) to be obtained to address Stream Depletions caused by the temporary continued use of water rights junior to the Compact Administration Date determined by the State Engineer in the accompanying Priority Administration regulations. These regulations shall not apply to water banks established by acequias or community ditches pursuant to NMSA §________.

RULE 4 STATUTORY AUTHORITY: These regulations are established pursuant to the authorities set forth in N.M.S.A. §§___ (H.B. 421); 72-1-2; 72-2-8; 72-2-9; 72-4-20; 72-5-3 through 5; 72-5-23; 72-5-24; 72-5-28(G) and (H); 72-6-1 through 7; 72-12-1; 72-12-2; 72-12-7; 72-12-8(D); 72-12-24; 72-13-2; 72-13-4; 72-15-19 *et. seq*.; and *Texas v. New Mexico*, 485 U.S. 388 (1987, 1988).

RULE 5 DURATION: These regulations are effective through December 31, 2005.

RULE 6 EFFECTIVE DATE: These regulations are effective as of _______________.

RULE 7 CONSTRUCTION: These regulations shall be construed consistent with and subject to the authorities of the State Engineer for the administration of water in the State of New Mexico, the Pecos River Compact, and the Decree and Amended Decree of the United States Supreme Court in *Texas v. New Mexico*. These regulations shall not be construed as imposing any limitation on the authority of the State Engineer to administer priorities of water rights, to approve changes of water rights, to permit water rights, or to order the curtailment in whole or in part of the use of water under any water right.

RULE 8 OBJECTIVE: The objective of these regulations is to establish a framework for the temporary accrual, pooling, exchange, assignment or lease of water rights for the purpose of Replacement of Stream Depletions, without the necessity of formal and time-consuming proceedings before the State Engineer. In furtherance of this objective, these regulations are designed to assure other water rights will not be impaired, water in the Basin will not be depleted above that level that would have occurred in the absence of the particular transaction, transactions occur in compliance with state law, and transactions occur within the same stream system or underground water source. The State Engineer finds that achieving this objective will facilitate compliance by the State of New Mexico with the Pecos River Compact by furthering the application of the principle of prior appropriation within the Basin.

RULE 9 AREA OF APPLICABILITY:

A. These regulations do not apply outside the Lower Pecos river basin below Fort Sumner Dam.

B. These regulations apply to Pecos River Basin surface and groundwater tributary to the Pecos River below Sumner Dam to the state line, including specifically the Roswell-Artesia and Carlsbad groundwater basins.

C. These regulations do not apply to transfers of water for use outside the state of New Mexico.

RULE 10 DEFINITIONS: Unless defined below or in a specific section of these regulations, all other words used herein shall be given their customary and accepted meanings.

A. **Augmentation of River Flow:** Bankable Water delivered to the Pecos River in order to increase the flow thereof.

B. **Bankable Water:** Historic Consumptive Use Credits, water stored in reservoirs, or stored water under Article 5A of Chapter 72 NMSA 1978, held by a Water Right Holder, which a Water Bank determines is eligible for Deposit.

C. **Basin:** The hydrologically connected surface and groundwater area bounded by Fort Sumner Dam in the north and the New Mexico-Texas state line in the south, including specifically the Roswell-Artesia and Carlsbad Basins.

D. **Compact Administration Date:** A date determined by the State Engineer pursuant to the Administrative Regulations for the Pecos River Basin. All use of water rights in the Basin junior to the Compact Administration Date shall be curtailed pursuant to said regulations.

E. **Charter:** The evidence of recognition by the Interstate Stream Commission of a Water Bank pursuant to NMSA 72-1-2.3 (Supp. 2002).

F. **Deposit:** A written agreement between a Water Bank and a Depositor, by which the Depositor makes available Bankable Water to the Water Bank for accrual and pooling for lease, assignment, or transfer to Purchasers.

G. **Depositor:** The owner, lessee or contractee of Bankable Water located within the geographic boundaries of a Water Bank who has entered into a Deposit with a Water Bank. A Water Bank may be a Depositor.

H. **Deposit Account:** The amount of Bankable Water a Depositor places in a Water Bank.

I. **Historic Consumptive Use Credit:** The amount of water actually consumed on an average annual basis for the previous five years pursuant to a Valid Existing Surface or

Groundwater Right with a Priority Date senior to the Compact Administration Date, made available on an annual basis as a result of fallowing the land irrigated under such right for an entire irrigation season.

J. **Measuring Devices:** Accurate and continuous gauging devices, as required by the State Engineer. Measuring devices will normally be required at the point of diversion, at all downstream diversions throughout an applicable section of stream channel, at appropriate groundwater locations and at the terminus of the water use.

K. **Priority Date:** The date reflected on State Engineer permits or licenses, or on accepted offers of judgment within the pending adjudication in *State ex rel Reynolds v. Lewis*, No. 20294, 22600 (Chavez County 1956) (consolidated), as the date at which a water right came into being, either by application, in the case of post-1907 rights, or by beneficial use in the case of pre-1907 rights.

L. **Priority Administration Regulations:** Regulations promulgated by the State Engineer pursuant to which water right holders with priority dates junior to a Compact Administration Date will be cut off, unless they obtain Replacement Water.

M. **Purchaser:** A holder of a water right which is junior to the Compact Administration Date determined pursuant to the Priority Administration Regulations who seeks Replacement Water to allow continued use of the water right, or an entity who seeks to augment the flows of a surface water body for purposes of compliance with Interstate Compacts or State or Federal law, and who enters into a Transaction with a Depositor through a Water Bank. A Water Bank may be a Purchaser.

N. **Replacement Water:** Water under a Valid Existing Surface or Groundwater Right required by the State Engineer to be provided as a condition of use of any water right with a priority date junior to the Compact Administration Date. The amount of Replacement Water shall be equal to Stream Depletions. Replacement Water may be provided through a Water Bank.

O. **Stream Depletions:** Total depletions, regardless of the time of such depletion in relation to the time of the diversion, to the Pecos River at the New Mexico-Texas state line caused by diversions of tributary ground or surface water in the Pecos River Basin in New Mexico under a Valid Existing Surface or Groundwater Right. For purposes of these regulations, Stream Depletions shall be deemed to occur, and shall be offset, in the same year in which the diversion is made. The State Engineer will calculate Stream Depletions on an average annual basis, gearing these calculations to the Texas-New Mexico State Line.

P. **Transaction Agreement:** A lease, assignment or option agreement between a Depositor and a Purchaser pursuant to which the Depositor shall forgo the use of and/or make available to the Purchaser water rights for a time certain for the purposes of Replacement of Stream Depletions or the Augmentation of River Flow.

Q. **Valid Existing Surface or Groundwater Right:** A surface or groundwater water right diverting water from the Pecos River Basin recognized by permit or license issued from the State Engineer Office, or by accepted offers of judgment within the pending adjudication in *State ex rel Reynolds v. Lewis*, No. 20294, 22600 (Chavez County 1956) (consolidated).

R. **Water Bank:** A plan chartered by the Interstate Stream Commission pursuant to these regulations to accept for deposit, accrual and pooling Deposited Water for lease, assignment, or transfer to persons, entities or other Water Banks for the purpose of Replacement of Stream Depletions or the Augmentation of River Flow.

S. **Water Right Holder:** The holder of any Valid Existing Surface or Groundwater Right.

RULE 11 CHARTER:

A. *Application for Charter.*

(1) Any irrigation district, conservancy district, artesian conservancy district, community ditch, acequia, or water users' association located in whole or in part in the Basin may apply to the Interstate Stream Commission for a charter to operate a Water Bank.

(2) All applications for a charter shall be made on a form provided by the Interstate Stream Commission, and shall be sufficiently complete so as to allow the Interstate Stream Commission to determine whether the proposed Water Bank is eligible to operate pursuant to these regulations, and whether the operations of the Water Bank may reasonably be anticipated to conform to these regulations. Any such application shall certify that the application and proposed charter have been duly adopted by the applicable entity pursuant to the regulations of governance of such entity.

(3) All applications for a charter shall include a description of the proposed geographic boundaries of the Water Bank.

(4) All applications for a charter shall set forth procedures by which the proposed Water Bank will provide notice and an opportunity for hearing to any Water Right Holder whose Valid Existing Surface or Groundwater Right may be impaired by any proposed Transaction Agreement.

B. *Procedure for Review of Application.*

(1) The Interstate Stream Commission shall establish an application fee.

(2) Upon receipt of a complete application, the Interstate Stream Commission shall refer the application to the Office of the State Engineer for review and comment. The Office of the State Engineer may recommend presumptive factors, limitations on operations or other terms and conditions that will facilitate banking transactions in compliance with these regulations.

(3) Within ___ days from the receipt of a complete application, the Interstate Stream Commission shall approve, deny, or approve on terms and conditions an application for a Water Bank charter. The decision of the Interstate Stream Commission

shall be the final agency action, and shall be in writing.

(4) Upon issuance of a charter, a Water Bank may conduct banking transactions consistent with these Regulations.

(5) No charter shall be approved which allows for water to be transferred by means of the Water Bank for any purposes other than obtaining Replacement Water to address Stream Depletions caused by temporarily continuing to use water rights that are junior to the Compact Administration Date, or Augmentation of River Flow.

C. *Termination*. The charter for any Water Bank shall terminate on December 31, 2005.

RULE 12 BANKING TRANSACTIONS:

A. *Deposit.* A Deposit shall provide or be based upon, at a minimum, the following:

(1) The payment by the Depositor to the Water Bank of any application and/or posting fees that may be required by the Bank.

(2) Authorization by the Depositor for the Water Bank to advertise and market the Bankable Water placed into the Deposit Account.

(3) The Depositor's agreement that the Water Bank shall have the exclusive right to market, accrue, pool, exchange, assign or lease deposited water on behalf of the Depositor for Offset of Stream Depletions or Augmentation of River Flow purposes for the term of the Deposit, and that the Depositor shall not independently market, accrue, pool, exchange, assign or lease the deposited water during the time the Deposit is in effect.

(4) The written agreement that the owner or operator of any facility from which water will be released or delivered to a Purchaser has approved such use of water and will properly account for the water in the facility and cooperate in regulating its delivery.

(5) If the Deposit is of water requiring the use of federal facilities, a contract with the United States for such use, if necessary.

(6) An affidavit by the Depositor, containing a description of the Bankable Water, including without limitation the following:

i. Proof of ownership, lease or contract that includes the right to use and control the disposition of the water.

ii. The amount and type of water that will be deposited.

iii. A description of the point of diversion, place of storage and historic place of use of the water for the previous five years, with meter readings where they exist. Sufficient descriptions may include maps, legal descriptions, and/or aerial photographs.

iv. A quantification of the Historic Consumptive Use Credits that will be deposited.

(7) In the case of Historic Consumptive Use Credits, deposit of all Valid Existing Surface or Groundwater Rights used upon or appurtenant to the land being fallowed, and certification by the Depositor that land fallowed in order to make Historic Consumptive Use Credits available will not be re-irrigated in the same irrigation season, from any source.

(8) Certification that Measuring Devices are or will be installed.

(9) Anticipated terms that may apply to the temporary accrual, pooling, exchange, assignment or lease of the Bankable Water, include, but are not limited to:

i. Applicable time frames, parameters and/or limitations for and on the use of the water.

ii. Where applicable, the minimum bid price the Depositor will accept for the water.

iii. The minimum amount of stored water or Historic Consumptive Use Credits the Depositor is willing to allow the Water Bank to accrue, pool, exchange, assign or lease.

iv. Contact information, including name, address, phone number and e-mail address (if available).

v. Any other relevant terms or documentation requested or deemed necessary by the Water Bank and the Depositor.

B. *Publication.*

(1) Upon finalization of a Deposit, the Water Bank shall list or market the availability of the Bankable Water. Listings of availability may also be available at the offices of the Interstate Stream Commission within the Basin, and on or linked to the Interstate Stream Commission's web site.

(2) The listing shall include, at a minimum, the minimum bid price, procedures for bid acceptance, the amount of water available, the stored location of the water, the point of diversion and place of use, and the historic type of use.

C. *Accrual, Pooling, Exchange.* A Water Bank may, if appropriate and practicable, accrue, pool or exchange Deposits for purposes of making water available to Purchasers; provided, however, that Historic Consumptive Use Credits shall not be carried over from year-to-year.

D. *Transaction Agreement.* Upon acceptance of a bid by a Depositor, the Depositor and Purchaser shall enter into a Transaction Agreement. No Transaction Agreement shall extend or be effective beyond December 31, 2005. Transaction Agreements shall only be for the purposes of Offset of Stream Depletions. All Transaction Agreements shall not impair other water rights; not deplete water in the system above the level that would have occurred in the absence of the transaction; comply with state law; and be within the same stream system or underground water source. Transaction agreements for the purpose of Offset of Stream Depletions may not allow an increase in water use or diversion above the Purchaser's Historical Use, or a change in the Purchaser's Place of Use, Point of Diversion or Purpose of Use. The Transaction Agreement shall describe the transaction in such terms as may be established by the Water Bank, but shall include, at a minimum, the following:

(1) The amount of water;

(2) The type of use;

(3) The point of diversion;

(4) The place of use and, if applicable, the number of acres to be irrigated;

(5) The proposed time of use;

(6) Provision for adequate Measuring Devices;

(7) Certification that any land fallowed for providing Historic Consumptive Use Credits shall not be re-irrigated in the same irrigation season;

(8) Certification that the Purchaser is using the water for replacement of water rights cut off by priority administration;

(9) A statement that the Purchaser is aware that replacement of water through water banking is a temporary expedient, and that the Purchaser intends to seek actively a permanent resolution of water supply concerns;

(10) If the Transaction Agreement requires delivery of water into a different distribution system, the consent of the owner or operator of the receiving facility or system, including any terms or conditions related to the use of such facility or system.

E. *Approval of Intra-Water Bank Transaction Agreement.* For a transaction in which the Depositor and the Purchaser are both located within the geographic boundaries of a Water Bank, the proposed Transaction Agreement shall be reviewed and approved by the Water Bank. The Water Bank may condition its approval upon terms and conditions necessary for implementing the Transaction Agreement. Such terms and conditions shall be consistent with the terms and conditions of the Water Bank's Charter, and shall include any necessary and/or desirable limitations upon the time, place or type of use of the water made available through the Water Bank, or other terms and conditions as deemed necessary, including dry-up provisions where applicable.

F. *Approval of Transactions Where the Purchaser is Outside the Geographic Boundaries of the Water Bank.* For a transaction in which the Purchaser is located outside the geographic boundaries of a Water Bank, the proposed Transaction Agreement shall be reviewed and approved by the Interstate Stream Commission. The ISC may condition its approval upon terms and conditions necessary for implementing the Transaction Agreement. Such terms and conditions shall be consistent with the Water Bank's Charter, and shall include any necessary and/or desirable limitations upon the time, place or type of use of the water made available through the Water Bank, or other terms and conditions as deemed necessary, including dry-up provisions where applicable. The ISC shall not approve a Transaction where the Purchaser is outside the geographic boundaries of the Water Bank unless the ISC finds that it is not feasible for the Purchaser to obtain water from a more local Water Bank.

G. *Implementation of Transaction Agreement.*

(1) Upon approval of a Transaction Agreement, including relevant terms and conditions, the Water Bank may finalize the Transaction Agreement between Depositor and Purchaser.

(2) A Depositor shall comply with all state and local laws and regulations, and terms and conditions imposed by the Water Bank, regarding land use and vegetation (e.g. weed control).

(3) A Water Bank may establish and charge sufficient fees to cover administrative costs incurred during the operation of the Transaction Agreement.

(4) Upon commencement of operations pursuant to a Transaction Agreement, the State Engineer will administer water as set forth under the Transaction Agreement.

RULE 13 QUANTIFICATION PROCEDURES: The Interstate Stream Commission may establish by policy presumptive factors that may be included in any Charter and that will be applied by Water Banks and/or the Interstate Stream Commission in approving and developing terms and conditions for the operation of proposed Transaction Agreements. To claim values differing from those established, or with respect to water outside the systems or factors addressed in the policy document, parties to a Transaction Agreement must submit to the approving authority with the proposed Transaction Agreement an adequate historic use analysis or other engineering information sufficient to allow the approving authority to evaluate whether different values may be used with respect to the proposed transaction. Such information shall be submitted to the Interstate Stream Commission for review and approval.

RULE 14 REPORTING: A Water Bank shall submit to the State Engineer and the Interstate Stream Commission monthly summaries of the Bank's transactions, including a summary of Deposits and Transaction Agreements.

RULE 15 ACEQUIA OR COMMUNITY DITCH WATER BANKS:

A. An acequia or community ditch may establish a water bank for the purpose of temporarily reallocating water without change of purpose of use or point of diversion to augment the water supplies available for the places of use served by the acequia or community ditch. The acequia or community ditch water bank may make temporary transfers of place of use without formal proceedings before the State Engineer, and water rights placed in the acequia or community ditch water bank shall not be subject to loss for non-use during the period the rights are placed in the water bank. Acequia or community ditch water banks established pursuant to this rule are not subject to recognition or approval by the Interstate Stream Commission.

B. The acequia or community ditch shall provide as requested to the State Engineer records of all such transfers, at least annually.

C. Any transfer undertaken pursuant to the authority of NMSA §72-1-2.3 shall not result in an increase in the rate or volume of diversion, or the actual average historic beneficial use of the water made over the five years immediately prior to the transfer, within the boundaries of the acequia or community ditch.

D. If any acequia or community ditch water bank desires to approve or enter into transactions with any Purchaser located outside the geographic boundaries of the places of use served by the acequia or community ditch, the acequia or community ditch water bank will become subject to, and must comply with, the full range of these regulations.

RULE 16 FORFEITURE: The four-year forfeiture period established by 72-5-28 or 72-12-8 NMSA 1978, shall be tolled for the period of time during which a water right or underground water right is deposited with a Water Bank or an acequia or community ditch water bank.

RULE 17 ENFORCEMENT:

A. The Interstate Stream Commission may enforce the terms of any Water Bank charter or the terms and conditions of any approval of a Transaction Agreement by appropriate order and injunctive relief.

B. A Water Bank charter and the approval of a Transaction Agreement will be conditioned to allow the Interstate Stream Commission to revoke the charter or cancel the Transaction Agreement if the terms and conditions of the charter or Transaction Agreement are not met or if the actions of the Water Bank, Depositor or Purchaser are not in accordance with such terms and conditions.

RULE 18 LIBERAL CONSTRUCTION: These regulations shall be liberally construed to carry out their purpose.

RULE 19 KNOWLEDGE OF AND COMPLIANCE WITH RELEVANT STATUTES, RULES, REGULATIONS, AND CODES: It shall be the responsibility of all applicants and permittees to know of and comply with all applicable statutes, rules, regulations, and codes.

RULE 20 STATE ENGINEER OPTION TO REVISE REGULATIONS: The State Engineer may modify these regulations as needed to assist in administering 72 NMSA 1978. Any major revision to these regulations shall be duly published and presented for public comment. Removal of a regulation or a section of these regulations, whether by a court or by the State Engineer, shall not affect the validity of the remaining regulations.

***Ed Archuleta** has served as General Manager for the El Paso Water Utilities Public Service Board since 1989. Under his management, the utility has been recognized regionally and nationally for leadership in conservation, reclamation, and management. From 1974 to 1989, Ed worked for the City of Albuquerque in various positions including Assistant Director/Operations, Public Works Department. Prior to that, he planned and designed water and wastewater projects for a multinational consulting engineering firm in Iowa and a regional firm in Albuquerque. Ed earned bachelor's and master's degrees in civil engineering from New Mexico State University, and a Master of Management Degree from the University of New Mexico. He is a registered Professional Engineer in Texas, New Mexico, and Iowa. Ed is a member of the American Water Works Association, the Water Environment Federation, and the National and Texas Societies of Professional Engineers. He is Chairman of the American Water Works Association Research Foundation, a trustee of the Association of Metropolitan Water Agencies, and an American Academy of Environment Engineers Diplomat. His civic involvement includes service or past service on the boards of United Way, Paso del Norte Health Foundation, Rotary Club, El Paso Home Builders Association, and El Paso Symphony.*

HOW A LARGE MUNICIPALITY PLANS TO MEET ITS FUTURE WATER SUPPLY NEEDS

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ABSTRACT

The City of El Paso, through its Water Utility, provides water and sewer services to approximately 700,000 people in the Greater El Paso metropolitan area. The area is growing at a rate of over three percent per year and has enormous challenges in being able to meet its future water needs.

The City is located in the Chihuahuan Desert, an area that receives approximately eight inches of rainfall per year. Managing water is further complicated by jurisdictional issues involving three states and two nations, all with different laws and regulations.

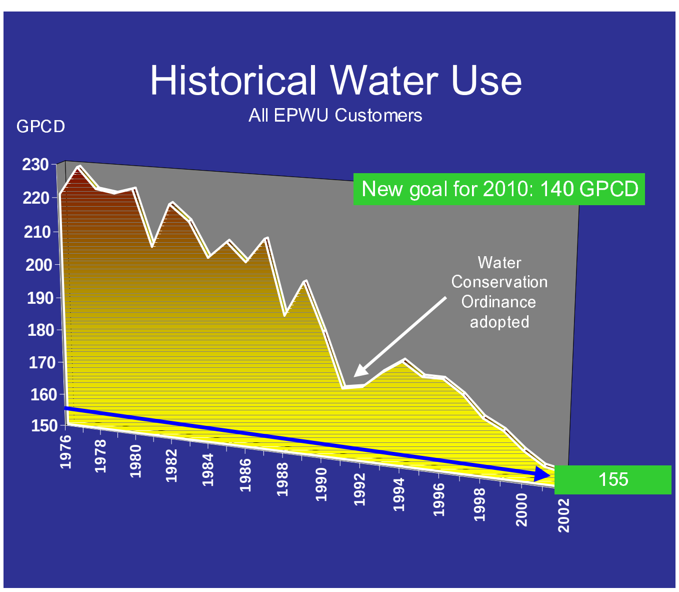
There are several competing interests for water including irrigation, municipal, recreational, and environmental needs. Providing for and balancing the needs is a major challenge.

However, El Paso Water Utilities has over the years done a considerable amount of water planning and has executed that planning. The Utility has a well-defined, diversified, strategic business plan along with capital, operating, and financial plans.

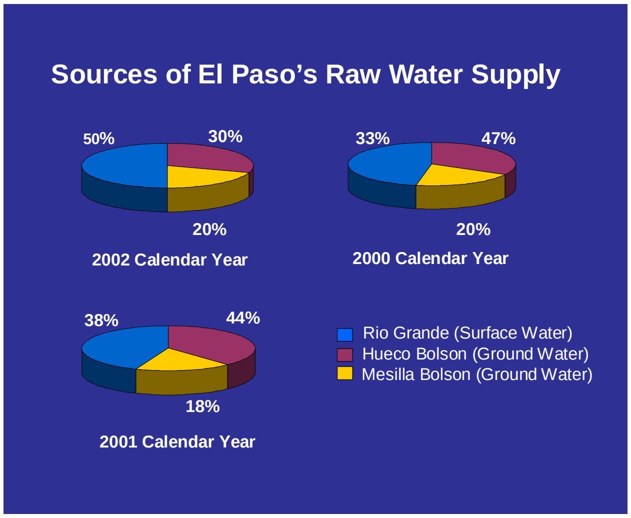
The paper will describe the means, methods, and cost ramifications of meeting water supply and water quality requirements for the foreseeable future.

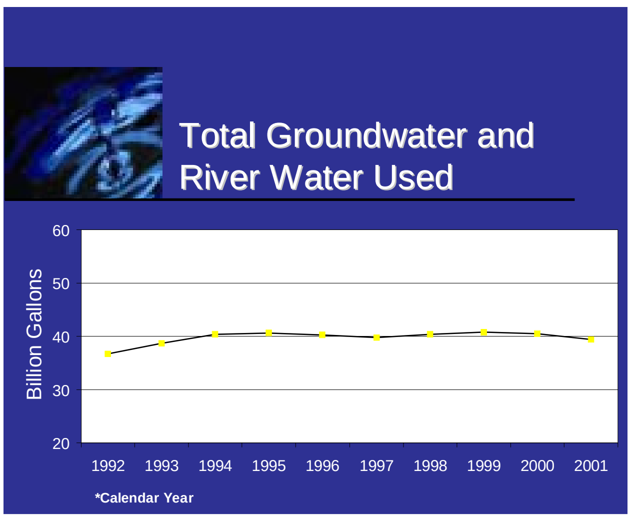
Editor's Note: The following PowerPoint presentation was given by Mr. Archuleta at the conference.

As our population grows and our service area expands, we must find additional sources of water. Our long-term water resource plan calls for a diversified portfolio which includes conservation, reclaimed water, river water, groundwater, desalination, and the eventual importation of water from areas beyond El Paso.

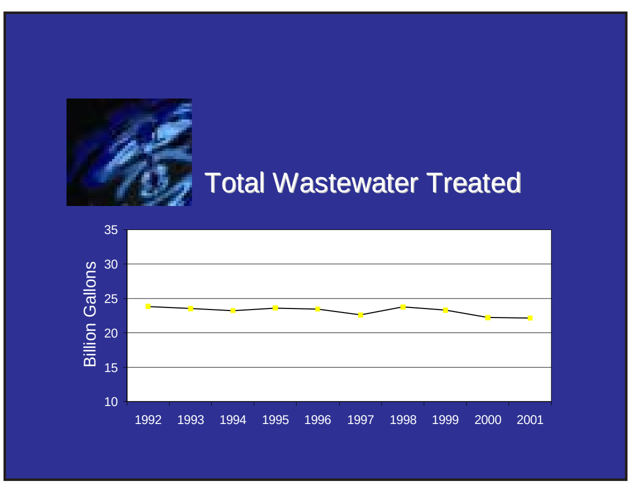


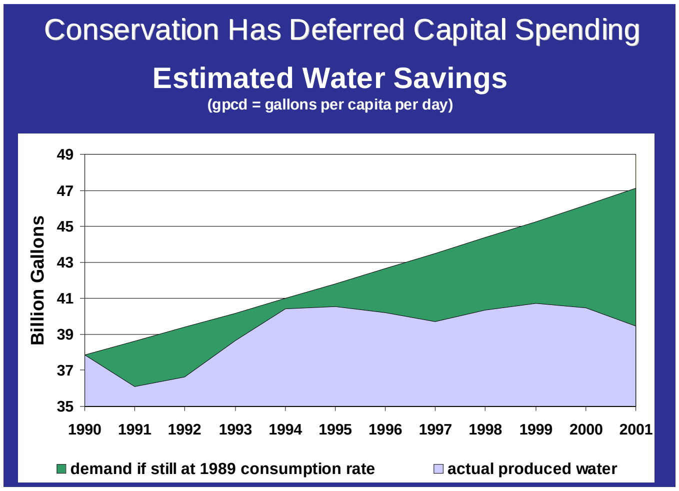
Conservation – Consumption
Per person consumption dropped from 159 gallons per day in 2000 to 155 in 2001, and we are on track for meeting our goal of 140 gallons per day by 2010. This is largely due to the water conservation ordinance, which was adopted in 1991, and our water conservation program, which is one of the most aggressive in the nation.



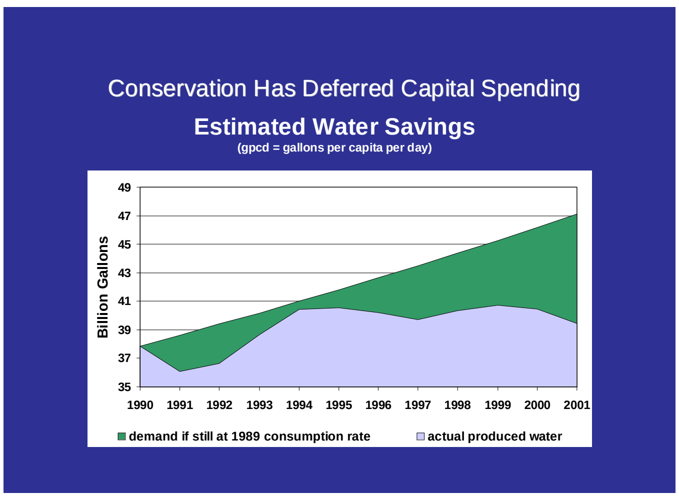


Because of proactive water conservation, the amount of water pumped by El Paso has remained relatively uniform over the past 10 years.

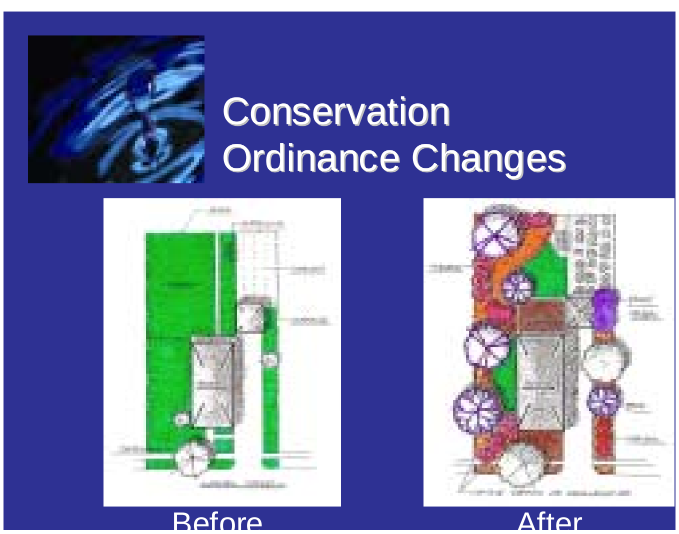




Water conservation in the form of time-of-day and day-of-week watering has dramatically reduced demand.



Over 10 years we estimate that we have saved more than $300 million in avoided capital costs.



Conservation – Programs

Education and incentives are key components of the conservation program, and one of the most popular programs this year is the turf replacement rebate. This program rebates $1.00 for each square foot of established grass that is replaced with water-efficient landscape materials.

By far one of the most effective indoor conservation programs has been the showerhead replacement program. We have distributed over 200,000 showerheads and last year saved a billion gallons of water. Other popular programs include the $200 washing machine rebate, the $300 refrigerated air conditioning rebate, and the evaporative cooler restrictor clamps, which restrict the flow of water through the units' bleed-off line. Restrictor clamps are free to customers who request them.

Jonathan Rogers Plant

In 1999, we began construction of the Jonathan Rogers Plant expansion. The plant began operating in 1993 with the capacity to treat 40 MGD. The expansion increases the capacity to 60 MGD to serve the additional customers in southeast El Paso and areas beyond the city limits. This project was partially funded by a $14.9 million EPA grant through the North American Development Bank. Construction was completed this spring.

El Paso needs to obtain more water from the river through the conversion of uses as the city continues to urbanize, through supply side conservation, and greater and greater efficiencies in the delivery of river water. This can all be done <u>without</u> impacting the El Paso agricultural community.

Northwest Plant Reclaimed Water Project

- Coronado Golf Course – 170 MG/Year
- 6 City Parks – 65 MG/yr
- 2 Schools – 18 MG/yr
- 5 Additional Schools (fall 2002) – 35 MG/yr
- 2 residential yard meters
- 1 EPWU yard meter
- Construction Water from Plant Standpipe: 2 MG/year

Total 290 MG/year

Fred Hervey & Bustamante Plant Reclaimed Water

Fred Hervey Plant

- Golf Course: 219 MG/year
- El Paso Electric: 980 MG/year
- Ranching/Construction: 8 MG/year
- Aquifer Recharge: 600 MG/year
- Construction Uses from Plant Standpipe: 4 MG/yr

Total 1811 MG/year

Bustamante Plant

- Garment Processing: 120 MG/year
- Median & Commercial Landscaping: 1 MG
- Construction Uses from Plant Standpipe: 2 MG/yr

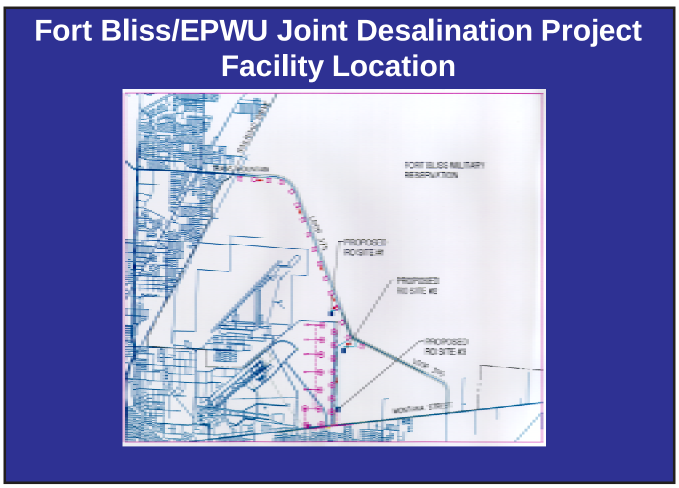
Total 123 MG/year

Total Reclaimed Water

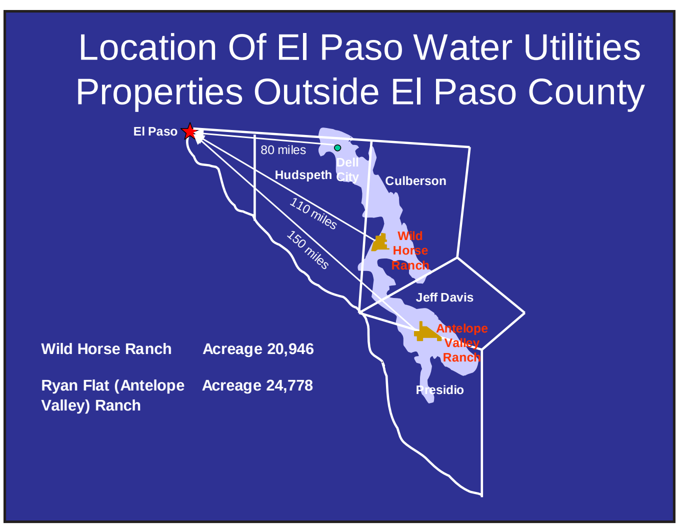
- 2.628 billion gallons or 6.6% of all water used or 11.9% of all wastewater treated

Joint Desalination Project

Fort Bliss and El Paso Water Utilities are collaborating to build a $60 million desalination plant. The 27.5 MGD facility will serve the Army post, the East Montana area outside the city limits, and customers in rapidly-growing east El Paso. Using desalinated water enables us to reserve the fresh water portions of the Hueco Bolson for drought protection and emergencies.



Congress approved $7 million in grant funds to El Paso last year. An additional $7 million has been requested this year. So far, the Congress has also funded $3.3 million for the military for this project. We will also receive a $1 million, no-interest loan from the Texas Water Development Board Water Assistance Fund, which will be used for the final design. The plant is scheduled to go on line in 2006.



Water Rights – Dell City

The Public Service Board owns several thousand acres of land for the purposes of providing water and water rights and for the protection of our source water. Some of the property is located outside of El Paso County, such as the ranches we own near Valentine and Van Horn. We are working with the underground conservation districts in these areas and plan to one day export water from these ranches to El Paso.

In April, the Public Service Board entered into an $8.2 million purchase option agreement for water rights in Dell City. A feasibility study is being conducted during the nine-month option period. If the Board is satisfied with the water quality and quantity, and the amounts of water that can be exported, the option will be exercised.

Any importation of waters will be done in accordance with the Far West Texas Water Planning Group, a State planning organization.

Land Management–Revised Policies and Procedures

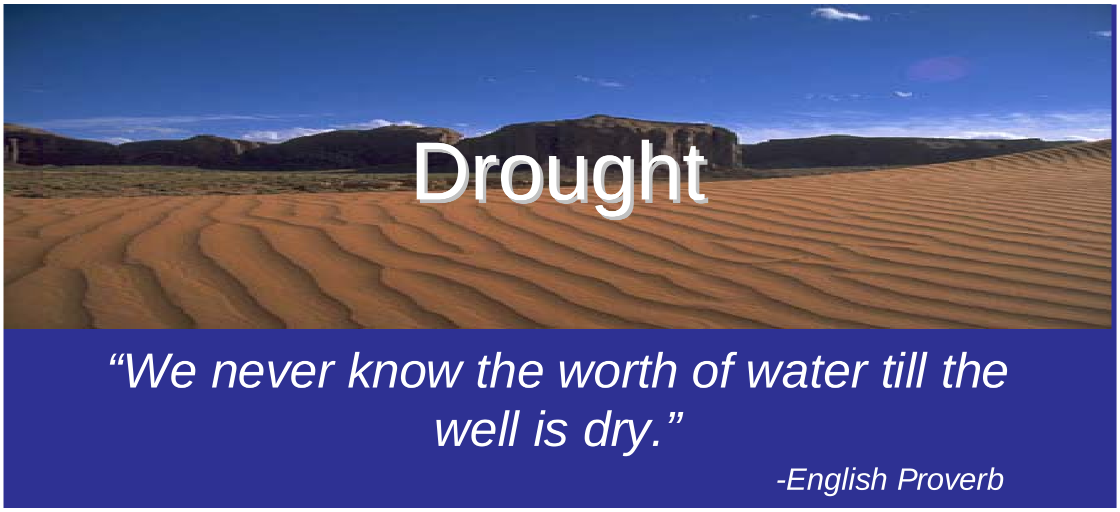
While the Public Service Board retains land for water management purposes, it periodically sells parcels of land to developers, the City, and school districts. The Board recently asked staff to examine the policies for selling and managing this property. The study is complete, and we are augmenting our policies to ensure that they lead to reasonable, smart, and sustainable growth in our city.

The new policies will enable us to maximize the return on our land assets, while improving the quality of life. We will master plan the land we sell, consistent with the City's and Public Service Board's strategic plans. These will be submitted to the City for approval as binding master plans. We will no longer exclusively sell land to be planned by others.

Bids will no longer be awarded solely based on price. We will factor in the economic opportunities that accompany mixed-use development, and the features that enhance quality of life, such as community centers, parks, trails, and open spaces.

All Public Service Board vacant lands will be categorized. Some will be leased, some will be sold, and others will be held in reserve. Five properties have been identified for immediate master planning. They are in the Artcraft, Canutillo Upper Valley, North Hills, Sean Haggerty and Painted Dunes areas.

A manual outlining the new land management policies and procedures will be available by the end of the year.



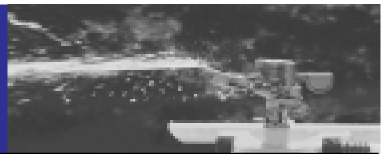
DROUGHT

While the threat of public harm from an attack on our water supply is small, conditions suggest that there will be a drought on the river system next year. This would seriously diminish our water supply next summer. The water that we treat in our plants is released from the Elephant Butte reservoir during the irrigation season. We are a customer of the Irrigation District. This year, El Paso will draw half of its water supply from the Rio Grande. Region-wide, 90 percent of the river water is used for agricultural purposes.

There has not been much snow in southern Colorado and northern New Mexico in recent years, and forecasters predict limited snowfall this winter. By the end of this year, the reservoir is expected to be at its lowest level since 1978.

Several of my staff were appointed to a task force, which is refining our drought management plan. This document specifies the events that trigger the three stages of the plan and the associated restrictions.

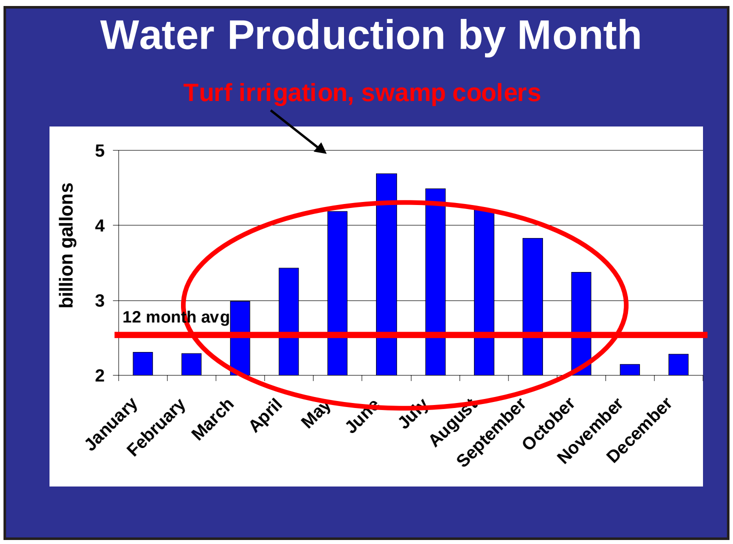
Drought

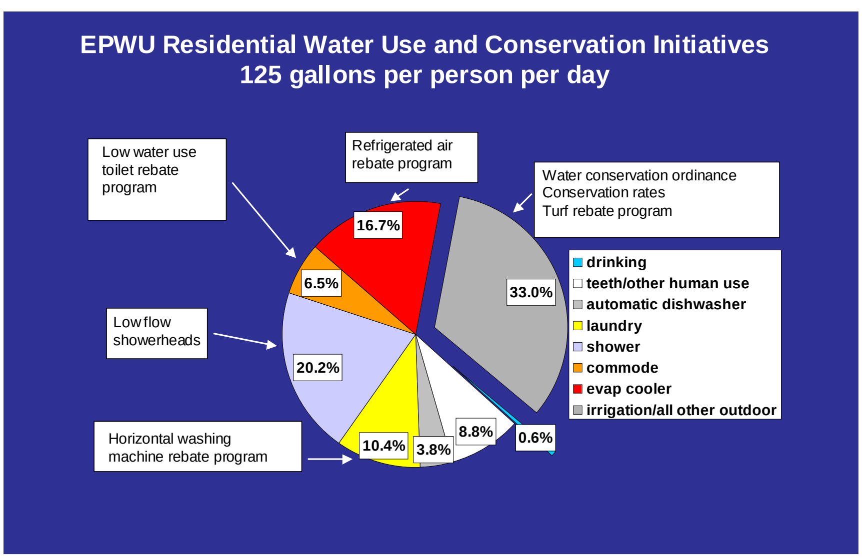


- A high percentage of El Paso's water is used outdoors
- PSB/City have a Drought Management Plan
- It is very likely that next year there will be severe cut backs in outdoor watering
- Drought conditions may persist for several years

Because so much of our water is used for outdoor watering, unless winter brings a tremendous amount of snowfall, it is very likely that next year there will be severe cutbacks in outdoor watering. Also, the drought conditions may persist for several years.

The revised drought management plan will be presented to the Public Working Committee, our citizens advisory group, for review before being presented to the Public Service Board and City Council for approval. With their approval, we anticipate beginning Stage One restrictions this fall.

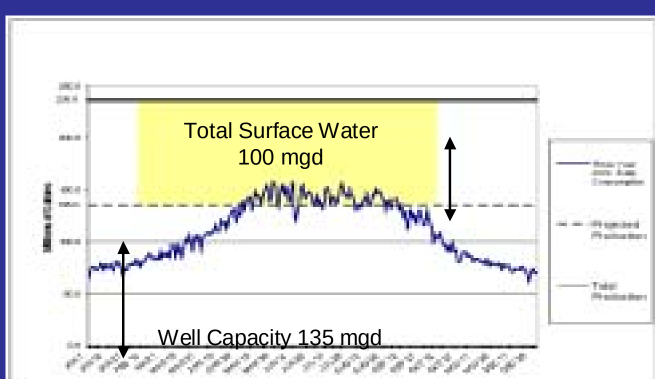




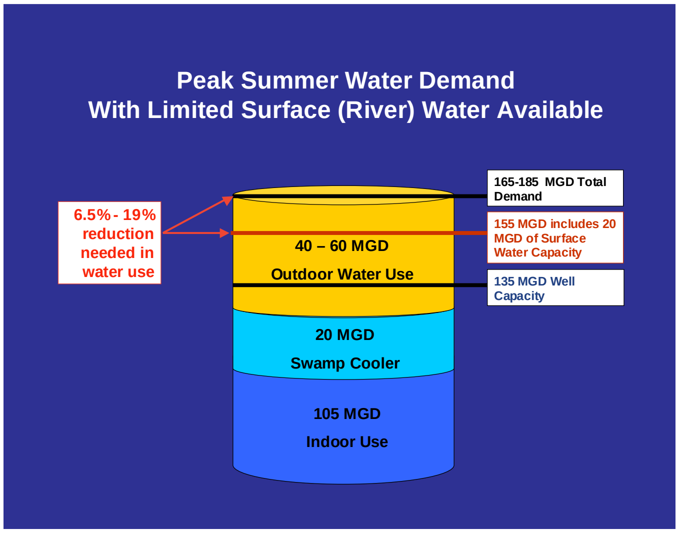
Meeting peek demand with limited surface water and maximum well capacity

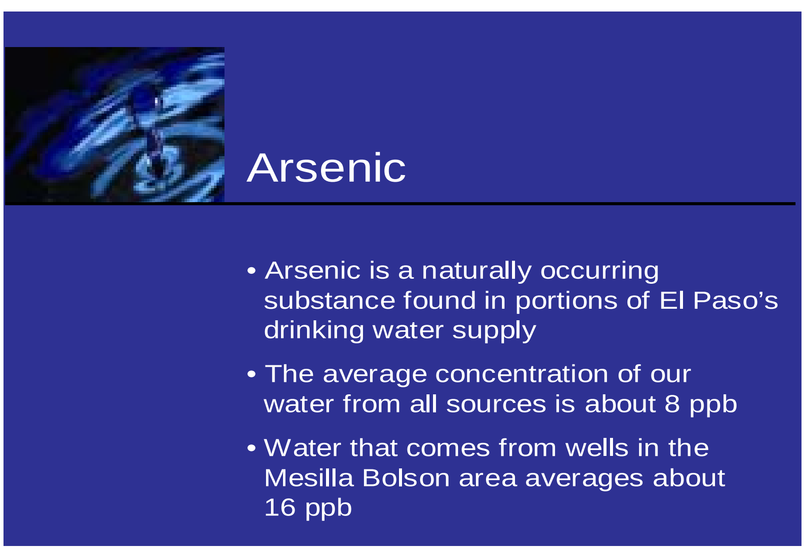
- Well capacity of 135 mgd is planned for at the 95% confidence level
- Total well capacity is 145 mgd
- Allowances made for normal downtime for preventive and scheduled maintenance of wells

Three Year AVG. Daily Consumption Compared to 135 MGD Production and 235 MGD Total Production

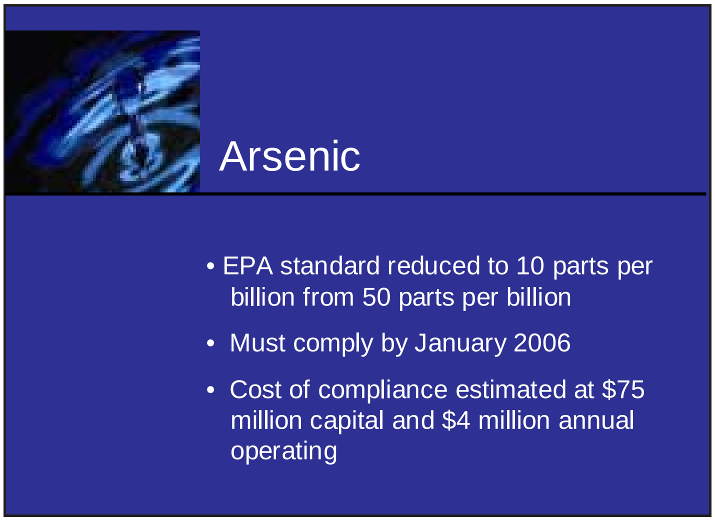


Total Surface Water





Arsenic is a naturally occurring substance found in El Paso's drinking water supply. The average concentration of our water from all sources is about 8 ppb; however, the water that comes from wells in the Mesilla Bolson area averages about 16 ppb.



The U.S. Environmental Protection Agency has reduced the federal standard for arsenic, which was 50 parts per billion for more than 50 years, to 10 parts per billion. Water utilities must comply by January 2006.

We are testing arsenic removal technology at a pilot plant in Canutillo. This is one of our first steps in complying with the regulation. Despite our plan to implement the most cost-effective strategies, we estimate that the cost of compliance may be as high as $75 million in capital costs and $4 million in operating costs. This will translate into a 13 percent water rate increase.

We will continue our leadership in regional and binational planning. Our success depends on cooperation from both the municipal and agricultural sectors.

We will continue to seek grants and low interest loans, but our customers will see their rates increase dramatically in the coming years, primarily due to growth, new regulations, and the development of new supplies.

__Len Stokes__ is President of Progressive Environmental Systems, Inc. He consults in the areas of water, wastewater, and environmental issues. Len is originally from the Roswell area where his family has been active in ranching and farming, and the construction industry for many years. He attended New Mexico Military Institute and New Mexico State University. He has managed the design, permitting, and construction of four major solid waste landfills in southern New Mexico. He has also served as project manager on three wastewater treatment plants in the state. For the past eight years, Len has focused primarily on water supply and water rights issues. He serves as consultant, facilitator, project manager, and as a legislative lobbyist for his clients on those issues. Currently, his clients include the City of Las Cruces, the City of Alamogordo, the Lea County Water Users Association, and the Village of Ruidoso.

HOW A SMALL TOWN IS DEALING WITH DROUGHT CONDITIONS

Len Stokes
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ABSTRACT

Most small towns in New Mexico face serious water supply problems. These problems range from lack of water supply, to lack of infrastructure, to pollution of the supply source. The one thing that is common among all small towns is a lack of financial resources to deal with the problems.

The lack of water supply can be caused by drought, by changing watershed conditions, by growth or lack of planning for that growth, or by a water supply that was expected to last forever coming to an end. Some small towns have water rights problems. However, most have "wet water" supply problems. One solution is for the water to run uphill to the money. All we need is the money.

Infrastructure problems and pollution problems are the same. There are remedies if there is capital.

One of the major problems facing many communities today is the administrative process involving appropriation of water, or transfer of water to municipal use. The current policy of allowing anyone and their dog fifty miles from the point in question to protest and have standing in the process is killing municipalities (especially small ones). This must be changed.

There are several possible solutions to the money problem available:

1. Municipalities must charge for the true cost of water.
2. The Water Trust Fund needs to dedicate a large portion of its funding to small municipalities.
3. The State Legislature needs to realize the problems facing these communities and take the steps to help them.

David Cowley *is an Assistant Professor in the Department of Fishery and Wildlife Sciences at New Mexico State University where he teaches ecology of inland waters and wildlife law, policy, and administration. His research integrates a broad perspective in fishery biology with extensive training in population genetics to develop pragmatic conservation strategies for rare species of aquatic organisms. Dave received the Young Investigator Prize from the American Society of Naturalists in 1988, and in 2001, the New Mexico Department of Game and Fish recognized him for his contributions to Rio Grande cutthroat trout management. He is a member of the American Fisheries Society, the American Institute of Fishery Research Biologists, the Society for Conservation Biology, and the American Association for the Advancement of Science. A graduate of Hot Springs High School in Truth or Consequences, Dave completed B.S. and M.S. degrees from Eastern New Mexico University, received his Ph.D. from the University of Wisconsin-Madison, and conducted postdoctoral research in genetics at North Carolina State University. He worked nine years as a self-employed consultant before joining the faculty at NMSU in 2001.*

WATER REQUIREMENTS FOR ENDANGERED SPECIES - RIO GRANDE SILVERY MINNOW (*HYBOGNATHUS AMARUS*)

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ABSTRACT

The biology of many endangered species is poorly known. This is well illustrated by the critically endangered Rio Grande silvery minnow. Clear understanding is lacking of its food habits, cover requirements, where and how it reproduces, river channel features that improve juvenile recruitment, and if the species retains sufficient genetic diversity to continue its evolutionary sojourn. It is well known that the Rio Grande silvery minnow's eggs and larvae can be transported downstream. Downstream transport in one phase of the life history must be offset by upstream passage, otherwise extinction is inevitable. Prior to 1975, the species was sustained in the middle Rio Grande by having an upstream source population in the perennially wetted reach from Algodones to Española and Abiquiu. Recurring dry riverbeds during this time did not have a large negative effect on the Rio Grande silvery minnow because it was often found to be an abundant species in the middle Rio Grande. Closure of Cochiti Dam in 1975 led to the loss of the upstream source population and to greater

modification of the river flows. The species currently has a high vulnerability to extinction because it is forced to live in reaches that have often gone dry in the past. Recovery of the species would be enhanced by (1) restoring the species upstream from Cochiti, (2) removal or re-engineering of Cochiti Dam to provide fish passage, (3) providing upstream passage at downstream diversions in the lower river reaches, and (4) developing naturalized refugial habitats in the lower desiccation-prone reaches. The parsimony here is that the Rio Grande silvery minnow and the valley's farmers coexisted for many years prior to Cochiti Dam without supplemental water for the minnow.

INTRODUCTION

Population growth in New Mexico has long been concentrated in the Rio Grande valley. Pueblo settlements arose in the valley, followed by Spanish settlements such as Las Cruces, Albuquerque, Bernalillo, Santa Fe, Española, and Taos. The settlement pattern under Spanish rule was the issuance of small land grants, first up the larger Rio Grande and Rio Chama, and then into mountain valleys with smaller tributary water sources (Scurlock 1986). Throughout the history of human occupation of New Mexico, population growth has been concentrated proximally to surface and groundwater supplies.

As towns grew into cities along the Rio Grande valley, demand for water elevated the depletions from surface and groundwaters from the river basin. Increased depletions elevated the stress on water supplies that contributed along with many other factors to the decline of native aquatic species. Today, long-standing human settlements across the American West, with their agricultural and urban uses of land and water, have begun to face the possibility of giving up water to save an endangered species (Adams and Cho 1998; Parker 2002).

Within the middle Rio Grande valley the fight for "water for the river" versus "water for traditional uses" is centered on water from the San Juan-Chama Project, an interbasin transfer of water across the Continental Divide. Since project completion in the 1970s, a number of cities and agencies contracted for depletion of the water transferred by the project. The availability of additional water encouraged populations of Santa Fe and Albuquerque to grow beyond their supplies of native Rio Grande basin water.

Agricultural interests in the middle Rio Grande valley have also used water from the San Juan-Chama Project. These supplies have provided a reserve in times of drought but they have not fueled growth in agriculture in the way that project water has aided urban population growth.

Demands and shortfalls of water in the middle Rio Grande valley have increased with population growth. Whereas agriculture and the Rio Grande silvery minnow survived together for many decades, burgeoning city limits have begun to convert historical farms into subdivisions and shopping malls. Increasing urban growth seems likely to further exacerbate stress on water supplies and the cascading negative effects on aquatic biota (Jackson et al. 2001).

This paper will address four topics related to water requirements for the Rio Grande silvery minnow and other pelagic-spawning fishes whose eggs and larvae drift passively downstream. First, the biology of the Rio Grande silvery minnow will be reviewed. Second, information from historical data will be used to develop a perspective for the water requirements for the endangered Rio Grande silvery minnow. Third, the water requirements for the Rio Grande silvery minnow will be deduced from biological information and contemporary records. Finally, recommendations will be made to facilitate short-term survival of the Rio Grande silvery minnow through extended shortfalls of water.

BIOLOGY OF THE RIO GRANDE SILVERY MINNOW

The Rio Grande silvery minnow [*Hybognathus amarus* (Girard 1856; Bestgen and Propst 1996)] is native to the Rio Grande basin. Its historical range on the Rio Grande was from near Española, New Mexico to the Gulf of Mexico (Figure 1) and on the Pecos River from near Santa Rosa, New Mexico to its confluence with the Rio Grande. The species appears to have been lost from the Pecos River by the late 1970s (Cowley 1979; Cowley and Sublette 1987). Currently the Rio Grande silvery minnow is restricted to the middle Rio Grande valley between Cochiti Dam and the headwaters of Elephant Butte Lake.[1] The species was listed as federally endangered in 1994 (U.S. Dept. of Interior 1994).

The Rio Grande silvery minnow is a member of a reproductive guild of fishes called pelagophils (Balon 1975). Pelagophilic spawners reproduce in open water and produce nonadhesive semi-buoyant pelagic eggs

(Moore 1944) that float downstream as they develop (Platania and Altenbach 1998). Concentrated saline or turbid, sediment-laden water can cause the eggs to float and modest current velocities can transport the eggs downstream. These species typically have a rapid mode of embryonic development and hatching can occur within 24-48 hours depending on water temperature (Moore 1944; Bottrell et al. 1964; Platania and Altenbach 1998). Thus, the life cycle of the Rio Grande silvery minnow consists of downstream displacement of eggs and larvae followed by upstream passage of juveniles and adults.

Other aspects of their biology are poorly known. It is assumed that Rio Grande silvery minnows are herbivorous since they possess a long coiled gut typical of other herbivorous minnows (Sublette et al. 1990). Unfortunately, their food habits have never been documented. This deficit in basic biology makes it difficult to assess if their food base in the river has changed from earlier times when the minnow was more widespread. Likewise, it is not possible to determine if the presence of nonnative salt cedar or the lack of large woody debris in the river limits food availability.

Biologists have devised ways to learn the habitat requirements for a species. However, it is difficult or impossible to deduce preferred environmental conditions for an endangered species when its habitats have been highly modified. As a result, we lack understanding of what channel features provide the best cover for Rio Grande silvery minnows. We do not know how sediment transport and deposition affects cover availability nor can we assess if the conversion of the middle Rio Grande into a floodway adversely affected the availability of cover.

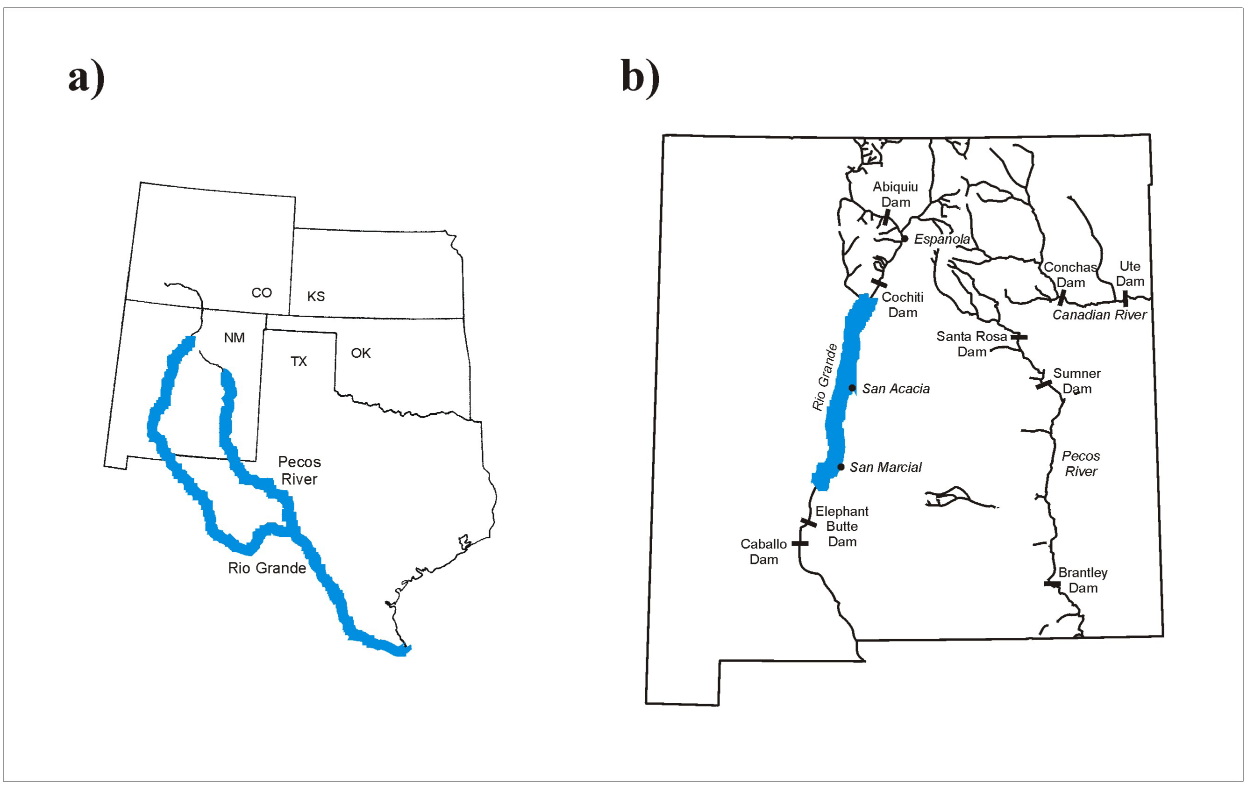

Figure 1. Historical (a) and contemporary (b) distributions of the Rio Grande silvery minnow are shown as thickened lines.

Aside from the basic knowledge of its life history, we know little about how Rio Grande silvery minnows reproduce. We do not know where they spawn in the river channel, what current velocity or channel depth they seek out, or how they find each other in a turbid river. Studies have not assessed the effects of hormones and their derivatives in sewage effluent on the minnow's reproduction. From a population dynamics perspective, it is unknown if there is a quasi-extinction threshold for the Rio Grande silvery minnow beneath which the minnows would have a very low probability of finding a mate.

Additional aspects of their biology are also unknown. For example, what channel features retain eggs and larval silvery minnows and stop their downstream drift? Are backwaters essential to recruitment? Is recruitment affected by predation from mosquitofish, carp, or nonnative game fish like white bass? Answers to these questions are critically important considerations for habitat restoration.

Questions remain regarding the genetic integrity of the Rio Grande silvery minnow. Does the species retain sufficient genetic diversity to continue its evolutionary sojourn? Should we expect deleterious effects from inbreeding to accrue in captive stocks or in the wild? Will propagation in captivity further erode their genetic diversity and continue the trend toward extinction? Is there evidence that Rio Grande silvery minnows in the Rio Grande have hybridized with Plains minnows as was found in the Pecos River (Cook et al. 1992)?

In spite of the vague and poorly known biology of the Rio Grande silvery minnow, it is possible to deduce approximations to their water requirements. In the following sections, historical and contemporary sources of information are evaluated to elucidate the water requirements of the Rio Grande silvery minnow.

RIVER MODIFICATIONS

In order to discuss water requirements for an endangered species of fish like the Rio Grande silvery minnow, it is informative to consider the history of river modification in the Rio Grande valley and the effect of drought conditions on the flows of the river. Three significant activities are relevant: irrigation diversions in the upper regions of the Rio Grande basin, construction of dams, and canalization of the middle Rio Grande.

Irrigation has a long history in the Rio Grande valley of New Mexico that extends back to the 1400s (Scurlock 1998). The first small-scale irrigation networks were constructed by Native Americans and led to a sizeable acreage under cultivation; perhaps as much as 30,000 acres were irrigated by pueblo residents by the late 1500s (Scurlock 1998). The Spanish introduced ditch irrigation to New Mexico in the early 1600s and it has been estimated that 125,000 acres of farmland were being irrigated in the middle Rio Grande valley by 1848. Presently there are about 57,000 acres under irrigation in the middle Rio Grande valley (Clark 1987; Wozniak 1987; DuMars and Nunn 1993).

Large-scale irrigation diversions on the upper Rio Grande began in Colorado during the late 1870s and early 1880s.[2] These diversions reduced river flows in the Rio Grande of New Mexico and when combined with significant soil erosion from heavily used rangelands, aggradation[3] of the river channel began in the vicinity of Albuquerque and areas downstream. As the river bed increased in elevation, flooding became more prevalent and soils formerly irrigated for crop production became waterlogged. The engineering solution to the flooding problem in the middle Rio Grande valley was two-fold. Dams were constructed to capture sediment and drains were excavated to alleviate soil saturation. Four sediment control dams were constructed: Jemez Canyon Dam (1954), Abiquiu Dam (1963), Galisteo Dam (1970), and Cochiti Dam (1975). Over four hundred miles of drains were excavated between Cochiti and Elephant Butte Lake.

The engineers were successful in capturing sediment and degradation[4] of the riverbed began from Albuquerque to past Socorro. As riverbed elevation dropped[4], irrigation diversions became barriers to upstream movement of fish (Figure 2) including the Rio Grande silvery minnow. Controlling sediment transport and regulating flows with dams fragmented the formerly connected habitat of Rio Grande silvery minnow into shorter segments. Recent population trends suggest that these shorter reaches of river may be insufficient to sustain a population of pelagic-spawning minnows (M. Hatch, personal communication).

Additional modifications to the Rio Grande occurred that were detrimental to the native fishes. Following the drought of the 1950s, the engineers set

Figure 2. San Acacia diversion weir, viewed from a downstream perspective, is currently a barrier to upstream fish passage. *(photo by D. Cowley, Nov. 23, 2002*)

out solve another problem. How could more water be delivered to Elephant Butte Lake?[5] The solution was to construct the Low Flow Conveyance Channel (LFCC) from San Acacia downstream to Elephant Butte Lake. The LFCC was excavated in the bottom of the valley roughly following the river channel at the time. It acted as a levee confining the present-day river channel to the higher, eastern side of the valley.

The LFCC was designed so that at low flow conditions, all of the river's flow could be diverted at San Acacia and moved downstream through a channel shorter than the river channel. It has not been fully operated since 1985 because of outfall problems at Elephant Butte Reservoir. Presently the LFCC functions as a large drain that grows in discharge with proximity to Elephant Butte Reservoir. The draining action of the LFCC and the confinement of the river channel to the higher eastern side of the river valley has made it even more difficult to maintain water in the river when drought occurs. The Biological Opinion for Rio Grande silvery minnow (U.S. Fish and Wildlife Service 2001) promotes pumping water out of the LFCC to help maintain a wet river channel lower in the valley. This has proven to be an expensive struggle against gravity.[6]

HISTORICAL RECORDS OF CHANNEL DESICCATION

A review of historical records indicates clearly that channel drying was a frequent event. Observations of channel desiccation during the 19^{th} century are recorded in a Senate document (U.S. Senate 1898, see Table 1). The observations in 1851, 1861, and 1879 predate the over-appropriations of Rio Grande flows that occurred in the San Luis Valley of Colorado. Considerable angst was expressed in 2002 regarding the possibility of the Rio Grande drying in the Albuquerque area. In spite of extensive and prolonged periods of channel desiccation in the 1890s that dried the river channel in the Albuquerque area for nearly three months in 1896, the Rio Grande silvery minnow persisted handsomely into the 1900s. It was often found to be extremely abundant in the middle Rio Grande.

Table 1. Historical records of channel desiccation in the middle Rio Grande valley during the 19th century (U.S. Senate 1898).

Year	Reach with Dry Riverbed	Notes
1851	Las Cruces	river dry for about 1 month
1861	Socorro to El Paso	
1879	Los Lunas to El Paso	dry 2 weeks at Los Lunas, 6 weeks at Socorro to Palomas, and 3 months at Las Cruces
1889	Socorro to El Paso	dry at El Paso for 5 months
1892	Los Lunas to El Paso	dry July 1-September 20 at Los Lunas
1894	Albuquerque to El Paso	dry 4 weeks at Albuquerque, 6 weeks at Los Lunas
1895	Socorro to La Mesilla	dry 2 weeks at Socorro, 6 weeks at La Mesilla
1896	Albuquerque to El Paso	dry June 22-September 19 at Albuquerque

Flow records on the middle Rio Grande during the 1900s were examined from gage station data (U.S. Geological Survey). The San Acacia and San Marcial gage data were of special interest because the Biological Opinion for Rio Grande silvery minnow established base flow requirements at these sites (U.S. Fish and Wildlife Service 2001).

During the 63-year period of record examined (May 1, 1936 through September 30, 1999), the Rio Grande had no flow 49 times at San Acacia and 225 times at San Marcial. Total days of no river flow were 347 at San Acacia and 6998 at San Marcial. The longest dry period was 60 days at San Acacia and 608 days at San Marcial. From these gage data, it is clear that the frequency of riverbed drying increased with distance downstream from San Acacia.

Another way to view the frequency of drought in the middle Rio Grande valley is to consider gage data at a site just upstream from the valley. The longest running period of record for gage data on the Rio Grande in New Mexico, 103 years, is at the Embudo gage. These data are used to study the probability of successive years of drought.[7]

Gage data (personal communication, Michael Hatch and Viola Sanchez, U.S. Bureau of Reclamation) indicate that two successive years of below average annual discharge occurred 25 times during the period of record for the Embudo gage; hence, the probability of two successive years of drought as deduced from historical data is about 24% (25/102). Three successive drought years occurred about 13% of the time. Four consecutive years of drought flows occurred five times at the Embudo gage.

It is clear that drought conditions are common in the Rio Grande basin. Rio Grande silvery minnow survived repeated droughts that dried lengthy reaches of riverbed in New Mexico for significant periods of time yet the species rebounded many times to become very abundant in downstream reaches.

It was a significant accomplishment for the Rio Grande silvery minnow to survive at least 125 years of recurring channel desiccation in the middle Rio Grande valley. The species biology and life history features facilitated its persistence. Prior to the closure of Cochiti Dam in 1975, the Rio Grande silvery minnow occurred up through the Cochiti reach all the way to at least Española and up the Chama River to near Abiquiu Dam. This upstream reach, thought to have been wet perennially (U.S. Fish and Wildlife Service 2001), supported a core population of the Rio Grande silvery minnow that enabled the species to survive extended drought conditions that dried the river as far northward as Albuquerque. During wetter years in the upper and middle Rio Grande, the pelagic spawning life history of the minnow enabled it to rapidly recolonize downstream reaches from which it was probably extirpated during extended drought.

Following closure of Cochiti Dam, the core upstream population of the Rio Grande silvery minnow was lost and a downward trend began in the remainder of the silvery minnow population. Whereas the minnow had endured significant, repeated channel desiccation events prior to Cochiti Dam, Cochiti Dam appears to have been the trigger toward extinction.

WATER REQUIREMENTS OF THE RIO GRANDE SILVERY MINNOW

In spite of the deep deficits in biological knowledge for Rio Grande silvery minnow, one can deduce general aspects about the water requirements for pelagic-spawning minnows. Recovery of the Rio Grande silvery minnow requires at least three things to occur with respect to wetted habitat requirements: (1) a sufficient number of miles of connected river habitat must be made available for the species to complete its life cycle, (2) at least some portion of the upstream end of that habitat needs to remain wet even during deep drought, and (3) individuals displaced downstream need the ability to reach upstream spawning places. All of these factors are critical for survival of the Rio Grande silvery minnow because its life history embraces downstream transport. It is a fundamental fact known as the "Drift Paradox" (Hershey et al. 1993) that extinction is inevitable if downstream drift is the only transport process (Speirs and Gurney 2001).

To estimate the length of connected habitat necessary to support pelagic-spawning minnows, data are examined for contemporary river reaches between reservoirs. River reaches that support one or more species of pelagic-spawning minnows are informative if some of those species have viable populations. Summaries of the distances between dams are shown on Figure 3.

Approximately 220 miles of connected habitat on the Pecos River (Figure 3) between Sumner Dam and Brantley Lake support five pelagic-spawning minnow species. The three native species include Rio Grande shiner (*Notropis jemezanus*), Pecos bluntnose shiner [*Notropis simus pecosensis*, federally threatened (U.S. Department of Interior 1987)], and speckled chub (*Macrhypobsis aestivalis*). Two of the species are nonnative: Arkansas river shiner (*Notropis girardi*) and plains minnow (*Hybognathus placitus*). No native or nonnative pelagic-spawning minnows remain in the 47 miles between Santa Rosa Dam and Sumner Reservoir.

About 148 miles (Figure 3) between Ute Dam in eastern New Mexico and Meredith Lake in the Texas panhandle support three native pelagic-spawning cyprinids. These include Arkansas River shiner, plains minnow, and four-barbled chub (*Macryhybopsis tetranemus*). Native pelagophils have been lost in the 58 mile reach between Conchas Dam and Ute Reservoir and no native pelagophils occupy the 130 miles of the Canadian River upstream from Conchas Reservoir.

Historically, the middle Rio Grande supported five pelagic-spawning minnow species (Sublette et al. 1990): Rio Grande shiner, Rio Grande bluntnose shiner (*Notropis simus simus*), speckled chub, and Rio Grande silvery minnow. The Rio Grande subspecies of bluntnose shiner went extinct in the 1960s and the speckled chub and Rio Grande shiner were extirpated from the Rio Grande about the same time (Sublette et al. 1990). Whereas the other pelagophils in the middle Rio Grande valley were extirpated before the closure of Cochiti Dam in 1975,[8] the Rio Grande silvery minnow became critically endangered after 1975.

Given that Rio Grande bluntnose shiner, speckled chub, and Rio Grande shiner survived in the middle Rio Grande valley for about 50 years after closure of Elephant Butte Dam (1916), it seems reasonable to conclude that the 205 miles of river between Española and Elephant Butte Reservoir were sufficient to support the four native pelagic-spawning minnows. There were several notable events prior to their extirpation in the 1960s: (1) an enduring drought occurred through most of the 1950s, (2) Jemez Canyon Dam was closed in 1954, and (3) Abiquiu Dam was closed in 1963.

The short distances shown on the Rio Grande (Figure 3) are between irrigation diversions. From north to south, areas not supporting a viable population of Rio Grande silvery minnows include 42 miles upstream of Cochiti Lake, 22 miles between Cochiti Dam and Angostura diversion, 40 miles between the Angostura and Isleta diversions, 53 miles between the Isleta and San Acacia diversions, and 56 miles from San Acacia diversion to Elephant Butte Reservoir. None of these distances appear to be sufficient in length to support a viable population of Rio Grande silvery minnow.

Other factors besides the miles of connected habitat may determine if pelagic-spawning minnows can survive over the long term. The length of connected habitat needed for a self-sustaining population is affected by biological features such as the specific gravity (buoyancy) of the eggs, the swimming ability of the species, and its life expectancy. Physical features of the channel like discharge, current velocity, channel complexity, and perhaps also sediment load and salinity may also affect habitat length. The conversion of the middle Rio Grande to a floodway following the closure of Cochiti

Dam probably reduced channel complexity to the point that the Rio Grande silvery minnow is no longer able to sustain its populations.

In summary, the contemporary river reaches on the Rio Grande, Pecos, and Canadian rivers suggest the following: (1) the Rio Grande silvery minnow survived historical droughts that shortened its occupied habitat in the middle Rio Grande valley to 75-80 miles (Albuquerque to Española); (2) different species may require different lengths of connected habitat (Rio Grande silvery minnow, Rio Grande shiner-speckled chub-bluntnose shiner); (3) flow regulations may have greater effects on Rio Grande bluntnose shiner, speckled chub, and Rio Grande shiner than on Rio Grande silvery minnow; and (4) short reaches of connected habitat less than about 60 miles appear to be insufficient to support pelagic-spawning minnows, especially in modified river channels.

In the author's opinion, several things need to happen to ensure the long-term survival of Rio Grande silvery minnow. First, barriers to upstream movement must be alleviated. Second, restoring the upstream source population in a permanently wetted reach of river will improve the chance that the Rio Grande silvery minnow will not go extinct. In order to provide an upstream source population like was once present, one that persisted through repeated channel drying events, the population upstream of Cochiti Dam needs to be restored. Restoration of the source population will require modifying Cochiti Dam to reconnect upstream and downstream reaches. Such an approach might forego the impoundment of water in Cochiti Lake while minimizing destructive flooding downstream and encouraging beneficial flooding.

Modifying Cochiti Dam as suggested above could provide two benefits. First, it may yield a better chance at avoiding extinction of the Rio Grande silvery minnow by restoring the species to permanently wetted habitat. Second, it would require far less water be taken from human use for recovery of Rio Grande silvery minnow, which is focused according to the recovery plan, in the desiccation-prone reach of river between Albuquerque and Elephant Butte Reservoir. A clear disadvantage of these recommendations is that implementing them will require a significant amount of study, public debate, and time. The Rio Grande silvery minnow is likely too vulnerable to extinction to discontinue on-going recovery activities. One could argue that additional recovery efforts are needed in downstream reaches of the middle Rio Grande valley to help the minnow avoid extinction caused by drought-related channel drying.

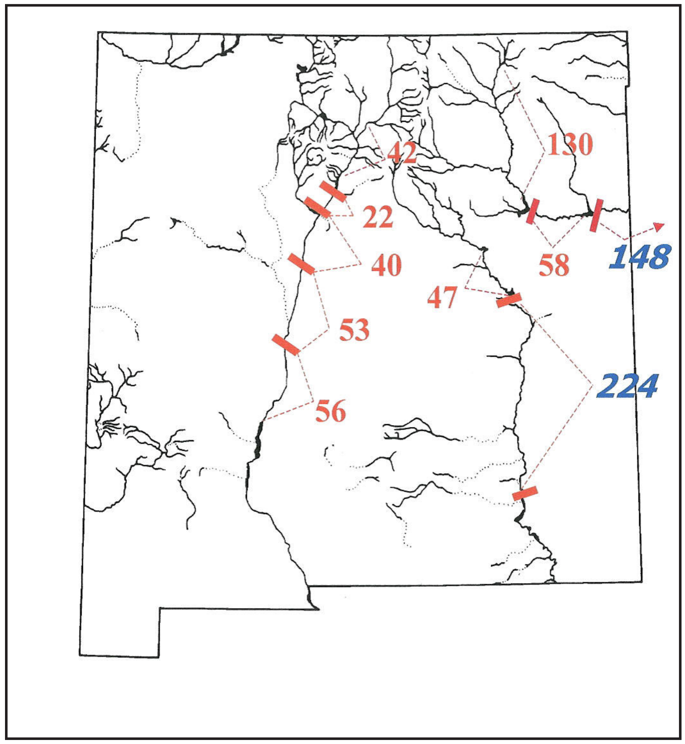

Figure 3. Miles of connected habitat between dams are shown for the Rio Grande, Pecos, and Canadian rivers.

REFUGES FOR RIO GRANDE SILVERY MINNOW

Refugial habitats are needed to promote short-term survival of the Rio Grande silvery minnow during periods of drought. Refugia on irrigation structures could address two problems, (1) provision of wetted habitats when the main river channel dries during extended drought and (2) entrainment of eggs, larvae and minnows into irrigation ditches. This paper concludes with some ideas on using existing agricultural irrigation ditches and drains to facilitate short term survival of the Rio Grande silvery minnow.

Concept for Refugial Habitats: Figure 4 shows a hypothetical deployment of conservation structures on an irrigation district. ***Propagaria***, or propagation aquaria, are installed as small diversions off a main irrigation delivery ditch very near its origin, close to a diversion dam. Depending on the distance back to the river, more than one propagarium could be installed on a single diversion. The diversions off the main ditch that contain propagaria provide a way to recover fertilized eggs, larvae, or minnows that become entrained into the irrigation ditch. A link back to the river ecosystem is shown in Figure 4.

Propagaria could also be constructed along the river channel to provide propagation and nursery areas. If the inlet to propagaria could be designed to capture eggs or larvae drifting downstream in the river, they might significantly shorten the distance that the silvery minnow offspring drift downstream.

Refugia are installed on a drain (Figure 4). The concept with refugial habitats on drains is to provide safe haven for minnows, especially those stranded in isolated river pools during droughts. Multiple refugia could be installed on a single drain.

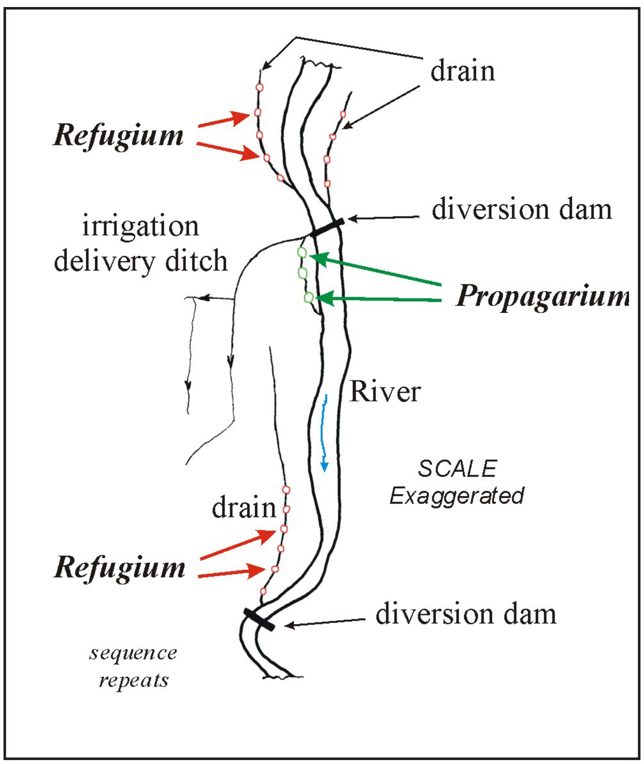

Figure 4. A deployment of refugia and propagaria is shown on a hypothetical irrigation system.

Naturalized Habitats: The ideas presented here for naturalized refugial habitats on irrigation conveyances were stimulated by a visit to the Armendaris Ranch south of Bosque del Apache National Wildlife Refuge and a short distance upstream from the headwaters of Elephant Butte Reservoir. After construction of the Low Flow Conveyance Channel, significant reaches of the Rio Grande were relocated to the eastern side of the valley. Evidence of the former braided and sinuous river channel was apparent from aerial photographs such as the one shown in Figure 5 and on the ground at the Armendaris Ranch.

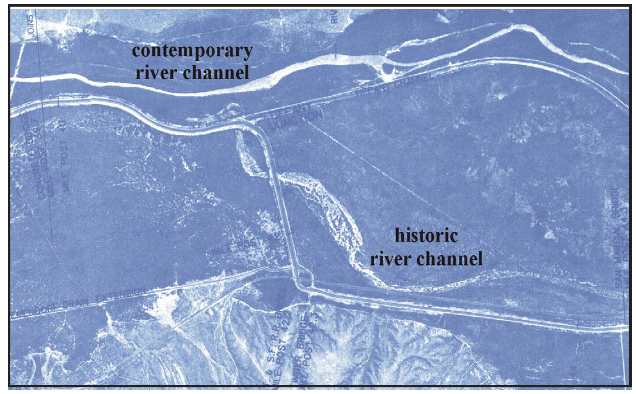

Figure 5. High altitude aerial photographs show historic and contemporary channels of the Rio Grande. [Image was provided by the U.S. Bureau of Reclamation (U.S. Department of Interior, Bureau of Reclamation 1997)].

At ground level, the historic river channel was composed of numerous relatively narrow diverging and converging channels that formed a highly complex, braided river channel. The high degree of channel complexity would have greatly increased the number of river miles of available minnow habitat per linear mile of valley. Many of the former channel braids were found to lie in remnants of the cottonwood bosque on the Armendaris Ranch just south of Bosque del Apache National Wildlife Refuge. Some of the abandoned channels were narrow and deep while others were wider and shallower.

The naturalized features envisioned for the ***Propagarium*** and the ***Refugium*** (Figure 6) are intended to mimic in a general way the abandoned channels of the Rio Grande. Features include a widened channel providing a slow-flowing pool habitat bisected by an island. Lateral shallow benches provide abundant substrate for periphyton colonization. Deep water provides cover from herons and other predators. Islands and borders of inflow and outflow channels provide native riparian vegetation and organic inputs to support a food web. A conceptual plan view of the pool-island feature common to both the ***Refugium*** and the ***Propagarium*** is shown in Figure 6.

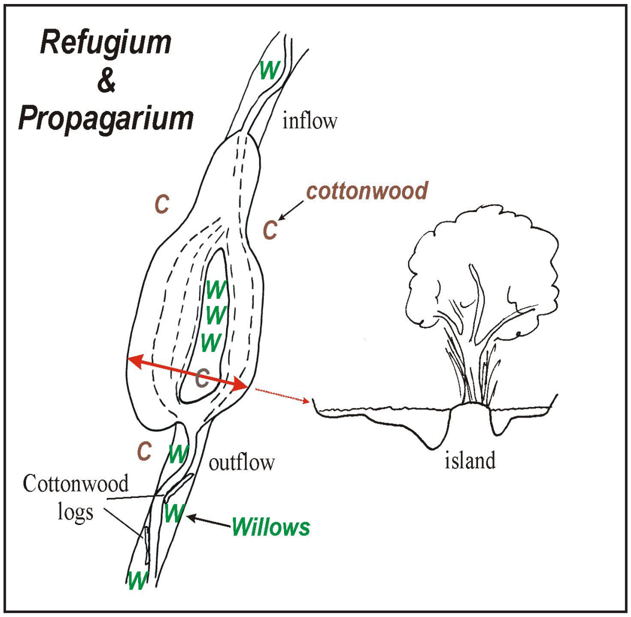

Figure 6. Plan and cross-section views show the naturalized habitats provided by the propagarium and the refugium.

The ***Propagarium*** and ***Refugium*** mimic a 0.15 acre pool on a historic river channel (Figure 6) approximately 120 ft in length and about 60 feet wide. Deep, low-velocity habitats are provided on each side of an island. Riparian vegetation is composed of native willows, cottonwoods, and grasses. Native vegetation proximal to the structure provides organic matter (leaves and twigs) that can support periphyton production, a potential food source for grazer minnows such as *H. amarus*. The riparian vegetation also provides habitat for the endangered Southwestern willow flycatcher.

The new strategy proposed here would provide wetted habitats during drought and it would enable fish eggs, larvae, or adults to be returned to the river after they have become entrained into an irrigation delivery system. Deployment of the proposed structures into irrigation ditches and drains, would provide significant additions of habitat along the river, which should improve retention of minnows in wetted habitats. Refuges on the middle Rio Grande should facilitate short-term survival of the Rio Grande silvery minnow. However, long-term recovery should seek to incorporate recovery actions that complement the minnow's biology. Restoring the upstream core population and re-engineering Cochiti Dam would help recovery of the Rio Grande silvery minnow.

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ENDNOTES

[1] Presently the Rio Grande silvery minnow is not known to occur upstream of Angostura.

[2] These diversions in the upper portion of the basin eventually led to adoption in 1938 of the Rio Grande Compact, an international treaty between the United States and Mexico.

[3] Aggradation is the deposition of sediment. Degradation is erosion of sediment.

[4] Degradation of the riverbed downstream of San Acacia diversion weir was probably accelerated by several causes including: (1) the very high river flows of the mid- to late 1980s associated with a series of El Nino Southern Oscillation events in the Pacific Ocean; (2) invasion of salt cedar and Russian olive that have contributed to stabilization of river banks; (3) the discontinued use of the LFCC beginning in 1985-86; and (4) delivery of nonnative water via the San Juan-Chama Project that elevated flows in the middle Rio Grande.

[5] Elephant Butte Lake is the point of reference for delivery of water to Texas under the Rio Grande Compact.

[6] In FY2001, about 82,700 gallons of diesel fuel was consumed to drive pumps. The estimated FY2002 budget for pumping was $2,037,695 (personal communication, M. Hatch).

[7] A drought year was defined as a year of below average river flow at the Embudo gage, where average flow was calculated over the entire 103 year period of record.

[8] This suggests that different species of pelagic-spawning minnows have different requirements for water.

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PROTECTING ENDANGERED SPECIES, RIVERS, AND HUMANS IN TIMES OF DROUGHT

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Thank you. In the interest of full disclosure, I should say that I also represent the plaintiffs in this Silvery Minnow litigation, which I think makes me not a very popular person. But I am going to try to give a thumbnail sketch of my perspective on the Middle Rio Grande. I wanted to talk about how we might go about protecting endangered species and rivers and people during times of drought. I think it really makes sense to talk about all that has been going on in the Middle Rio Grande–it's a microcosm of all the problems that come up and it's a particularly difficult situation. If we can solve some of the problems we have been dealing with in the Middle Rio Grande, then we probably can extrapolate and take those lessons that we have learned to other rivers and other species around the state.

I should start by saying that I'm pleased to note actually how much I agree with what Dave Cowley just said. In fact, there was a gathering about a year-and-a-half ago of people advocating for the Rio Grande, up and down the entire basin, New Mexico, Texas and Mexico. One thing we all agreed on was that the single most important action to restore the health of the river would be the removal of Cochiti Dam as Dave has suggested, so I will cast a vote for that. But I think we will have to look for other solutions since that one may be a long time in coming.

Just a few words about the history of the Rio Grande, or the Middle Rio Grande. I would like to take it a couple of steps back further in time than the late nineteenth century, which is when the San Luis Valley was developed in Southern Colorado, and New

Mexico lost between a half and two-thirds of the flow of the river that was crossing the state line at that time. Before all that agricultural development, the Middle Rio Grande was a perennially flowing river with a braided channel that would migrate back and forth across the flood plain. It supported a very dense cottonwood-willow bosque and an awful lot of fish and wildlife. Of course, the flow levels have always been highly variable depending both on seasons and on climate. But the evidence seems to indicate that before the late nineteenth century, even during the most extended periods of drought, there probably was water flowing in much of the Middle Rio Grande, and there certainly were deep water holes, which preserved some fish in the river even in times of extended drought. The river was home to an abundance of fish, including some large fish species such as the shovel-nosed sturgeon as well as smaller fish, such as the American eel, speckled chub, Rio Grande shiner, phantom shiner, Rio Grande bluntnose shiner and blue catfish, all of which are gone now.

Even in the sixteenth century when the Spanish arrived there was already significant agricultural diversions by the Pueblo Indians. It's interesting to read some of the Spanish comments about the river in the Middle Rio Grande area. I'm going to give just a couple of quotes: "[A] large and mighty river" that "flows through a broad valley planted with fields of maize and dotted with cottonwood groves" (Albarado, 1540); describing the area just above Elephant Butte, "along the river banks there were many cottonwood groves and some patches of white poplar four leagues wide" (Especjo, 1583); "a deep river" and "the river with much water" (Castano de Sosa, 1590) "swift and beautiful, surrounded by numerous meadows and farms" (Obregon, late 1500s). Even now the bosque in the Middle Rio Grande is the largest intact stretch of native cottonwood-willow bosque anywhere in the southwest.

But the bosque is deteriorating as the cottonwoods that were seeded in the floods of the 1940s are dying off, and as invasive species are coming in. Every year the density of cottonwoods in the Middle Rio Grande is decreasing.

There is also an abundance of wildlife that uses the Middle Rio Grande area. About 400 of the 600 wildlife species that have historically been found in New Mexico have been found in the Middle Rio Grande area. A number of those have already gone extinct or been extirpated from this area. There are 14 species on the state threatened or endangered species list and there are two on the federal list: the ones you have heard a lot about, the Rio Grande silvery minnow and the Southwestern willow flycatcher. Of about 17 fish species that are native to the Rio Grande, at least seven have been extirpated or have become extinct, and those are the seven I listed above.

The Rio Grande silvery minnow was historically one of the most abundant and widespread fish in the Middle Rio Grande. It lived all the way from Española down to the Gulf of Mexico and through the Pecos River. Now however, it has been eliminated from 95 percent of that original habitat and is only located in the 170 miles between Cochiti Dam and Elephant Butte Dam. The whole 170 miles is chopped up by diversion dams. As Dave Cowley said, chopping up a river stretch is definitely a big problem for the silvery minnow. Also, by far the most silvery minnows are in the lower 60 miles below San Acacia Dam, and unfortunately, as statistics also verify, that's the part of the river that dries the most frequently.

Since the silvery minnow was placed on the endangered species list in 1994, notwithstanding lots of efforts, it has continued to decline. The most recent surveys done this year show that it is at the lowest levels ever. There was a brief bump up last year; but it's still at alarmingly low levels.

I know you have heard before -- but it really is true -- the significance of the minnow is not the minnow itself, it really is the canary in the coal-mine. It's the indicator of big problems with the river and the associated ecosystem. We believe that if the silvery minnow goes extinct we will not only lose a minnow, but we will lose a chance to save the Middle Rio Grande and save the bosque. We are very concerned that the Middle Rio Grande will follow the same steps as so many other rivers in the Southwest and turn into a dry wash or a concrete lined ditch. And, of course, the situation is extremely complicated. Officials from the Department of the Interior who have been working on extremely complex water problems all around the west for years, including the Everglades and the California Bay Delta and others, have told me that they think our problems in the Middle Rio Grande are harder than any of those. One of the reasons is that we are using virtually all of our replenishable water supplies even now, and yet every day the population is growing and the need for water is growing. And as the title to this conference denotes, we are dealing with two drought years out of the last three and maybe looking at a lot more.

So how are we going to put this together? How are we going to address this, and how do we improve the health of our rivers and our native fish while still supplying the water that we need? How do we avoid killing our rural farming communities and killing our rivers in order to supply more and more water for our growing cities in the state? Well, that's a really difficult problem, and I'm not sure we can solve it. I think we can, and I think we have made some really important steps forward that we need to continue. Certainly the drought is not making it easy, but we need to redouble our efforts.

First of all we have a collaborative program with most if not all of the stakeholders participating, that is making important progress toward restoring habitat in the Middle Rio Grande and investigating how to help the recovery of the silvery minnow. Also, I believe the silvery minnow federal court litigation has helped provide an engine for that collaborative program to move forward as quickly as possible.

When I think of the things we need to do, I think back to what the high school students were talking about when they read their essays yesterday. In my view, they are wise beyond their years, because they said most of the things we need to do. None of them said that we should let the "Rio Gota" dry up and lose all the fish in that river. They had a lot of other ideas, and those are basically the ideas that we need to put into action. One thing they didn't talk so much about, but I really believe we need to do, is to move forward on our long-term water planning and budgeting. Just letting the private marketplace rule is not going to work here. We are going to lose our rural communities, and we are going to lose our rivers unless we get a state water plan that builds on the regional water plans that are being prepared now, and that we put into action.

We certainly need water conservation in every arena. We have heard today about municipal water conservation. If we could get every city in New Mexico to look closely at what El Paso is doing and what Ruidoso hopefully will be doing, a lot of progress can be made there. We just need to carry it out. I think that is actually one of the easier parts of the puzzle.

One of the more difficult conservation issues is how to conserve water used by riparian vegetation. As you have heard, that is a huge water use. In addition, we need to figure out how to conserve water in the agricultural arena. Both those areas have been very gnarly problems, though I think we are making progress on both. With respect to invasive riparian species, we have learned that when you take them out, you have to replace them with something that uses less water or you are not going to save any water. But we are making progress on that and we can definitely improve, do more research, and get water savings there. Similarly, there are some exciting pilot projects for agricultural water conservation. We definitely cannot delay any longer on that; we have to move forward.

Concerning river habitat restoration, I agree with David Cowley and Subhas Shah, that water is not everything for fish. Fish do need water as we heard– they don't burrow into the riverbed. They need water; but they also need habitat, particularly in areas of the river where there are perennial flows. Those ought to be areas where we need to be doing the most habitat restoration, and we are. There are some exciting projects, but it is going to take quite a bit more work.

Another real key here is re-establishing the silvery minnow in parts of its historic habitat. We need to get out of the situation of having virtually the entire population of an endangered species in a 60-mile river stretch that goes dry very frequently. Obviously that is not going to work over the long-term. So we need to re-establish that fish and hopefully we can re-establish them in parts of their original habitat that have much better perennial flows. The Fish and Wildlife Service is looking at the Big Bend area as a possible location for restocking silvery minnow, although perhaps Texas won't be interested in having the silvery minnow come stay there. The Service is also looking at the Pecos River as a possible location. Since it is unlikely that we will ever take out Cochiti Dam, perhaps there will be some way of building structures whereby fish can migrate up and down past Cochiti Dam and can be re-established upstream of Cochiti.

We are also going to need some federally funded water lease programs to be worked out with the irrigation districts, which are agreeable to them and to farmers. We need voluntary water leasing whereby we can have water go into the river at times and in places where it is most needed.

In the long-run, in terms of water supply, I believe we are going to have to do desalination. We will probably also have to look at moving our water storage away from high evaporation surface reservoirs to underground reservoirs.

I want to speak briefly about the litigation that has been going on and about Judge Parker's recent order requiring some release of water from Heron Reservoir to avoid massive river drying this fall. Unfortunately, it is exactly the kind of court blow-up that we the plaintiffs and a lot of other people have been working very hard to avoid. We did not want this to happen. We tried everything to avoid it, including settlement offers that didn't ask for much water. But it's been a very difficult situation: extreme drought and an extremely imperiled species. We couldn't get anyone to talk about settlement. So we did have to go back to court, because what would have happened is that virtually the entire Middle Rio Grande, which is the only place where the silvery minnow is left, was going to go dry, with the exception of sewage effluent from Albuquerque, and a few miles just below Cochiti Dam, which right now is not good habitat for the silvery minnow. So the plaintiffs had to go back to court and make sure that the few minnows that we still have in the river get through this year. If we lose them, we don't have enough minnows in tanks yet to repopulate the river. No fish species has ever been successfully repopulated into the wild once it has been taken out of the river and put into tanks. Repopulating a river with fish from tanks is particularly difficult when you are talking about a short-lived species like the minnow that basically lives only one year.

Just a couple more things about the court order. Judge Parker–contrary to what the mayor of Albuquerque said–Judge Parker actually chose a middle ground. He didn't even require that the government meet the minimum flows that were specified in the 2001 Biological Opinion. He said, "The Government can let the 60 miles of river between Isleta Dam and San Acacia Dam go dry because I don't want to use too much water." Now it appears that with the rains we had in September, maybe only a small amount of water will be needed to comply with that order. Right now the estimates are that it would take somewhere between 10,000 and 12,000 acre-feet of water to keep much of the river flowing. If you take that amount of water out of Heron Reservoir, it is really not clear that will ever result in any reduced deliveries to the San Juan/Chama contractors. The San Juan/Chama project is not yet fully contracted; there is about 3,000 acre-feet per year that is unallocated. If you can get through four years, then maybe you won't have to reduce deliveries at all.

In conclusion, I would just say that I hope this situation will lead all of us stakeholders to try all the harder to negotiate a solution to this problem for next year and for the following years. Speaking for the plaintiffs, I can say that we would give up Judge Parker's ruling in the snap of a finger if we could get people to agree to some sort of long-term solution to the problems of the Middle Rio Grande. We know that litigation cannot solve these problems; we have to solve them ourselves. Let's use the crisis of the drought to force ourselves to take actions we did not really want to take in order to solve these problems.

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WATER REQUIREMENTS FOR ENDANGERED SPECIES IN NEW MEXICO RIO GRANDE SILVERY MINNOW

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ABSTRACT

The Rio Grande silvery minnow (silvery minnow) was federally listed as endangered under the Endangered Species Act on July 20, 1994 (U.S. Fish and Wildlife Service 1994). The species is also listed by the State of New Mexico as an endangered species.

Historical populations of the silvery minnow were known to have occurred from Española, NM upstream from Cochiti Reservoir; in the downstream portions of the Chama and Jemez Rivers; throughout the Middle (NM) and Lower (TX) Rio Grande to the Gulf of Mexico; and in the Pecos River from Sumner Reservoir (NM) downstream to the confluence with the Rio Grande (TX) (Sublette et al. 1990, Bestgen and Platania 1991). The silvery minnow currently occurs in 170 miles (274 km) of the Rio Grande, from Cochiti Dam downstream to Elephant Butte Reservoir, comprising only five percent of its historic range.

The Federal listing of the silvery minnow, critical habitat designation, publication of the species' recovery plan, legal challenges to the critical habitat designation, the reproposal of critical habitat, legal challenges to the June 29, 2001 Biological Opinion, and the 2001/2002 drought have led to the silvery minnow being vilified or championed by a number of different groups and segments of the population of New Mexico. The species' biological needs cannot be disputed, however, one cannot view the species' needs in a vacuum. The species' needs are more properly examined in relation to the current natural conditions of its habitat (severe drought) and the needs of other species (including other aquatic and non-aquatic species and human considerations such as farming). The duty to conserve and ultimately recover imperilled species such as the silvery minnow is shared by all stakeholders, and this can only occur through collaborative efforts that involve and consider the many needs of the entire ecosystem.

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