New Mexico Universities Working Group on Climate Variability

Moderated by J. Phillip King, New Mexico State University

J. Phillip King, P.E., Ph.D., is Associate Professor and Associate Department Head, Department of Civil Engineering and Associate Director, Institute for Energy and the Environment, at New Mexico State University. He specializes in civil (water resources) and agricultural engineering and teaches graduate and undergraduate courses in computing, water resources engineering, irrigation and drainage, hydraulics, hydrology, geohydrology, hydraulic structures, construction, and engineering economics. Phil has a BS in civil engineering from Berkeley, an MS in agricultural engineering from Colorado State University, an MBA from New Mexico State University, and a Ph.D. in agricultural engineering.

Groundwater Vulnerability Under Climate Change

Peggy Johnson, Principal Hydrologist,
NM Bureau of Geology and Mineral Resources, NM Tech

Peggy Johnson is a Principal Hydrogeologist with the New Mexico Bureau of Geology and Mineral Resources in Socorro, New Mexico. She received her M.S. in hydrology from New Mexico Tech in 1990, and her B.S. in geology from Boise State University at Boise, Idaho in 1987. Her research interests focus on integrating geology, hydrology and geochemical tracers of water flow to characterize basin-scale flow systems. Peggy has 25 years of experience in applied research of the hydrogeology of New Mexico. She has completed numerous hydrogeologic studies in the northern Rio Grande rift, including the Placitas area, the southern Española Basin, and throughout Taos County, with a view toward supporting informed development of groundwater resources.

Groundwater has generally served as a stable water reserve during short-term droughts when surface supplies are depleted. However, where aquifer storage is limited or groundwater levels have been reduced by long-term depletion prior to drought, groundwater becomes less resilient to drought-related shortages. Groundwater research on the effects of climate change consistently indicates that disruption of the precipitation-evapotranspiration balance during long-term drought (decades to centuries), which is predicted for the Southwestern and Western U.S., will fundamentally change the distribution of groundwater recharge and availability. Assessments of groundwater vulnerability to climate change using regional scaling of global climate models project that groundwater resources will be adversely affected even under minimum and average CO2 scenarios. By increasing the global mean temperature (GMT) by a small amount (~1.0 °C), regardless of changes in rainfall, research shows a cascade of possible negative impacts on groundwater resources. These include:

- A large increase in the evaporative demand
- A decrease in soil-water content

- A decrease in water infiltration below the root zone
- Significantly reduced groundwater recharge
- Increased evaporative losses from shallow groundwater and reservoirs
- Increased groundwater pumping

Higher global and regional temperatures and extended severe drought can compound groundwater depletions and put subsurface water reserves at greater risk. This is particularly true in a severe, protracted drought and a warming climate, where already impaired aquifers are under additional stress.

Groundwater vulnerability — The primary threats to groundwater reserves during an increasingly dynamic climate characterized by extreme ranges and temporal shifts in rainfall, temperature and ET are:

Long-term drought —reduced precipitation and increased PET (meteorological drought), and reduced streamflow and groundwater levels (hydrologic drought)

Localized flooding and groundwater level rise — extreme flood events become more common

Rapid depletion —rates of withdrawal far exceed the long-run average recharge ("groundwater mining") and are aggravated by drought-related pumping and growing demand

Groundwater depletion — Groundwater withdrawals and depletions in New Mexico and the Rio Grande Basin are estimated for the period 2000 to 2010 from NMOSE's water-use reports (Technical Report (TR) 51, Wilson and others (2003); TR52, Longworth and others (2008); TR54, Longworth and others (2013)) (Figure 1). Depletions for 2005 and 2010 are estimated from the 2000 depletion-to-withdrawal ratio.

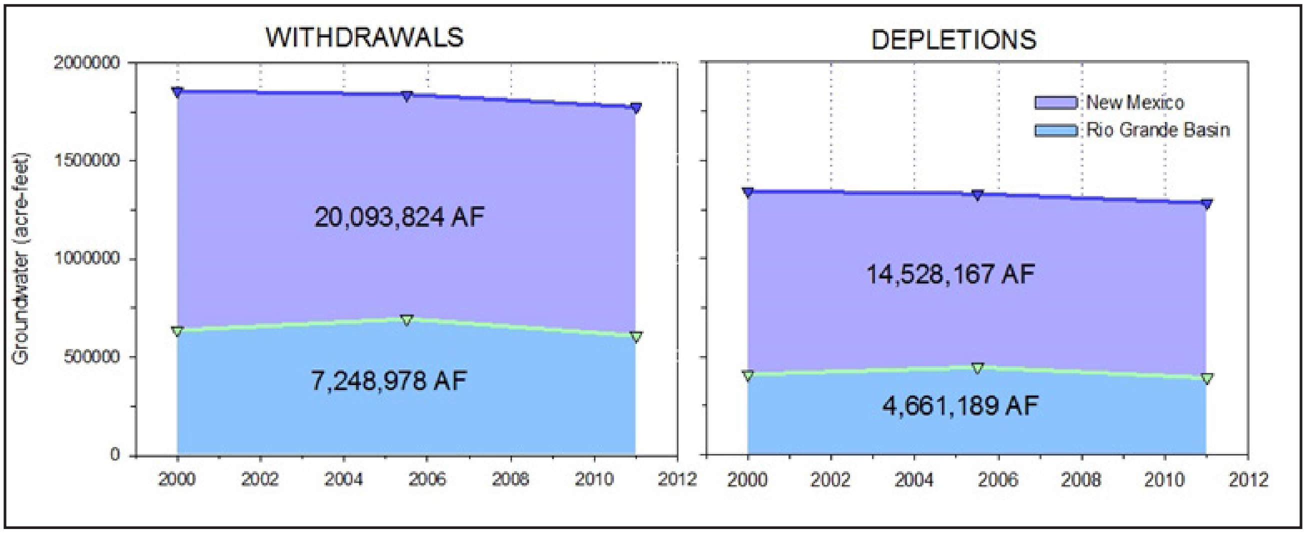
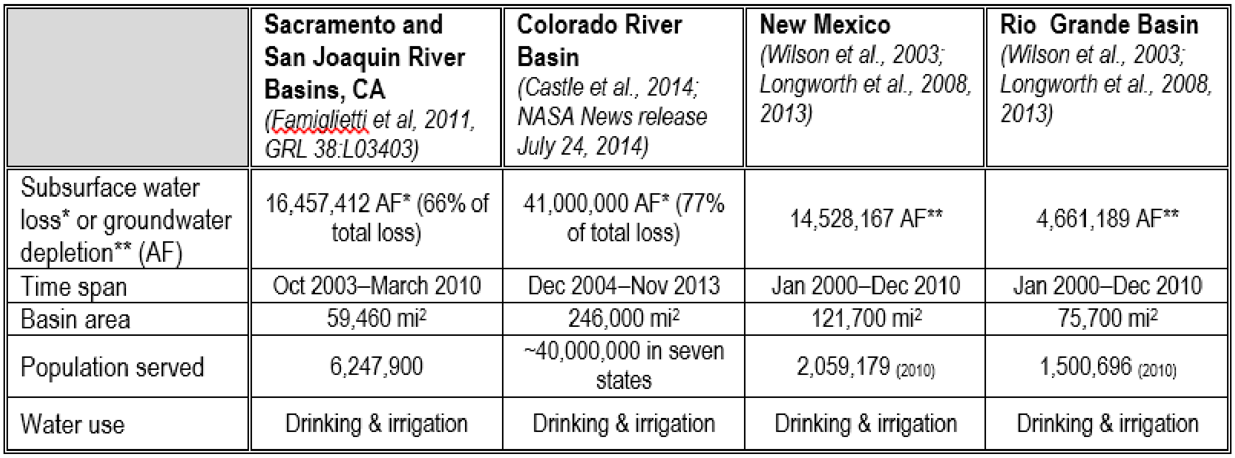


Figure 1. Groundwater withdrawals and depletions estimated for the 11-year period 2000–2010.

Satellite gravimetry data from NASA's Gravity Recovery and Climate Experiment (GRACE) project provide an independent method of estimating changes in total water storage (TWS) and groundwater storage. GRACE-based estimates of groundwater storage losses in California's Sacramento and San Joaquin River Basins and the Colorado River Basin (CRB) are compared with NMOSE-derived depletion estimates in New Mexico (Table 1, Figure 2). Groundwater depletion in the CRB is roughly **9 times** the depletion estimated in the Rio Grande Basin for a comparable time period, but the annual per capita depletion in the RGB (~0.35 AF) is nearly **4 times** that in the CRB (~0.09 AF). Using gravimetry methods to quantify groundwater depletions gives a holistic view of aquifer behavior that is not otherwise possible. Applying the method in New Mexico could influence groundwater management to minimize depletions and improve resilience of the groundwater-surface water system to drought and increasing demand.

Table 1. Groundwater depletions and basin characteristics for New Mexico, the Rio Grande Basin, the Colorado River Basin, and the Sacramento and San Joaquin Basins.



	Sacramento and San Joaquin River Basins, CA *(Famiglietti et al, 2011, GRL 38:L03403)*	**Colorado River Basin** *(Castle et al., 2014; NASA News release July 24, 2014)*	**New Mexico** *(Wilson et al., 2003; Longworth et al., 2008, 2013)*	**Rio Grande Basin** *(Wilson et al., 2003; Longworth et al., 2008, 2013)*
Subsurface water loss* or groundwater depletion** (AF)	16,457,412 AF* (66% of total loss)	41,000,000 AF* (77% of total loss)	14,528,167 AF**	4,661,189 AF**
Time span	Oct 2003–March 2010	Dec 2004–Nov 2013	Jan 2000–Dec 2010	Jan 2000–Dec 2010
Basin area	59,460 mi^2	246,000 mi^2	121,700 mi^2	75,700 mi^2
Population served	6,247,900	~40,000,000 in seven states	2,059,179 (2010)	1,500,696 (2010)
Water use	Drinking & irrigation	Drinking & irrigation	Drinking & irrigation	Drinking & irrigation

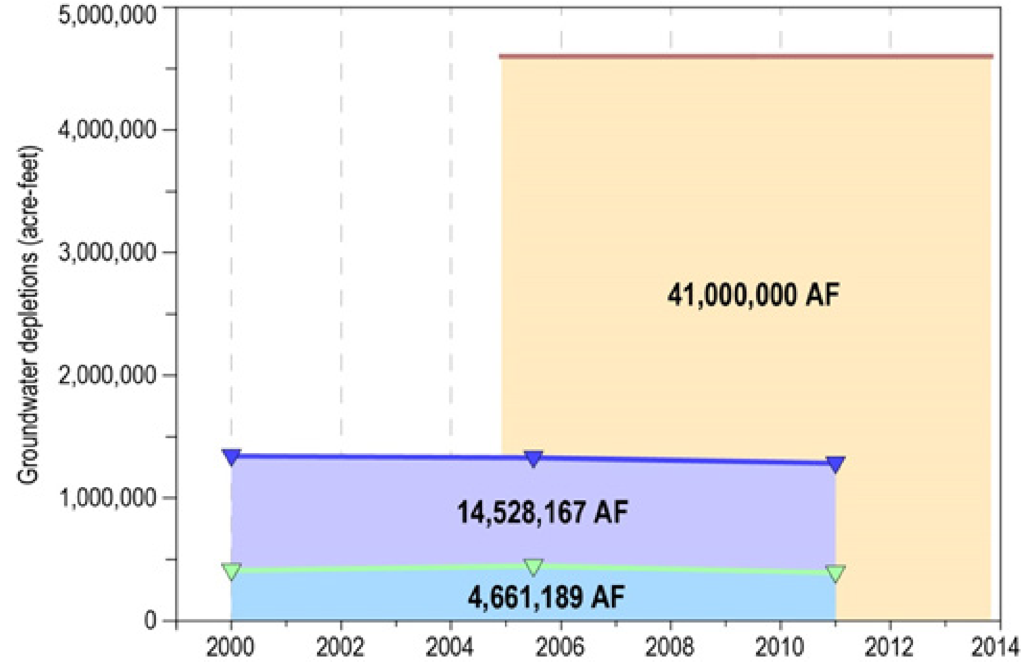


Figure 2. Groundwater depletions in New Mexico and the Rio Grande Basin compared with GRACE-based estimates of subsurface water storage losses in the Colorado River Basin.

The GRACE study in the CRB explored how much water users were relying on groundwater to make up for the limited surface supplies. They found that long-term reliance on groundwater to bridge the supply-demand gap, combined with the 14-year drought, drove the rapid groundwater depletion, which is compounded by leading to further declines in streamflow. The depletions threaten the long-term ability of the basin to meet its water allocation commitments to the seven basin states and Mexico. A similar scenario is occurring in the Rio Grande Basin, where record low streamflow, high seepage and a dropping water table threaten water availability and deliveries.

Resilience versus vulnerability — Negative effects of climate warming and drought are similar for surface water and shallow groundwater (≤30 m). Both resources are affected by lower precipitation, higher temperatures, increasing ET, and shifts in the seasonal distribution of precipitation. Dropping water tables and deep-aquifer storage losses are aggravated during drought due to an increased reliance on groundwater. The consequences include higher seepage losses in connected streams and increased reductions to surface supplies. Shallow groundwater and the streams, wetlands and springs it supports are most vulnerable to climate variability and drought.

Deep aquifers are buffered from the meteorological effects of climate change. However, New Mexico's deep aquifers in alluvial basins with large river systems are heavily used for drinking and irrigation water. They have been "mined" for decades, resulting in pressure and storage losses. These deep systems are vulnerable to rapid, irreversible depletion when subjected to increased drought-related withdrawals.

Groundwater vulnerabilities related to climate variability and megadrought, include:

- Shallow aquifers and decreased flows in interconnected streams, wetlands, and springs
- Water quality degradation in shallow, stream-connected aquifers due to changes in groundwater/surface-water exchange
- Severely reduced heads in deep aquifers can cause or renew land subsidence
- Unplanned increases in groundwater development during drought may become permanent, and aggravate both groundwater depletions and drought-related declines.

References

Vaccaro 1992, JGR 97(3):2821-2833—Columbia River Plateau, current recharge decreases under GCM scenario with CO2 doubling

Rosenberg et al. 1999, Climatic Change 42:677-692—Ogallala Recharge decreases 17-25% with 1.0°C increase in GMT

Bouraoui et al. 1999, Climate Dynamics 15:153-161—Rhône Valley, large increase in PET and decrease in groundwater recharge

Loáiciga et al. 2000, J. Hydrology 227:173-194—Edwards Aquifer TX could be severely impacted by climate warming, even if current average pumping does not increase

New Mexico Universities Working Group on Water Supply Vulnerabilities

Editor's Note: In lieu of a panel discussion, we have included the final report to the Interim Committee on Water and Natural Resources with permission from the authors.

Janie Chermak, Professor and Chair, Department of Economics, The University of New Mexico

Janie Chermak is Professor and Chair of Economics at UNM. Her research interests include natural resource and environmental economics with an emphasis on energy, water, and invasive species, along with interdisciplinary modeling and applied microeconomics. She received a BA in geology from Western State College, and MS and PhD in mineral economics from the Colorado School of Mines. Janie has been at UNM since 1999.

David Gutzler, Professor, Department of Earth and Planetary Sciences, The University of New Mexico

David Gutzler is Professor of Meteorology and Climatology at the University of New Mexico. He and his students combine observed data and large-scale model output to assess the causes of global and regional climate variability, and to improve the skill and application of hydroclimatic predictions on seasonal and longer time scales. He holds degrees from the University of California at Berkeley (B.S., Engineering Physics) and MIT (PhD, Meteorology).

Lee Reynis, Director, Bureau of Business & Economic Research, UNM

Lee A. Reynis is a Research Professor in the Department of Economics at the University of New Mexico and the former Director of the UNM Bureau of Business and Economic Research. She has been a close observer of the New Mexico economy for more than 30 years and participates in the process of developing BBER's consensus forecast using the FOR-UNM model. She holds an M.A. and a Ph.D. in economics from the University of Michigan.

Lee continues to be very involved in the research efforts of BBER where she has served as the prinicipal investigator on a number of projects. She is currently working with other BBER staff and students to analyze the economic impacts of climate variability and drought as BBER's contribution to a Legislative appropriation. She is also heading up an analysis requested by the Middle Rio Grande Conservancy District of their finances and options. And she is also leading up an effort to analyzing the results of a UNM faculty survey on work-life balance.

Before joining the BBER staff as Associate Director in 1998, Lee was the City Economist for the City of Albuquerque. Prior to working for the City, she worked as an economic analyst and then as the Chief Economist for the New Mexico Department of Finance and Administration in Santa Fe. Lee has taught a number of courses over the years at the University of New Mexico and was formerly on the faculty at the University of Utah.

The final report entitled *New Mexico Universities Working Group on Water Supply Vulnerabilities, Final Report to the Interim Committee on Water and Natural Resources* on August 31, 2015 is presented here in its entirety by permission of the authors of the report:

Janie Chermak, Professor of Econimis and Chair of the Department of Economics at the University of New Mexico

David S. Gutzler, Professor of Earth & Planetary Sciences at the University of New Mexico

Peggy Johnson, Principal Hydrogeologist with the New Mexico Bureau of Geology and Mineral Resources at New Mexico Tech

J. Phillip King, John Clark Distinguished Professor and Associate Department Head in the Civil Engineering Department at New Mexico State University

Lee Reynis, Research Professor of Economics attached to the UNM Bureau of Business and Economic Research (BBER)

Gwendolyn Aldrich, natural resource economist and work as a Research Scientist at the UNM Bureau of Business and Economic Research

Michael O'Donnell, Research Scientist at the UNM Bureau of Business and Economic Research.

New Mexico Universities Working Group on Water Supply Vulnerabilities

Final Report to the Interim Committee on Water and Natural Resources

August 31, 2015

Table of Contents

Executive Summary

This Working Group was funded by the State Legislature in 2014 to: (1) assess the current status of water supply and demand after years of severe drought in New Mexico; (2) put the current drought into long-term context with reduced surface water, groundwater depletions, and economic activity; and (3) develop a list of vulnerabilities and promote policy strategies to mitigate these vulnerabilities. Funding for the Working Group uniquely and directly involves researchers from all three research universities in New Mexico, and includes both water and social scientists. We report here on findings generated in Fiscal Year 2014-15, during which we focused on the Lower Rio Grande, which is heavily affected by extremely low water storage in Elephant Butte Reservoir. We have compared the current drought situation with the historical drought of the 1950s, examining hydroclimatic changes that have occurred over the past half-century, which impact surface water and groundwater supplies, and the economic and social impacts of the 1950s and current droughts.

We do not address the ongoing Supreme Court litigation regarding the Rio Grande Compact and Rio Grande Project area. While it certainly is a threat to the economy and water resource management, it is very early in the process, and it is a legal rather than a scientific issue.

Key findings:

- Water storage on the Rio Grande is very low; another year of deficient snowpack and warm temperatures in winter/spring 2015 has led to current forecasts for below-average Rio Grande streamflow in water year (WY) 2015.

- We currently have little prediction skill concerning the demise of multi-year drought. El Niño conditions in the equatorial Pacific belatedly strengthened in spring 2015, shifting the Pacific storm track southward and providing abundant precipitation to the eastern two-thirds of New Mexico over the past several months. However New Mexico's vulnerability to continuation of drought remains high, especially if El Niño does not persist through next winter. Previous long-term droughts, such as occurred in the 1950s, have been both longer and more severe than the current drought in terms of precipitation deficit. The current drought is exceptionally severe in terms of streamflow deficits, associated with much higher temperatures now compared to the 1950s.

- During the past few years of drought, early season streamflow forecasts issued by the U.S. Natural Resources Conservation Service (NRCS) have tended to systematically overestimate subsequent observed flows, making the current WY 2015 water supply outlook potentially even more severe than indicated by the forecasted values. Our research suggests that recent forecast overestimates are associated with above-average temperature in March and April in recent years. March 2015 was exceptionally warm again this year, and the most recent NRCS forecast for the middle Rio Grande is for lower-than-average flow, despite recent spring rainfall.

- Drought has a direct impact on groundwater resources by reducing natural recharge. Drought is also a catalyst for the intensive use of groundwater, which is associated with over pumping and extreme lowering of groundwater levels. An escalation in the number of wells drilled during the 1950s drought contributed to dropping groundwater levels in 1951–1957, but the water table rebounded during the year following the end of the drought.

- The most productive and heavily pumped aquifer zones in the Mesilla Valley, which are about 600 feet thick near Las Cruces, are well integrated with the surface-water system (river channel, canals, and irrigated fields). Current groundwater levels are affected by both deep groundwater pumping (greater than 120 feet) and a reduction in surface recharge.

- The Mesilla Valley aquifer was impaired by groundwater pumping and water table decline prior to the onset of recent drought conditions, and continued in a severe decline during drought years 2008–2014. Between 2002 and June 2015 the combined effects of pumping and drought resulted in a 26-foot water-level decline at one location. The aquifer has not yet recovered, which suggests that the Mesilla Valley aquifer may no longer have the capacity to provide a reliable, supplemental supply during extended drought conditions and with the current levels of intensive use of groundwater.

- The drought of the 1950s was associated with a dramatic shift away from agriculture as the primary driver of the state's economy, as other goods industries like manufacturing and the service sector became more important sources of jobs. The same shift did not occur during the current drought or in the wake of the Great Recession (2008-13). Indeed, according to US Bureau of Economic Analysis statistics, agricultural employment increased by 16.0% statewide while non-farm employment actually declined 2.9%. In Doña Ana County agricultural employment was up 16.8% between 2008 and 2013, while the growth outside of agriculture was only 2.3% over the same period.

- Farm characteristics and agricultural production in southern New Mexico have changed since the 1950s. There are more small farms and production has shifted toward permanent crops, such as pecans, that require long-term water supply commitments to keep trees productive. While profitable, such crops typically have high water demands and decrease the short-term ability to reduce watering in times of severe shortages. However, the economic impact of pecans must be weighed against the water requirements.

- Much of the economic growth in Doña Ana County is occurring near the border in Santa Teresa. During 2014, Union Pacific completed construction on a new intermodal facility at

Santa Teresa on the Sunset Route between Los Angeles and El Paso. The growing concentration of economic activity and population on both sides of the border is creating new demands for water.

Recommendations:

- **C**onsider the entire spread of seasonal streamflow outlooks rather than just the median value, to explicitly account for the possibility of a continuation of forecast overestimates of snowmelt runoff.

- Continue assessment of the principal social and economic vulnerabilities associated with water shortages in the Lower Rio Grande, and update these vulnerabilities as the 2015 water supply situation becomes clearer.

- Initiate development of possible strategies for strengthening long-term resiliency to water shortages by bringing supply and demand closer to balance. Specifically, consider strategies that allow flexibility in times of shortages that consider the physical and the economic impact of the choices.

- Initiate development of possible strategies for addressing short-term deficiencies in surface water supplies based on prudent use of groundwater resources, and cooperate with legislators and water managers in the LRG to develop effective, resilient water policy and practices to be more responsive to short, medium, and long-term fluctuations in available water supply.

- Consider better integrating the management of groundwater and surface water resources by, for example, optimizing the municipal-industrial use of groundwater during severe drought to minimize impacts to surface water and shallow aquifers.

- Investigate feasible means of reducing groundwater pumping and artificially enhancing groundwater recharge in order to mitigate the depletion of groundwater storage.

- Research and assessment of additional water sources should begin immediately. Due to stress imparted upon the region's water supplies by the ongoing drought, it is unlikely that additional freshwaters will be available. Given the availability of brackish water, a desalination plant is an option that should be given serious consideration.

- Implement policies that will aid in the conversion of farmland from flood irrigation to more efficient irrigation methods such as subsurface drip. Seek to develop partnerships between farmers, Elephant Butte Irrigation District (EBID), NRCS, the Bureau of Reclamation, and other relevant agencies to plan and fund water conservation projects that address both delivery system efficiency and on-farm water conservation.

Principal Vulnerabilities:

- Extended, severe drought significantly affects both surface water and groundwater supplies by disrupting the balance between precipitation and evapotranspiration in the hydrologic cycle. All credible projections of 21st century climate call for continued warming in the decades to come. Numerous assessments of groundwater vulnerability to a warming climate project that groundwater resources will be adversely affected by even small increases in temperature, regardless of changes in rainfall. The most significant adverse effects that severe drought and a warming climate have on groundwater resources are: (1) reducing the availability and distribution of groundwater recharge; (2) compounding groundwater depletions with additional pumping; and (3) intensifying groundwater declines that result in a permanent loss of groundwater storage.

- Recent investments and developments in the Santa Teresa, NM area will likely lead to additional businesses (re)locating to the area, and thus to additional population growth. The current water supply is anticipated to meet the area's needs for the next decade only.

- Continuing drought will be increasingly detrimental to agriculture. Various strategies and technologies can be used to increase resiliency to drought, although all require additional expenses that present an additional financial burden, particularly difficult for small farms.

- Economic development and growth that does not consider the interactions and tradeoffs between human activity and the physical realities of water supply (and variability of supply) may result in increasingly severe constraints in times of drought that cannot easily be mitigated.

Introduction

This Working Group was funded by the State Legislature in 2014 to:

1) assess the current status of water supply and demand after years of severe drought in New Mexico;
2) put the current drought into long-term context with reduced surface water, groundwater depletions, and economic activity; and
3) develop a list of vulnerabilities and promote policy strategies to mitigate these vulnerabilities.

The Working Group is unique in composition and directly involves researchers from all three research universities in New Mexico, and includes both water and social scientists. We report here on findings generated in Fiscal Year 2014-15, during which we focused on the Lower Rio Grande. This area is heavily affected by extremely low water storage in Elephant Butte Reservoir, has a strong agricultural component, and a growing and diverse economy. We've compared the current drought situation with the historical drought of the 1950s, examining hydroclimatic changes that have occurred over the past half-century, which impact surface water and groundwater supplies, and the economic and social impacts of the 1950s and current droughts.

We do not address the ongoing litigation in the US Supreme Court. Texas has filed suit against New Mexico over issues regarding the Rio Grande Compact and administration of groundwater in the Lower Rio Grande administrative basin. While the potential economic and water supply impacts of that proceeding on the state of New Mexico in general and the study area in particular are substantial, it is early in the proceeding, and we do not venture into legal analysis or strategy.

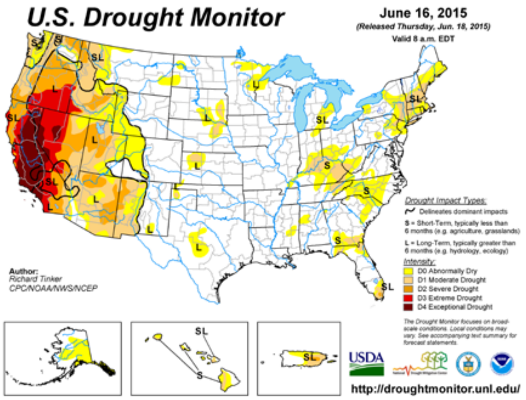


Figure 1. US Drought Monitor (June 16, 2015). The Drought Monitor is a weekly subjective assessment of overall drought severity across the United States, on a scale of no drought (white areas) through five levels of drought (D0-D5). [droughtmonitor.unl.edu]

The severity of drought, defined in terms of precipitation, and associated vulnerability to short-term water shortages varies across the state and can change quickly. The current (June 16, 2015) weekly U.S. Drought Monitor (Figure 1) shows a range of drought conditions across the state ranging from no drought in eastern New Mexico to severe drought in the northwest. This is a considerable improvement over recent years, resulting from near average precipitation across much of state during recent summer monsoon seasons and a very wet spring in 2015 east of the middle Rio Grande. However, because Elephant Butte Reservoir is only modestly affected by summer rains the regions and economic sectors of the state that depend on streamflow in the Rio Grande are still vulnerable to water shortages. The lower Rio Grande Valley is still considered to be in moderate drought (D1 on a scale of 0-4) in the US Drought Monitor.

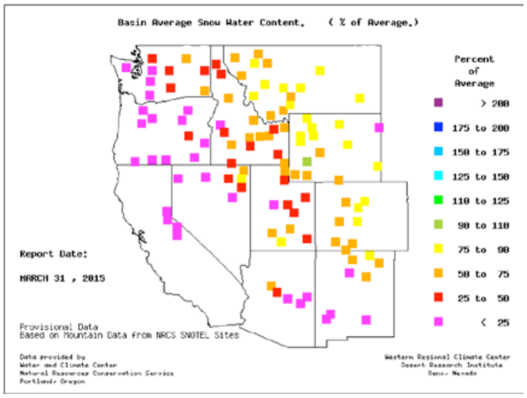


Figure 2. Percentage of long-term average snowpack in high elevation basins across the western U.S. on March 31, 2015, near the peak of the annual snowpack accumulation season. Basins that supply runoff to rivers in New Mexico all reported less than 75% of the long-term average snowpack. [Data from Western Regional Climate Center, Reno NV; http://www.wrcc.dri.edu/snotelanom/basinswe.html]

Snowpack in the headwaters basins of major snow-fed rivers in New Mexico (Figure 2) was far below the long-term average again this winter, for the fifth consecutive year. Surface water for irrigation supplied from Elephant Butte and Caballo Reservoirs on the Rio Grande is projected to be in short supply, as it has been each year during this drought. Rio Grande streamflow forecasts from the U.S. Natural Resources Conservation Service (NRCS) on 1 May (Figure 3) predicted a best estimate of 58% of long-term average April-September flow at Del Norte in southern Colorado, and just 29% of long-term average April-July flow at San Marcial. Considerable uncertainty is associated with these predictions, and high spring precipitation totals over the past two months have lessened water shortages across much of the state. The principal area of water concern in New Mexico at present is the volume of water stored in major reservoirs. Specifically, storage in Elephant Butte Reservoir is higher than in late winter, but still is far below capacity.

Groundwater plays a fundamental role during periods of drought as a vital water source to supplement surface supplies when reservoirs and streamflow decline. Drought also triggers the intensive use of groundwater, which increases groundwater depletion and stresses already impaired aquifers. Declines in streamflow and groundwater storage associated with drought are amplified by geologic factors and local patterns of water development and use. In downstream areas, such as the Lower Rio Grande in New Mexico, groundwater resources are replenished both locally and by headwater discharge. In such settings the effects of drought on groundwater reflect a complex interaction of regional and local conditions for precipitation, streamflow, climate-runoff relationships, geology, patterns of water use, and human modifications of the surface-water system. This assessment of groundwater vulnerability in the Lower Rio Grande Basin addresses groundwater occurrence, depletion and declining groundwater levels in the Mesilla Valley during the extended droughts of 1950–1957 and 2008–2014.

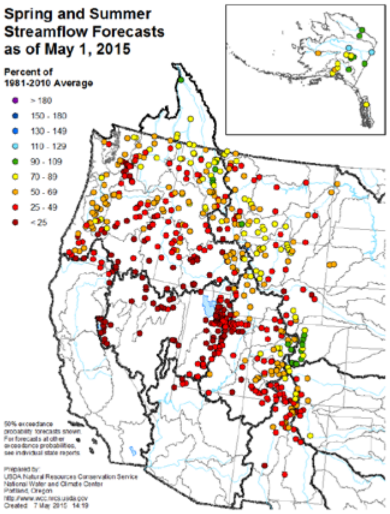


Figure 3. Median estimate of forecasted Spring and Summer 2015 river flows at major gaging points on rivers throughout the western U.S., expressed as a percentage of average (1981-2010) "naturalized" flow (attempting to remove the effects of dams and diversions from the flow). Forecast issued by the U.S. Natural Resources Conservation Service on 1 May 2015. [http://www.wcc.nrcs.usda.gov/wsf/westwide.html]

Hydroclimate

Despite the recent run of years with below-average snowpack, it is still the case that multi-year precipitation deficits across New Mexico are not as severe as the historic drought of the 1950s (Figure 4, bottom curve). In that decade New Mexico statewide precipitation was below average for seven consecutive years, without the summer season respites from drought conditions that have characterized the past five years. The fact that the 1950s drought was worse from a precipitation deficit perspective should be interpreted as bad news for New Mexico's current vulnerability to drought.

We know that multi-year precipitation deficits in the past have persisted longer, and have been considerably more severe, than the state has experienced in recent years. Rio Grande flow at Otowi has been reconstructed for the past half-millennium using tree-ring records (Figure 5). The reconstructed estimate of Otowi flow shows that multi-decade droughts, characterized by lengthy periods of flow less than 1.5 million ac-ft./yr, occurred in the late 1500s, early 1600s, and late 1700s. Each of those droughts is estimated to have featured lower flows in the upper Rio Grande than occurred during the historic drought of the 1950s.

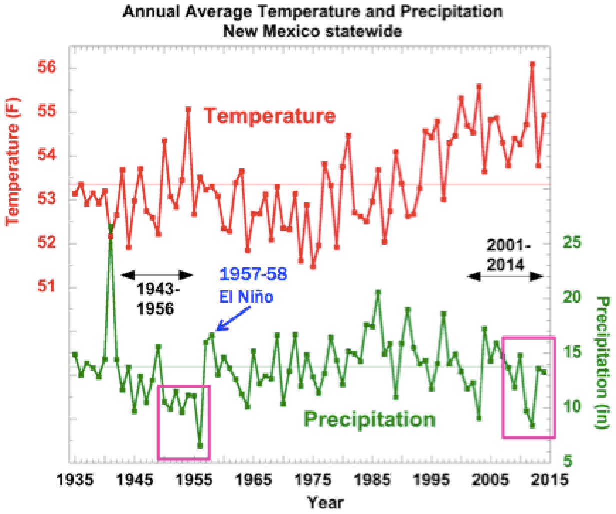


Figure 4. Time series of annual average temperature (red curve, top) and precipitation (green curve, bottom) averaged over the state of New Mexico for the period 1935-2014. Boxes on the precipitation plot show the major multiyear periods of drought in the 1950s, and in recent years. [Source of data: U.S. National Oceanic and Atmospheric Administration, obtained from the Western Regional Climate Center, Reno NV]

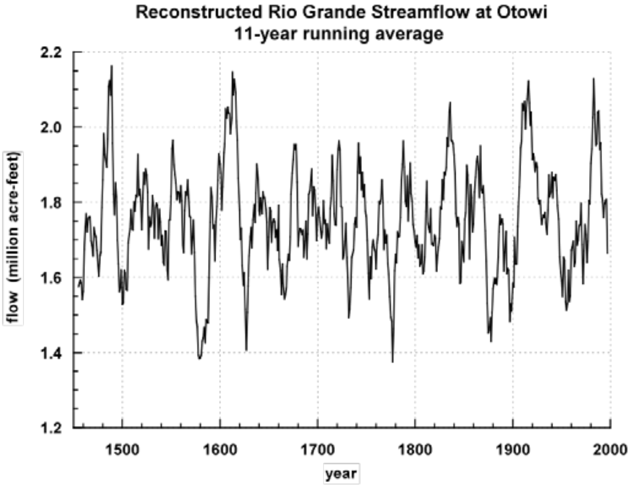


Figure 5. Reconstructed annual streamflow on the Rio Grande at Otowi for the period 1450-2000, derived from tree ring records correlated with 20th Century observed flow at Otowi. Annual values have been smoothed with an 11-year running average to emphasize decade-scale fluctuations. [adapted from Gutzler, D.S. 2013. Regional climatic considerations for borderlands sustainability. Ecosphere 4(1):7. http://dx.doi.org/10.1890/ES12-00283.1. Source of data: Meko, D.M., et al., 2010: TreeFlow: Streamflow reconstructions from tree rings. http://treeflow.info/

Deficits in snowpack and snowmelt runoff have actually been worse during the current drought than they were in the 1950s, despite the worse deficits in precipitation sixty years ago. The reason is that temperature is considerably higher now -- approximately 2°F higher on average -- compared to the 1950s (Figure 4, top curve). Higher temperatures, especially in the late winter and spring snowmelt runoff season, lead to early snowmelt and increased evaporation rates that diminish the total volume of snowmelt runoff in major rivers. Because of this temperature effect, it is likely that streamflows in major snow-fed rivers will decline in coming decades even after the demise of the current drought[1]

Abundant rainfall in April and May 2015 have substantially ameliorated local short-term drought conditions across most of New Mexico, and have raised hopes that the multi-year drought of recent years has been broken. Until a winter with relatively heavy snowpack occurs, however, it will be difficult to replenish water storage in major reservoirs on the Rio Grande (particularly Elephant Butte). If Pacific Ocean temperatures along the equator remain anomalously warm (the pattern known as El Niño) through next winter, then the chances for abundant snowpack across the southwestern U.S. will improve. Dynamical models used to forecast the evolution of El Niño generally anticipate that this El Niño event will indeed persist through next winter; the NOAA Climate Prediction Center currently asserts >80% probability that El Nino conditions will extend through next winter. El Niño conditions currently extend across almost the entire Pacific Ocean, belatedly exhibiting incipient characteristics of a major warming event which would be more likely to persist for many months. Despite these grounds for optimism for a snowy winter in 2015/16, we should keep in mind that El Niño is notoriously difficult to forecast through the spring and summer months, these same models have done poorly at predicting the evolution of this El Niño event to date, and the ongoing event has exhibited very unusual seasonal timing so historical analogues provide shaky guidance.

Regardless of the short-term outlook for continuation (or not) of the current drought, New Mexico should be prepared for diminished surface water resources on average in coming decades. All major snow-fed river systems in New Mexico, including the Rio Grande, have in recent years exhibited earlier peak flows and diminished streamflow efficiency, defined as the volume of downstream snowmelt runoff per unit of winter precipitation. Climate forecast models for the 21st century project a continuation of this trend. Projections call for diminished snowpack, earlier snowmelt, earlier peak flows, and less total water volume derived from snowmelt runoff. All of these features have been observed in recent years, including the current year.

Research supported by this project has examined in detail recent NRCS forecasts for the past five years, motivated by anecdotal reports of forecast overestimates by stakeholders in the lower Rio Grande[2]. We have found that the best estimates of projected flow issued early in the snowmelt runoff

---

[1] Milly, P.C.D., et al., 2008. Stationarity is dead: Whither water management? *Science* **319**, 573-574; Hurd, B.H., and J. Coonrod, 2012: Hydro-economic consequences of climate change in the upper Rio Grande. *Climate Research* **53**, 103-118.

[2] We gratefully acknowledge Dr. Angus Goodbody, U.S. Natural Resources Conservation Service in Portland OR, for his assistance with NRCS streamflow forecast and validation data.

season have indeed tended to overestimate the seasonal runoff subsequently observed. The best estimates for projected naturalized flow at Otowi, from the set of forecasts issued on 1 February for the past five years, all overestimated the subsequent March-July flow on the Rio Grande. In Figure 6, predictions of flow at Otowi that overestimated the subsequent flow are shown as open circles (i.e. every prediction), with the area of the circle proportional to the magnitude of the forecast error.

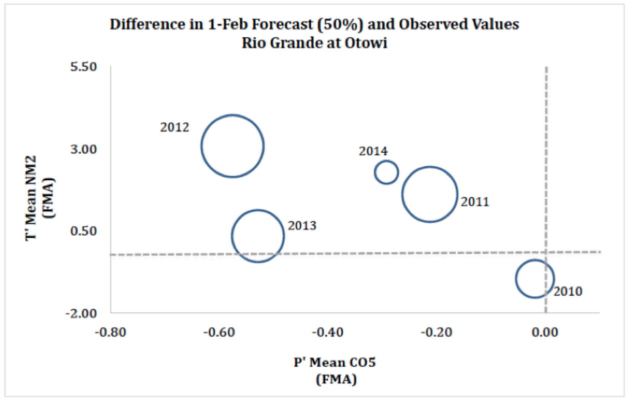


Figure 6. Assessment of the five most recent Spring-Summer streamflow forecasts for Rio Grande flow at Otowi (naturalized), issued by NRCS on 1 February for year 2010-2014. The size of each circle represents the magnitude of the forecast error relative to what was subsequently observed. Open circles represent over-estimated flows; solid circles (there are none of these) would represent underestimated flows. Each forecast error circle is plotted on an x-y plot where the x-axis represents the observed precipitation anomaly for February-April, and the y-axis represents the observed temperature anomaly for February-April. The plot shows that overestimates of streamflow tend to be associated with deficient precipitation (negative values on the x-axis) and warmer than average temperatures (positive values on the y-axis). [Streamflow forecast data from the U.S. Natural Resources Conservation Service; temperature and precipitation climate divisional data from the U.S. National Oceanic and Atmospheric Administration, obtained from the Western Regional Climate Center, Reno NV]

The overestimates have been associated with a succession of anomalously hot and dry spring seasons (the x and y axes on Figure 6), which are not explicitly factored in to the NRCS retrospective regression algorithm that is the basis for the forecast. Warm and dry spring anomalies enhance premature snowmelt and increase evaporation rates, decreasing the total subsequent snowmelt runoff into mainstem rivers. As one might expect, there is a general correspondence between the magnitude of the forecast error and the magnitudes of the temperature (positive, warm) and precipitation (negative, dry) anomalies during the spring months. Warm/dry conditions are strongly correlated so, at present, we cannot definitively separate the temperature and precipitation effects on the forecast error.

If warm and dry spring anomalies become the norm, as climate models project to continue into the future, then the NRCS algorithm will need to be adjusted to take account of trends in climate. In other words, the current seasonal forecasting scheme, based on retrospective analysis of historical statistics, may not be suitable for the current changing climate and will need to be adjusted downward in expectation of lower flows.

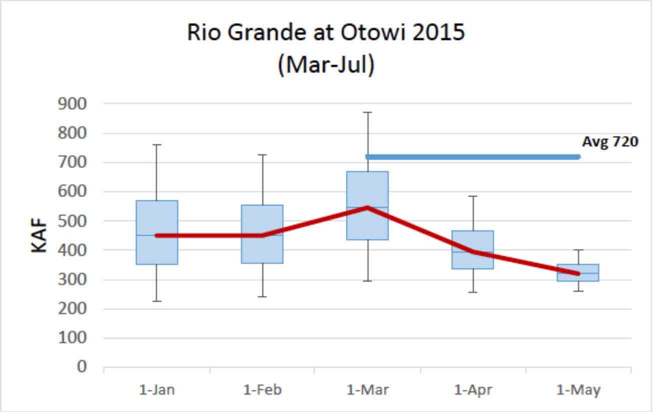


Figure 7. Evolution of Spring-Summer streamflow forecasts for Rio Grande flow at Otowi between March and July 2015, issued by NRCS between 1 January and 1 May 2015. The long-term average (naturalized) flow at Otowi, 720 Kaf, is shown by the horizontal blue line. On the first of each month, starting on 1 January, NRCS forecasts Mar-Jul flow; each of these forecasts is shown here as a box-and-whiskers plot. The most probable flow, the median estimate, is the center of each box (connected by the red line). This most-probable flow is shown on the associated forecast map such as in Figure 3. Uncertainty in each forecast is indicated by the width of the box and whisker about each median estimate. Uncertainties tend to be large for the early forecasts (1 Jan through 1 Mar) and get much smaller for the later forecasts. As shown in Figure 6, in recent years the early season (1 Feb) forecast tends to overestimate the subsequent flow. This trend is reflected this year by the decrease in projected flow in forecasts issued in recent months (1 Apr and 1 May). [Source of data: U.S. Natural Resources Conservation Service]

At the present time, our recommendation is for water managers and stakeholders to consider the full range of NRCS predicted flows (Figure 7), not just the "best estimate" shown on maps such as Figure 3 which may be unduly optimistic. Currently (as of 1 May) NRCS projects a 30-70% probability that March-July flow on the Rio Grande at Otowi will lie between 300 and 350 kaf, less than half of the long-term average flow (Figure 7). The forecast for April-July flow at San Marcial (not shown) are even lower, between 10% and 49% of the long-term average. Based on recent experience (Figure 6), we should be prepared for flows at the low end of those ranges. In this regard we note the dismal 10% of average at the low end of the range of projected flows at San Marcial. As an extreme possibility, NRCS acknowledges at least a 10% probability of zero naturalized flow at San Marcial this summer.

Water Use and Groundwater Depletion

In Doña Ana County, groundwater contributes to the two major water uses: irrigated agriculture and public and domestic water supplies. In 2010, about one-third of withdrawals for irrigated agriculture within the area of Elephant Butte Irrigation District (EBID) (120,800 acre-feet) came from groundwater (from NM Office of the State Engineer (OSE) water-use reports). Groundwater also provided 100% of drinking-water withdrawals (42,087 acre-feet). Overall groundwater withdrawals have increased since 1985, with the exception of the wet years of the mid-1990s (Figure 8).

Groundwater depletions — that part of a withdrawal that has been evaporated, transpired, incorporated into crops or products, consumed by man or livestock, or otherwise removed from the aquifer — have been estimated in NMOSE water-use reports for 1990, 1995, and 2000. According to these sources, about 68% of groundwater withdrawn for irrigated-agriculture, and 67% of groundwater withdrawals as a whole, was depleted during these years. The remaining 32–33% was recycled to the river and aquifer to be reused by downstream users. By using an average depletion factor for years since 1985, a 25-year history of groundwater depletion is estimated for the region (Figure 8). The cumulative volume of groundwater loss, about 2.5 million acre-feet, is comparable to the capacity of Elephant Butte Reservoir.

Drought is recognized as a catalyst for the intensive use of groundwater, sometimes with negative effects, namely over pumping, deterioration of water quality, and extreme lowering of groundwater levels. Over exploitation of groundwater during drought often becomes a part of the normal water-supply network after drought conditions end. This policy diminishes both surface-water and groundwater reserves, and threatens the overall resiliency of the water supply.

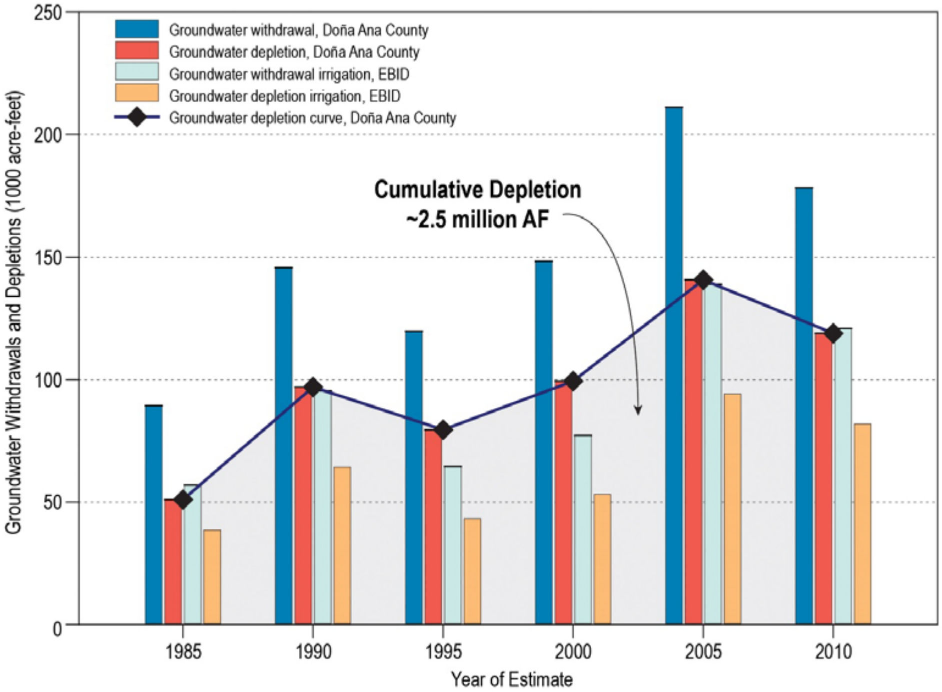


Figure 8. Groundwater withdrawals and depletions in Doña Ana County, 1985-2010, are estimated from NMOSE water use reports. A bar chart shows withdrawals and depletions of groundwater in the county (for all water-use categories) and in the area of EBID (for irrigated agriculture). Calculating the area under the depletion curve provides an estimate of the cumulative groundwater depletion in Doña Ana County for the 25-year period, 1985-2010. The volume of groundwater loss, about 2.5 million acre-feet, is comparable to the capacity of Elephant Butte Reservoir.

Interconnection of Surface Water and Groundwater

Beneath a large part of the Mesilla Valley, the most productive aquifer zones (with a high groundwater production potential, "GWPP") are well integrated with the surface-water system. The total thickness of the very productive aquifer ranges from about 600 feet near Las Cruces to 2,000 feet in the Mesilla Valley and 250 feet at Canutillo. Except in times of surface-water shortage and extreme drought, aquifer recharge occurs primarily as infiltration from the river and its associated canals, drains, and irrigated cropland. Prior to development, most discharge occurred through evapotranspiration from extensive valley-floor wetlands, but the water table is now influenced by new hydrologic conditions established by the river, irrigation works, pumping wells, and heavily irrigated fields. Discharge now occurs through evapotranspiration from irrigated croplands and riparian vegetation, flow to drains, and an increasing amount of pumping from all aquifer zones for consumption by municipal-industrial and irrigated agriculture.

Much of the groundwater pumped for irrigation is derived from the shallow aquifer zone that is hydraulically connected to the valley-fill aquifer and the surface-water system. The effects of groundwater pumping, both deep and shallow, in the lower Mesilla Basin are readily transmitted to the interconnected river channel, canals, and drains. Measurements made by the U.S. Geological Survey (reported in WRRI Report 332) demonstrate that the river loses water in the areas of the Las Cruces, Mesquite, and Canutillo well fields. See Appendix 2 for a discussion of the GWPP for segments of the aquifers in the Mesilla and Rincon valleys.

Groundwater Conditions Before and During the 2008–2014 Drought

Groundwater measurements in three wells in the lower Mesilla Valley are used to evaluate the effects of groundwater pumping and the 2008–2014 drought. USBR well 13 (30 feet deep) and USGS well M-4 (a multi-level monitor well with piezometers M-4C and M-4B at 40 feet and 120 feet, respectively) are completed in river alluvium of the shallow aquifer, which is hydraulically connected to the surface-water system (see Appendix 2 for well locations). Measurements in wells USBR 13 and M-4C combine to form a 70-year record (1946–2015) of changes in the water table and provide a contrasting view of the shallow aquifer's response to the 1950s drought and the drought of 2008-2014 (Figure 9A). See Appendix 3 for a thorough discussion of groundwater conditions during the 1950's drought.

Groundwater levels in well USBR 13 (Figure 9A) replicate the 1950s fluctuation pattern in the average hydrograph, but with a 16-foot (instead of 6-foot) decline. Through the 1960s and 1970s, the pre-1951 seasonal pattern of summer highs and winter lows was repeatedly disrupted, likely in response to pumping from the large number of irrigation wells. Consistently high summer water levels and seasonal fluctuations, which are key characteristics of the pre-1951 hydrograph, were not fully restored until the very wet years of the 1990s. Even then, water-level highs were 2 to 3 feet lower than pre-1951 levels. In short, the assumption that the 1950s development did not exceed the capabilities of the aquifer may have been incorrect.

Hydrograph B (Figure 9B) focuses on measurements from USBR 13, M-4C, and M-4B between 1995 and 2015, which demonstrate the combined effects of groundwater pumping and drought. The hydrographs for wells USBR 13 and M-4C show that the seasonal water-level pattern of summer highs and winter lows re-established in the 1990s continued until the winter of 2003. Between winter measurements in 2003 and 2005, before the onset of drought conditions, the water table in M-4C dropped 7.5 feet, and then remained steady with a weak seasonal fluctuation for the next five years.

Meanwhile, during 2002–2003, seasonal water-level fluctuations in well M-4B (monitoring water pressures at the 120-foot depth) visibly shift from a pattern characteristic of surface recharge (summer high level, winter low level) to a drawdown-and-recovery pattern indicating groundwater pumping from irrigation wells (summer low level, winter high level). Between winter 2005 (after the large pre-drought water-table drop) and 2010, hydrographs for M-4C (40 feet deep) and M-4B (120 feet deep) illustrate entirely dis-synchronous seasonal water-level patterns wherein shallow water levels (40 feet) are controlled by recharge from the surface-water system and deep water levels (120 feet and greater) are controlled by seasonal groundwater pumping.

The large drop in shallow and deep water levels in 2003–2005 and the notable shift in the water-level patterns in M-4B between 2002 and 2010 are clear markers of seasonal pumping in irrigation wells. The groundwater response to drought is not apparent until April 2011 when the water level in M-4C failed to respond to summer recharge and began a 16-foot decline to an all-time low of 35.6 feet below land surface. Since 2002, the combination of groundwater pumping and drought has created a 26-foot decline in the water table in the lower Mesilla Valley. As of June 2015, the water level was at an all-time low of 36.7 feet below land surface and the aquifer had not recovered from the combined effects of pumping and drought.

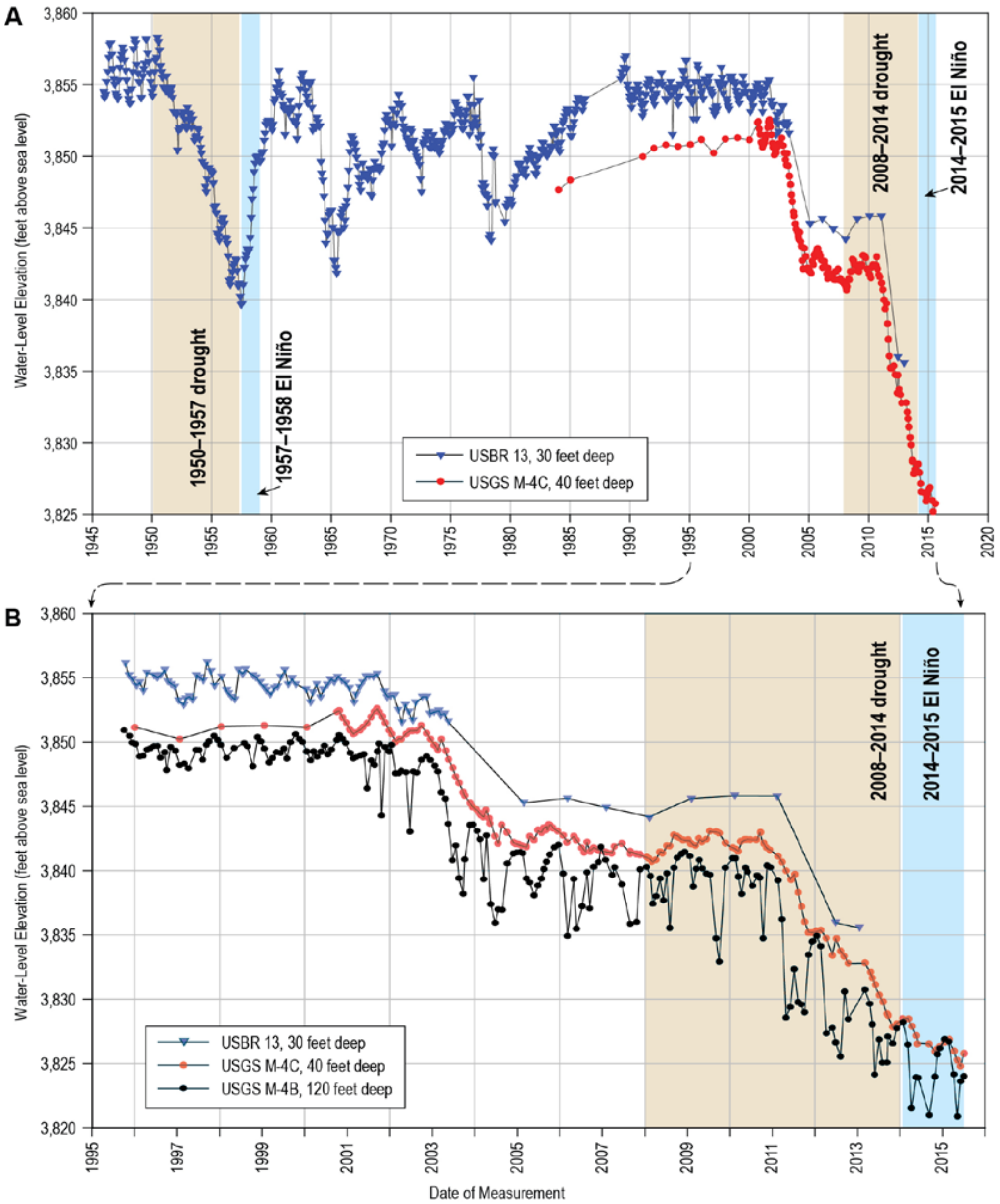


Figure 9. Hydrographs from wells USBR 13, M-4C, and M-4B are used to evaluate the effects of groundwater pumping and drought in the lower Mesilla Valley. **A.** The combined hydrograph (1946–2015) shows a 16-foot water-level decline and recovery during the 1950–1957 drought, a 16-foot water-level decline during the 2008–2014 drought, and a 7.5-foot decline between winter measurements in 2003–2005 prior to drought conditions. **B.** Seasonal water-level fluctuations in the 1995–2015 hydrograph for M-4B shift from a pattern of summer recharge to one of summer groundwater pumping during 2002–2003, indicating the pre-drought decline was due to groundwater pumping. The water level declined 26 feet from 2002 to June 2015and the aquifer had not yet recovered from the combined effects of pumping and drought.

Contrasting the 2008–2014 and the 1950s Droughts

Many factors that affect the groundwater balance in the Lower Rio Grande have changed between the 1950's and the current droughts. In response to these changing conditions, the water table in the

Mesilla and Rincon valleys has equilibrated to a new set of hydrologic conditions established by erratic and limited surface flows, lower recharge, higher evaporation, greater crop demands, and continually increasing groundwater withdrawals. The following recaps the current state (as of June 2015) of the Mesilla and Rincon aquifers after the 2008–2014 drought.

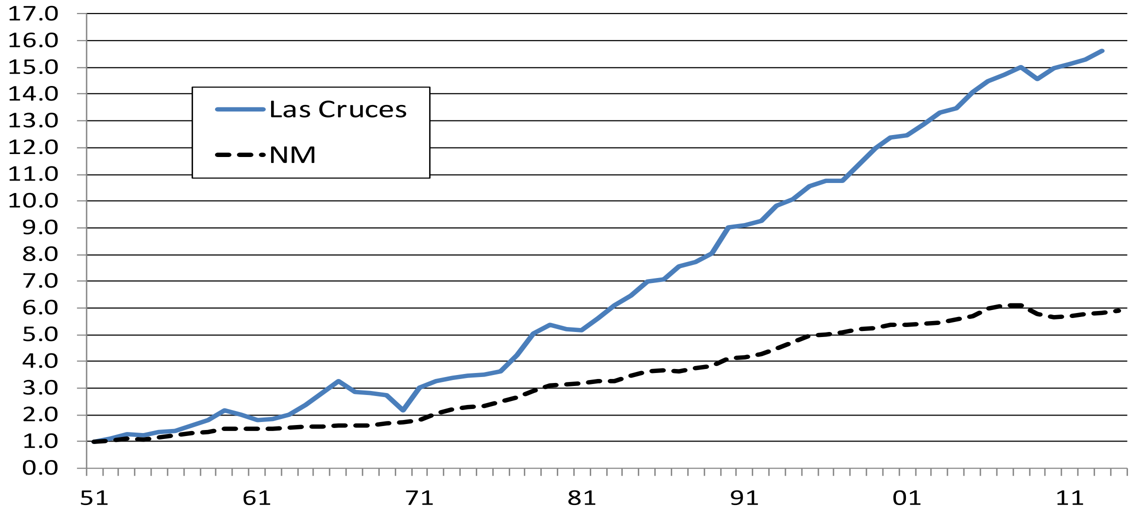
- Groundwater declines and a shift in the seasonal fluctuation pattern beginning in 2003 indicate that the Mesilla Valley aquifer was impaired by extensive groundwater pumping, largely from irrigation wells, prior to the onset of drought conditions in 2008.
- The large 16-foot decline in groundwater levels during the drought (April 2011 to November 2014) and the lack of recovery as climate conditions and surface flows improved, suggest that the groundwater reservoir in the Mesilla Valley no longer has the capacity to provide a reliable, supplemental supply during extended drought conditions and surface shortages such as those encountered in 2008–2014.
- Extreme water-level declines (26 feet since 2002) have decoupled the shallow aquifer and the surface-water system, causing excessive seepage losses from the river channel and canals.
- The Mesilla Valley aquifer may no longer have the capacity to overcome the effects of extended severe drought with current levels of intensive groundwater pumping.

Sixty years of groundwater pumping and two extended severe droughts have diminished the groundwater reservoirs and threaten the overall resiliency of the water supply of the Lower Rio Grande.

Impacts of Economic Development and Population Growth

The Las Cruces MSA is coincident with Doña Ana County. Compared with NM as a whole, the Las Cruces MSA private economy has been a fairly consistent performer since the 1950s (Figure 10). The composition of the economy has changed over time – being heavily reliant on agriculture in the 1950s, with increased diversity over time. Today, agriculture and non-agricultural activity are both important in the area and, as in the 1950s the economic activity is providing dynamic opportunities. But these opportunities are constrained due to limited availability of both surface water and groundwater.

In the past few years, much of the economic activity has focused on the border at Santa Teresa. Below we discuss how water resources in the Southern Rio Grande valley are being affected by (1) the development occurring at Santa Teresa, (2) economic and population growth more generally within Doña Ana County, and (3) developments in the area's agricultural sector.



Source of data: US Bureau of Labor Statistics, *Quarterly Census of Employment and Wages*

Figure 10. Total Private Sector Employment Indexed to 1951 Las Cruces MSA and New Mexico (through 2013)

Santa Teresa

The Santa Teresa Port of Entry (opened in 1992) is becoming an increasingly important hub for transportation and industrial activity. The port of entry is located 42 miles south of Las Cruces and 20 miles from downtown El Paso, Texas. Union Pacific (UP) operates an east-west rail line that connects California's San Pedro Bay ports to the eastern US. In early 2014 the UP Santa Teresa Intermodal Terminal was opened and is located 5 miles from the port of entry. The terminal includes fueling facilities and crew change buildings, and can handle 250,000 shipping containers annually. Santa Teresa also boasts two industrial parks – Verde Santa Teresa Intermodal Park and Verde Bi-National Industrial Park.

The UP terminal is attracting businesses to the area. Expansion of industrial and economic opportunities in Santa Teresa has been accompanied by rapid population growth in recent years. According to the decennial census, Santa Teresa had a population of 4,258 in 2010, reflecting growth since 2000 in excess of 63%. Continued development of economic opportunities at Santa Teresa will result in significant population growth for the foreseeable future. In 2013 New Mexico Governor Susana Martinez and Chihuahua, Mexico Governor Cesar Duarte signed an agreement to cooperate on a master plan to build neighboring towns on opposite sides of the border – Santa Teresa, NM and San Jeronimo, Mexico. The planned community is comprised of 70,000 acres owned by Verde Realty in New Mexico and Corporacion Inmobiliaria in Mexico.

The developments at Santa Teresa have been a major part of the success of the Las Cruces MSA economy over the past few years and are key to the area's economic future. However, this development at Santa Teresa presents another challenge to New Mexico's water future. Santa Teresa derives its water solely from the Mesilla Bolson, which is also the primary source of groundwater for Las Cruces and Sunland Park. Management of the Mesilla Bolson is complicated by the fact that the aquifer spans parts of New Mexico, Texas, and Mexico. Groundwater pumping rates have been sufficiently high to raise concerns regarding the ability of the aquifer to be recharged by the Rio Grande and the valley's irrigation system. In addition to deriving its water from an aquifer shared by the US and Mexico, Santa Teresa also has an aging water utility infrastructure. During June/July of 2013 Santa Teresa's aging water utility infrastructure had such high demands placed upon it that four well outages occurred. That same year the New Mexico Legislature provided $6 million in funding to address Santa Teresa's water supply and water treatment needs. According to Economic Development Department Cabinet Secretary Jon Barela, the improved water supply system can meet the needs of growth projected for the next decade. After that time the availability of water is uncertain.

Additional pressure will be imposed on existing water supplies by the growing population as well as new businesses and increased economic activity. The future water supply of the West Mesa area west of the Rio Grande's Mesilla Valley consists mostly of the large quantities of brackish water stored below the freshwater aquifers. For this reason, a binational desalination plant is the being discussed for Santa Teresa and San Jeronimo, Mexico. If a desalination plant were to be built, there are significant concerns with inland desalination that must be addressed: efficiency, concentrate management, energy requirements, and cost.[3] Additionally, it is unknown how brackish and fresh groundwater may be connected, and thus whether the extraction of brackish water would affect fresh groundwater. Clearly this relationship will differ for each brackish aquifer and needs to be studied and considered. To assess how these and other desalination concerns may be most effectively addressed, El Paso's Kay Bailey Hutchison Desalination Plant (the world's largest inland desalination plant) should be studied and used as a relevant and nearby source of lessons learned. The Brackish Groundwater National Desalination Research Facility (located in Alamogordo) is another source of valuable information and expertise. In addition to addressing water supply issues, water demand should also be addressed through development of programs aimed at promoting enhanced water conservation and recycling (e.g. an increasing block rate structure, rebates for water saving appliances, and incentives for xeriscape landscaping).

In summary, the future development of Santa Teresa, NM as an industrial and transportation hub is likely inevitable due to the level of public and private investment that has already occurred. Water supply issues are also inevitable; the existing water supply system is able to meet the area's projected needs only for the next decade. After that time it is uncertain whether supply will be sufficient to meet demand, especially during drought. Meeting water demand beyond the next decade through further development of fresh water supplies is improbable due to (a) limited fresh water in the region's aquifers and reservoirs, and (b) additional strain placed on the region's fresh water supplies by the ongoing drought. A desalination plant therefore appears to be a logical means of meeting Santa Teresa's future water supply needs. Because the area's water needs are currently met only for the next decade, and because the design and construction of any water supply system, and in particular a binational

---

[3] A 2012 study by the Texas Water Development Board found that the average cost to produce desalinated water from brackish groundwater ranged from approximately $1.25 to $2.60. for 1,000 gallons, or $357 to $782 per acre-foot. Approximately half this cost is associated with the energy required.

desalination plant, involves numerous challenges that will take considerable time to address, we recommend that a decision regarding how to supplement the area's water supply be made and pursued directly.

Population Growth

Doña Ana County is the second-most populated county in New Mexico, and Las Cruces has been ranked as one of the United States' fastest growing communities since the early 2000s. Between 2000 and 2010 Doña Ana County was the second fastest growing county in the state – second only to Sandoval County. Projections developed by UNM Geospatial and Population Studies indicate that between 2010 and 2040 the population of Doña Ana County will grow by nearly 50%, so that in 2040 the County will be home to nearly 300,000 people. A 2004 report detailing a regional water plan for New Mexico's Lower Rio Grande includes low, medium, and high population growth projections for the region. The high population growth projection yields a population of nearly 540,000 by 2040 (approximately a three-fold increase from the area's year 2000 population). Thus although agriculture consumes the vast majority of the region's water, urban water use (primarily associated with sizeable and growing Las Cruces) is also of concern.

The City of Las Cruces 40-Year Water Development Plan (published in 2008)[4] describes how the City plans to meet the water needs associated with a high population growth scenario, projected growth along the U.S./Mexico border, and other planned developments (including Vistas at Presidio and Sierra Norte). Single-family homes account for the largest portion of the Las Cruces metered water use (55%), while multi-family residential accounts for only 13%. Commercial and industrial uses account for approximately one-quarter of water use. The remainder is comprised of parks, golf courses, and bulk sales. The inclusion of plans to reduce single family residential use by more than 20% is clearly an important component in limiting growth in residential water consumption. The plan includes other assorted conservation plans, as well as the development of various additional water sources – groundwater, surface water, and the construction of a reclamation facility (already completed).

The 2004 New Mexico Lower Rio Grande Water Plan[5] provides a more all-encompassing picture of the region's current water situation, and includes projections for the region's future water supply as well as residential, commercial/industrial, and agricultural demand. There are four groundwater basins that supply water to the region – Rincon Valley, Mesilla, Jornada del Muerto, and Hueco. The available supply in the Jornada del Muerto and Hueco basins is essentially fixed, and thus use of this water mines the aquifers. In contrast, the Rincon Valley and Mesilla groundwater basins are interconnected with the Rio Grande. When the Rio Grande replenishes these two aquifers, flows in the river are reduced, which is detrimental to the State's ability to meet compact obligations to Texas and Mexico. Withdrawals from the Rincon Valley and Mesilla groundwater basins therefore pose a concern not only for water levels in the basins themselves, but also for water levels in the Rio Grande. Water management issues are further

---

[4] Available online: http://www.las-cruces.org/~/media/lcpublicwebdev2/site%20documents/article%20documents/utilities/water%20resources/40%20year%20plan.ashx?la=en

[5] http://wrri.nmsu.edu/lrgwuo/rwp/LowerRioGrandeRegionalWaterPlan.pdf

complicated by the fact that the Mesilla and Hueco aquifers are shared by New Mexico, Texas, and Mexico.

The NM LRG Water Plan projects that total water diversions for the region may increase from their 2000 level of 495,000 acre-feet to as much as 572,000 acre-feet in 2040. Water use associated with agriculture, livestock, and the environment is expected to remain constant. Water use associated with power production and commercial, industrial, and mining activities in the region is projected to increase from 9,000 acre-feet in 2000 to 15,000 acre-feet in 2040 (an increase of 67%). Power generation constitutes a significant portion of this increase; water use associated with power generation is expected to increase by 260%, from 2,500 acre-feet in 2000 to 6,500 acre-feet in 2040. In contrast, commercial, industrial, and mining water use is expected to grow by only 30% during this same time period. The projected increase in private/public water supply use varies widely, from approximately 60% to more than 300%, due to different assumptions made regarding population growth. The Las Cruces water development plan notes that GPS addressing of utility meters occurred during 2005-2010. As a result the City's Water Conservation Coordinator should now be able to assess use patterns based upon neighborhood, building and infrastructure age, and socioeconomic characteristics. This may prove to be of greater importance as the area's population grows, commercial and industrial development expands, demands on the water system increase, and the water supply becomes ever more stressed.

Every five years the OSE publishes a New Mexico Water Use by Categories report. The most recent was published in 2010. As detailed in the report, the majority of non-agricultural water use in Doña Ana County occurs through the public water supply; in 2000 the region's public water supply systems accounted for 35,000 acre-feet. Self-supplied commercial use, and to a lesser extent industrial and mining uses, account for the next largest demand – 6,500 acre-feet in 2000. Details obtained from OSE indicate that NMSU is the largest user in this category, followed by several area golf courses.

For fiscal year 2012, which is the most recent year of publicly available data,[6] the City of Las Cruces utilities department reported 32,169 individual water accounts using 5.8 billion gallons of water in the year – or nearly 18,000 acre-feet.[7] Note that these data do not include system losses. While many of the accounts were households, the largest individual users of city-delivered water by volume were generally municipal and industrial (M&I) users. In particular, the top-25 highest water users in the fiscal year, which were all M&I, constituted fewer than 0.1% of all accounts while accounting for nearly 10% of all water deliveries by volume (572 million gallons or about 1,750 acre-feet). Of the top-25 users of city water, the city directly accounted for 27% of all deliveries by volume. These were deliveries for irrigating public spaces, providing city buildings with water, and the like. However, if deliveries to the detention centers, Doña Ana County and the school districts are included, that figure increases to around 40%. Physicians' offices/hospitals accounted for around 13% of the volume delivered. The remaining 47% of water delivered to the top-25 users was a mix of industrial/commercial (goods producers, hotels, etc.), construction and multi-family (apartment and mobile home parks) uses. It is important to point out that

---

[6] Las Cruces Sun-News (January 12, 2013). http://www.lcsun-news.com/las_cruces-news/ci_22361847/water-consumption-las-cruces-down-by-6-percent, accessed June 4, 2015.

[7] This paragraph only discusses water delivered by the city of Las Cruces.

the fiscal year data are a snapshot for the year and water use varies seasonally. For instance, water use by the city of Las Cruces increases in the spring and summer months (to irrigate public spaces) and declines in the fall and winter months. In addition, although the largest water users tend to be M&I, the overwhelming majority of connections to the city utility are single family residences and those users generally account for between 50% and 60% of total water delivered by the city utility (58% in 2010).[8] Furthermore, water delivery through the City's utility system has declined over the last several years, from 21,700 acre-feet in 2011 to 20,700 acre-feet in 2012[9] and then to 19,600 acre-feet in 2013 (all inclusive of system losses).[10]

A growing population will increase stress on the area's limited water supply. The region should continue to gather additional data regarding water use (such as through metering, and in particular GPS metering). Data can provide valuable insights to use patterns and where and how water can be effectively conserved. Golf courses are one example of an area in which there is room for additional conservation – rather than using potable water to water golf courses and other green areas, reclaimed water can be used for this purpose.

Agriculture

New Mexico's largest user of water is irrigated agriculture; according to a 2010 report by the NMOSE, agriculture accounts for 80% of surface water withdrawals, 77% of groundwater withdrawals, and 79% of total withdrawals.[11] The dominance of irrigated agriculture is even more pronounced in Doña Ana County, where in 2010 irrigated agriculture accounted for nearly 100% of surface water withdrawals, 68% of groundwater withdrawals, and 87% of total withdrawals. Rio Grande water is allocated to approximately 90,000 irrigated acres by EBID. Although a full EBID allocation is 3 acre-feet, in recent years farmers have received far less due to the drought, and have turned to groundwater to make up the difference. Because the aquifer is recharged in part by the Rio Grande, continued high levels of pumping is not a viable solution to long-term drought. Furthermore, as the water table drops, pumping becomes more expensive, well capacity declines (fewer gallons/minute can be pumped), and groundwater quality declines as salt and minerals concentrate. Ultimately wells may not be able to pump enough water sufficiently fast, and thus wells might need to be deepened or new wells might need to be drilled (both at considerable cost).

The continuing drought is forcing farmers to consider various options for maintaining a viable farming operation, including allowing land to lie fallow, switching to more drought-tolerant crops, and changing to more efficient irrigation systems. In some cases irrigation water has been insufficient to

---

[8] Las Cruces Utilities Water Conservation Plan (March 8, 2012)

[9] Las Cruces Sun-News (January 12, 2013). http://www.lcsun-news.com/las_cruces-news/ci_22361847/water-consumption-las-cruces-down-by-6-percent, accessed June 4, 2015.

[10] AWWA Water Audit for 2013. http://www.las-cruces.org/~/media/lcpublicwebdev2/site%20documents/article%20documents/utilities/res%20ts/water%20conservation/awwaaudit2013.ashx?la=en, accessed June 4, 2015.

[11] New Mexico Water Use by Categories 2010. Available online: http://www.ose.state.nm.us/Pub/TechnicalReports/TechReport%2054NM%20Water%20Use%20by%20Categories%20.pdf

meet the needs of crops already planted, and farmers have had to plow under a portion of their crops in order to concentrate what little water they do have on fewer acres. Other options include the installation of pipelines to reduce evaporation losses and the lining of ditches to reduce seepage losses. Some farmers have also begun to use more advanced means of monitoring soil moisture so that they can time irrigation more accurately. Farmers have also devised creative market solutions. For example, some pecan growers have leased their water rights to farmers in the northern EBID reaches in exchange for an amount sufficient to cover the added cost of pumping an equivalent amount of water. However, many of the available methods for coping with drought entail a sizeable financial investment that can prove prohibitive, especially for smaller farms. For example, the cost of deepening existing wells or drilling new wells can be quite substantial, as can the cost of installing more efficient irrigation systems. Even seemingly low-cost solutions such as planting crops that require less water can be "costly" due to the "use it or lose it" provision in New Mexico's water law; switching to crops that require less water can ultimately result in the loss of one's water rights.

According to information published by OSE in their 2010 report, nearly all irrigated acres in Doña Ana County are irrigated using flood irrigation; drip irrigation and sprinklers are used on less than 1% of irrigated acreage in Doña Ana County. However the irrigation efficiency of flood irrigation is estimated to be around only 50 or 60%. Although flood irrigation is "easy" to use and requires less technology than either sprinkler or drip systems, flood irrigation systems are more labor intensive. Various methods can be used to improve the irrigation efficiency of flood irrigation, including laser leveling, the use of large turnout water ditch boxes, and surge flooding. In contrast to flood irrigation, sprinklers have an estimated irrigation efficiency of 60-80%, while that of drip irrigation is approximately 90%. Although flood irrigation does not offer significant irrigation efficiency, it is relatively affordable; a Texas A&M Extension Service publication reports estimated gross investment costs for flood irrigation, sprinkler systems, and subsurface drip of approximately $210, $340-$560, and $1,200 per acre, respectively.[12] Irrigation system costs will vary with design; a subsurface drip irrigation (SDI) demonstration site near Hatch, NM had a per-acre cost of $2,000, while another NM farmer paid $2,500/acre for his SDI system.[13,14] Although sprinklers may seem a more affordable alternative to flood irrigation, because wind and evaporation are of concern with sprinkler systems, they are seldom used in the desert Southwest. Thus the two primary irrigation systems of concern for Doña Ana County are flood irrigation and SDI.

In addition to cost and financing options, several factors should be considered when assessing whether to convert from flood irrigation to SDI, including impacts on field operations and labor requirements, energy source and price, the system's operating pressure and application efficiency, water availability, and pumping lift. New Mexico farmers who have invested in SDI have experienced a

---

[12] Amosson, Steve et al. 2011. Economics of Irrigation Systems. Texas AgriLife Extension Service, Texas A&M. Report B-6113.

[13] Drip Irrigation for Row Crops. NMSU Cooperative Extension Service, Circular 573. Available online: http://aces.nmsu.edu/pubs/_circulars/CR573.pdf

[14] Onion production and marketing in New Mexico. NMSU Cooperative Extension Service Circular 577. Available online: http://aces.nmsu.edu/pubs/_circulars/CR577.pdf

decrease in water requirements[15] (and thus less pumping and less energy), decreased fertilizer and pesticide needs, the ability to simultaneously harvest and irrigate, fewer tractor passes and thus less diesel, fewer weeds, increased yields, and improved crop quality. Although there are numerous benefits to SDI, several barriers have prevented its wide-spread adoption, including potentially prohibitive cost (especially for small farms); a significant learning curve for equipment operation; time required for data collection, management, and interpretation; and technical difficulties and equipment malfunction.

Due to the significant cost of SDI, high-value crops are often seen as most suitable for this irrigation system, as yield increases can quickly recover the cost of SDI purchase and installation. Because pecans are more permanent and thus more of a long-term investment than other crops grown in NM, pecan farmers are more likely to invest in irrigation systems than are other farmers. Furthermore, farmers are more likely to adopt SDI when there is an increase or variance in fuel price, pumping lift, water requirements, and/or wage rates, as these factors influence the cost of production more with flood irrigation than with SDI.[16]

Crops

Primary crops grown in Doña Ana County include pecans, alfalfa, cotton, onions, and chile. While cotton, onions, and chiles are annual crops, alfalfa and pecans are perennial. Alfalfa can produce for seven to 15 years, depending on the type of alfalfa. Pecans differ from other crops in that they are a long-term investment, do not yield a profit for at least seven years, must be irrigated every year, and have heavy production one year followed by lighter production in the next. In southern New Mexico, where pecan trees require between 5 and 6 acre-feet of water each year, most pecans are grown using flood irrigation. In addition to the tactics discussed above (such as lining ditches, drilling new wells, etc.), during periods of extreme drought pecan farmers can potentially trim trees to their trunks so that the trees use less water. The water requirements of chile and other crops grown in Doña Ana County are less than those of pecans. Chile requires between 4 and 5 acre-feet of water. A survey conducted in the late 1990s found that nearly all (87%) of southern New Mexico chile farmers used flood irrigation only.[17] In 2010 it was estimated that the majority of New Mexico's chile farmers (70%) had converted to subsurface drip irrigation, although a similar estimate is not available for *southern* New Mexico chile farmers. Chile production is not impacted by drought as severely as that of other crops, such as onions; whereas chile production may decline approximately 5% due to deficit irrigation, onion yields will likely decline around 30%.[18]

---

[15] It is important to note that plants grown using drip irrigation systems are not allowed to undergo water deficit stress; drip irrigation systems apply water to fields before plants become stressed due to water deficit. In this manner SDI systems can actually increase consumptive water use and decrease downstream flows. (Skaggs, Rhonda. 2000. Drip Irrigation in the Desert: Adoption, Implications, and Obstacles. Available online: http://ageconsearch.umn.edu/bitstream/36412/1/sp00sk01.pdf)

[16] Amosson, Steve et al. 2011. Economics of Irrigation Systems. Texas AgriLife Extension Service, Texas A&M. Report B-6113.

[17] Skaggs, R. et al. 2000. A Survey of Southern New Mexico Chile Producers: Production Practices and Problems. NMSU Agricultural Experiment Station, Bulletin 782. Available online: http://aces.nmsu.edu/pubs/research/agronomy/BL782.pdf

[18] http://www.lcsun-news.com/las_cruces-news/ci_25469929/new-mexico-chile-acreage-hits-four-decade-low

In southern NM alfalfa requires approximately 5 acre-feet of water. However, alfalfa can go dormant and thus tolerate long-term drought, as long as the crown and roots remain viable. Most other crops do not have this capability. Thus although alfalfa is a crop that requires significant water, it is also a crop that can tolerate drought more readily than other crops. Cotton is another crop that uses relatively less water than other crops discussed herein (2-3 acre-feet), and is also a drought tolerant plant. Cotton plants have a tap root and lateral roots and can effectively use small amounts of water. Furthermore, cotton plants start and stop boll production depending on water availability, and are more tolerant of salt than are other crops. However cotton production has declined, as input prices have increased and lint prices have fluctuated. Finally, onions grown in southern NM require between 4 and 5 acre-feet of water. In the Mesilla Valley of southern New Mexico most onions are grown using furrow irrigation. Light frequent irrigations are best for onion production, yet the least amount of water that can be applied using furrow irrigation is 2 acre-inches. Onion production in southern New Mexico therefore presents a potential for improved irrigation efficiency through the use of SDI.

Drought, Crop Production, and Economic Impact

As discussed earlier, drought impacts crops differently. Furthermore, studies indicate the severity and duration of drought also impacts crops differently. An analysis of the relationship between drought and New Mexico's chile, pecan, and milk production suggests that production and economic impact vary greatly depending on the severity of the drought.[19] For example, pecans and chile production are more impacted by the severity and duration of drought than is milk production. In addition, the impact on county (or state) revenues will be dependent upon the impact New Mexico production has on the market. New Mexico, Georgia, and Texas are the three largest pecan producing states in the nation. Depending on weather conditions, the states often trade places for the top spot. Further, the US is the largest single producer of pecans in the world. In 2012, the US accounted for almost 80% of world production.[20] Because of the importance of the US in the global market, the price of pecans often shifts in the opposite direction of US production trends. For example, while 2012 US pecan production increased 12%, the value of the crop declined 27% from the previous year.[21] Thus, the impact of pecan production in the LRG on Doña Ana County and New Mexico depends upon the production in the region, as well as other production in the US (which is also impacted by drought and weather) and the subsequent impact on price. Table 1 shows the impact on revenues for 2011-2013.[22]

---

[19] Chermak, J.M. and J. Wang (2010). *The Economic Impact of Drought on Agricultural Sectors in New Mexico: assessing a simple modeling framework.* A report prepared for the Drought Mitigation Center, University of Nebraska.

[20] http://www.agmrc.org/commodities__products/nuts/pecans/ (last accessed 06/06/2015).

[21] http://www.agmrc.org/commodities__products/nuts/pecans/ (last accessed 06/06/2015).

[22] http://www.ams.usda.gov/mnreports/fvwtvpcn.pdf (last accessed 06/06/2015).

Table 1. New Mexico Pecan production and revenues, 2011-2014

Year	Production (million lbs)	Price per pound	Production Value (millions of $s)
2011	61 (22% US total)	$2.67	$162
2012	65 (20% US total)	$1.70	$110
2013	72 (27% of US total)	$1.90	$136
2014	65 (25% of US total)	$2.00	$130

The lesson from this is that the impact of drought and the vulnerabilities of drought are not single dimensional. Mitigation of the vulnerabilities requires an assessment of the physical and the economic impacts.

Summary and Recommendations

The widespread use of the inefficient flood irrigation practice is clearly of concern for the lower Rio Grande. However, impacts of converting from flood irrigation to SDI are ambiguous; conversions may in some cases increase water consumption and in other cases decrease water consumption. Thus conversions may in some cases increase LRG instream flows, but in other cases decrease LRG instream flows; impacts likely depend upon site, weather, crop, and soil-type. To aid in assessing where SDI may be most beneficial, a research team should develop a summary of the results experienced by LRG farmers who have switched from flood to SDI, as well as existing research pertaining to SDI use in southern NM or similar areas. Because converting from flood irrigation to SDI can be prohibitively costly, in particular for smaller farms, provision of financial assistance might be necessary. The State may be able to partner with various agencies, such as the USDA Natural Resources Conservation Service and the Bureau of Reclamation, in providing such assistance to farmers.

The implementation of improved irrigation is a longer-term solution and may or may not reduce vulnerabilities to drought. Improved irrigation infrastructure can improve water conservation. Whether this becomes a mitigation strategy will depend on how the conserved water is used. If it is banked for times of drought, this can become a mitigation strategy. However, if the water is moved to other beneficial uses instead, it will not be available to mitigate the impact of drought. Thus, any policy developed needs to consider the impacts in totality, including the impacts of other policies, laws, and/or regulations that may result in unintended consequences.

The heterogeneous impact of drought on individual crops and revenues suggests that a better understanding is needed of not only the physical impact of drought on crop types (e.g., the ability of alfalfa to go dormant) and on the economy (e.g., the inverse relationship between US pecan production and pecan prices), but also of the relative impacts and importance between crop types. This can provide a basis for a shorter-term drought mitigation strategy that can provide a hierarchy of choices whereby water could be diverted from crops that would suffer shorter-term physical impacts and smaller economic impacts, and that enables specific areas to withstand droughts with minimal consequences. But again, this requires an agreement or policy that provides flexibility of water use and, most likely, subsidization to those who forego their water. Several methods have been utilized in different areas, including shortage sharing agreements, as well as water markets that provide for the short-term lease of water across uses. The efficacy of these mechanisms is highly dependent upon the structure and relevance of the market or agreement to the water shortage characteristics.

Appendix 1. Working Group Members

This Working Group was funded by Senate Bill 138 passed during the 2014 legislative session to: (1) assess the current status of water supply and demand after years of severe drought in New Mexico; (2) put the current drought into long-term context with reduced surface water, groundwater depletions, and economic activity; and (3) develop a list of vulnerabilities and promote policy strategies to mitigate these vulnerabilities. The Working Group consists of researchers from all three of New Mexico's research universities, and includes both water and social scientists.

Janie Chermak is Professor of Economics and Chair of the Department of Economics at the University of New Mexico. Professor Chermak is an applied natural resource economists who focuses much of her research on water resources and the demand for water. Her work on the economic impacts of drought for this research was assisted by Sarah Pesko, a Masters of Economics student at UNM. Ms. Pesko completed her MA in spring 2015.

David S. Gutzler is Professor of Earth & Planetary Sciences at the University of New Mexico. Professor Gutzler studies climate variability and change. His work on climate analysis and streamflow forecasts for this project was assisted, through support from NM 138, by UNM undergraduate student **Shaleene Chavarria**. Ms. Chavarria, a member of Santa Clara Pueblo, used the results she generated for the Working Group as the core of her senior undergraduate honors thesis for her B.S. degree in Environmental Science. She defended her thesis and graduated in May 2015, and has been accepted into the graduate program in Earth & Planetary Sciences where she will study hydrology.

Peggy Johnson is a Principal Hydrogeologist with the New Mexico Bureau of Geology and Mineral Resources at New Mexico Tech. She has applied her research interests on the geology, hydrology and geochemistry of basin-scale groundwater systems to New Mexico's aquifers with the goal of supporting informed development of groundwater resources.

J. Phillip King is the John Clark Distinguished Professor and Associate Department Head in the Civil Engineering Department at New Mexico State University. He specializes in water resources, agriculture, and engineering education. Dr. King has worked with government agencies, irrigators, municipalities, Native American tribes, and environmental groups to develop new and innovative approaches to water management and education. He served as a Peace Corps volunteer in Malawi, Africa, and as a Science and Policy Fellow with the American Association for the Advancement of Science at the National Science Foundation. Dr. King has Ph.D. from Colorado State University, a B.S. from Berkeley, and an M.B.A. from NMSU. He is a registered Professional Engineer in New Mexico.

Lee Reynis is a Research Professor of Economics attached to the UNM Bureau of Business and Economic Research (BBER), where she was Director for many years. She has closely watched the New Mexico economy for many years and since coming to BBER in 1998 has been part of the team which produces quarterly economic forecasts using the FOR-UNM model.

Gwendolyn Aldrich is a natural resource economist and works as a Research Scientist at the UNM Bureau of Business and Economic Research. During her time at BBER she has worked on a broad array of projects pertaining to environmental and socioeconomic issues. Her work on this project was assisted by BBER Research Assistants and UNM students Deborah Anyaibe and Alison Turner.

Michael O'Donnell is a Research Scientist at the UNM Bureau of Business and Economic Research. At BBER, he is responsible for modeling and forecasting the economy of the state of New Mexico as well as conducting research on a variety of environmental, economic and socioeconomic topics including water-use policy, economic development, housing and tax policy.

Appendix 2. Discussion of GWPP for the Mesilla & Rincon Valleys

An ignorance of the hydrogeologic characteristics of aquifers, the amount of available groundwater, and the interconnection of groundwater and surface water increases the overall vulnerability of our water supply to drought-related threats. Comprehensive hydrogeologic framework models of the Mesilla and Rincon basins (from WRRI Technical Completion Report 332 and Addendum) provide the critical hydrogeologic information New Mexico requires to understand how the aquifers of the Lower Rio Grande Basin function. The Mesilla Basin stretches from Leasburg (irrigation-diversion) Dam at the mouth of Selden Canyon 45 miles to the International Boundary, and an additional 20 miles south into Chihuahua. The Rincon Valley extends from Caballo Dam to Selden Canyon, which links the Rincon and Mesilla valleys.

A hydrogeologic cross section from WRRI Report 332 (Figure 2) shows the groundwater production potential ("GWPP") of the aquifers in the Mesilla and Rincon valleys between Caballo Dam and Vado (about 10 miles north of Canutillo, Texas). Productive aquifers are contained in thick sedimentary deposits (known as the Santa Fe Group) and overlying thin fluvial deposits from an ancient Rio Grande. Near Las Cruces, extensive layers of clean sand up to 2,000 feet thick form the major aquifer zone in the basin. Near the El Paso Water Utility Canutillo well field at the Texas Stateline, the aquifer thins to 500 feet or less. This is the most heavily developed aquifer zone for drinking water and industrial consumption, and is increasingly being pumped for irrigation. Deeper and adjacent strata are mostly fine grained and partly consolidated, with a low to very low GWPP.

The most striking difference between the Rincon Valley-Selden Canyon area and the Mesilla Basin is the very limited extent of the major Santa Fe Group aquifer zones. The productive aquifers of the lower valley are absent from Caballo Reservoir to below Leasburg Dam (Figure 2). In the Rincon Valley, Selden Canyon and the upper Mesilla Valley, the productive aquifer is constrained to thin (60–80 feet) valley-fill deposits beneath the river channel and the valley floor. These deposits are continuous through the river corridor from Elephant Butte and Caballo reservoirs to the El Paso Valley. In the Mesilla Basin, this shallow aquifer is hydraulically connected to deeper basin-fill aquifers.

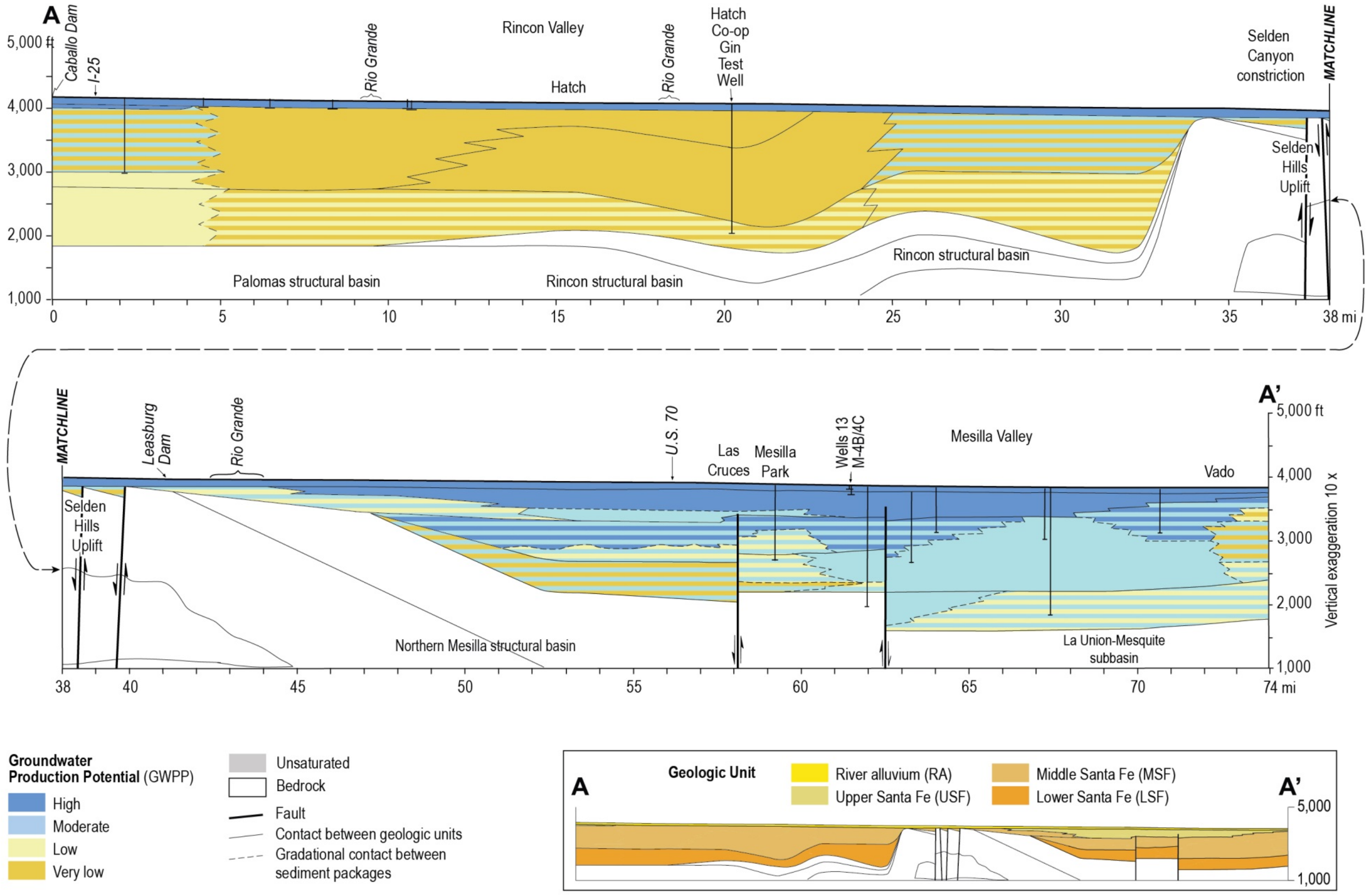


Figure 2. Hydrogeologic cross section (A–A') along the length of the inner Rio Grande valley from Caballo Dam to south of Mesilla, including the Rincon, Selden Canyon and Mesilla segments. The figures show the groundwater production potential of Santa Fe Group aquifers in the Lower Rio Grande study area using a classification system developed by Hawley and Kennedy (2004).

Appendix 3. Groundwater Conditions during the 1950s Drought

An analysis of the effects of the 1950–1957 drought in the Rio Grande Basin (U.S. Geological Survey Professional Paper 372-D by H.E. Thomas (1963)) identified several common drought-related hydrologic conditions in the Mesilla and Rincon valleys, including: (1) insufficient long-term surface storage to supply adequate water through a series of dry years; (2) increased utilization of groundwater; and (3) conveyance losses to groundwater. The increase in groundwater usage during the drought was illustrated by the dramatic rise in irrigation wells between 1946 and 1955. In 1946, when inflow to Elephant Butte Reservoir was low, only 11 wells were pumped. In 1947, which was almost as dry, the number of irrigation wells increased to more than 50. Groundwater development continued to increase with the installation of an estimated 1,600 irrigation wells by 1955. Most wells obtained water from the alluvial sand and gravel underlying the floodplain at depths of 60–100 feet in the Rincon Valley and up to 200 feet in the Mesilla Valley.

The 1950s drought survey also noted that shallow groundwater was recharged directly from the river channel, its associated canals and ditches, and from river water applied for irrigation. A hydrograph of the average depth to water below land surface in 39 Mesilla Valley wells between 1946 and 1958 (taken from USGS Report 372-D and shown in Figure A3) demonstrates the interconnection between the river, shallow groundwater, and pumped wells. The hydrograph shows that:

- Prior to 1951 the water table rose to within 6 or 7 feet of land surface during the irrigation season (April through September) then dropped a foot or two during the winter.
- In 1951, with a shortage of supplies from Elephant Butte, there was no appreciable rise of the water table during the summer irrigation season.
- In 1952 and 1953 the water table was lowered by pumping early in the irrigation season, then rose in late summer when some surface water was available.
- In the four succeeding years (1954–1957), when wells were the main source of water for irrigation in the valley, the water table declined each summer. By the end of 1956, the average water level was 6 feet lower than it had been at years end in 1946 through 1950.
- In late 1957 to 1958, following the end of the drought, water levels rapidly rose to within 2 feet of pre-drought levels and resumed a weak seasonal fluctuation of summer highs and winter lows.

The Rincon Valley had a similar water-level history from 1946 to 1955 based on observations in half a dozen wells.

The USGS drought report provided the following perspective of the Mesilla and Rincon aquifers during and after the 1950s drought:

- The groundwater reservoirs in the Rincon, Mesilla, and El Paso Valleys had sufficient capacity to provide supplementary supplies for several consecutive years of deficient streamflow.
- Rapid refilling of the Mesilla Valley groundwater reservoir in 1958 was seen as a sign that the 1950s development did not exceed the capabilities of the aquifer.

- Pumping in the Rincon and Mesilla Valleys may have been responsible for increased canal losses below Caballo Dam, which were low before 1950 but increased to about 65% in 1955 and to 75% in 1956.
- The Mesilla Valley aquifer was perceived as a new reservoir with a projected capacity equivalent to that of Elephant Butte Reservoir.

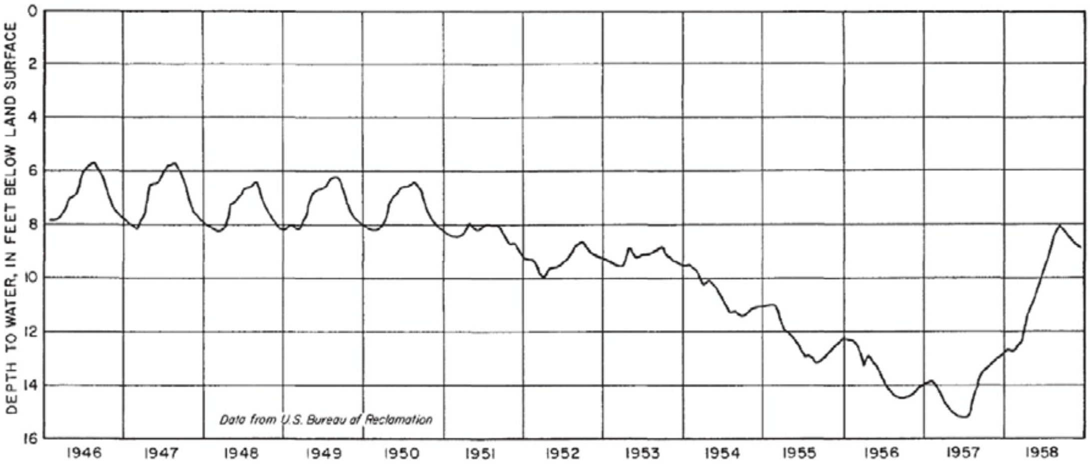


Figure A3. A groundwater hydrograph showing the average depth to water in 39 wells in the Mesilla Valley, 1946–1958. The graph clearly shows the dropping groundwater levels in drought years 1951–1957 and the rapid rise at the end of the drought.