

New Mexico Statewide Water Assessment

Assessment of Spatiotemporal Groundwater Level Changes Throughout New Mexico

Kenneth C. Carroll
Spencer E. Willman

Plant & Environmental Sciences Department and Water Science & Management Graduate
Program, New Mexico State University

6/29/2015

“The New Mexico Water Resource Research Institute and affiliated institutions make no warranties, express or implied, as to the use of the information obtained from this data product. All information included with this product is provided without warranty or any representation of accuracy and timeliness of completeness. Users should be aware that changes may have occurred since this data set was collected and that some parts of these data may no longer represent actual conditions. This information may be updated without notification. Users should not use these data for critical applications without a full awareness of its limitations. This product is for informational purposes only and may not be suitable for legal, engineering, or surveying purposes. The New Mexico Water Resource Research Institute and affiliated institutions shall not be liable for any activity involving these data, installation, fitness of the data for a particular purpose, its use, or analyses results.”

Contents

Contents	1
Background	4
Literature review:	5
Purpose and Scope:	9
Methods	10
Data Sources:	12
Data Limitations:	13
Measurement Accuracy and Data Compilation:	13
Results.....	13
Change in water Level Map.....	14
1970-1975	14
.....	15
.....	15
1975-1980	15
.....	18
1980-1985	19
.....	20
.....	20
.....	21
.....	21
1985-1990	22
1990-1995	25
.....	26
.....	26
.....	27
.....	27
1995-2000	28
2000-2005	31
.....	32
.....	32
2005-2010	34

2010-2014	37
.....	38
.....	38
1970-2012	39
Hydrographs.....	41
.....	42
.....	42
Southwestern New Mexico	43
Northeastern New Mexico	55
Southeastern New Mexico	65
Conclusion	78
Table 1: Summary of spatial analysis for each of the 5 year time periods.....	78
Table 2: Summary of temporal analysis for each of the basins.....	79
References.....	81

Abstract

The southwest region of the United States has recently been under drought conditions, and this has the potential to harm the long term sustainability of agriculture production, industrial innovation, and drinking water quality. Trends suggest that the region is likely to become drier and experience more severe droughts. This will make sustaining water supplies in the Southwest even more challenging (Cayan et al, 2010). The inaccessibility and variability in groundwater data can make it challenging to examine impacts such as drought, changes in agriculture, and population variability. We have utilized both the spatial and temporal methods to plot and evaluate groundwater level and the changes in groundwater level data. The purpose of this study is to advance our understanding of changes in groundwater levels and how they relate to water use and sustainability across the state of New Mexico. This report used historical data provided by several state governmental agencies. Microsoft Excel was used for plotting and statistical analysis, and R statistical software was used to simulate (loess nonlinear regression) periods of time when no data were collected. Data were also exported from Excel into ESRI's ArcGIS software to represent changes in groundwater levels spatially for different time intervals. Impacts of the largest use sectors (i.e., agriculture and domestic use) were evident, and impacts were more significant when both use sectors were collocated. Wells located near major rivers typically had the lowest rate of decrease in water elevation. Areas with restricted surface water supplies experienced higher levels of withdrawals and potentially lower rates of recharge; resulting in a higher rate of groundwater level decrease. If drought conditions continue, access to surface water reservoirs may be restricted, this could increase the rates of groundwater elevation decline in some areas. Additional research is needed to understand what policy actions need to be taken to preserve the equity for future generations in New Mexico.

Background

The population of New Mexico is just over 2 million people (U.S. Census Bureau, 2010), making it the 36 most populated state in the United States. It has a total surface area of approximately 121,666 square miles, making it the 5th largest state. Much of this land is considered arid to semi-arid which is surprising consider there are 1,976,689 acres of crop land (USDA economic research service). Surface and groundwater is also relied upon but other industries in the state, these include but not limited to: livestock production, mining (includes oil and gas), commercial, and hydropower plants. As surface water becomes scarcer and groundwater elevations become deeper, and we will be required to drill deeper wells. This doesn't only lead to higher initial capital exponders but also higher cost through the lifetime of the well (Wichelns, 2010).

In the past, most surface water originated as snow pack in the northern part of the New Mexico and Colorado. As the western part of the country has experienced a documented reduction in snowpack this source of water is becoming less and less reliable (Pederson et al., 2011). To compensate for the reduction in surface water; agricultural and urban areas have increased the amount of groundwater pumping. Throughout New Mexico, these two water resources are closely linked; the quantity of one will have a direct relationship with the other. There has also shown to be a link between urbanization and water both water quality and quantity (Hall et al. 1999). As urban areas expand, water quality and quantity will degrade, this can be partly contributed to decreased recharge (Vazquez-Sune et al, 2005 and Choi et al, 2003). For generations, water demand was met by surface water supplies in many parts of the country. However, due to the increased length and occurrence of drought, demand for water originating from rivers has outpaced supply. This had led to increases in pumping from the aquifers beneath farms, rangelands, and urban areas.

At the current time over 80% of water in New Mexico is used in some form of agriculture (e.g., Ackerman and Stanton, 2011). This includes traditional forms of farm such as alfalfa production, but it also includes ranching and dairy production. The second largest use sector is domestic use. New Mexico is not considered a highly-populated state. However, much of the population tends to concentration in a few localized urban areas. Several of the urban areas may also be collocated with agriculture, which concentrates the water resource demand for those areas. A majority of agriculture production can be found around the two main surface water sources in the state, the Rio Grande and Pecos River. The remaining share of total water is used primary by municipalities. The Rio Grande has played a key role in developing regional cities and the agricultural business sectors. The agricultural industry and the associated water rights legal system were developed and based on the surface water. However, groundwater is being increasingly utilized to support both domestic and agricultural demands. With a sharp increase in population and fields in production in the last 100 years, the river (surface water) has been the focus of policy, regulation, management, and even legal disputes (Ingram, 1990; Hall, 2002).

Increases in regulation, policy, and management have done little to combat the effects of longer and intense droughts present in New Mexico while demand outpaces supply.

New Mexico also has a significant amount of groundwater. There are 42 defined aquifers in the New Mexico with varying size and depths (New Mexico State Engineers Office). Eight of which are governed by interstate compacts with neighboring states. Groundwater is typically much older and has a much larger residence time compared to surface water. This suggests that the groundwater is not recharged or replenished as rapidly as surface water. Use of groundwater capital (storage) to compensate for losses in surface water without decreasing demand supports the short-term resiliency of the water resources system, but it comes at the potential cost of long-term sustainability. As we move forward, questions have been raised about the security of food production even with the use of groundwater (Postel, 1998).

Literature review:

Current surface water supplies are unable to meet the demand of water users resulting in groundwater extraction. Several factors are believed to have led to this water shortfall. Including increased agricultural production, drought, climate change, and urban expansion has all contributed to the added demand. To meet crop needs, farmers have been forced to adopt more aggressive groundwater pumping practices (Ahmed et al, 2014; Chew and Small, 2014; Dourte et al., 2014; Scibek and Allen, 2006, Wakode et al., 2014). In New Mexico it is hypothesized that in areas experiencing increased agricultural production, drought, climate change, and urban expansion will exhibit a water resource deficit resulting in declining water levels. The null hypothesis states that there is no correlation between the above factors and declining water levels. The following articles will help to support the purposed hypothesis and the need for a compressive water level study for New Mexico.

In a study conducted by Burns et al. (2012), the authors attempted to evaluate widespread water level declines associated with development of groundwater for irrigation and other uses, and they examined impacts of reduction in base flow in rivers on water temperature, water quality, fish, and other aquatic organisms. They also examined current and anticipated effects of global climate change on recharge, base flow, demand, and ultimately, groundwater availability. The area of interest of this study was the Columbia Plateau regional aquifer system in Washington, Oregon, and Idaho. Characteristic wells were chosen to categorize areas of similar hydraulic heads and temporal trends. This allowed Burns to identify vertical and horizontal barriers, flow within the aquifer, and interconnection of adjacent aquifers. The sample size included wells dating back to 1940. Of the total wells available, the research team used 7,772; and a total of 147,563 depths to water measurements were used for analysis. Areas where groundwater was used as the main irrigation source experienced the greatest change, with a cumulative decline of over 200 feet. The research team also found that using stratigraphic coordinates to identify aquifer characteristic is a useful tool when evaluating the elevation of groundwater and its change over time.

In another study, Campos-Gaytan et. al (2014) evaluated the growing demand of groundwater caused by increased agriculture production and domestic water requirements. This has caused groundwater levels to decrease as natural recharge rates are unable to meet current extraction rates. The purpose of this study was to simulate different water management scenarios for the period of 2007-2025 in northwestern Mexico. Research suggests that if current extraction is reduced by 50%, recharge will have the ability meet demand and water levels will be brought back to historical levels. The Baja region of California is characterized by a similar climate as a majority of the State of New Mexico. Semiarid regions rely heavily on groundwater and surface water, water is typically supplied by mountains that have snow pack. In the Baja of California, 60% of water is sourced from surface water with the remaining 40% coming from groundwater pumping (Commission Nacional del Agua, CONAGUA. 2010). Even though water levels have been found to be cyclical and varying from year to year, overall levels have decreased 20 meters for the whole study area. These findings strengthen the argument made by previous studies conducted in the same region. Concluding that pumping for agriculture, industry, and domestic usage have led to excessive pumping (SARH 1967; CONAGUA 1990; CONAGUA 1998; SARH 1982; Andrade 1997). Different methods for determining aquifer properties were borehole and pumping tests, lithological logs, and geophysical methods (Instituto Nacional de Estadística, Geographic e Informatics (INEGI) 1976; Andrade 1992; Beltrán 1998; CONAGUA 1998). They concluded that most of the predicted groundwater levels were constant with observed levels. For other wells however, short term fluctuations in groundwater levels were not clearly illustrated by the model.

In another article, Kettle et. al (2007) discussed how changes in the amount of water resources have affected land use. Water supplies have been determined to be inadequate if so heavily relied on into the future, having serious economic and social impacts (Jury and Vaux, 2005). The reliance on water by both municipalities and farmers can't be understated. However, a majority of use is centered on the agriculture industry; with 85% of total water being allocated to the agriculture industry in Wichita County, Kansas (Gleick, 2003). This is similar to the amount of water used by agriculture in New Mexico, which stands at around 80% (Ackerman and Stanton, 2011). This is one reason why monitoring land use change has become a powerful tool for assessing and integrating social, geographical, and natural data (Rindfuss et al. 2004). The scale of evaluation may also be an issue, because the accuracy of the findings is based on the resolution of the data. When monitoring land cover change, remote sensing technologies are heavily relied upon. Landsat imagery is the most widely used source of images in this study as well as past studies (Nellis et al. 1996; Egbert et al. 1998). Accuracy of water level measurements are based on the number of wells in the study area (change in depth to water or change in water elevation) (Liverman 1999; Lambin et al. 2001; Skole 2004). Most research that has been conducted in the Great Plains region of the US has been on a regional scale (e.g., Qi et al. 2002), as opposed to a single county. Narrowing the scope is one of the key elements that separate the Kettle article from previous ones. The objectives of this project and the reason why the researchers used a more focused study area are to understand the sustainability of areas

within a region; identify major human causes of changes in the environment (National Research Council, 1999). Over the whole time period evaluated (1975-2001) total groundwater levels decreased by 6 to 11 m, resulting in a 20-40% change. The greatest amount of change occurred between 1975 and 1985, where the water table dropped 3 to 6 m depending on where in the county the level was measured. Irrigated cropland also had its greatest decrease within that window as well, when a total of 4.6 percent of the total land areas was left fallow or not irrigated. In areas of high withdrawals and declining water levels, the rate at which land was being taken out of irrigation was much greater. There are multiple factors influencing irrigation such as federal and local policies, government programs, energy cost, crop price, just to name a few. The framework presented by Kettle and group will allow other researches to start to predict how change may occur by using remote sensing and GIS technologies.

Other prior research that has evaluated the change in groundwater levels based on urban development as opposed to irrigated agriculture (Choi et al 2012). The research team used geographic information systems and spatial analysis with respect to Waukesha County in Wisconsin to determine groundwater withdrawals. Groundwater levels, land use/land cover, precipitation utilizing correlation analysis, geographically weighted regression, land use changes analysis, and map overlay. The goal of this study was to improve the management team's knowledge about the spatial unevenness of groundwater withdrawals and its effect on recharge and overall groundwater levels. As groundwater resources are starting to become threaten more and more, sources of clean and available water are decreasing, which has had a serious impact on development and quality of life (Jaiswal et al. 2003) and not just in arid regions like the Southwest (Vazquez-Sune et al, 2005). Previous studies show that that not only are cities forced to pump more groundwater but they are also seeing huge drops in natural recharge. The cause of this can be traced to changes in land use and land cover such as roads, buildings, drive ways, and parking lots. Zellner (2007) estimated that the groundwater recharge could be affected by as much as 16%. Erickson and Stefan (2009) reported that an urban center could expect a 30-40 percent reduction in recharge for every 30 percent increase in the urban area. To address the main goal of analyzing spatial and temporal groundwater level changes using GIS and spatial analysis, we must not only evaluate the recharge but a number of factors, such as geological characteristics of the areas. Wisconsin is known to have a varying vertical gradient across the land scape. However there are 17 counties in Wisconsin that have similar geological profiles to Waukesha County (Great Lakes WATER Institute [GLWI] 2007). The in situ data used for the research are based on groundwater withdrawals between 1964 and 2005 below the county of interest, which was provided by the U.S. Geological Survey (Buchwald et al. 2010). This data was used, in conjunction with contour maps, to determine the level above sea level. The potentiometric surface value for high, moderate, and low permeability zones for each year data was available. The ancillary data collected described the change of the urban sprawl over time. This information was provided by the local land commission office in April of 2010. The data was provided in the form of numerical data sets and ArcGIS shape files. This allowed the research team to assign land classes to each area, which was an important step in determining

what areas would have the greatest effect on recharge. The importance of this step was also mentioned in the Kettle et. al (2007) article. Precipitation data was then added to evaluate the difference in recharge rate. By combining all in situ and ancillary data, a correlation between variables was made.

Watershed systems provide multiple goods and services that sustain human population and ecosystems (Randhir and Shriver, 2009). This article calls for better management, policy decisions, and information to maintain and possibly improve the resource on a spatial and temporal scale. Water quality and sustainability are being influenced by biophysical and socioeconomic drivers. To understand these drivers, the research team broke up the watershed based on the spatial, structural, and functional patterns determined by (Hobbs, 1997) which were determined to be the essential characteristics of landscape ecology (McGarigal and Marks, 1995) and establishes the need for a spatially explicit land use change model. This paper is unique in that it links water resources and water quality within a dynamic model framework as opposed to evaluating them independently. The model is then applied to a typical watershed to evaluate spatial distribution, temporal trends, and policy options. This process fits in with the general goals of the study which are to assess the nature and emergence of spatial patterns in land use and the response of water resources in a small watershed system at long term temporal scales. The model was applied to a small watershed in the Blackstone River Basin of central Massachusetts. This watershed was selected based on the diversity of land use. The area was then broken up in a grid like system, with each grid being one square acre and assigned a location value using GPS mapping. Each land use cell was influenced by the interaction between temporal and spatial factors in the watershed. This allowed the research team to determine the change in land use type over time or when land classifications may need to be updated. The data used was sourced from MassGIS and placed into 37 categories, and then placed into 4 different major categories. To estimate soil erosion over time, the research team used the RUSLE2 model over a 100 year period, with measurements made every year. The RUSLE2 model was also calibrated then validated using information found in regional studies from 1999 to 2005. Land use predictions may also be calibrated and validated using another method; the kappa Index (Chust et al. 1999). The study area is comprised of 4 major different land cover: forest, agriculture, suburban and urbanized areas. Areas categorized as urban had the greatest effect on water quality in respect to hydrology (Randhir, 2003), water quality (Randhir and Tsvetkova, 2009), and habitat in the watershed; which makes up 34% of the study area. The remaining 66% is made up of: urban (46%), agriculture (12%), and other (8%). The study found a pattern of rapid urbanization with agricultural land decreasing the most over the past 25 years. Patterns also show that there has been vast urban encroachment on forest areas. Causing forests to become more disperse and fragmented. If current trends continue, urbanized land will overtake forests as the main land use. This study builds on and extends the knowledge of the impact land use change has on the watershed and the expected change in land use.

In a recent report by Leonard F. Konikow and Eloise Kendy (2005), the team focused on outlining the status of groundwater around the world and presentation of innovative management practices to combat the current trend. Technological advancements have led to groundwater exploration not experienced in previous generations. Some estimates have placed total groundwater withdrawals at a staggering 750-800 km³/year globally. However this water hasn't been wasted in most cases. Farmers have seen their economic prosperity sore during this time. Cheap readily accessible groundwater has been harder to find however. Evidence also suggest this trend will continue as pumping cost increase, water quality decreases, and well yields decrease (Konikow and Kendy, 2005). Unsustainable water management practices are present as far away as China and Australia and as close as the deserts of the southwestern United States. A prime example of this is the High Plains aquifer system in the central United States. During the 20th century, cumulative depletion of this aquifer system has reached a total of 240 km³. Recharge to the aquifer system has proven to vary from location to location as the geological characteristics of the system vary dramatically.

Even though estimates have been placed on total water withdraw, aquifer management has been poor to nonexistent, which is common in what are classified as third world countries. Depletion is classified using 2 methods for quantification. The first is what we would commonly characterize as depletion, and that is total water volume loss. The second is loss in total usable water. This water isn't useless however and as the cost of water increases, the price to desalinate this water is becoming more realistic. The most common and direct way to measure total volume loss is measured by calculating the well head change which is then multiplied by a storage coefficient. Total loss derived using this estimate can be challenged however because of the role leakage plays. As aquifer systems are more heavily pumped and drawdowns increase, leakage from surrounding systems could make decreases in groundwater elevation seem less severe.

Purpose and Scope:

New Mexico is in a long-term drought that threatens the sustainability of the agricultural industry as well as drinking water supply. Surface water is continuing to decrease despite being over allocated, and groundwater is being used without replenishment to buffer declines in surface water. The problem is that we do not have a way to evaluate the decline in groundwater levels spatially or over time. Fluctuations in groundwater levels are a fundamental metric for assessing changes to the total water storage within an aquifer system.

Fundamentally, fluctuations in groundwater levels reflect changes to the total groundwater storage within an aquifer or aquifer system, which can highlight changes in either recharge or discharge. Understanding these changes is vital to the security of the semiarid to arid landscape of New Mexico. As groundwater is an important freshwater resource for both agriculture and municipal use in New Mexico, tracking and understanding changes in groundwater levels is beneficial for the overall assessment of freshwater resource allocation. More importantly, identifying localized changes in groundwater trends on a regional to statewide scale can help

identify potential areas of current or future water stress, where groundwater is being mined instead of being pumped at a sustainable rate.

This report describes the results of a spatiotemporal investigation that focused on groundwater level changes at specific well locations located across the state of New Mexico. The purpose of this investigation was to use both spatial and temporal evaluations to examine the changes in groundwater elevation. The investigation was used to identify where the most significant changes in groundwater elevation were occurring and to identify if there were any significant changes in groundwater elevations over time.

The hypothesis evaluated herein is that the spatial and temporal distribution and magnitude of change in groundwater elevation can be assessed and will support the evaluation of groundwater pumping change on the potential depletion of groundwater as a resource. The objectives of this study are to 1) transmit data from a groundwater database into a Geographic Information System (GIS) to map the spatial distribution of groundwater level changes for visual and spatial analysis, 2) calculate groundwater elevation, change in groundwater elevation, and 3) evaluate the potential impact of increased groundwater pumping on changes in groundwater elevation. The potential impact is being evaluated through comparisons of changes in groundwater elevation change and groundwater pumping through space and over time.

This work has been developed to illuminate changes in water levels on a state wide scale, while also highlighting data gaps where future work may be needed. In many regions of New Mexico, water levels are declining, but until now the data have not been compiled and analyzed to quantify regional changes in groundwater levels. Specifically, this project aims to update statewide groundwater level maps and to quantify the change in groundwater levels from 1970 to 2014, over 5 year time intervals, within the state of New Mexico. As a result of this project, regional to statewide scale maps of changes in groundwater levels are being produced alongside a spatial database containing groundwater level data for New Mexico. Additionally, this project has attempted to identify trends in groundwater use, population increase, change in land use, or other possible causes for changes in groundwater levels by creating maps comparing changes in groundwater levels with changes in the external variables mentioned above.

Methods

Methods:

Recent and historical water-levels were recorded at a variety of wells and at different times throughout New Mexico. A loess nonlinear regression analysis method was used to predict water levels during times with lower frequency data. A script was developed using R programming language, which contained the loess method. The script was developed to iterate through the data, performing analysis on each well, and exporting the predictions of groundwater levels, which were plotted and compared with the observed data. After trend analysis was used to

predict water levels over time and water level changes over 5 year time periods, wells were grouped based on their geographic location. To determine each of the aquifer boundaries, wells were grouped based on depth to water measurements. Wells with similar water levels suggest that they were pumping from the same aquifer.

To determine the actual change in groundwater level in each aquifer, a trend analysis was conducted based on water level data measured at each well. The change in depth to water is based on the difference between water levels from an earlier year to a later year. Due to data limitations, years before 1970 have been omitted. The remaining available data were separated into five year increments, for example 1970-1975. This was illustrated in the form of point data on a map in ArcGIS. Well point locations were displayed with varying types of symbols. The symbol size was varied to signify magnitude of change in water level. We decided to use the default setting of five classes when assigning unique symbology to each variable. For maps that show change in water elevation only, we used rings that varied in size with amount of change and color indicating an increase or decreases in groundwater elevation. It is important to note that increase in water elevation (water level elevation rising) and decrease in water elevation (water level elevation falling). The range of each class of water level change was kept consistent for each layer as well as for every map. Once water level change data was collected, analyzed, and imported into ArcGIS, different surface condition map layers were produced, such as groundwater used in agriculture, in an attempt to understand the relationship between groundwater levels and groundwater water use.

The first variable analyzed was irrigated agriculture water use, because this has been by far the largest water user in the state of New Mexico. For example in 2010 irrigated agriculture accounted for 78.62% of total water use or 3,000,155 acre feet (Longworth et al, 2011). The Office of the State Engineer (New Mexico) used two metrics to determine water use. The first was the Original Blaney-Criddle (OBC). This method was developed by Blaney and Criddle to produce an estimation of ET for the Pecos River between 1939 and 1940 (Longworth et al. 2011). This has become a well excepted way to determine ET in the western United States as well as in other arid regions (Xu and Singh. 2002). This method however does not take into account the effective of frost (Longworth et al. 2011). The second method, the Modified Blaney-Criddle can be used for all month, and can account for late and early year freezes (Xu and Singh. 2001). Quantifying irrigation withdrawals has been a complicated process, and the Office of the State Engineer used an eleven step process. It was based on data collected on: crop acreage, temperature and precipitation, and growing season data. Irrigated agriculture was not the only water use category analyzed in the report, but was the only use mapped for this report. Other water used the State Engineer included in the report were: commercial, domestic, industrial, livestock, mining, power, and public water. These data were presented in a graphical form. A bar chart was created back to the date water use data was collected and separated into specific uses at specific times (e.g., 1980). A characteristic well was then added to the plot to show the relation

between water level change and water use. Only water specified as pumped/groundwater was used in this analysis.

To illustrate the nonlinear and transient nature of the changes in water level, hydrographs were produced for changes in water level as function of time. These included the changes in water level observed as well as predicted depth to water from 1970 to ~2014. To account for the different aquifer systems in the same basin, the graph was analyzed, and an attempt to separate them based on their depth was made; more attention is given to shallow water systems (≤ 150 ft). 150 feet was chosen because a majority of wells fell into this category and it allowed analysis of wells over the whole time series. The shallow wells (depth to water ≤ 150 ft) and deep wells (depth to water > 150 ft) were evaluated and plotted separately when data were available for the deeper wells. The first was the observed depth to water collected in the field. These were illustrated as point data on the graph. The second source of data was the smoothed loess predictions for individual wells produced in R software. These were illustrated as black lines. The above processes describe the steps to show changes in water levels over time and space. The third dimension we hope to describe is the statistical description of changes in water level over time and space. By comparing individual basins, the relative magnitude of change in groundwater level was clearly observable for each basin. We also showed which of the wells had increases and decreases in groundwater elevation. This was done by exporting the wells from ArcGIS as a dbase file. Once in this form, the dbase file can be opened in Excel. Excel was used because of the tools available such as the descriptive statistic tool and the ability to handle large datasets.

We displayed the results of the study in the following form. We placed a heading with the five year interval being analyzed. First, we included a map of the whole State. We then included one map with each of the four regions/quadrants. Then we added the hydrographs after. It is important to note the difference between change in groundwater elevation and depth to water. A decrease in depth to water equates to an increase in water elevation, meaning that groundwater levels are rising or moving closer to the surface. An increase in depth to water equates to a decrease in groundwater elevation, meaning that groundwater levels are dropping or moving further away from the surface. However, we focused on calculating and comparing changes in water levels. The magnitude of the change in groundwater elevation is equal to the change in depth to water.

Data Sources:

Determining changes in depth to water and the health of respective aquifers depended heavily on quality well measurements. The data used was collected by a range of governmental agencies including the New Mexico Bureau of Geology and Mineral Resources (NMBGMR), United States Geological Survey (USGS), and the New Mexico Office of State Engineer (NMOSE).

Water level data

The United States Geological survey provided much of the groundwater data. They provided information detailing: location, altitude, well and hole depth, date of construction, and depth to water. To maintain the highest degree of accuracy, focus was placed on wells with the largest number of well measurements. Depth to water data was available for 5,428 wells. A total of 129,497 water level measurements were made at the 5,428 wells. The oldest well measurement dates back to 1900 and the most recent measurements were made in 2014. Data was stored in Excel, then manipulated, and saved in proper format to be either opened in R software or imported into ArcGIS. Data that was evaluated in R, were cleared of all unnecessary rows such as surface elevation. The three rows most crucial for analysis were: well identification, date, and depth to water. The loess regression analysis within R was performed only on wells that had 7 or more measurement between 1970 to ~2014.

Data Limitations:

Data collected must attempt to represent the true status of water levels at each well. Accurate evaluation is depended on numerous factors that could affect depth to water measurements at any point in time. By running a regression analysis, many of these variabilities were removed and the relationship between points was summarized (Cleveland, 1979).

Measurement Accuracy and Data Compilation:

Water level measurements had a precision of 0.01 feet to 1 foot; with a majority of measurements having accuracy of one foot in either direction. This however doesn't imply that the accuracy of the true depth to water is within this range; some of the factors that may affect accuracy are: seasonal variability, increased extraction, aquifer transmissivity, or hydraulic conductivity may cause readings to vary considerably (Jacobs, 2007).

The data collected from the selected agencies was evaluated for accuracy before being contributed. Each agency has their own criteria when collecting water level data. Effort was made to correct instances where this occurred. Another source of error, were those that had unrealistic depth to water measurements. Some of these unrealistic depths include those that were recorded as negative values and those with depths greater than the surface elevation. Wells that are also defined as not representative of the true depth to water were those that were dry at any point or those affected by pumping in other areas.

Results

The depth to water at each well differed greatly over the state, with some depths being less than a foot and some as deep as 500+ feet. Individual water level measurements were used to determine the long term change in depth to water. Using trend analysis allowed us to smooth out variations in yearly water level measurements (Loess analysis). Many factors contributed to

decreases in water elevation, some of these are: drought, water used in irrigated agriculture, mining, livestock production, and municipal water use. Through the research, the most common cause wasn't the presence of agriculture but where water for agriculture was being sourced. In Dona Ana county which had the highest total water use, did not have changes in groundwater level to the same degree as in areas like Curry or Chavez County who had the eighth highest total water use. This is due to the amount of surface water made available by the Rio Grande. In 2010, Dona Ana County received over 271,000 acre feet (AF) of surface water and pumped an additional ~122,000 AF of groundwater. Curry County did not receive any surface water but pumped ~167,000 AF of surface water. Chavez County only received ~16,000 AF and pumped ~226,000 AF.

Change in water Level Map

1970-1975

The first map (Figure 1) illustrates changes in water level from 1970-1975. As the map shows, changes in water levels can be seen as far back as the first half of the 1970's. For this time series, 1,357 wells were sampled. The average decrease in groundwater elevation for the whole state was 1.84 feet over five years. The standard deviation was 5.95 feet. This number was relatively large because of the amount of wells being analyzed. This is expected to decrease as the state is broken up into regions. This range can be explained by simply looking at the maximum and minimum change value. The well that had the greatest decrease in groundwater elevation (61.8 feet over five years) was located in Bernalillo County. The well that had the greatest increase in groundwater elevation (25.9 feet over five years) was located in eastern New Mexico.

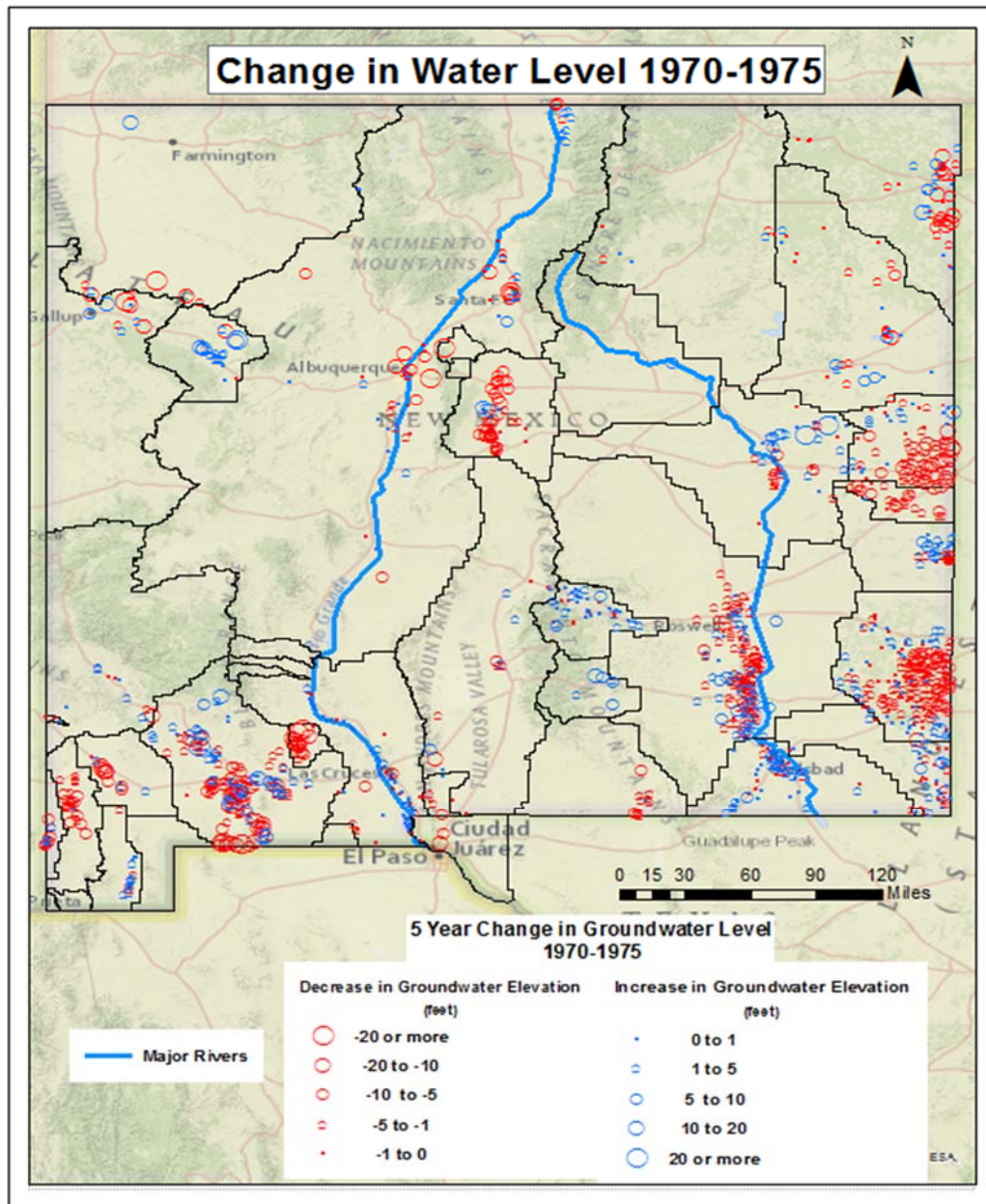


Figure 1: This map illustrates change in water levels for 1,357 wells sampled between 1970 and 1975. The back lines outline the defined basins in New Mexico.

1975-1980

The first figure for 1975-1980 (Figure 2), illustrates the change in groundwater level between 1975 and 1980. If compared to the previous map, they are comparable and generally very similar. For this data set there were 1,626 wells. The mean change in groundwater elevation was a 1.34 foot decreases in groundwater over five years. The standard deviation for this time period was 6.6 feet. The well that had the greatest decrease in groundwater elevation was located in the Northwestern part of the state near Gallup. The decrease in groundwater elevation was estimated at 121 feet over five years. The well that had the greatest increase in groundwater

elevation is also located in the Northwestern part of the State and is 45 miles northeast of the well noted above. The increase in groundwater elevation is estimated at 58 feet over five years.

The next map (Figure 3) for 1975-1980 took water use into account and more specifically, groundwater used in irrigated agriculture. The county that used the most groundwater was Chaves County, using 255,790 AF of groundwater in agriculture. The top five users of groundwater were all located in the Southeastern part of the state. Other Counties that use a substantial amount of water were Dona Ana and San Juan when including surface water. Dona Ana used a total of ~454,000 AF but only pumped ~58,000 AF of groundwater. San Juan used a total of ~365,000 AF but didn't pump any groundwater. The total groundwater used in the state of New Mexico in 1980 was 1,452,446 AF. The average amount of water used per county in agriculture was 44,013 in 1980. All but four counties had a measured irrigated agriculture groundwater withdraw. Agriculture water use was chosen because for almost every county it was by far the greatest user of groundwater and has the greatest impact on changes in water levels.

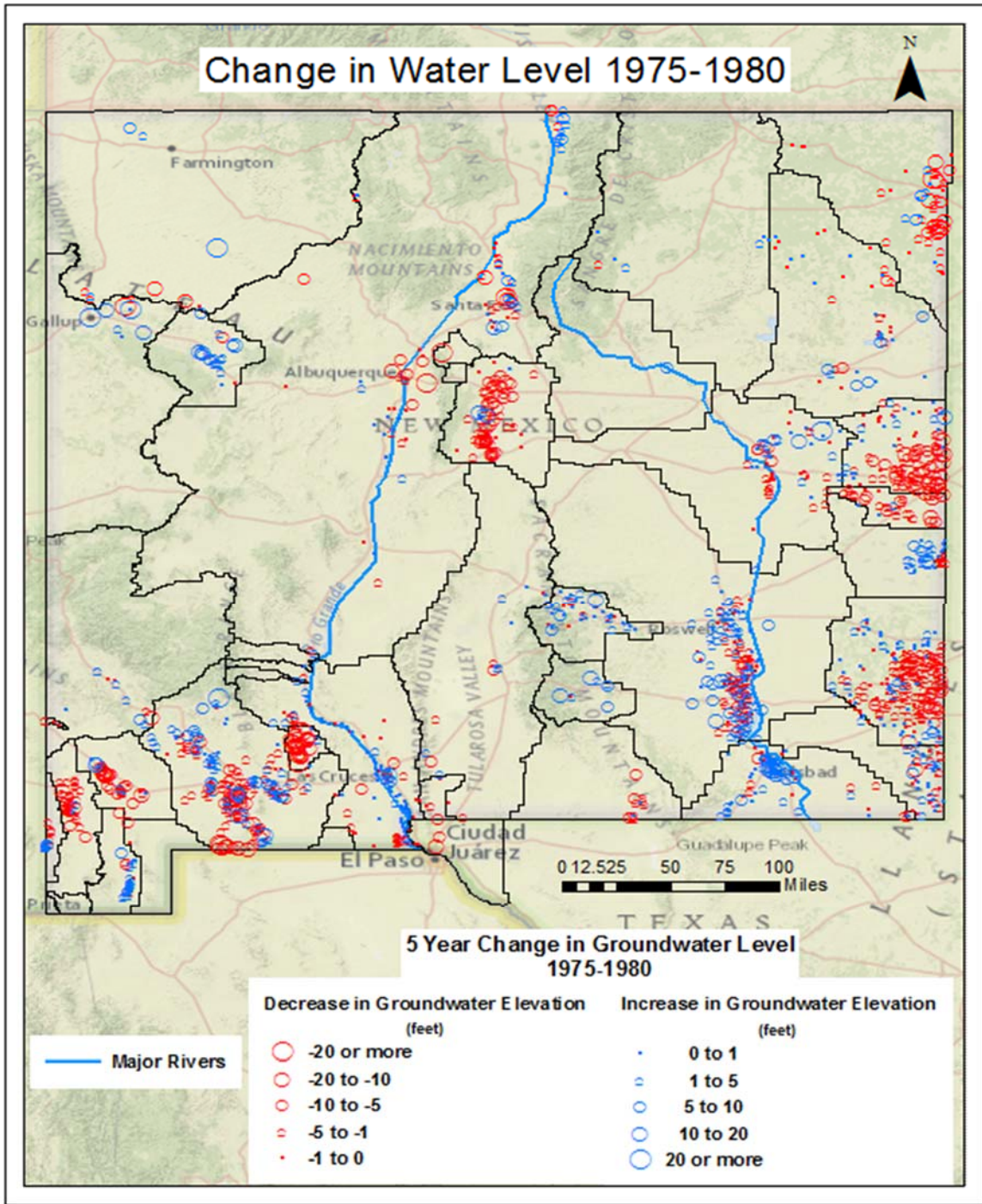


Figure 2: This map illustrates change in water levels for 1,626 wells sampled between 1975 and 1980. The back lines outline the defined basins in New Mexico

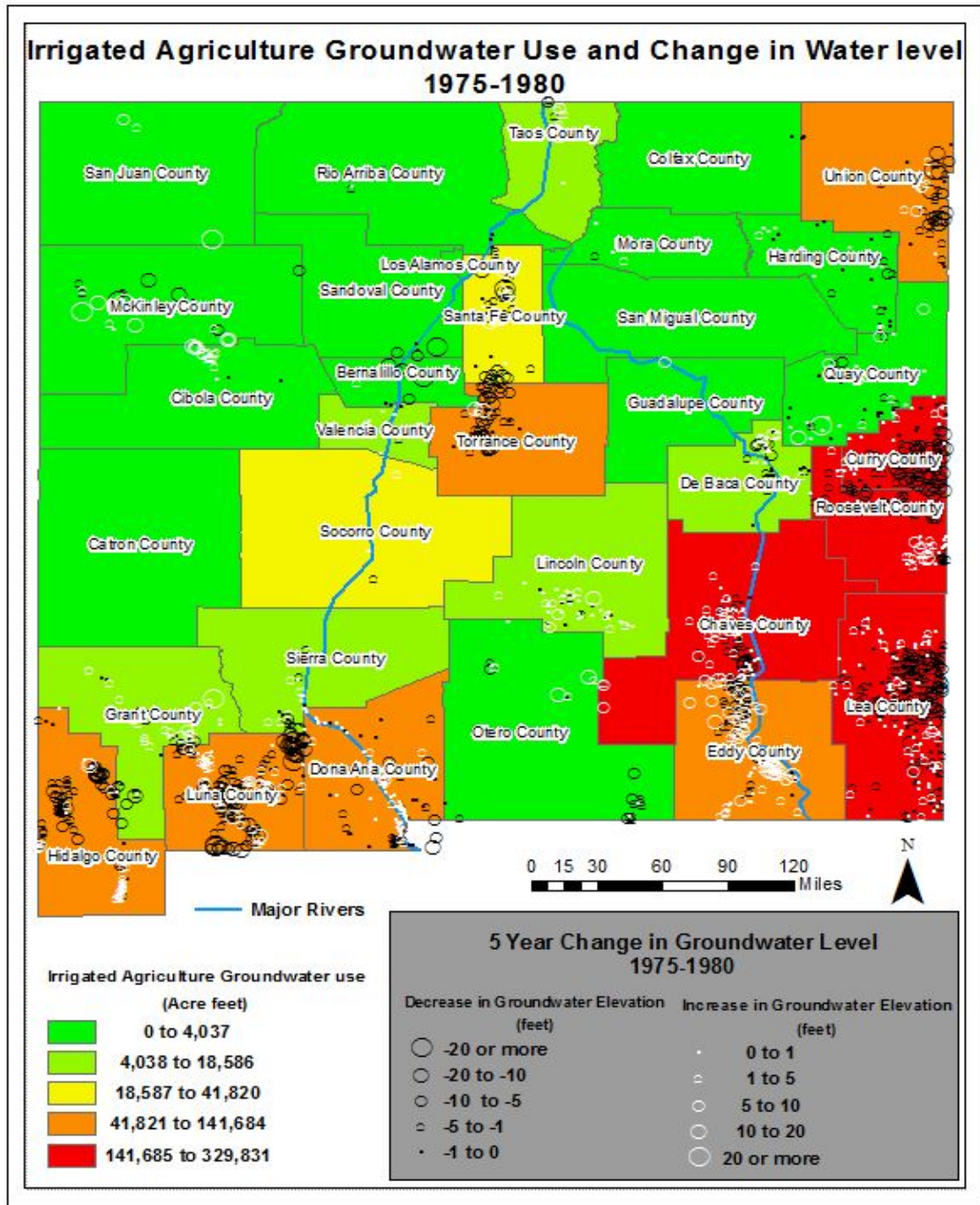


Figure 3: The map above illustrates groundwater used in irrigated agriculture per county in New Mexico in 1980 as well as change in groundwater levels between 1975 and 1980.

1980-1985

For the time series of 1980-1985; 1,858 wells were sampled (Figure 4). Little change can be seen from the previous time series. The descriptive statistics tell a different story however. The average change in water level per well in the state was a decrease in groundwater elevation of 0.72 feet over five years. The standard deviation, 8.09, remained high due to the vast size of the study area. Many wells however had large decreases in groundwater level. Six wells had decreases of more than 40 feet. The same well, located outside of Gallup in the Northwestern part of the state, NM-01448; had the largest decrease in water level. In 1975 the depth to water at that well was 169 feet and in 1985 the depth to water was 432 feet. The well that had the largest increase was located just west 13 miles away and had an increase in groundwater of 72 feet over five years.

From 1980 to 1985, water use in irrigated agriculture decreased. The same steps were taken in 1985 (Figure 5) as in 1980 (Figure 3) i.e. the range for each class in the symbology. Due to the large range in the symbology, it is difficult to truly understand which counties are using more, the same, or less water. 11 counties in total used more water in 1985 than in 1980. Roosevelt County pumped over 40,000 AF more water in 1985 than in 1980. Twenty counties were able to decrease use. Two counties, Lea and Curry, were able to decrease use by over 50,000 AF from 1980 to 1985. Chaves County again was the largest user of groundwater, using 236,499 AF. Three counties used no groundwater for agriculture: Los Alamos County, McKinley county, and San Juan. The average groundwater use in 1985 was 39,800 AF per county this is 4,213 AF less than the 1980 report. Total groundwater used in agriculture for the state was 1,313,421 AF in 1985.

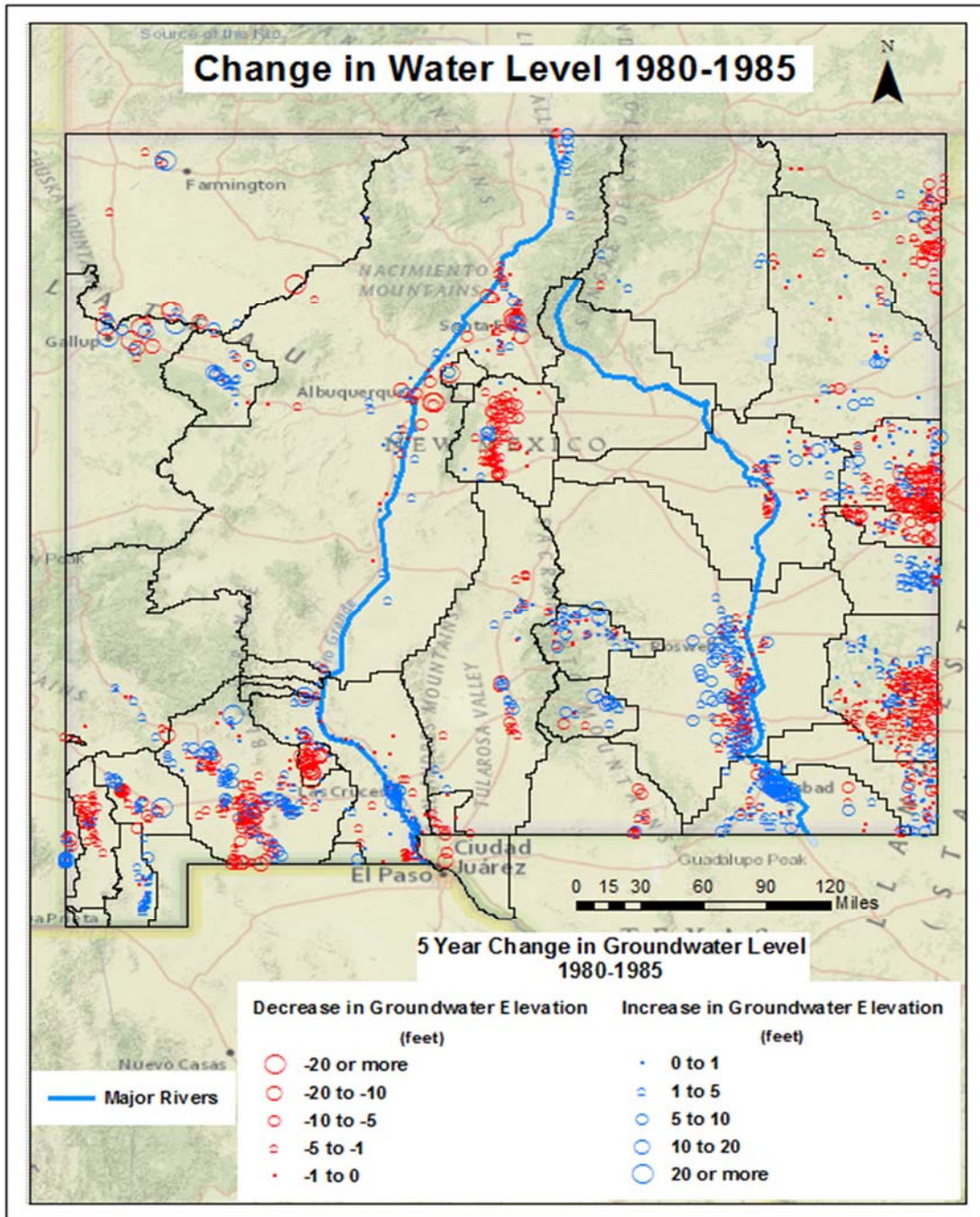


Figure 4: This map illustrates change in water levels for 1,858 wells sampled between 1980 and 1985. The back lines outline the defined basins in New Mexico.

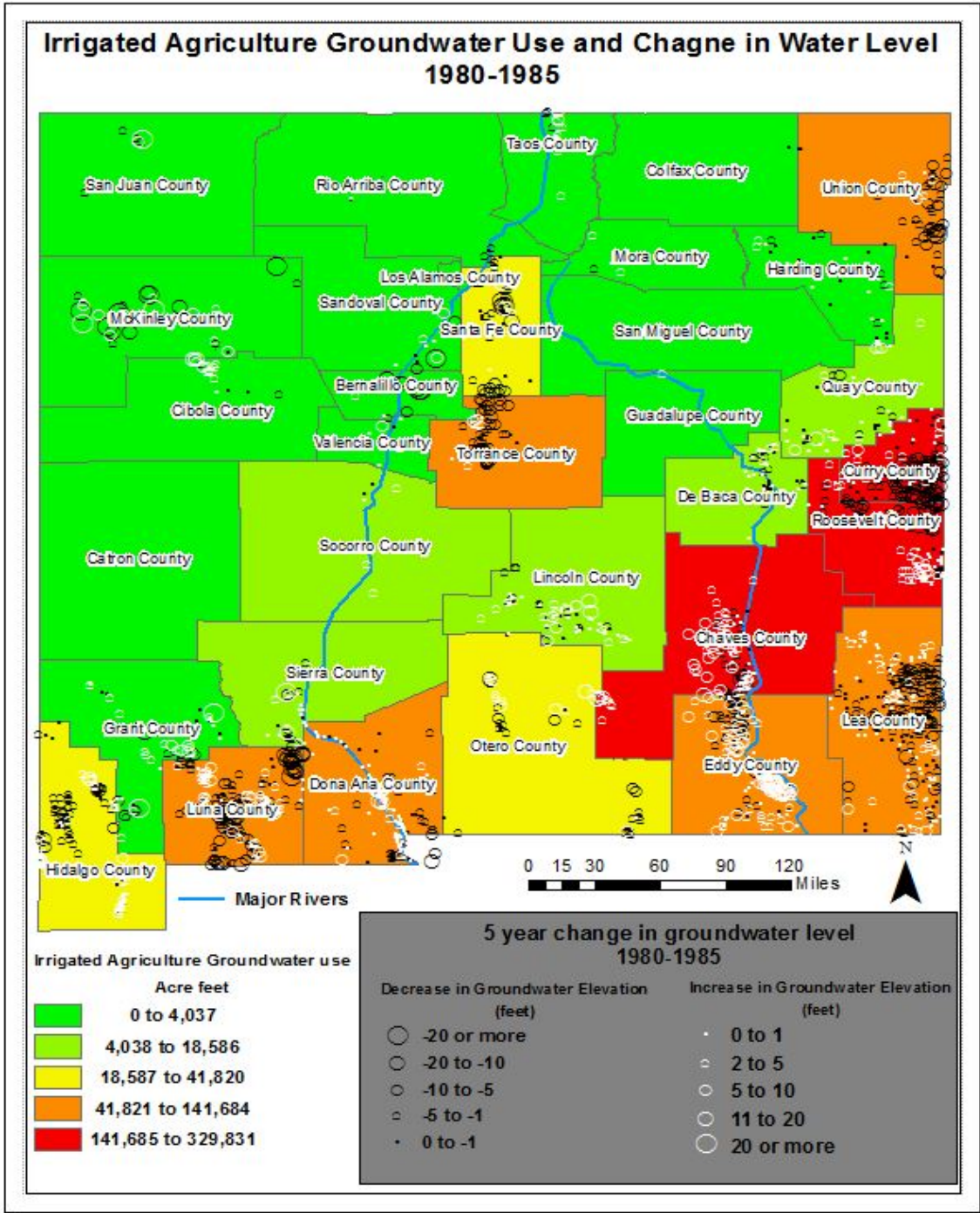


Figure 5: The map above illustrates groundwater used in irrigated agriculture per county in New Mexico in 1985 and the change in groundwater level from 1980 to 1985.

1985-1990

From the years of 1985-1990, Figure 6 illustrates the change in water elevation for 2,093 wells across the state of New Mexico. Of those 2,093; 1,125 (53%) wells had decreases in groundwater elevation. The remaining 968 (46%) had increases in groundwater elevation. Four wells within 1.5 miles of each other located in the Northern part of the state along the Rio Grande had the largest decreases in water elevation, one losing 171 feet in groundwater elevation over five years. Two wells located, within 5 miles of each other; in the Northwestern part of the state, just west of Gallup, experienced increases in groundwater elevation of 51 and 46 feet respectively over the same five year period. The mean change per well over the whole state was a decrease in groundwater of 1 foot over five years or 2.4 inches a year. The standard deviation was 9.6 this can be explained by the range of the change in water level of 222 feet.

Water used in agriculture map (Figure 7) shows the dispersion of irrigated agriculture groundwater use in the state of New Mexico. Extraction of groundwater in the state increased in 1990 as a whole when compared to 1985. Eighteen counties extracted more water in 1990 than in 1985. Curry County extracted more than 134,000 more AF than it did in 1985. Thirteen counties extracted less water in 1990 with Union County decreasing groundwater extraction by over 36,000 AF. Two counties did not use any groundwater in either 1990 or 1985. The mean use per county was 58,236 AF in 1990; 18,436 AF more than in 1985. The greatest user of groundwater in 1990 was Curry County, pumping almost 330,000 AF (68% increase from 1985). This was the most groundwater pumped by any county for any year a report was published. Roosevelt County was able to decrease pumping by over 33%, decreasing use by over 36,000 AF. The total groundwater used in irrigated agriculture for 1990 was 1,921,796 AF. This is 608,375 AF (46%) more than in 1985.

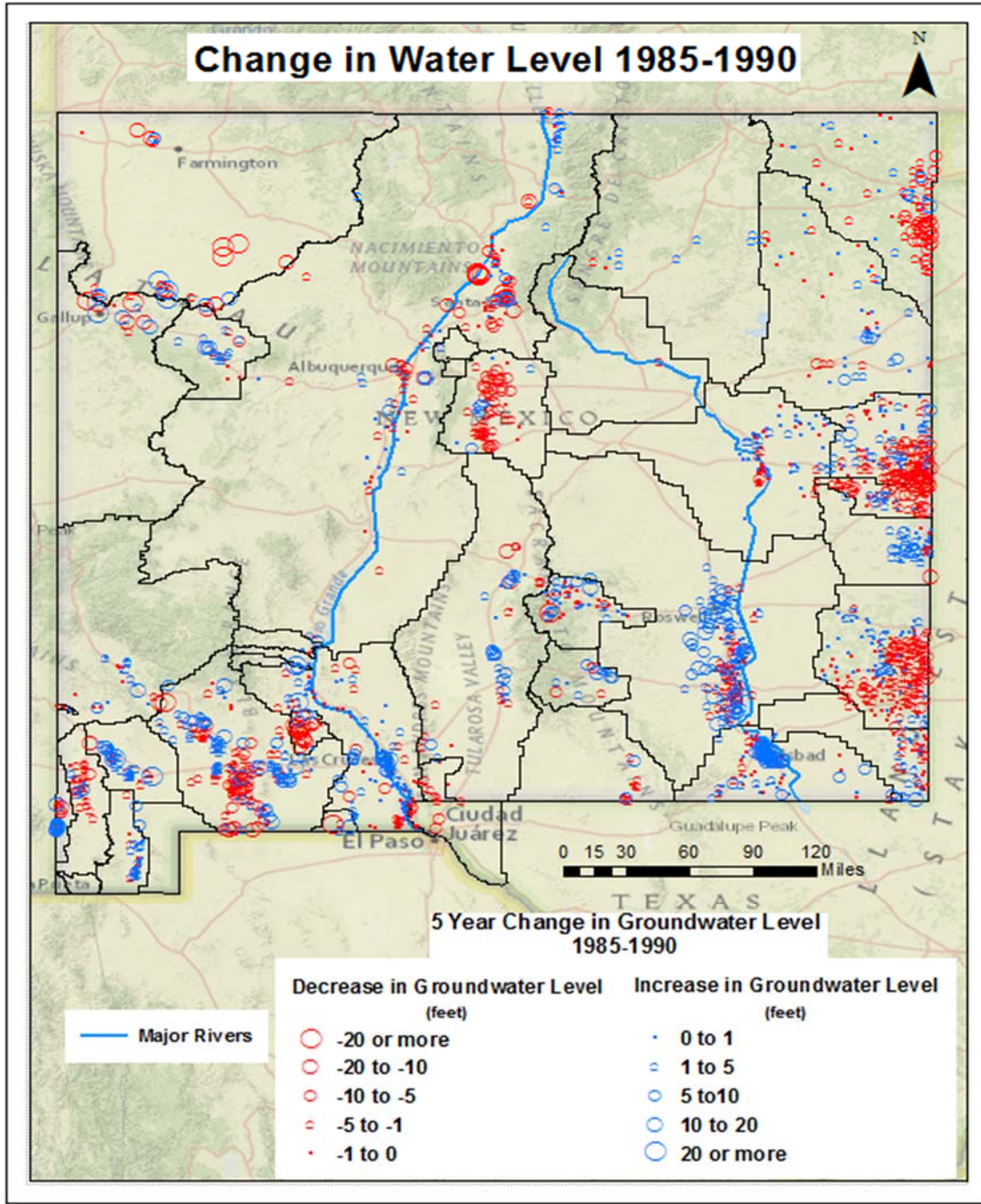


Figure 6: This map illustrates change in water levels for 2,093 wells sampled between 1985 and 1990. The back lines outline the defined basins in New Mexico.

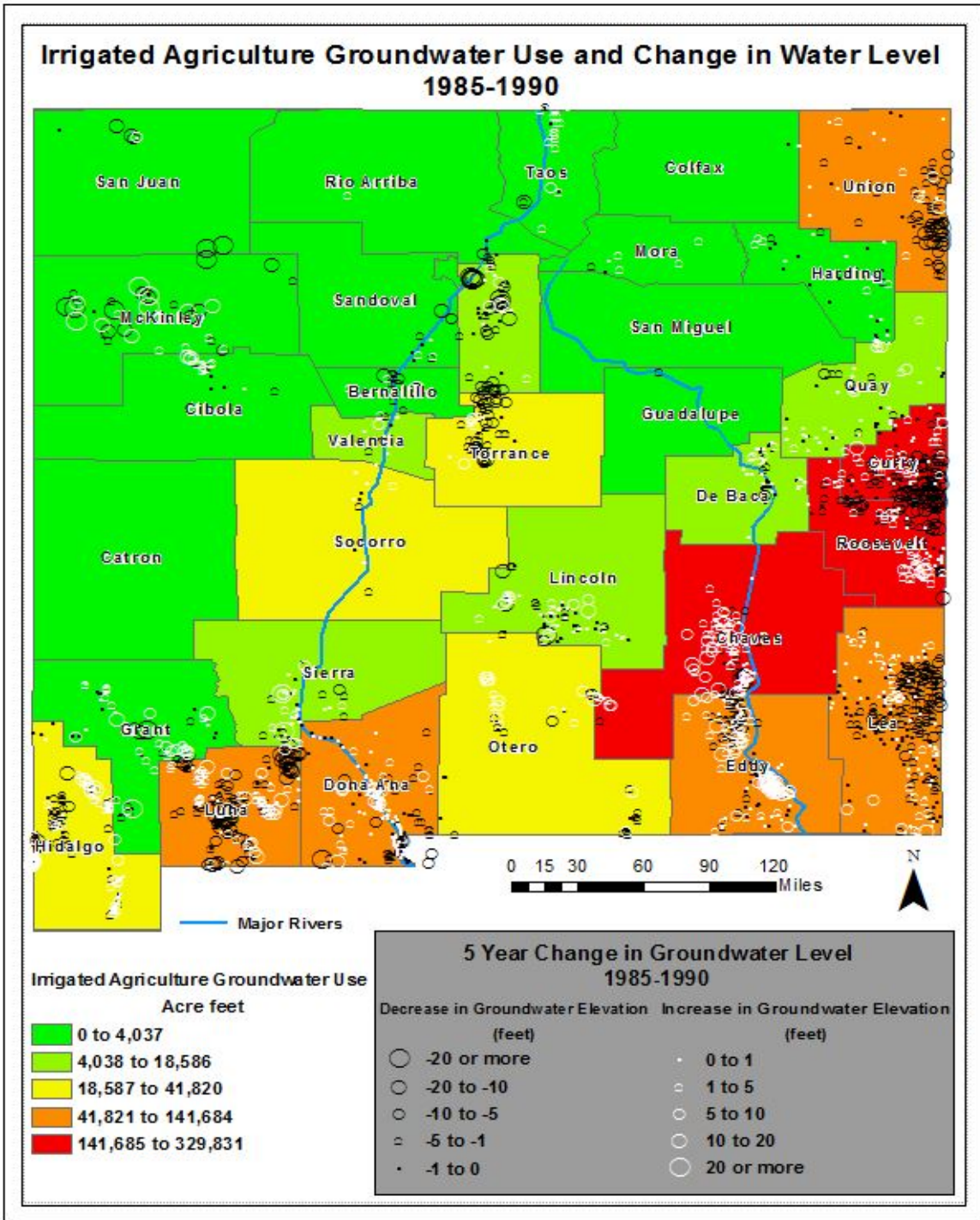


Figure 7: The map above illustrates groundwater used in irrigated agriculture per county in New Mexico in 1990 and the change in water level from 1985 to 1990.

1990-1995

Changes in groundwater elevation for 1,989 wells were calculated for 1990 to 1995 (Figure 8). Of those 1,989, decrease in groundwater elevation occurred at 1,235 (63%) wells. Increases in groundwater elevation occurred at the remaining 754 (38%) wells. The same group of wells that experienced steep decreases in groundwater elevation appeared to have even greater decreases in groundwater elevation when compared to the previous five year increment (1985-1990). Of the wells that had the highest decrease in groundwater elevation, 9 of the top 11 were located in the same area of Northern New Mexico; with decreases in elevation ranging from 158 feet to 52 feet over five years. The well that had the highest increase (65 feet) in groundwater was located in the same area as the 1985-1990 maps (McKinley County). The well that had the second largest increase was located 8 miles east of Albuquerque; the change at this well was 55 feet over five years. The mean change per well was a decrease in groundwater elevation of 1.54 feet over five years, or 3.69 inches a year. The decrease in groundwater elevation was 54% greater than the previous time period.

Figure 9 shows the spatial distribution of irrigated agriculture groundwater use in the state of New Mexico. Water use in 1995 decreased 105,260 AF when compared to 1990; 20 counties increased groundwater use. This is mostly due to the amount of water pumped in Curry County in 1990. Lea County had the greatest increase in groundwater use. The county as a whole used 39,000 AF more water for irrigated agriculture in 1995. Luna county also increase use by over 21,000 AF in 1995. Two counties didn't use any water for irrigated agriculture making change zero, and 12 counties used less water. Curry County had the largest decrease in pumping, decreasing use by over 84,000 AF. Roosevelt County was also able to decrease use by over 72,000 AF. The mean water use per county was 43,389 AF. This is a decrease of 14,847 AF per county which translates into a 25% decrease from 1990. If the top 7 water users and counties that didn't use any water are omitted, the average per county water use drops to 14,856 AF.

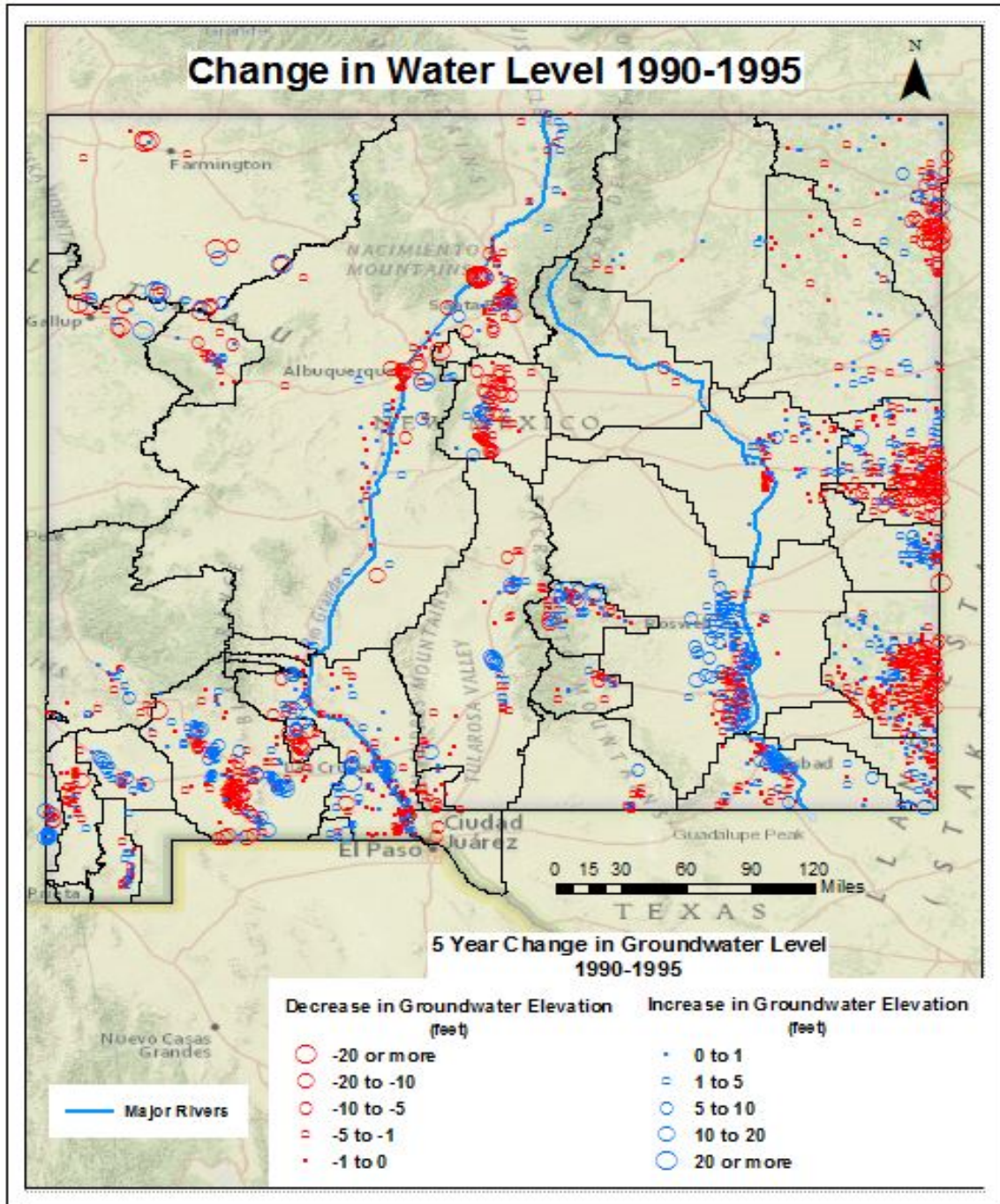
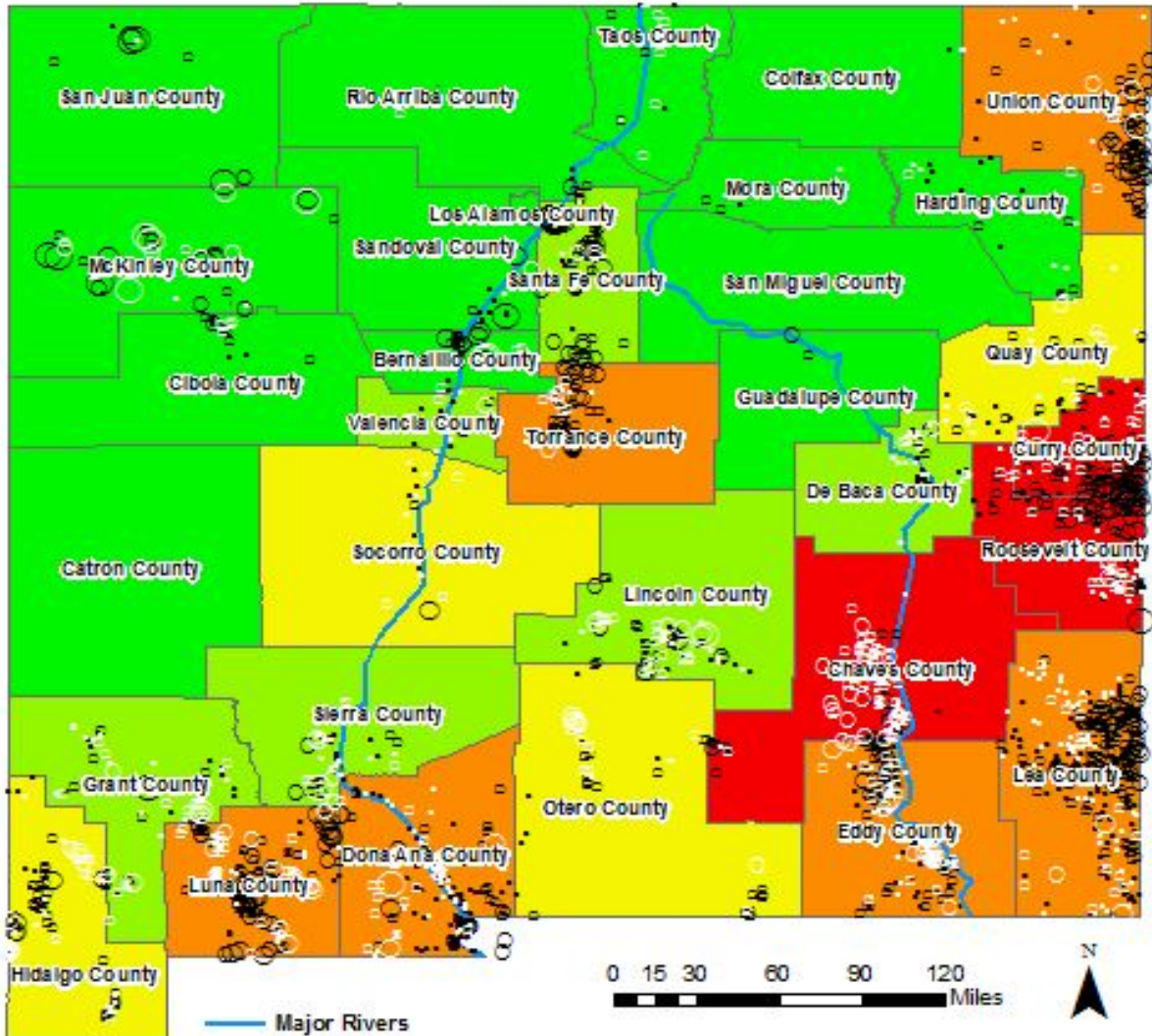


Figure 8: The above map illustrates the change in water elevation for 1,989 wells for the years of 1990-1995

Irrigated Agriculture Groundwater Use and Change in Water Level 1990-1995



Irrigated Agriculture Groundwater Use
(Acre feet)

■	0 - 4,037
■	4,038 - 18,586
■	18,587 - 41,820
■	41,821 - 141,684
■	141,685 - 329,831

**5 Year Change in Groundwater Level
1990-1995**

Decrease in Groundwater Elevation (feet)		Increase in Groundwater Elevation (feet)	
○	-20 or more	●	0 to 1
○	-20 to -10	○	1 to 5
○	-10 to -5	○	5 to 10
○	-5 to -1	○	10 to 20
●	-1 to 0	○	20 or more

Figure 9: The above map shows water used in irrigated agriculture for the year of 1995 and the change in groundwater level from 1990 to 1995.

1995-2000

Changes in water elevation for 2,065 wells were calculated for the time series of 1995 to 2000 (Figure 10). Of those 2,065; 1,443 (70%) wells had a decrease in groundwater elevation. The remaining 622 (30%) wells had an increase in groundwater elevation. The same group of wells in northern New Mexico along the Rio Grande continued to experience the sharpest water level declines. Of the top ten wells that had declines, 8 were located in the same area, declines in groundwater elevation ranged from 191 feet and 62 feet over five years. The wells that had the highest increase in groundwater elevation were located in the same area as the 1985-1990 maps. Between 1995 and 2000, these wells had groundwater elevation increases of 98 and 93 feet respectively. The mean change per well was a decrease in groundwater elevation of 2.08 feet over five years, or 5 inches a year. This is a 35% increase at which groundwater is declining when compared to 1995.

Figure 11 shows the dispersion of groundwater used for irrigated agriculture in the state of New Mexico. Water use in 2000 decreased 55,245 AF when compared to 1990; only 9 counties increased use. Only 3 counties used substantially more groundwater. Chaves County used 49,697 AF more groundwater; Dona Ana County used 24,948 AF more groundwater; and Eddy County used 9,681 AF more groundwater. Four counties didn't use any water for irrigated agriculture making their change zero. Twenty counties used less water. Curry County was able to decrease pumping the most out of any county, decreasing use by over 49,000 AF. Luna and Quay Counties were also able to decrease use by over 20,000 AF each. The mean water use per county was 41,715 AF. This is a decrease of 1,674 AF per county which translates into a 3.8% decrease in the amount of groundwater used when compared to 1995. This is most likely because either fields were left fallow, more innovative technology, or land use changes. Total water used in agriculture (surface and groundwater) decreases by 129,684 AF from 1995 to 2000.

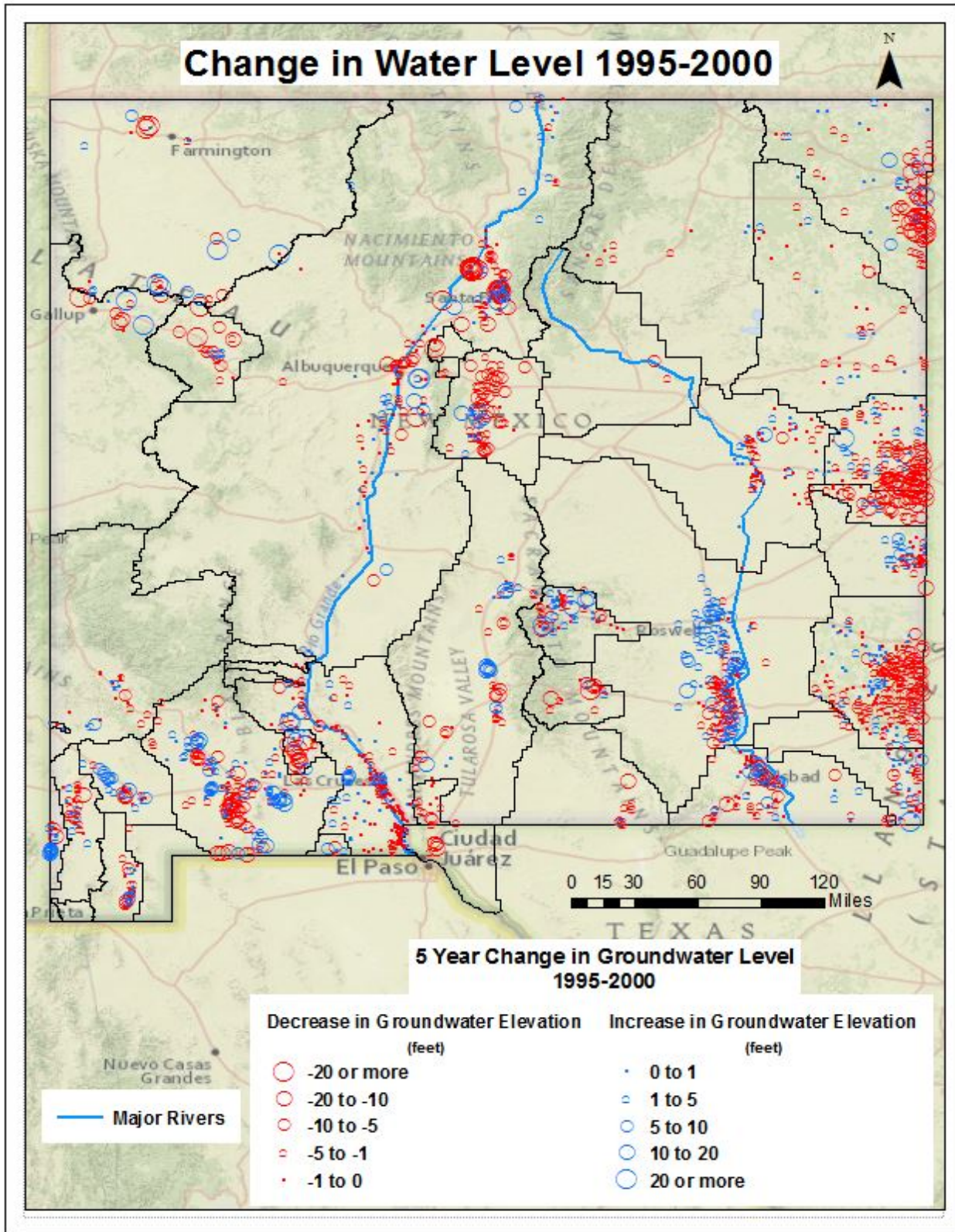


Figure 10: The above map illustrates the change in water elevation for 2,065 wells for the years of 1995 to 2000.

Irrigated Agriculture Groundwater Use and Change in Water Level 1995-2000

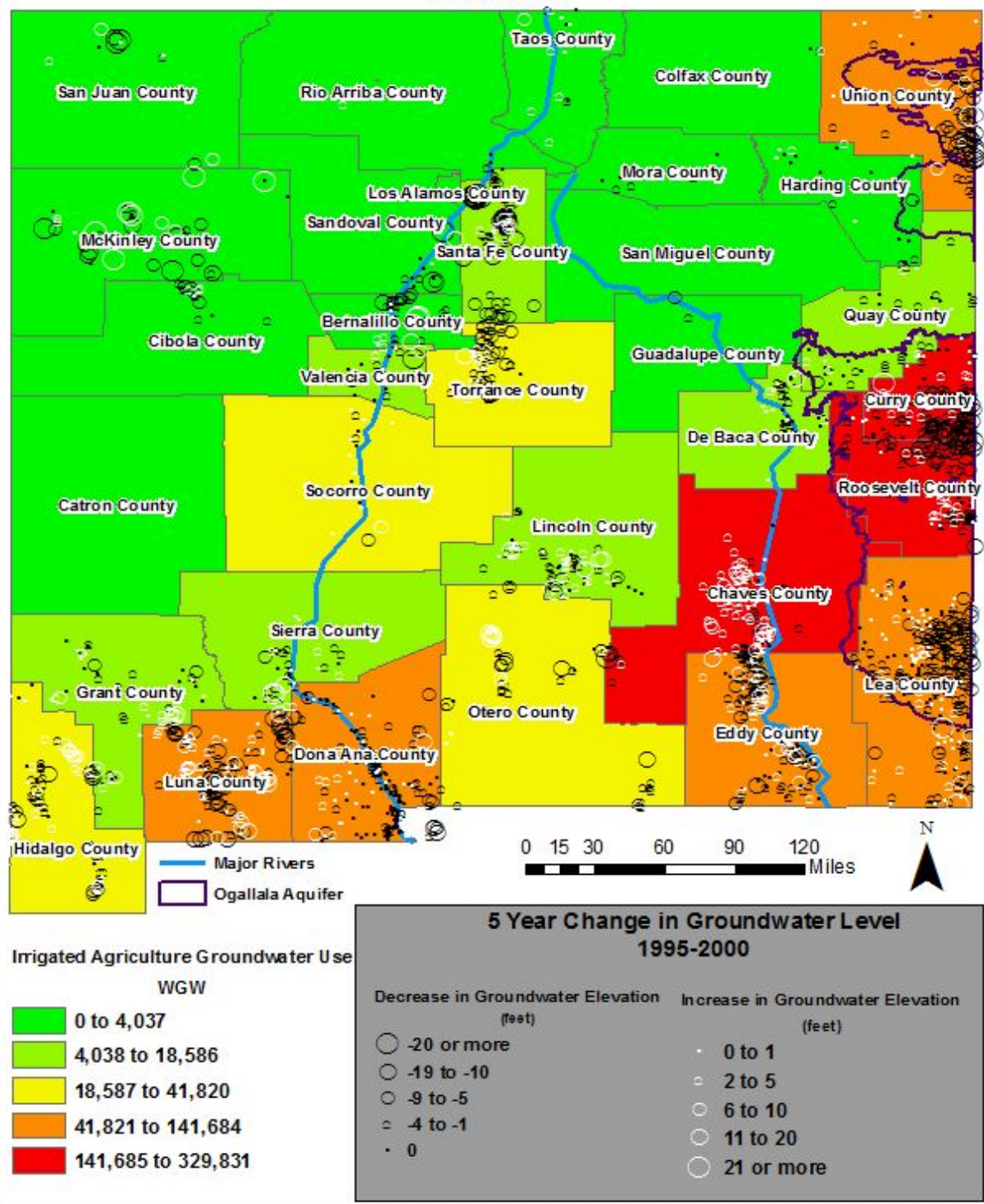


Figure 11: The above map shows the range of irrigated agriculture groundwater use in the State of New Mexico for 2000. And the change in groundwater level from 1995 to 2000.

2000-2005

Changes in groundwater elevation were calculated for 1,622 wells between 2000 and 2005. Of those 1,622; 1,212 (75%) wells had a decrease in groundwater elevation. The remaining 411 (25%) wells had an increase in groundwater elevation. For the five year change between 2000 and 2005, one well experienced groundwater elevation decrease over 100 feet. This well was located in northwestern New Mexico just west of Farmington. The well that experienced the third greatest decrease in groundwater elevation was less than 1.5 miles from that point, indicating significant pumping in the area or the effect that adjacent wells have on each other. The well that had the greatest increase in groundwater elevation is located near the wells that had the sharpest declines earlier in the study (northern New Mexico). During this time interval, it had increases of 164 feet. The well that had the third most increase (87 feet) is the same well that experienced the greatest increase between 1995 and 2000. The average decrease in groundwater elevation per well was 2.12 feet over five years or 0.424 feet per year. Decreases in groundwater elevation increased 0.03 (1.92%) feet over this time period.

Figure 13 shows the large range between counties when related to groundwater usage for irrigated agriculture in the State of New Mexico. Water use in 2005 decreased 32,011 AF when compared to 2000. Even though state wide water usage decreased, 18 counties increased pumping. Hidalgo County and Dona Ana increased groundwater use the most. Hidalgo increased groundwater pumping by 54,444 AF and Dona Ana county increased groundwater pumping by 52,737 AF. This is more staggering when computing the percentage change. Hidalgo increased groundwater pumping by 164%. Dona Ana increased pumping by 54%. Four counties didn't use any water for irrigated agriculture making change zero. Eleven counties used less water. Chaves County was able to decrease pumping the most, decreasing use by over 94,000 AF. Curry, Union, and Luna Counties were also able to curb use by 67,940, 26,449, and 24,535 AF respectively. The mean water use per county was 40,745 AF. This is a decrease of 970 AF per county which translates into a 2.8% decrease. One explanation for the increase in groundwater use in Dona Ana is because of the change in surface water allotments. Access to surface water decreased by nearly 100,000 AF according to the Office of State engineer's water use report for 2005.

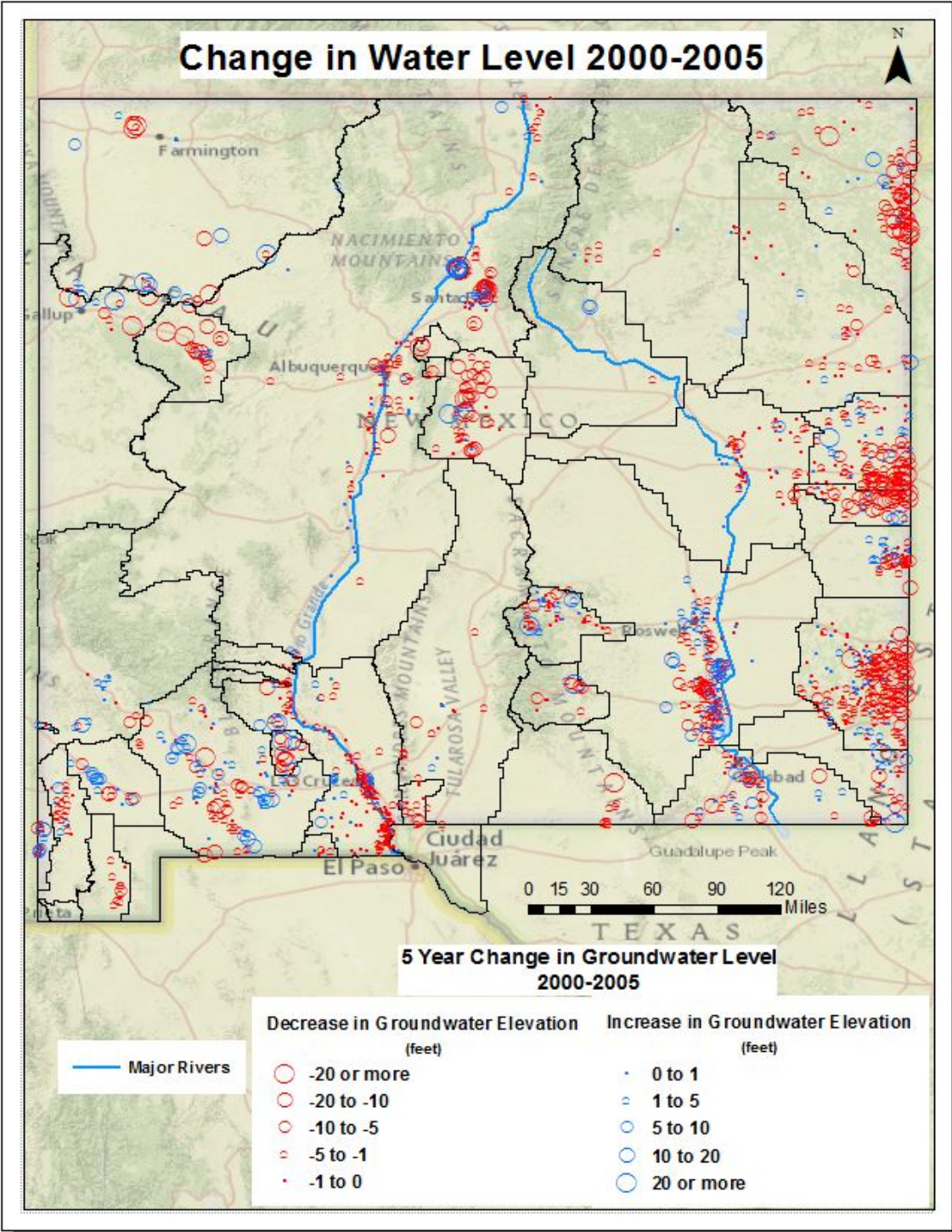


Figure 12: The above map illustrates the change in water elevation for 1,622 wells in the state of New Mexico between 2000 and 2005.

Irrigated Agriculture Groundwater Use and Change in Water Level 2000-2005

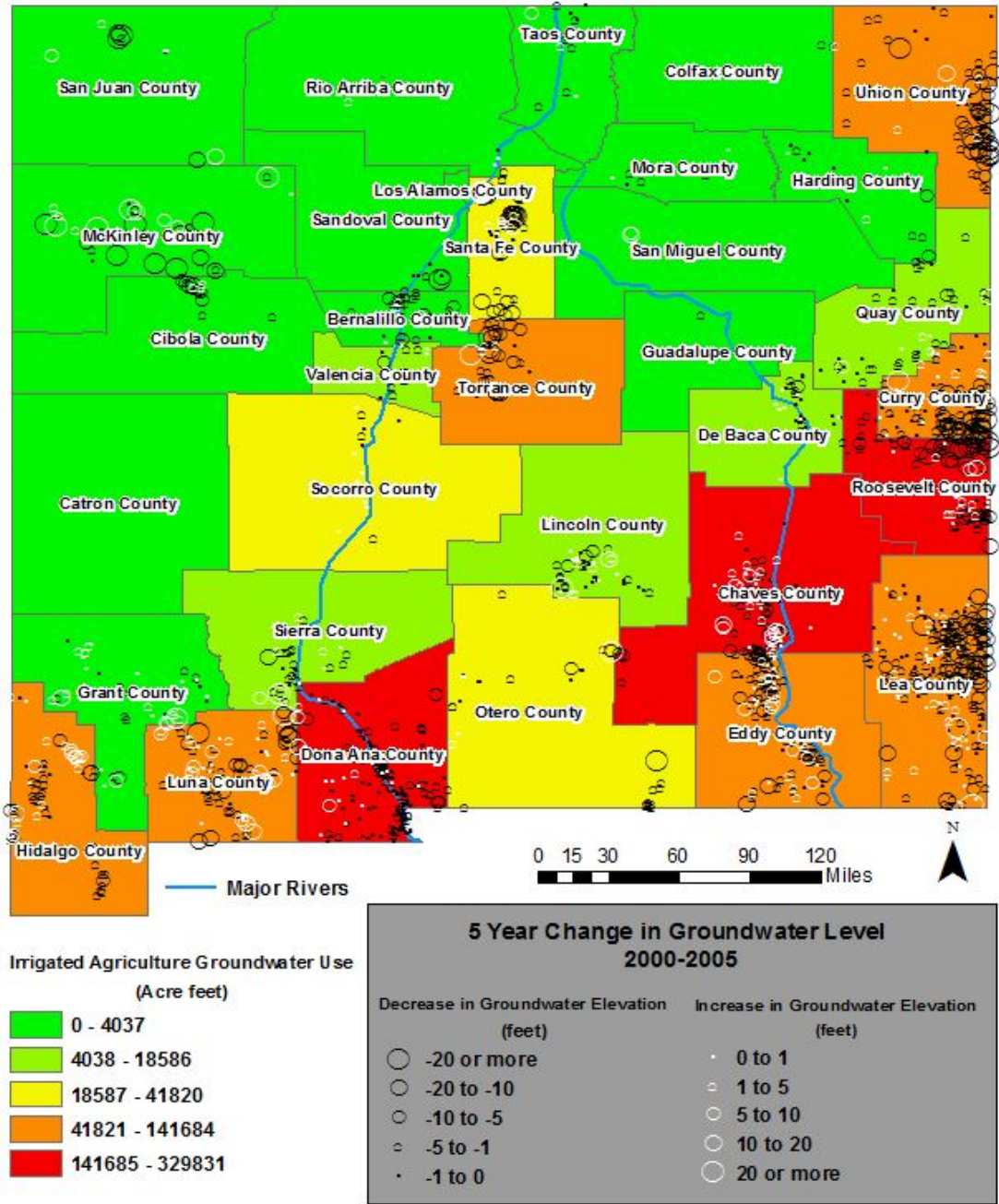


Figure 13: The above map shows the dispersion of groundwater used for irrigated agriculture in the state of New Mexico in 2005 and the change in groundwater levels between 2000 and 2005.

2005-2010

Changes in groundwater elevation were calculated for 1,203 wells between 2005 and 2010 (Figure 14). Of those 1,203; 911 (76%) wells had a decrease in groundwater elevation. The remaining 293 (24%) wells had an increase in groundwater elevation. For the five year change between 2000 and 2005, the well that had the greatest decrease had changes of over 200 feet. This well was located in Northwestern New Mexico near Farmington. Other wells that had large decreases were one located near Clovis (41 feet) and another located in Luna County (37 feet). The well that had the greatest increase in groundwater elevation is located near the wells that had sharp declines earlier in the study (northern New Mexico, along the Rio Grande). During this time interval, it had increases of 144 feet. In the previous time interval, it showed an additional 164 feet increase in groundwater level. Each well had an average decrease in groundwater elevation of 3.04 feet over five years or 0.60 feet per year, a 30% increase in the rate at which water levels were decreasing when compared to 2005. This is not surprising as the drought that hit New Mexico worsened.

Figure 15 shows the range of groundwater used for irrigated agriculture in the State of New Mexico. Water use in 2010 increased 21,629 AF when compared to 2005. Fourteen counties had their water usage increase; with Curry County and Lea County pumping over 30,000 AF more water than in 2005. Four counties didn't use any water for irrigated agriculture making their change zero. Fifteen counties used less groundwater. Hidalgo County had the largest decrease in pumping, decreasing use by over 28,000 AF. Dona Ana and Luna counties were also able to decrease groundwater use by 27,930 and 18,007 AF respectively. The mean water use per county was 41,400 AF; this is 653 AF more than in 2005 representing a 1.5% increase. Total use of groundwater for irrigated agriculture was 1,366,215 AF. Total water use increases by ~75,000 AF.

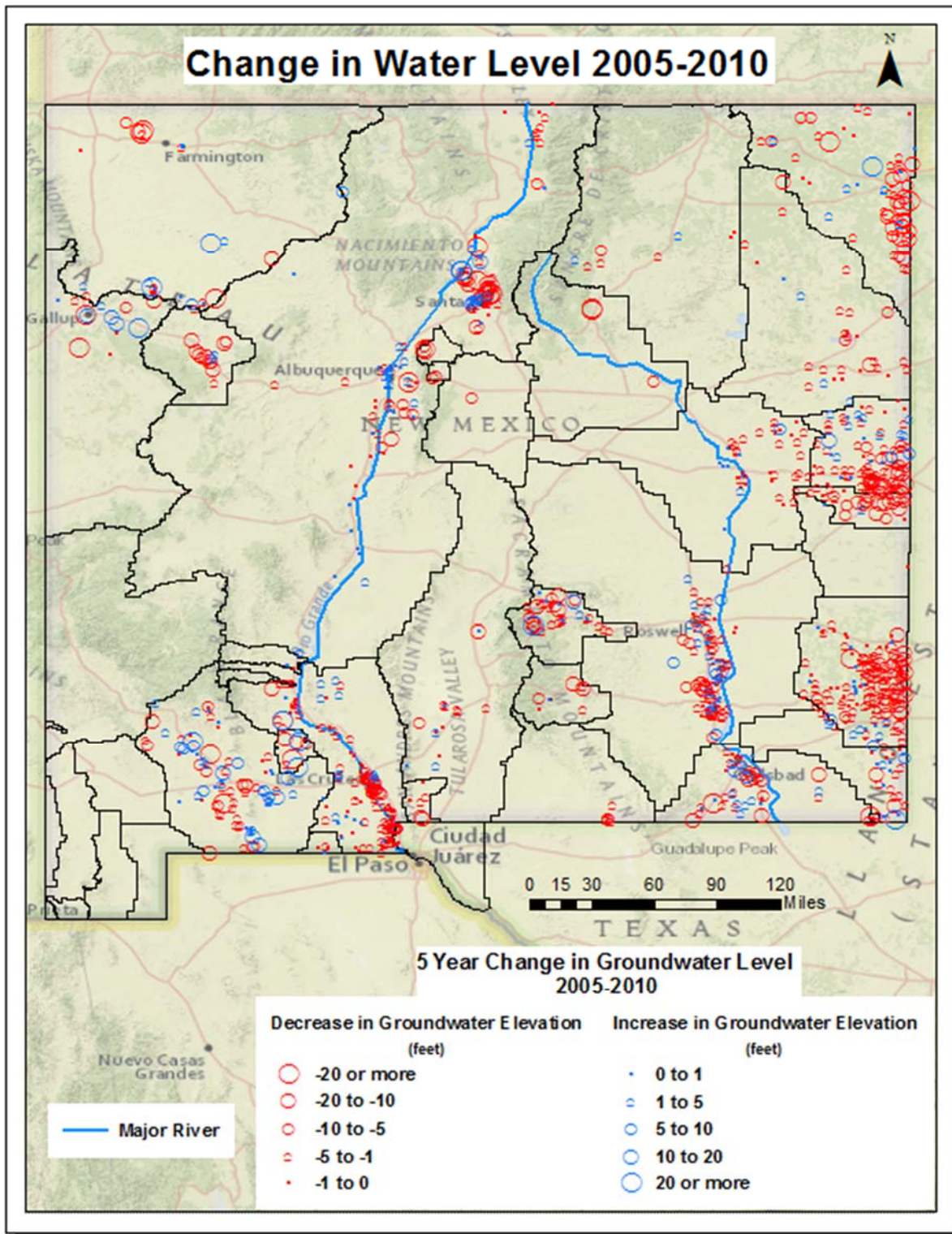


Figure 14: The above map illustrates the change in groundwater elevation for the years of 2005-2010 in the State of New Mexico.

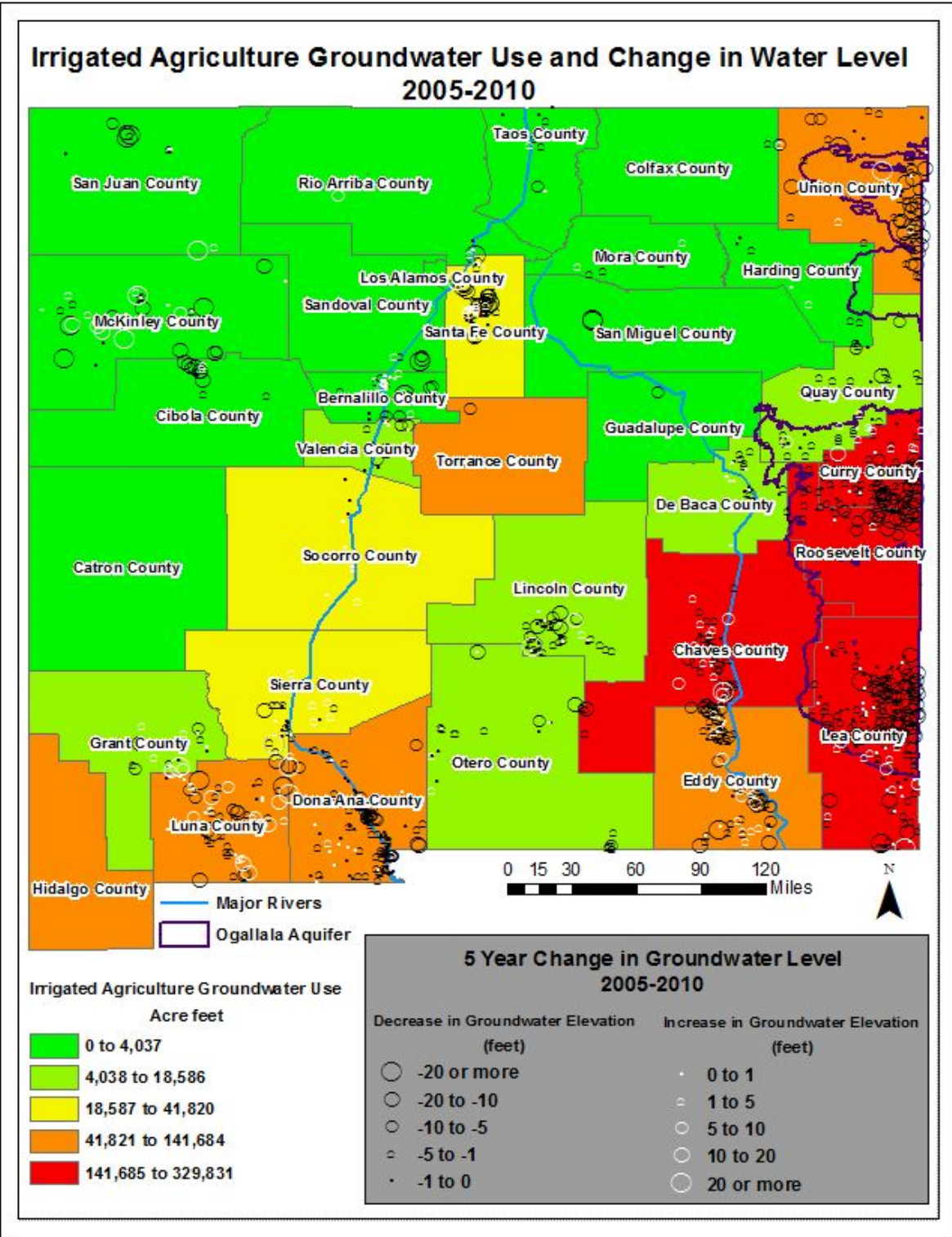


Figure 15: The above map shows the dispersion of groundwater used for irrigated agriculture in the State of New Mexico in 2010 and the change in groundwater levels between 2005 and 2010.

2010-2014

Changes in groundwater elevation were calculated for 434 wells between 2010 and 2014 (Figure 16). Of those 434; 296 (68%) wells had a decrease in groundwater elevation. The remaining 138 (32%) wells had an increase in groundwater elevation. Between 2010 and 2014, one well had groundwater elevation decrease over 135 feet. This well was located in northeastern New Mexico and 15 miles east of the Pecos River. Other wells that had large decreases were ones located in the southern part of the state (69 ft) and another located in the northwestern part of the state (66 ft). The well that had the greatest increase in groundwater elevation is located in the southeastern part of the State; it had groundwater elevation increase 141 feet. The average decrease in groundwater elevation was 1.9 feet, 37% less than the previous time period.

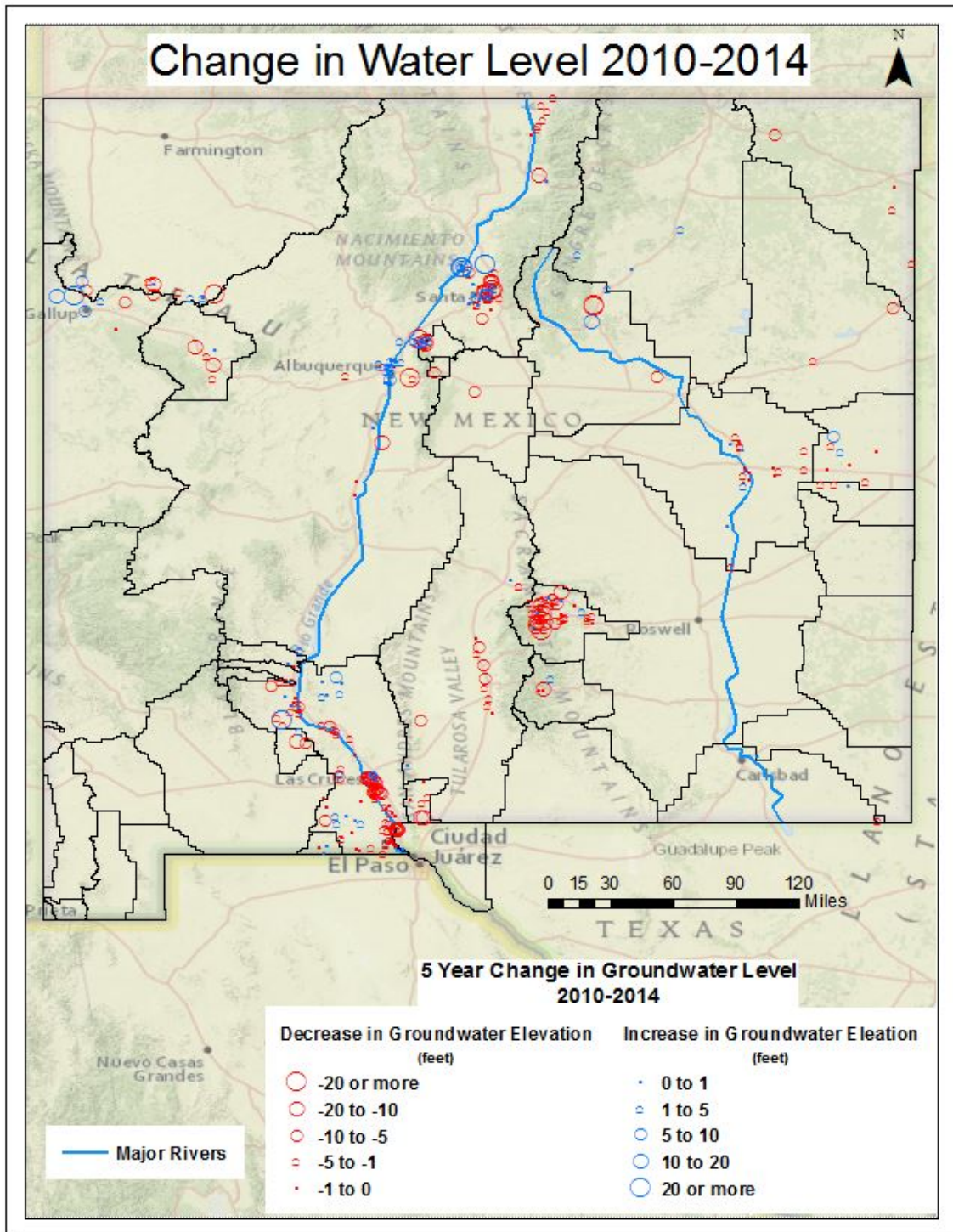


Figure 16: The above map illustrates the change in groundwater for the years between 2010 and 2014.

1970-2012

Change in groundwater elevation for 452 wells was calculated for the time period of 1970-2012 (Figure 17). Of those 452; 307 (68%) wells had a decrease in groundwater elevation. The remaining 145 (32%) wells had an increase in groundwater elevation. This map was produced to show the change over the lifetime of the wells, the wells present in this map have been monitored from 1970 to 2012. One well had groundwater elevation decrease over 191 feet or 4.5 feet per year. This well was located in the Ogallala Aquifer system which extends into the eastern part of the state it also lacks access to surface water. Other wells that had large decreases were one located in the northern part of the state, 9 miles from the Rio Grande (158 ft or 3.7 ft per year) and another located in the southern part of the state, 10 miles from the Rio Grande (153 ft or 3.6 ft per year). The well that had the greatest increase in groundwater elevation is located in the southeastern part of the state; where groundwater elevation increase 128 feet or 3.04 feet per year. Two wells located in the Members River Basin (Southwestern part of the state) had increases in groundwater elevation of over 100 feet 2.3 feet per year. The mean decrease in groundwater elevation was 11.7 feet or ~0.27 feet per year.

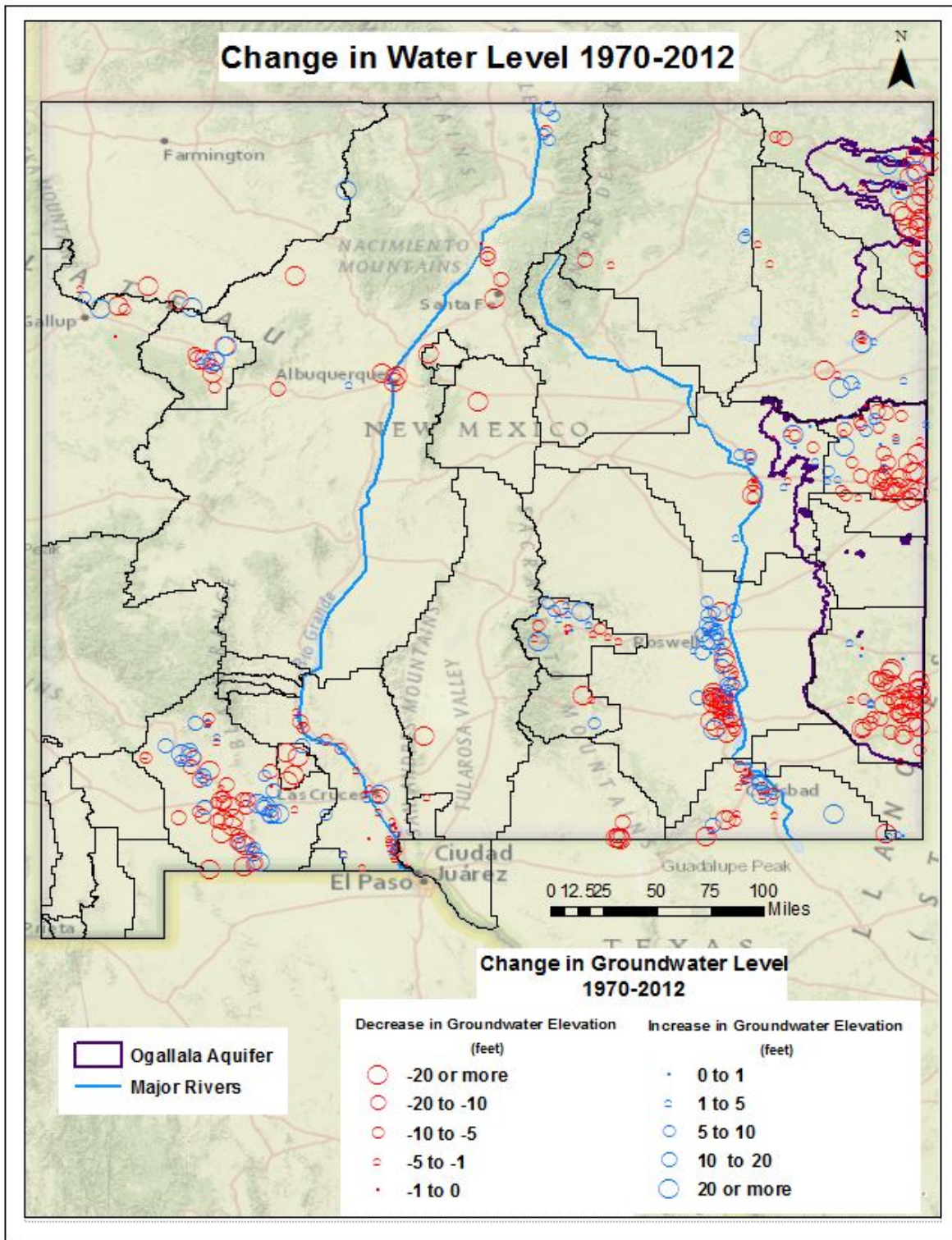


Figure 17: The above map illustrates the change in groundwater levels for the years of 1970-2012.

Hydrographs

Hydrographs were produced for individual wells in each defined basin in the state, and the location of each basin is indicated on Figure 18, below. This allows us to show both the observed depth to water as well as the depth to water estimations derived from the loess analysis as a function of time for each well. Observed depths are shown as points, and the black line illustrates the predicted loess results. To account for instances where more than one aquifer may be present in a basin, characteristic wells were separated into “shallow” and “deep”. Shallow wells ranged from land surface to around 150 feet. Hydrographs for deep wells were produced to illustrate change in depth to water for all other wells. Not all basins have a hydrograph for deep wells, this could be due but not limited to lack of data, no data was collected at those depths, or there is no aquifer system at that depth. The Lower Rio Grande is the first hydrograph illustrated, and the presentation of the remaining basins will flow in a counter clock wise motion around the state.

New Mexico Basins

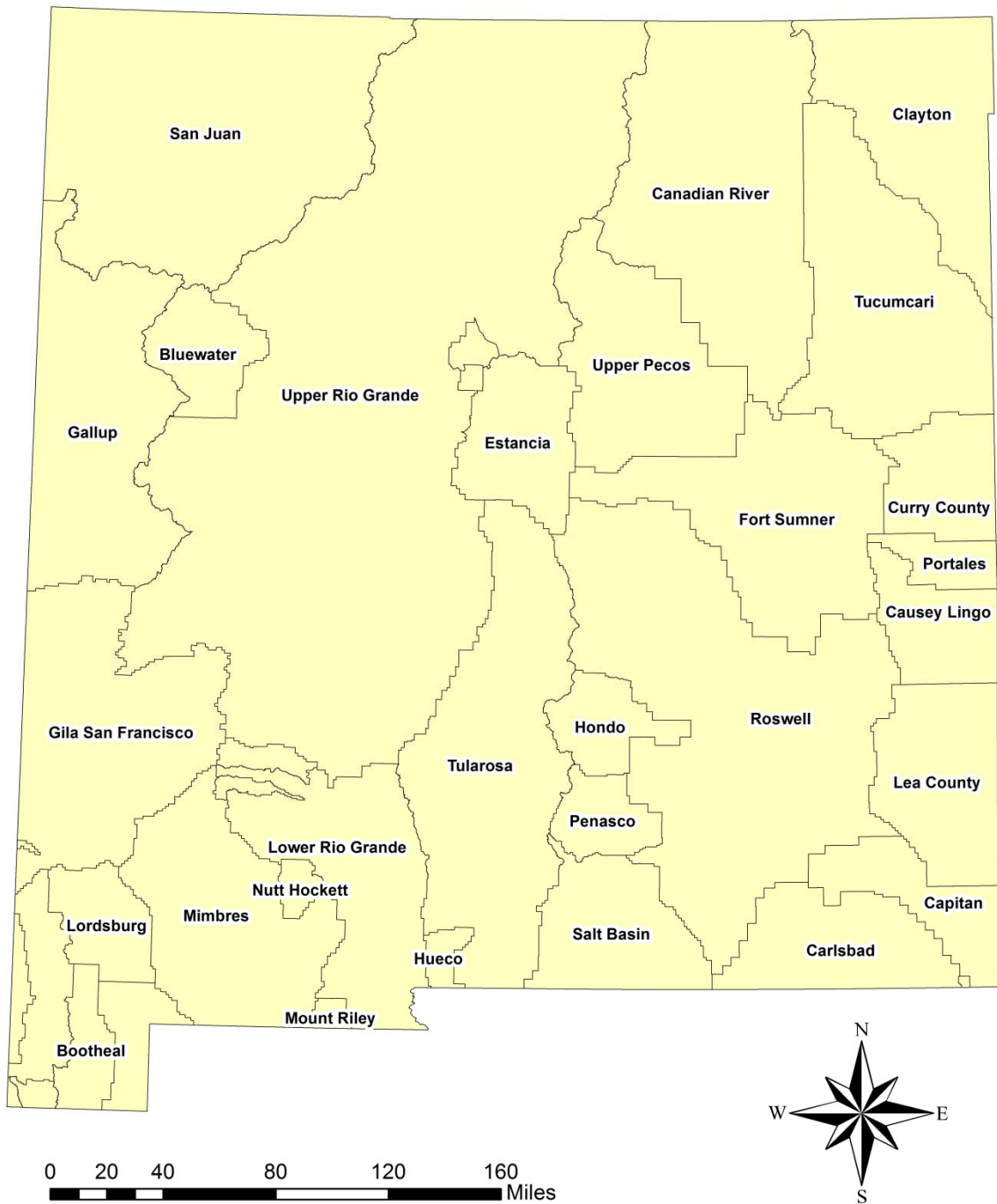


Figure 18: Map of the State of New Mexico and all of the basins within the State.

Southwestern New Mexico

In total, there were 165 wells within the Lower Rio Grande Basin that were measured (Figure 19). An average change per year was calculated for the years of 1970-2013. Of the 216 wells, 37 have been measured over this time period. The well that had the greatest increase in water elevation averaged 0.54 feet per year. For shallow wells (<150ft) the well that had the greatest increase in groundwater elevation was calculated to be 0.03 feet per year. The well that had the greatest decrease in groundwater elevation had 0.33 feet of change per year, which is not very significant. The yearly change was estimated to be an increase in groundwater elevation of 0.04 feet per year. This trend is not representative of current trends however. When looking at the average change for the same wells between 2000 and 2013 the yearly change results in a decrease in groundwater level of 0.185 feet per year or a ~440% increase. Even though there was a large percentage increase in the rate at which water levels are declining, changes in groundwater are not significant. Dona Ana County is the largest user of water in the state. Using nearly 450,000 AF of which, 393,480 AF was used in irrigated agriculture.

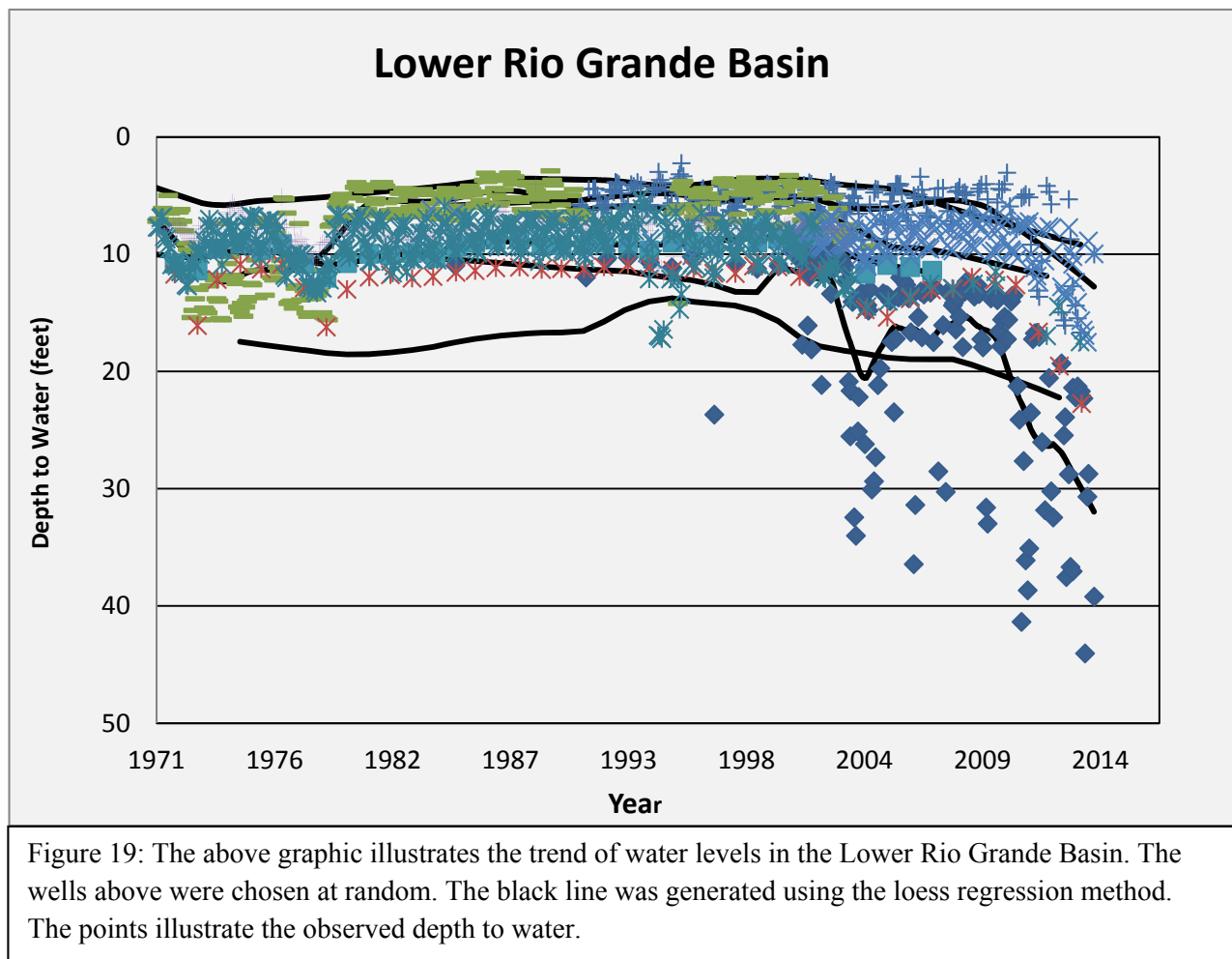


Figure 19: The above graphic illustrates the trend of water levels in the Lower Rio Grande Basin. The wells above were chosen at random. The black line was generated using the loess regression method. The points illustrate the observed depth to water.

An average change per year was calculated for the years of 1980-2012 for the Mimbres (Figure 20). Of the 213 wells, 76 were measured over this time period. Of the 76 wells, 34 experienced increases in groundwater elevation: 24 of which had increases of less than 0.50 feet per year, 4 between 0.50 and 1 foot per year, 4 between 1 and 2 feet of change, 1 between 2 and 3 feet, and the remaining 2 wells had increases in groundwater elevation of between 3 and 4 feet of change. The remaining 42 wells experienced overall groundwater elevation decrease. The well that had the greatest decrease in groundwater elevation had 3.10 feet of change per year (1980 depth: 151 ft and 2013 depth: 250 ft). For shallow wells (<150 ft) the one which experienced the greatest decrease had 1.14 feet of change per year (1980: 112 ft and 2013 depth: 149 ft); 23 wells had average decrease in water elevation of less than 0.05 feet per year. These results suggest similar findings as the hydrograph, water levels are relatively stable. The average decrease in groundwater elevation per well was 0.04 feet per year from 1980 to 2012. The average decrease in groundwater elevation per well from 2000 to 2012 was 0.03 per year. The rate at which water was being extracted actually decreased as much of the state was in a drought. Luna County which lies within the Mimbres Basin used an average of over 100,000 AF in agriculture since 1990. Since 2000, much more water came from surface sources, which can partially explain why declines in water levels slowed between 2000 and 2012.

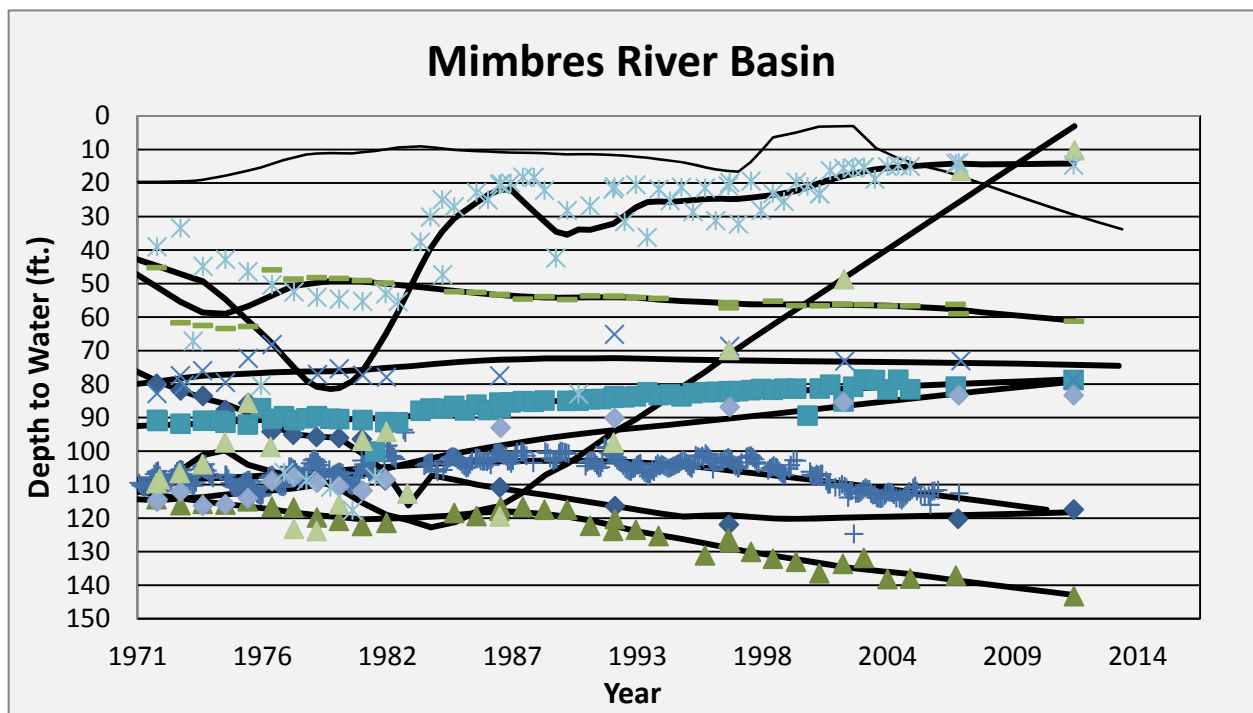


Figure 20: The above graphic illustrates the trend of water levels in the Mimbres River Basin. Hydrograph depict the observed change in water level for single wells and the respective loess curve for each of the representative wells.

An average change per year was calculated for each well measured between the years of 1980-2008 in the Lordsburg Basin (Figure 21). Of the 43 total wells, 19 were measured over this time period. The well with the most year to year increase in groundwater elevation had changes of 2.5 feet per year (1980 depth: 304 ft and 2008 depth: 233 ft). Of the 19 wells, 14 experienced increases in groundwater elevation; 6 of which had increases of between 0.00 to 0.50 feet of change per year. Decreases in groundwater elevation occurred in only 5 wells. The well that had the greatest decrease in groundwater elevation had changes of 1.30 ft per year (1980 depth: 87 ft and 2008 depth: 124 ft). This happened to be the shallowest well in the study area. The other 4 wells had average decrease in water elevation of less than 0.50 feet per year. These results suggest the same findings as the hydrograph; a majority of wells had very little change. This however is based on a low number of measurements, and there were no measurements for any wells after 2008. The average change over all the wells was 0.40 feet per year of the years between 1980 and 2008. From 2000 to 2008 the rate at which increases in groundwater elevation was occurring decreased to 0.27 feet per year.

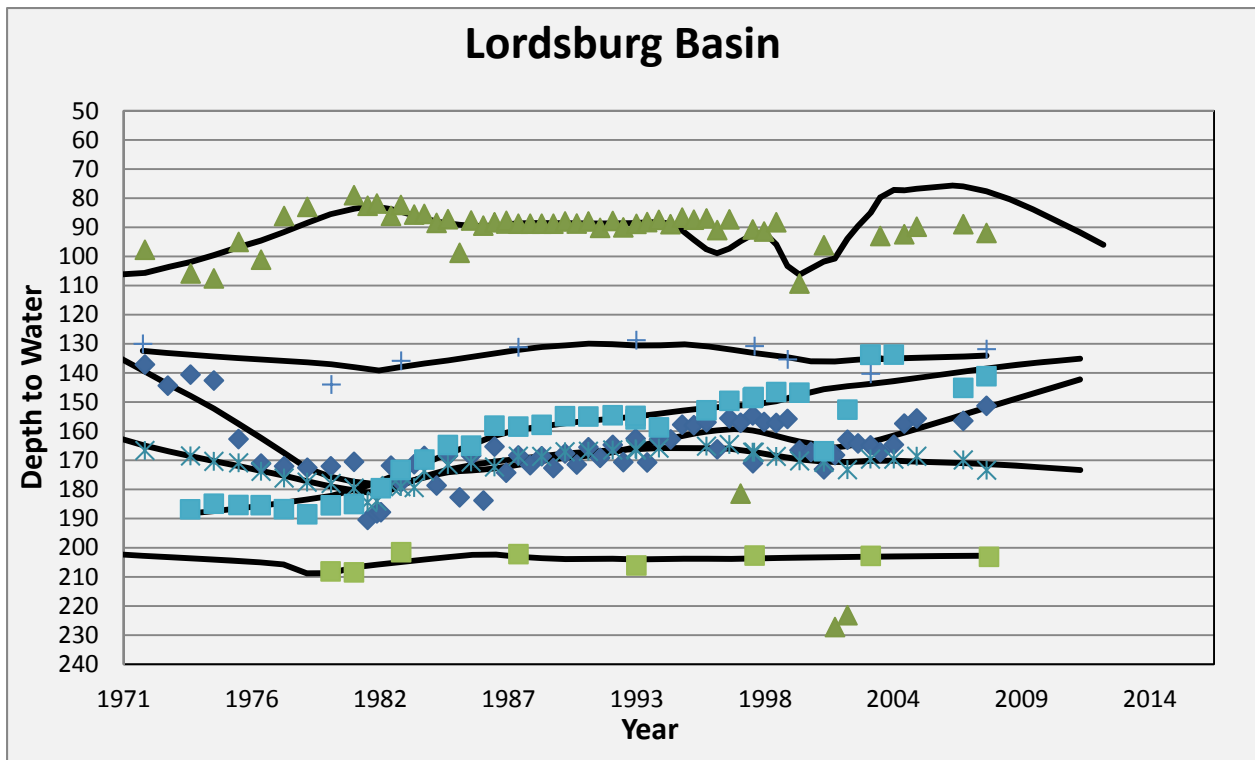


Figure 21: The above graphic illustrates the trend of water levels in the Lordsburg Basin. Hydrograph depict the observed change in water level for single wells and the respective loess curve for each of the representative wells.

The next hydrograph includes multiple basins in the Boot Heal in New Mexico (Figure 22). The boot heal is comprised of Hatchita, Playas, Cloverdale, Animas, and San Simon Basins. An average change per year was calculated for each well for the years of 1975-2008. Of the 101 wells, 33 were measured over this time period. The well with the greatest increase in groundwater elevation averaged 1.36 feet of change per year (1975 depth: 157 ft and 2008 depth: 112 ft), There were 5 additional wells that had increases in groundwater elevation: 3 between 0.00 and 0.50 feet per year and 2 between 0.50 and 1 foot per year. Decreases in groundwater elevation occurred in the remaining 27 wells. The well that experienced the greatest decrease in groundwater elevation had 1.07 feet of change per year (1975 depth: 131 ft and 2008 depth: 166 ft). The remaining 26 wells had a range of changes: 2 between 1 and 0.50 feet per year and 24 wells with between 0.50 and 0.01 feet of change. The average decrease in groundwater elevation per well was 0.20 feet per year between 1975 and 2008. From 2000 to 2008, the rate at which water levels were declining decreased to 0.187 feet per year. These results suggest the same findings as the hydrograph; a majority of wells had steady declines in water levels but at a low rate, especially the deep wells. A similar problem in the Lordsburg basin is present in the Boot Heal; no wells were measured after 2008.

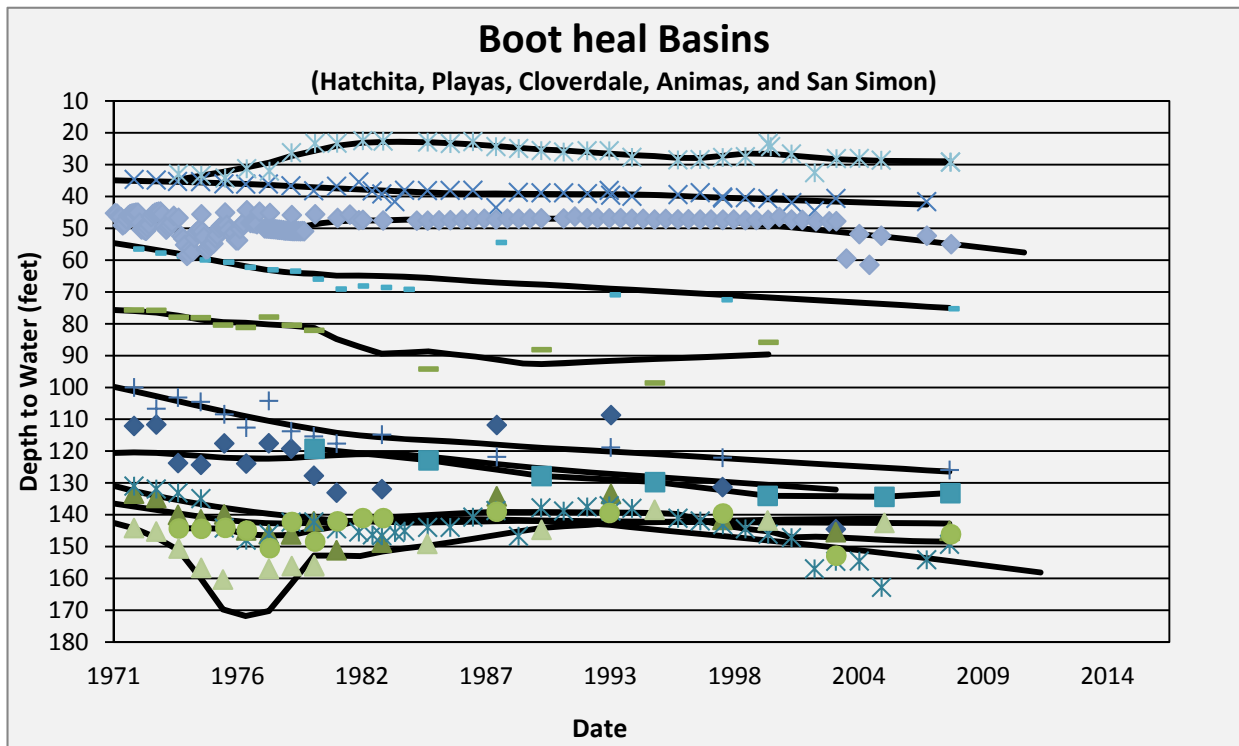


Figure 22: The above graphic illustrates the trend of water levels of wells in the boot heal of New Mexico. This includes the Hatchita, Playas, Cloverdale, Animas, and San Simon Basins, Hydrograph depict the observed change in water level for single wells and the respective loess curve for each of the representative wells..

An average change per year was calculated for the years of 1983-2005 in the Gila San Francisco Basin (Figure 23). Of the 22 wells, 14 were measured over this time period. Of these 14 wells, 11 had an increase in groundwater elevation. The well with the greatest increase in groundwater elevation averaged 0.90 feet per year of change (1983 depth: 26 ft and 2005 depth: 6 ft). The remaining 3 wells had overall groundwater elevation decreases. The well that had the greatest decrease in groundwater elevation had an average decrease of 0.85 ft per year (1983 depth: 283 ft and 2005 depth: 302 ft). This well was not presented in the hydrograph however. Of the shallow wells, one well had decreases in water elevation of 0.43 feet a year (1983 depth: 51 ft and 2005 depth: 60 ft). These results suggest the same findings as the hydrograph; a majority of wells are showing steady increases in water levels. These wells are also clustered around the southern part of the basin. The lack of data and the temporal scale of the data may be an issue in this basin.

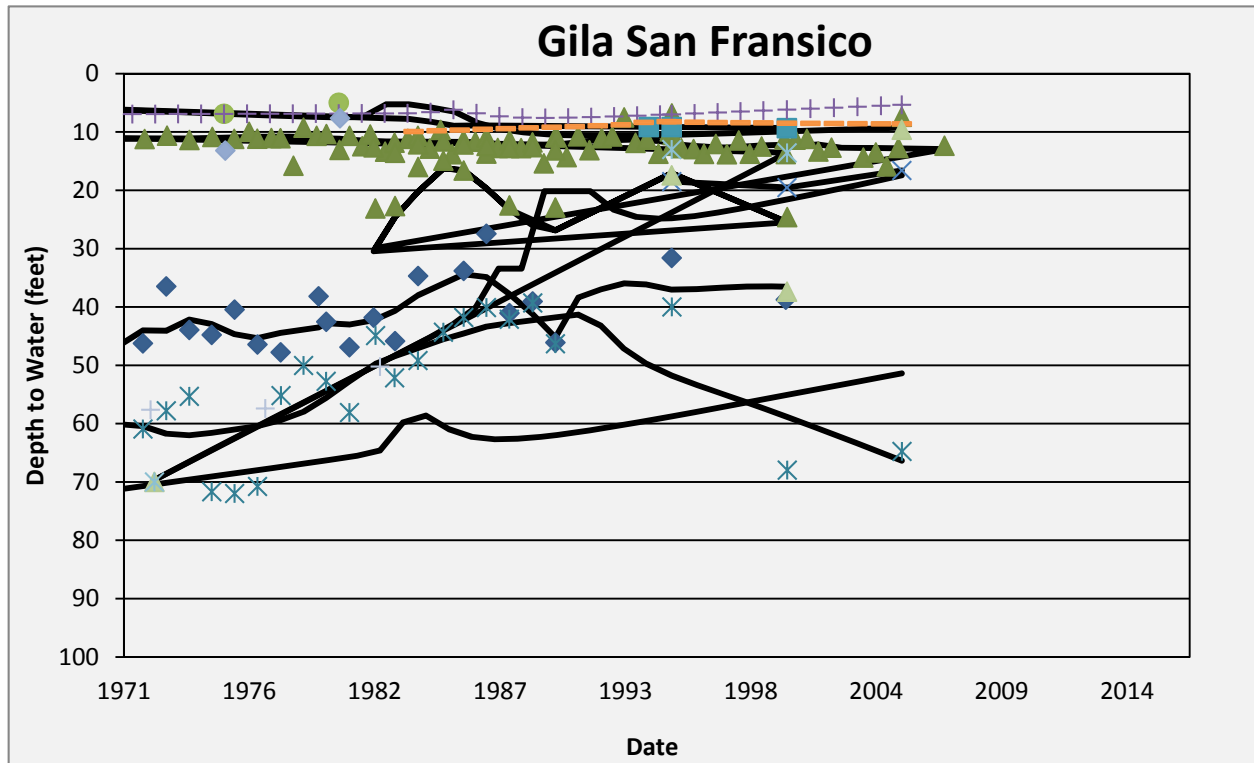


Figure 23: The above graphic illustrates the trend of water levels of wells in the Gila San Francisco Basin. Hydrograph depict the observed change in water level for single wells and the respective loess curve for each of the representative wells

Northwestern New Mexico

The first basin in the Northwestern quadrant of New Mexico to be analyzed is the Gallup Basin. In this Basin, there was enough data to separate the basin into two hydrographs. For the shallow wells, an average change per year was calculated for the years of 1980-2013 (Figure 24). Of the 21 wells, 4 met the criteria of being shallow, and were monitored over the above time period. Of these 4 wells, all had a decline in water level. The well with the greatest decrease in groundwater elevation averaged 2.24 feet per year of change (1980 depth: 23 ft and 2013 depth: 103 ft) and another had an average decrease in groundwater elevation of 1.46 feet per year (1980 depth: 19 ft and 2013 depth: 67 ft). For the deep wells (Figure 25), an average change per year was calculated for the years of 2003-2013. Of the 5 wells with sufficient data, one well had an average decrease in groundwater elevation of 2.65 ft per year (2003 depth: 184 ft and 2013 depth: 213 ft) and another had an average decrease in groundwater of 2.21 ft per year (2003 depth: 420 ft and 2013 depth: 446 ft). Two wells had increases in groundwater elevation over this time, the well with the most had changes of 1.01 feet per year (2003 depth: 603 ft and 2013 depth: 573 ft). Water levels in this area have fluctuated dramatically. One well had changes in groundwater level of 414 feet between 1970 and 1995, 109 feet in 1970 and 524 feet in 1995, but from 1996 to 2014 water levels recovered and returned to almost 1970 levels; resulted in only a 19 foot decrease in water elevation from 1970 to 2014. The average change over all shallow wells was a decrease in groundwater elevation of 1.04 feet. This trend is surprising, and the cause remains uncertain. When evaluating water use in the area, pumping of groundwater never exceeded 22,000 AF per year over all uses since 1990.

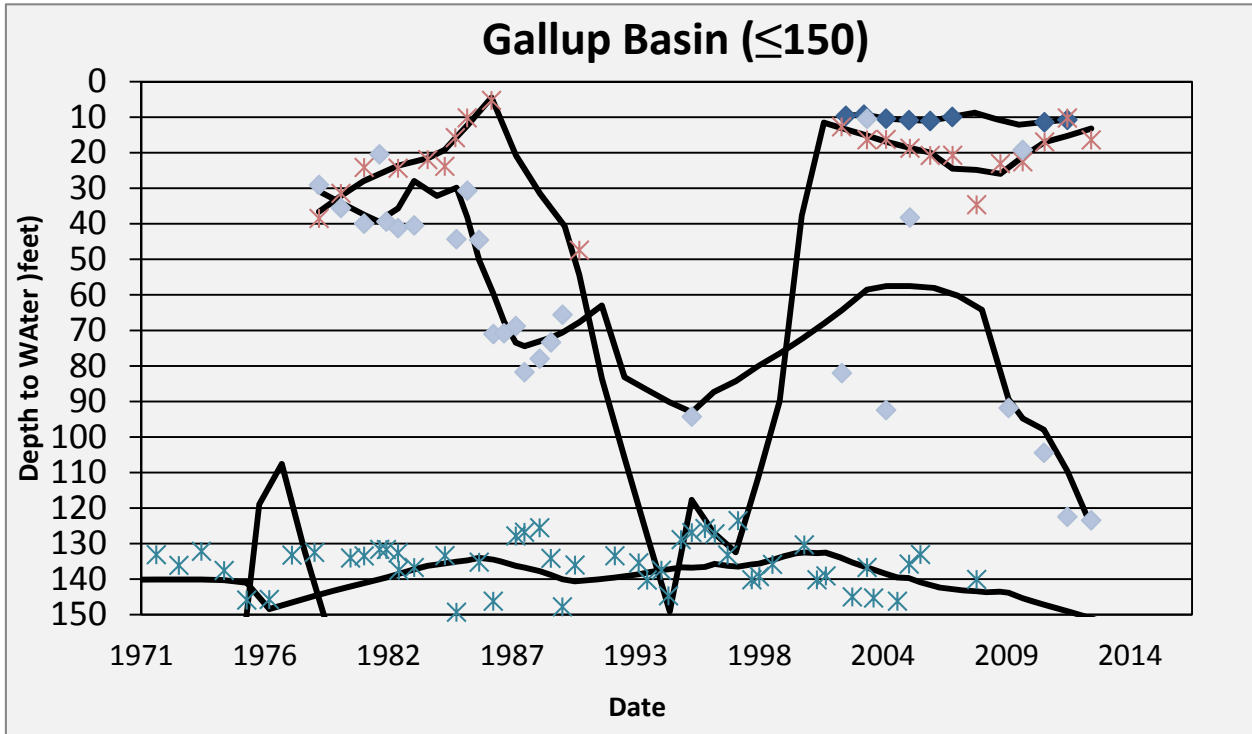


Figure 24: The above graphic illustrates the trend of water levels of wells for shallow wells in the Gallup Basin. Hydrograph depict the observed change in water level for single wells and the respective loess curve for each of the representative wells.

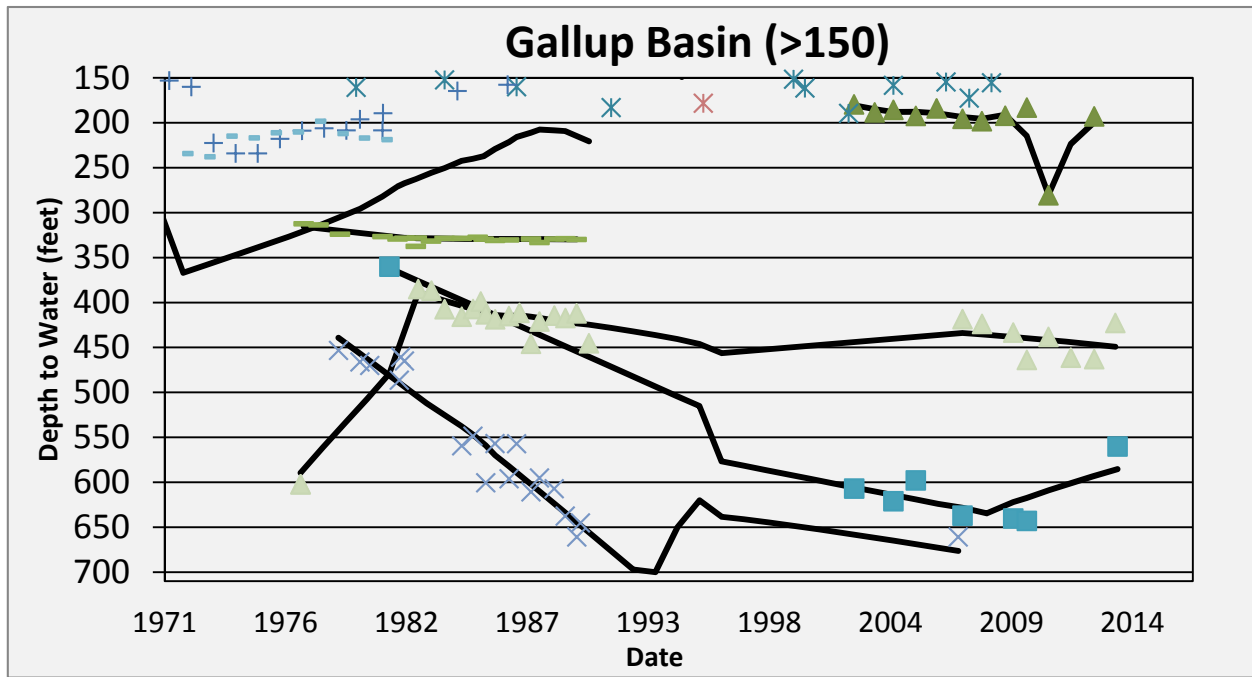


Figure 25: The above graphic illustrates the trend of water levels of wells for deep wells in the Gallup Basin. Hydrograph depict the observed change in water level for single wells and the respective loess curve for each of the representative wells.

An average change per year was calculated for the years of 1983-2013 in the San Juan Basin (Figure 26). Of the 42 wells, 17 were measured over this time period. Of these 17 wells, 10 had decreases in groundwater elevation. The well with the greatest average decrease in groundwater elevation had over 9 feet of change per year (1983 depth: 117 ft and 2013 depth: 415 ft). Seven out of the ten wells had decreases in water elevation of over 1 foot per year. The remaining 7 wells had overall groundwater elevation increases. The well that had the greatest increase in groundwater elevation was 7.54 ft per year (1983 depth: 458 ft and 2013 depth: 223 ft). Of the shallow wells, one well had an increase in groundwater elevation of 0.67 feet per year (1983 depth: 80 ft and 2013 depth: 53 ft). Wells were not separated because of the amount of change observed. From 2005 to 2013, the aggregate decrease in water elevation was 1.50 per year; a 0.5 foot increase from the average decline from 1983-2013. Much like in the Gallup Basin, it is difficult to pinpoint a cause to the decreases in groundwater elevation. Even though agriculture is a large part of the area's economy, all of the 313,322 AF of water used was surface water in 2010.

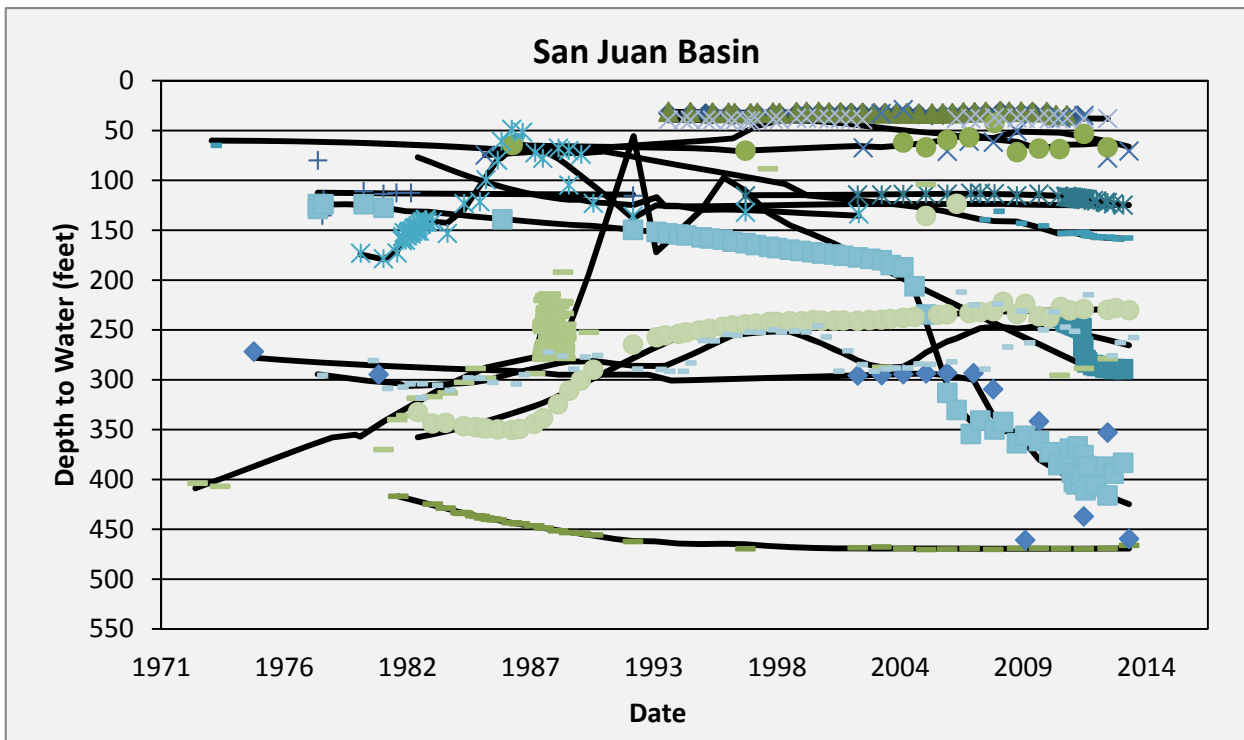


Figure 26: The above graphic illustrates the trend of water levels of wells in the San Juan Basin. Hydrograph depict the observed change in water level for single wells and the respective loss curve for each of the representative wells.

An average change per year was calculated for the years of 1970-2010 in the Bluewater Basin (Figure 27). Of the 27 wells, 13 were measured over this time period. Of these 13 wells, 8 had decreases in groundwater elevation. The well with the highest rate of decrease in groundwater elevation averaged 1.24 feet of change per year (1970 depth: 63 ft and 2010 depth: 120 ft). Four experienced between 1 foot and a 0.50 foot of change per year. Three experienced less than 0.5 foot of decrease in groundwater elevation per year. The remaining 5 wells had overall groundwater elevation increases. The well that had the greatest increase in groundwater elevation had 0.84 ft per year (1970 depth: 132 ft and 2010 depth: 98 ft). The average decrease in groundwater elevation between 1970 and 2010 is 0.20 feet per year. The hydrograph suggests that this is indicative that water levels are relatively stable until the mid-1990s. The average change per year from 1998 to 2013 was -1.5, meaning average decrease in groundwater elevation of 1.5 feet per year. This is a ~650% increase in the rate of water level declines. Three wells had more than 2.95 feet per year of change from 1998 to 2013. The rate of change is surprising when evaluating the amount of total groundwater used. Since 1990 total groundwater use has not exceeded 21,000 AF, none of which was used in irrigated agriculture.

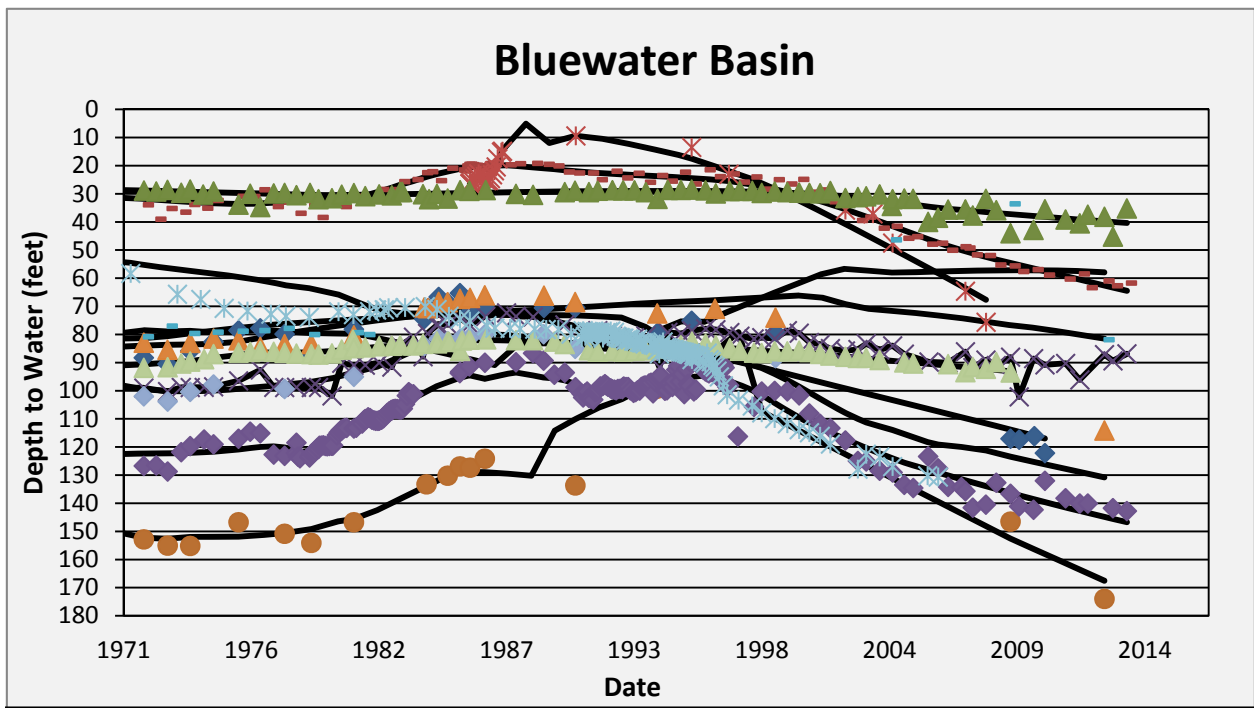


Figure 27: The above graphic illustrates the trend of water levels of wells in the Blue Water Basin. Hydrograph depict the observed change in water level for single wells and the respective loess curve for each of the representative wells.

The Upper Rio Grande Basin is by far the largest basin in the State. An average change per year was calculated for the years of 1989-2014 for the shallow wells in the basin (Figure 28). Of the 106 shallow wells, 56 were measured over this time period. Of these 56 wells, 48 had decreases in groundwater elevation. The well that had the greatest decrease in groundwater elevation had a change of 1.5 feet per year (1989 depth: 1 ft and 2014 depth: 40 ft) which is located ~14 miles northeast of Rio Rancho. Four wells had between 1 foot and 0.5 foot of change per year. Forty-two wells experienced less than 0.5 feet of decrease in groundwater elevation per year. The remaining 8 wells had overall groundwater elevation increase. The well that had the greatest increase in groundwater elevation had 3.97 ft of change per year (1989 depth: 168 ft and 2014 depth: 65 ft) which is located 16 miles northwest of Santa Fe, and there are similar trends for the remaining wells. Water levels are relatively constant with a few outliers. The average change of all wells during this time period was a decrease in groundwater elevation of 0.03 feet a year.

Average change per year was calculated for the years of 1994-2014 for deep wells in the Upper Rio Grande Basin (Figure 29). Of the 274 deep wells, 17 were measured over this time period. Of these 17 wells, 15 had decreases in groundwater elevation. The one with the greatest amount of decrease in groundwater elevation had 3.7 ft of change per year (1994 depth: 113 ft and 2014 depth: 193 ft) which is located in Santa Fe. Six had between 2 feet and 1 foot of change per year. Eight wells experienced less than 1 foot of decrease in groundwater elevation per year. The remaining 2 wells had overall groundwater elevation increases; both were less than 0.20 feet per year; one was located just south of the New Mexico and Colorado boarder, and the other is located west of Albuquerque and Rio Rancho. The average change across all 17 wells was a decrease in water elevation of 1 foot a year. The temporal frequency of measurement varied greatly. For example for the range of 1974 to 2006 there were 27 wells and during this time period the average decrease in groundwater elevation was 0.56 feet a year. The findings suggest what both hydrographs predict. Shallow groundwater system had little change, whereas the deep groundwater systems are changing more significantly. Figure 30 includes both shallow and deep wells on the same graph.

Upper Rio Grande (>150)

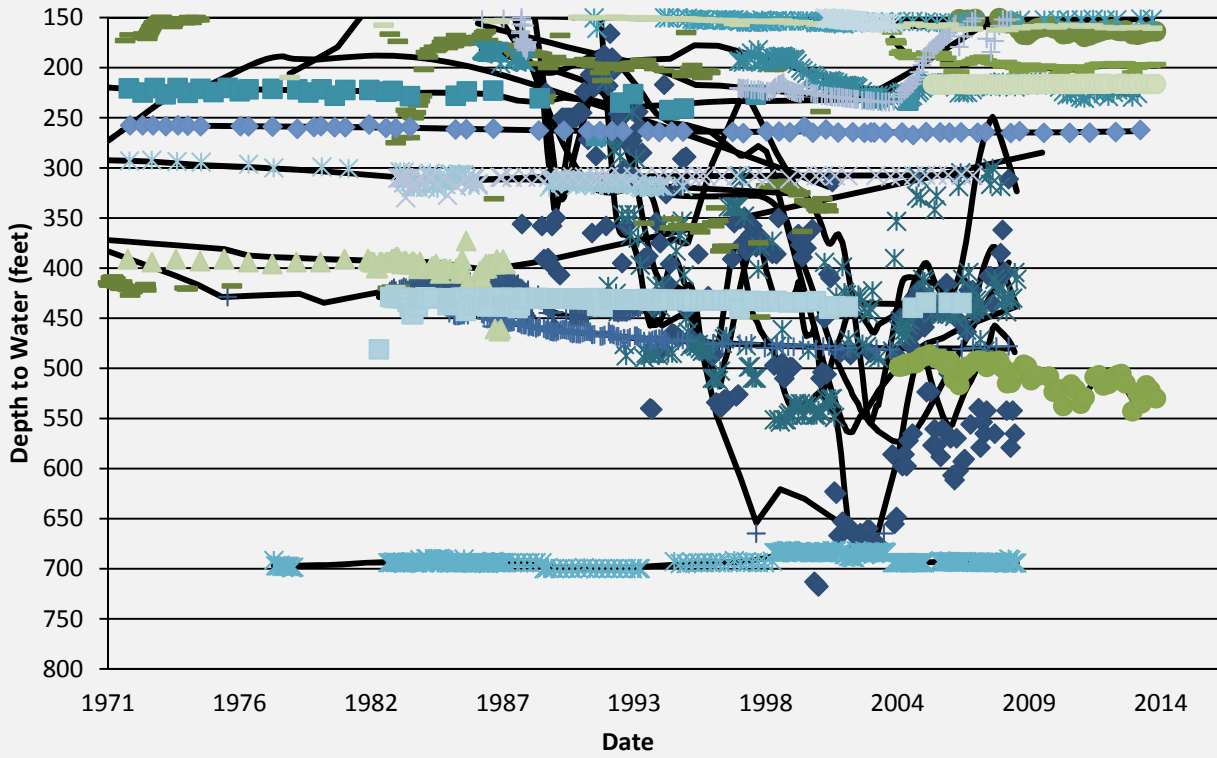


Figure 29: The above graphic illustrates the trend of water levels of deep wells in the Upper Rio Grande Basin. Hydrograph depict the observed change in water level for single wells and the respective loess curve for each of the representative wells.

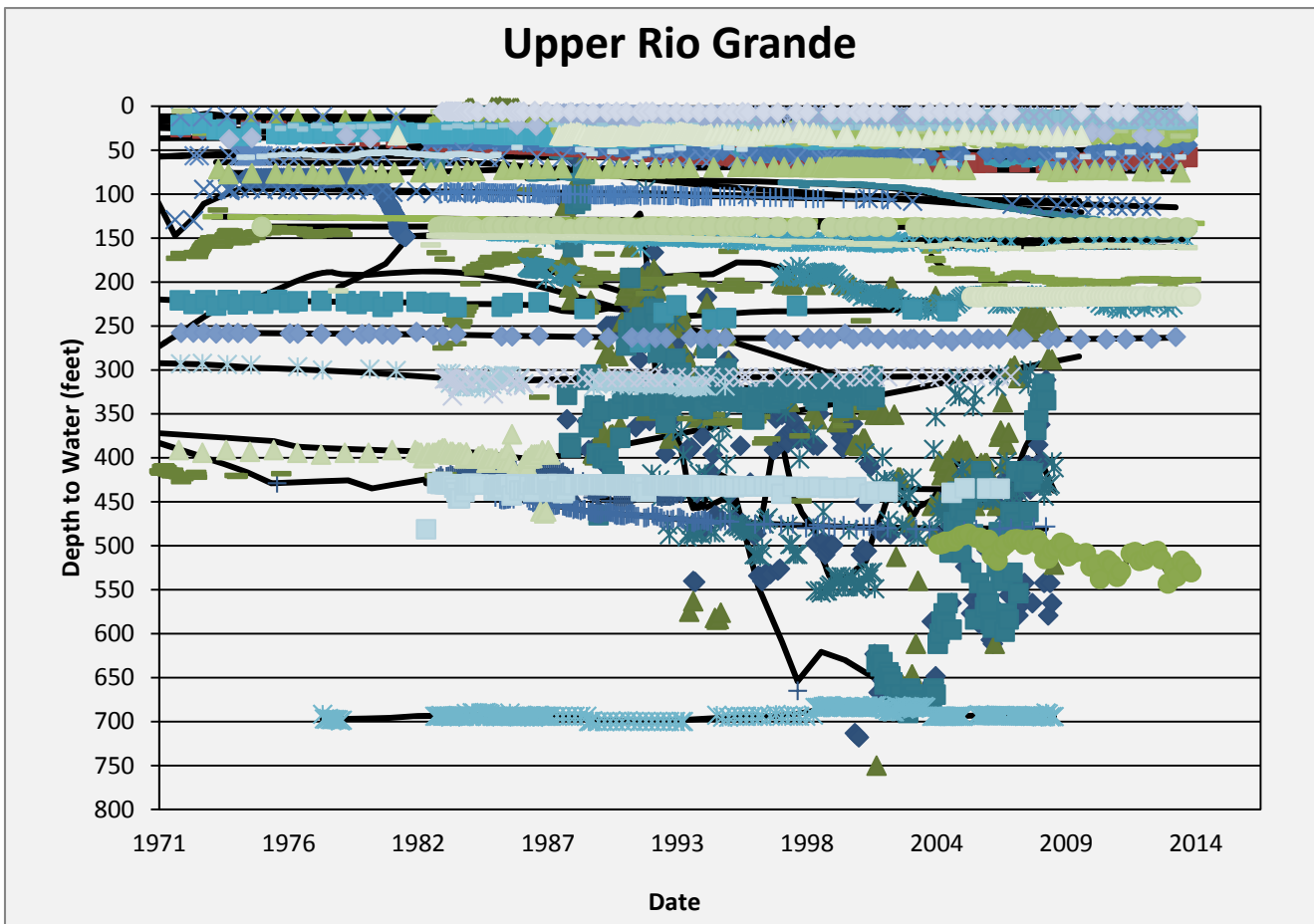


Figure 30: All sampled wells in the Upper Rio Grande Basin.

Northeastern New Mexico

An average change per year was calculated for the years of 1983-2010 in the Canadian River Basin (Figure 31). Of the 13 wells, 8 were measured over this time period. Of these 8 wells, 5 had decreases in groundwater elevation. All wells had less than 0.3 feet of change per year, ranged from 0.26 to 0.11 feet per year. The remaining 3 wells had overall groundwater elevation increases; increases ranged from 0.20 to 0.09 feet per year. This mirrors the findings of the hydrograph. Little change in either direction has been occurring.

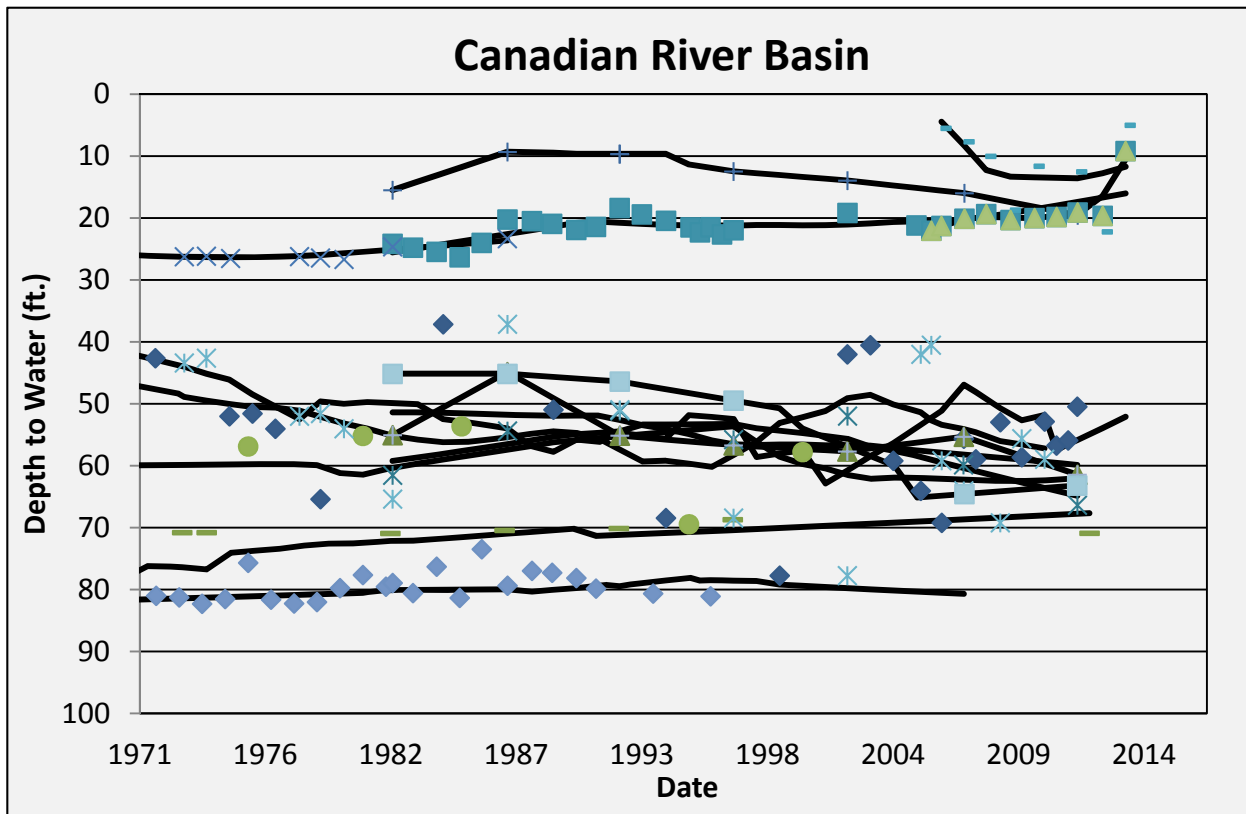
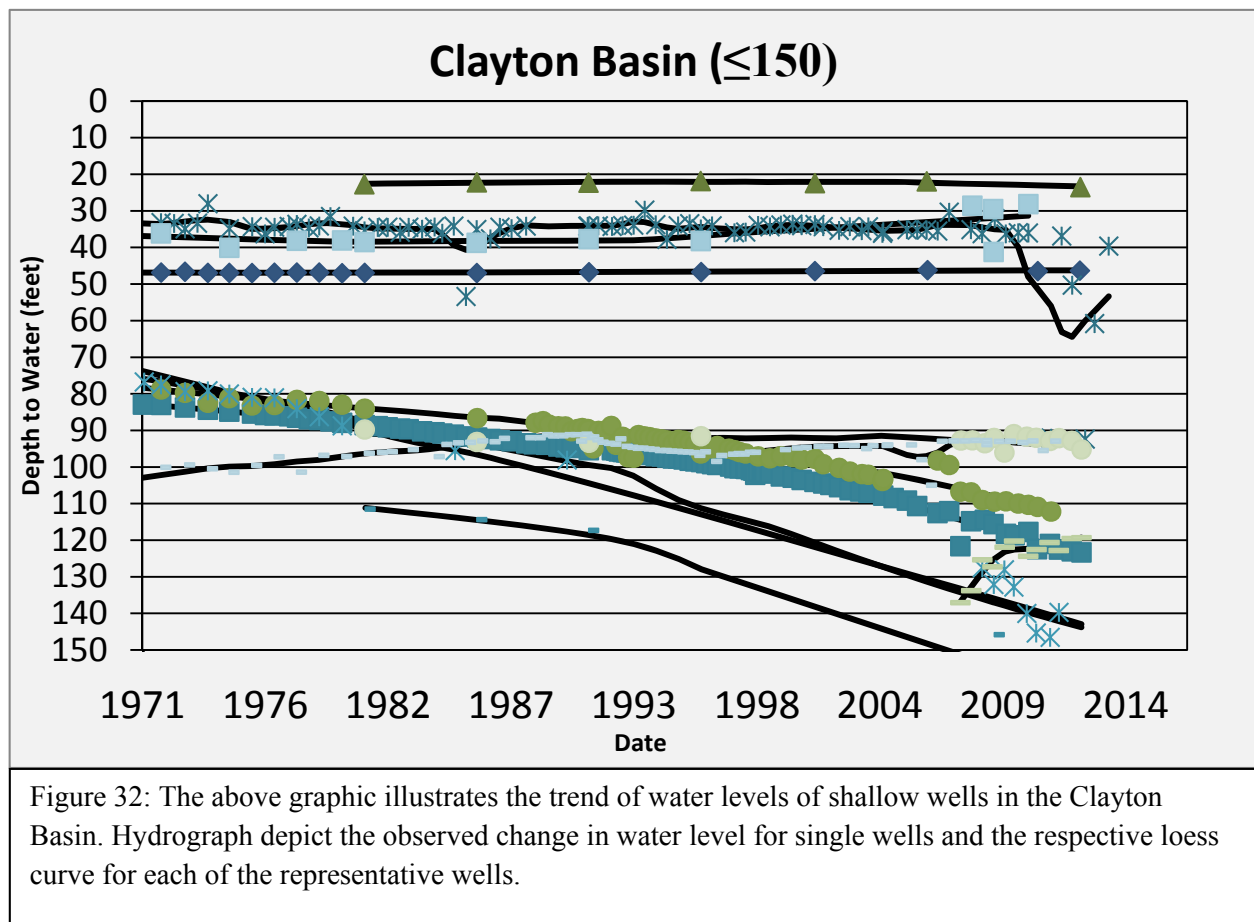


Figure 31: The above graphic illustrates the trend of water levels of wells in the Canadian River Basin. Hydrograph depict the observed change in water level for single wells and the respective loss curve for each of the representative wells

Similar to the Upper Rio Grande Basin, The Clayton Basin had shallow and deep clusters of wells. An average change per year was calculated for the years of 1982-2010 for shallow wells (Figure 32). Of the 39 shallow wells, 32 were measured over this time period. Of these 32 wells, 26 had decreases in groundwater elevation. The well that had the highest rate of decrease in groundwater elevation had 2.2 feet of change per year (1982 depth: 77 ft and 2010 depth: 140 ft). Six experienced between 2 feet and 1 foot of change per year. Eighteen wells experienced less than 1 foot of elevation change per year. The remaining 6 wells had overall groundwater elevation increase or stayed the same. The well that had the greatest increase in groundwater elevation had 2.43 feet of change per year (1982 depth: 139 ft and 2010 depth: 69 ft). The average per year change is a decrease in groundwater elevation of 0.45 ft per year. Since 2005 pumping has intensified with the well that had 2.2 feet per year of change from 1982 to 2010 increasing to 8.3 feet of change per year from 2005 to 2012. Another well that had an increase in the rate that groundwater levels were dropping, increased from 2.06 feet of change per year to 4.38 feet per year. For this time series, the average rate of decrease in groundwater elevation

increased to 0.89 feet per year, a 97% increase. An average change per year was calculated for the years of 1982-2012 for the deep wells in the same basin (Figure 33). Of the 69 deep wells, 23 were measured over this time period. Of these 23 wells, 21 had decreases in groundwater elevation. The well with the greatest average decrease in groundwater elevation had 4.38 feet of change per year (1982 depth: 136 ft and 2012 depth: 267 ft). Three had between 4 feet and 3 foot of change per year. Four wells had between 3 and 2 feet of change. Six had between 2 and 1 foot of change. Seven experienced less than 1 foot of decrease in groundwater elevation per year. The remaining 2 wells had overall groundwater elevation increase; one had increases of 0.11 per year and the other 1.2 feet per year. The average change for all wells was a decrease in groundwater elevation of 1.52 feet per year. The average change per year for each well increased between 2005 and 2012. Groundwater levels declined an average of 1.84 feet per year between 2005 and 2012, a 21% increases when compared to 1982-2010.



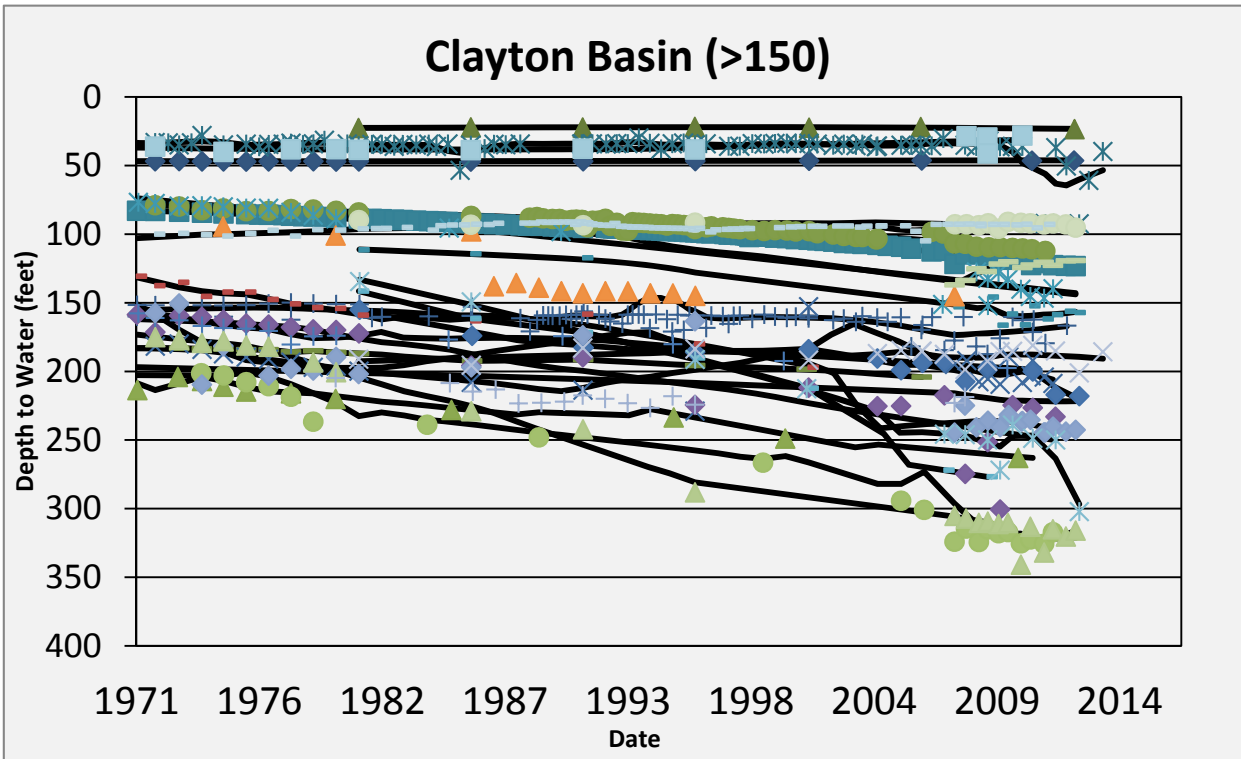


Figure 33: The above graphic illustrates the trend of water levels of deep wells in the Clayton Basin. Hydrograph depict the observed change in water level for single wells and the respective loess curve for each of the representative wells.

The Tucumcari Basin is located south of the Clayton Basin. An average change per year was calculated for the years of 1980-2012 (Figure 34). Of the 60 wells, 21 were measured over this time period. Of these 21 wells, 12 wells had decreases in groundwater elevation. None of the wells measured during this time period had a decrease in groundwater elevation of more than 0.65 feet per year. The remaining 8 wells had increases in groundwater elevation. The well that had the greatest increase in groundwater elevation was 0.85 ft per year (1980 depth: 47 ft and 2010 depth: 19 ft). The average decreases in groundwater elevation for the whole basin was 0.01 per year over this time period. For the same wells, the rate at which groundwater levels were decreasing increased to 0.24 feet per year. The hydrograph suggest that this is indicative of current trends. Overall change is not significant, over the time period. The current trend however may deserve some attention as the recent data show a higher rate of groundwater elevation decline.

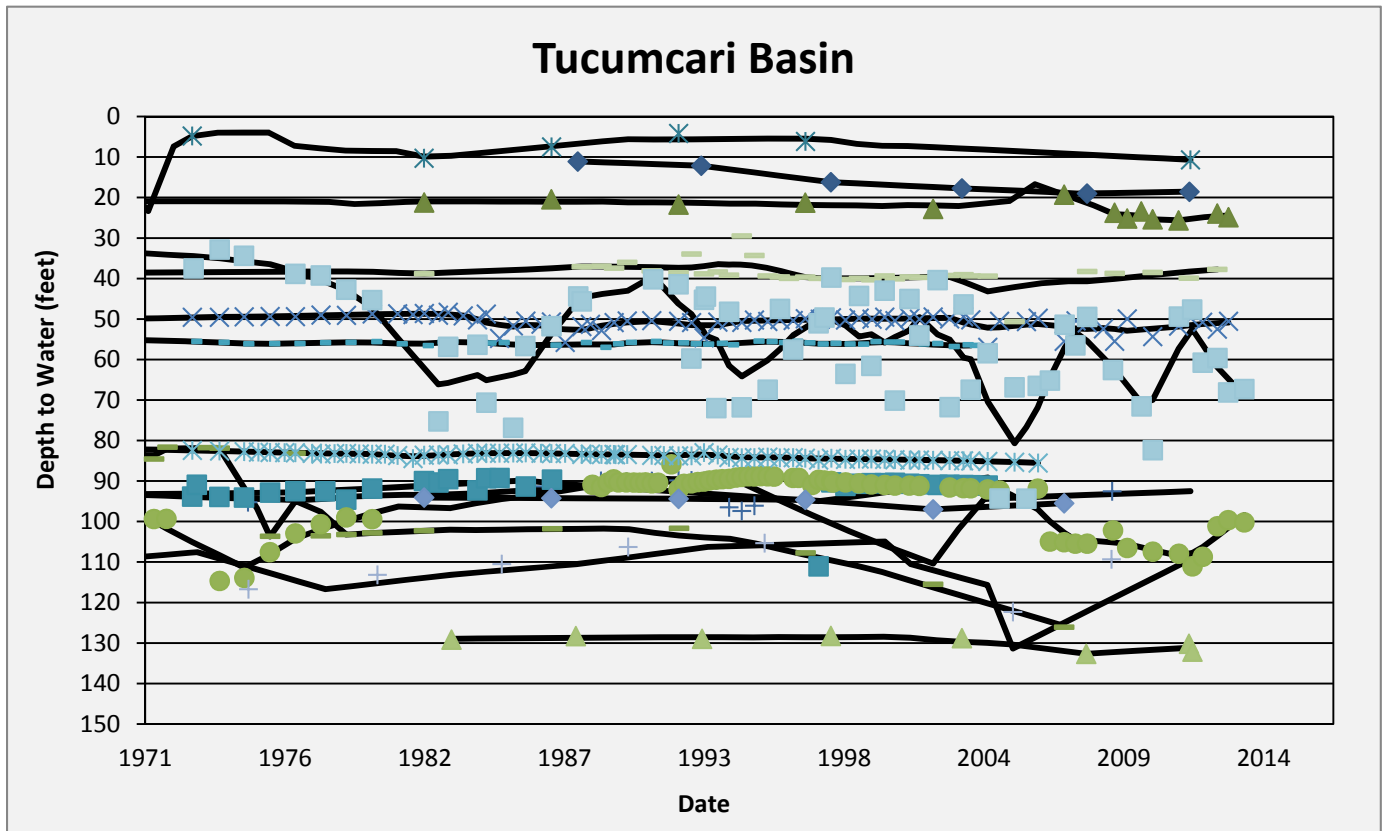


Figure 34: The above graphic illustrates the trend of water levels of wells in the Tucumcari Basin. Hydrograph depict the observed change in water level for single wells and the respective loess curve for each of the representative wells.

The Upper Pecos Basin which is the riverhead of one of the major surface water resources for the State had a surprising lack in data. An average change per year however was calculated for the years of 2000-2013 (Figure 35). There were only 7 wells measured within this Basin, and the findings should not be considered conclusive. Of the 7 wells, only 3 fit within this time period. One had decreases in water elevation of 21.25 feet per year, the other 15.03 feet a year, and the last 1.23 feet per year. These results in an aggregate decrease in groundwater elevation of 12.50 ft per year per well; which supports the argument that serious consideration and additional monitoring data collection should occur within this basin.

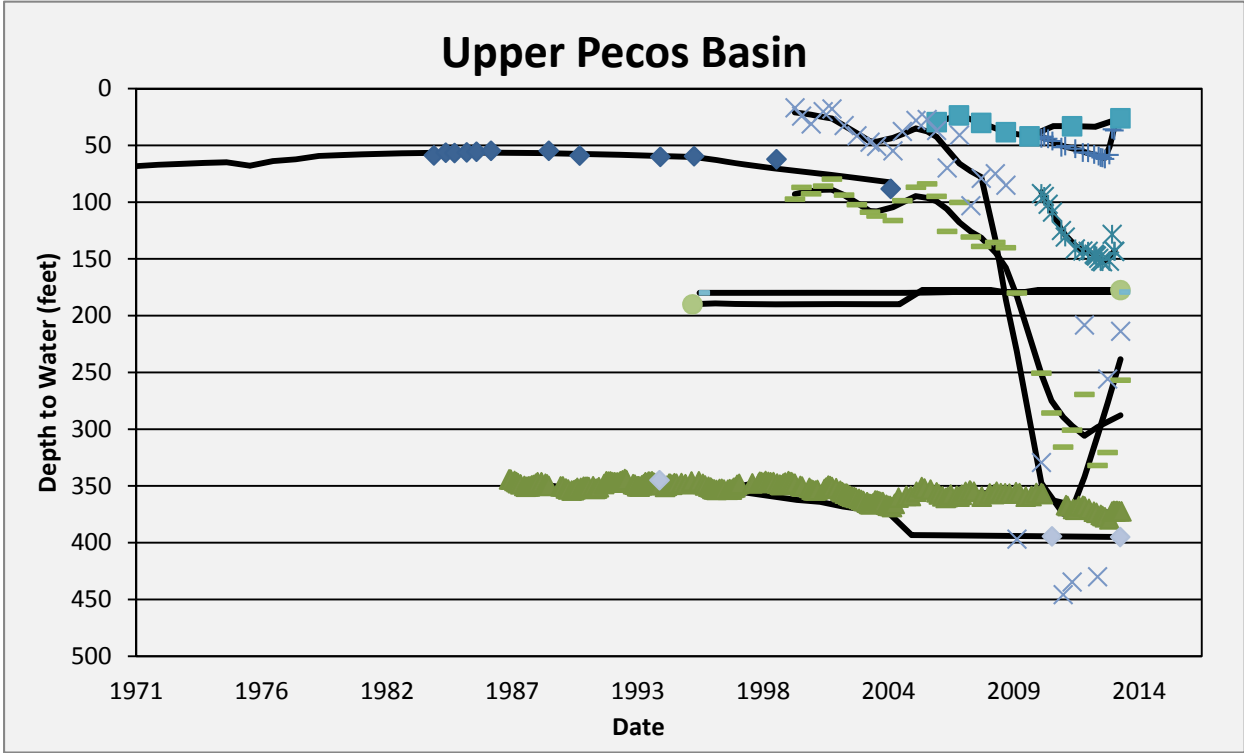


Figure 35: The above graphic illustrates the trend of water levels of wells in the Upper Pecos Basin. Hydrograph depict the observed change in water level for single wells and the respective loess curve for each of the representative wells.

Curry County Basin unlike the Upper Pecos had a large data set for deep wells. This Basin was separated into two hydrographs. For the shallow wells, an average change per year was calculated for the years of 1970-2012 (Figure 36). Of the 21 shallow wells, 11 were measured over this time period. Of these 11 wells, 5 had decreases in groundwater elevation. All of which were less than 0.3 feet of change per year. Increases in groundwater elevation occurred in the remaining 6 wells, all of which, experienced less than 0.2 feet of change per year. A decrease in groundwater elevation of 0.03 feet per year was the average of the 11 wells. Shallow groundwater in Curry County isn't the major source of groundwater, as the next hydrograph will show.

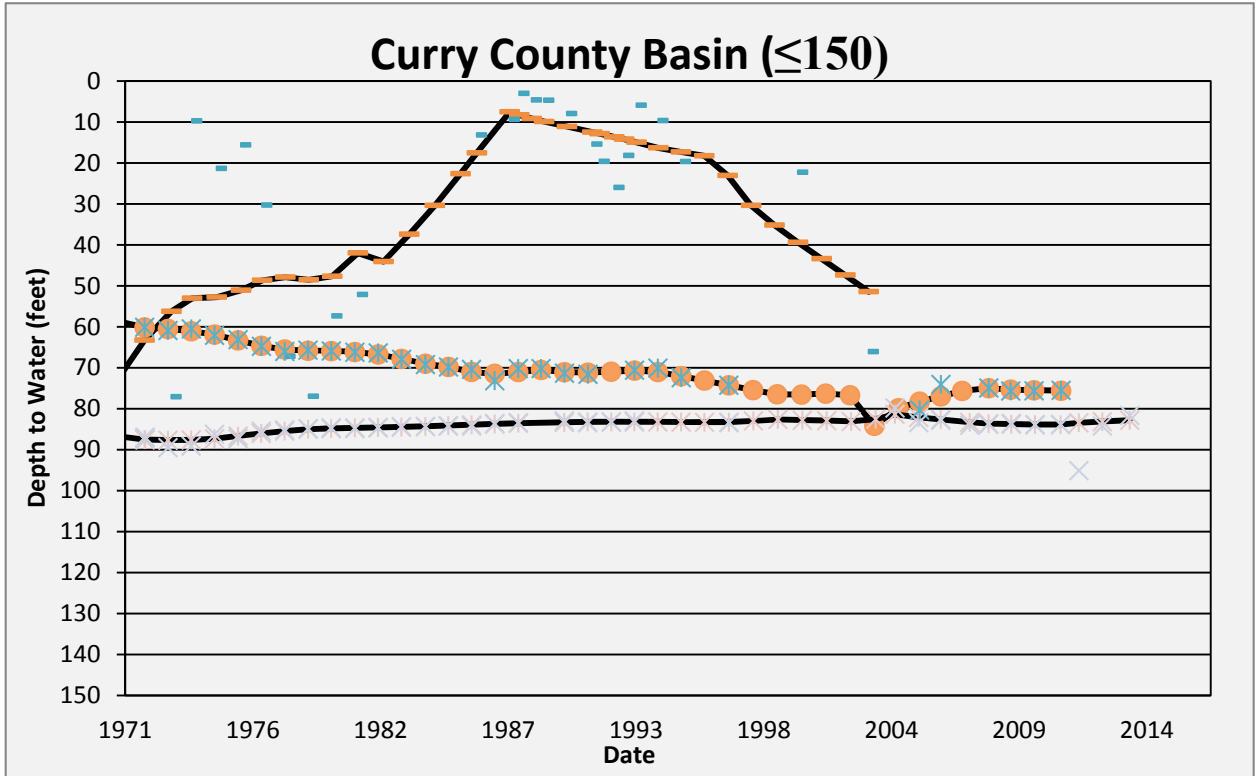


Figure 36: The above graphic illustrates the trend of water levels of shallow wells in the Curry County Basin. Hydrograph depict the observed change in water level for single wells and the respective loss curve for each of the representative wells.

An average change per year was calculated for the years of 1980-2012 for the deep wells in the Curry County Basin (Figure 37). Of the 137 deep wells, 47 were measured over this time period. Of these 47 wells, 35 had decreases in groundwater elevation. The one which had the greatest average decrease, experienced decreases of 5 feet per year (1980 depth: 225 ft and 2012 depth: 388 ft). One well experienced a decrease between 5 and 4 feet. Two between 4 and 3 feet., three between 3 and 2 feet, four between 2 and 1 foot, and the remain 24 wells had less than 1 foot of decrease in groundwater elevation per year. The remaining 12 wells had increases in groundwater elevation. All except one experienced less than 1 foot of increase a year. That one well had increases of 4.1 feet per year. The average decrease in groundwater elevation for the 47 wells was 0.69 feet per year. From 2000 to 2012 this increased by 0.14 feet resulting in a decrease in groundwater level of 0.82 feet per year, a 19% increase. From 2005 to 2012, The rate at which groundwater levels were decreasing increased even further with the per year average change in groundwater level being 0.90 feet per year. This however is not a surprise when

considering that groundwater is the main source of water used in irrigated agriculture. The last report that shows surface water use was in 1990. Groundwater use was on a steady decline until 2010 when use reached over 160,000 AF.

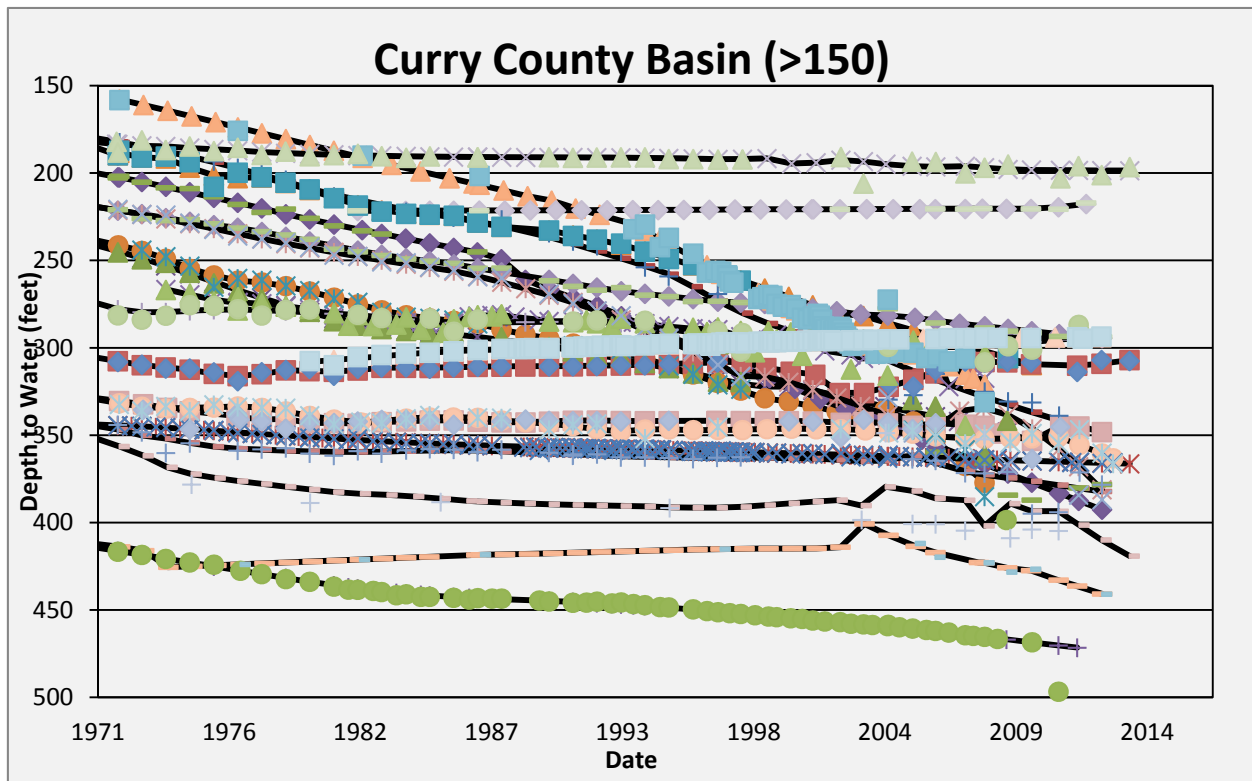
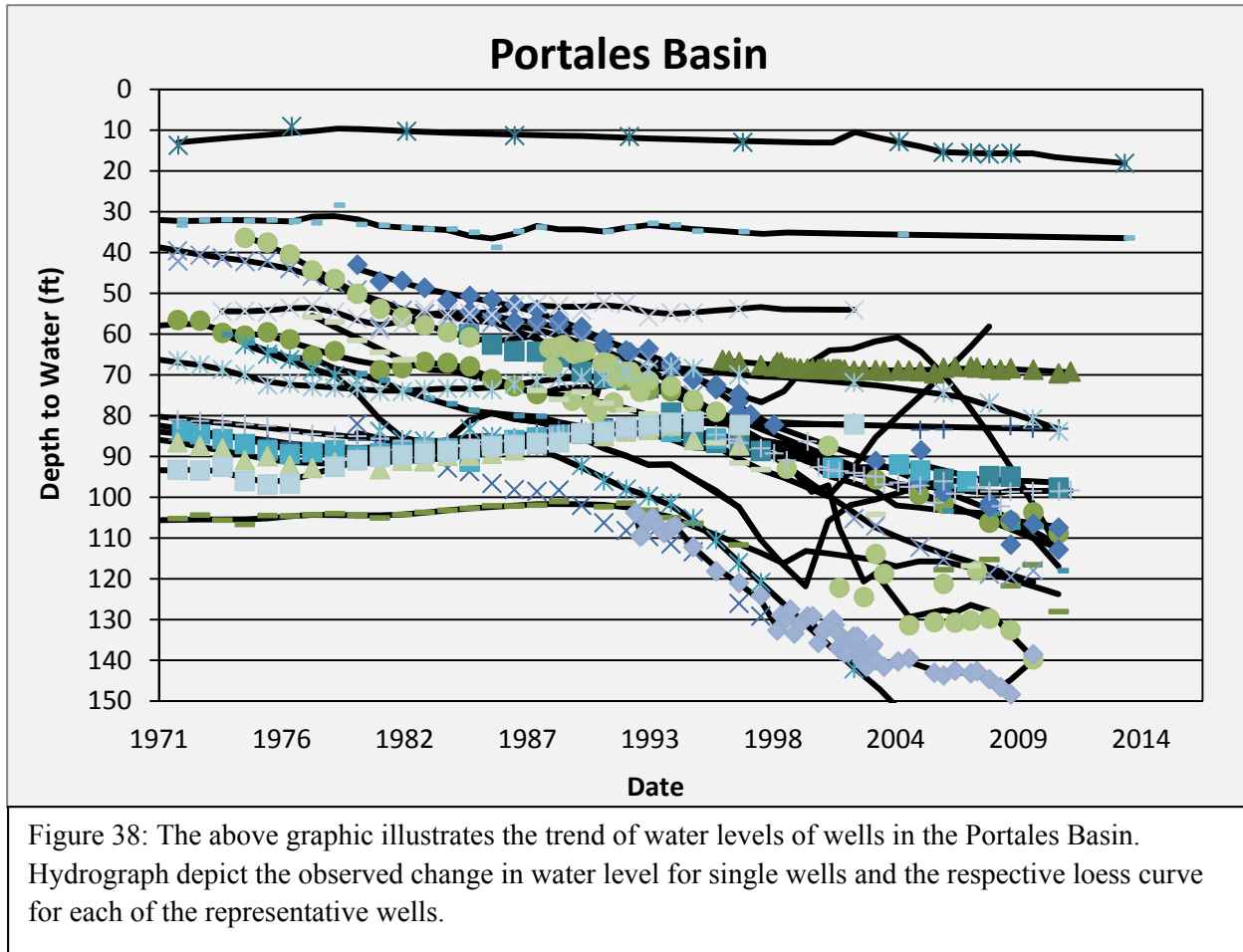


Figure 37: The above graphic illustrates the trend of water levels of deep wells in the Curry County Basin. Hydrograph depict the observed change in water level for single wells and the respective loess curve for each of the representative wells.

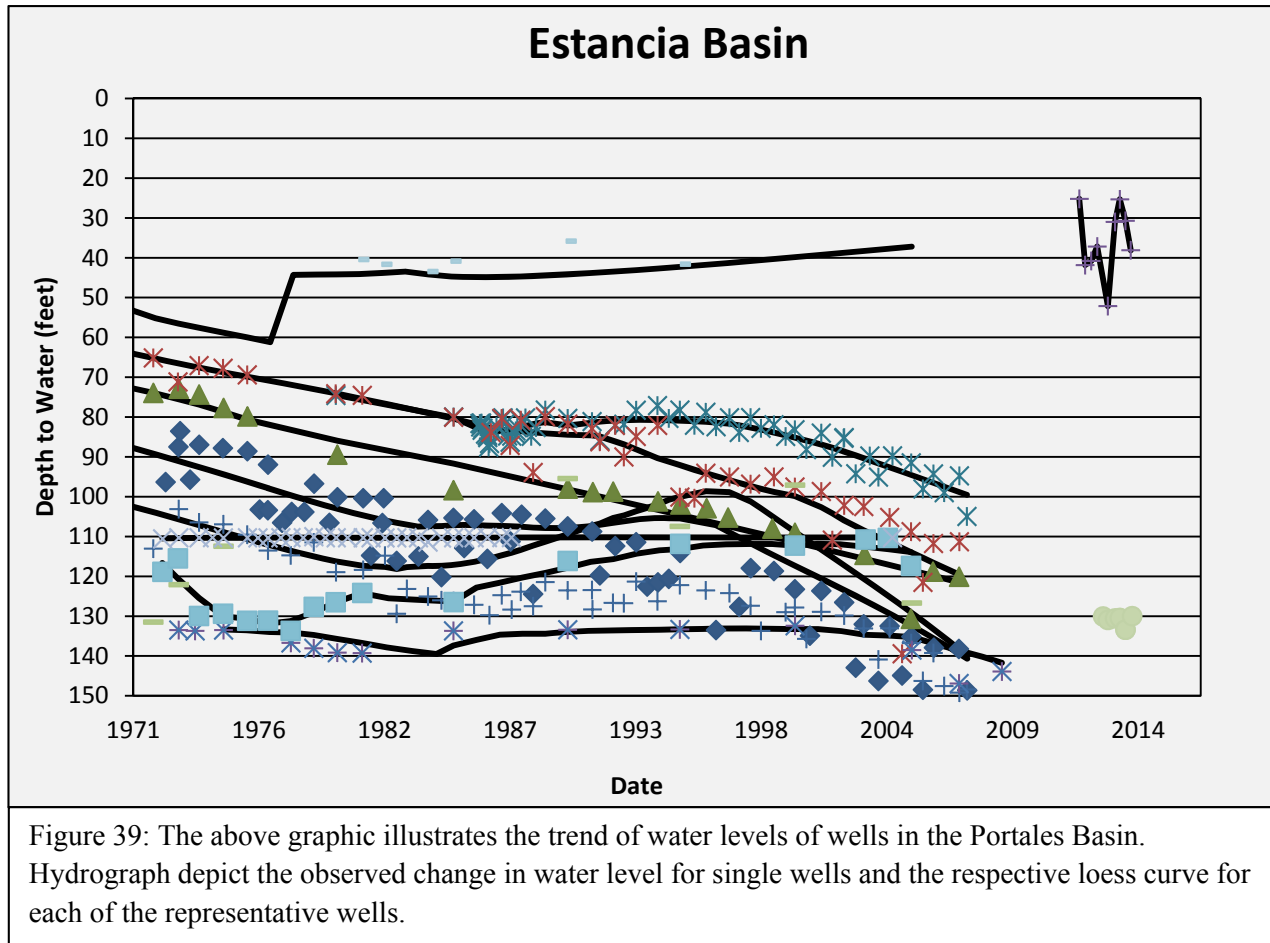
An average change per year for wells in the Portales Basin was calculated for the years between 1980 and 2008 (Figure 38). Of the 68 wells, 26 were measured over this time period. Of these 26 wells, 23 had decreases in groundwater elevation. There were 4 wells that had depth to water measurements of over 250 feet; these four wells had the greatest decreases in water elevation from 4.91 feet per year to 3.47 feet per year. For the more shallow wells, the well that had the greatest decrease in groundwater elevation had changes of 3.43 feet per year (1980 depth: 73 and 2008 depth: 169 feet). Five wells had groundwater elevation decrease by over 2 feet per year, four wells had decreases between 2 and 1 foot, and ten wells had decreases of less than 1 foot a year. Three wells had increases in groundwater levels but none more than 0.2 feet a year. When

excluding the 5 deepest wells, average decreases in groundwater elevation per wells were 0.95 feet per year. Declines in large part can be attributed to agriculture. Water used in agriculture comes solely from groundwater. Since 1990, average water used in agriculture per year was ~180,000 AF. In 2010 water use used by the city of Portales was roughly 2,895 AF and in the same year agriculture used 186,020 AF of groundwater.



An average change per year was calculated for the years of 1970-2000 in the Estancia Basin (Figure 39). Of the 80 wells, 47 were measured over this time period. Of these 47 wells, 42 wells had decreases in groundwater elevation. There were 20 wells that had decreases in groundwater elevation of between 2 and 1 foot per year, with the most being 1.96 feet per year. There were 22 wells which had decrease in water elevation of less than 1 foot per year. Average change per well was a decreases in groundwater elevation of 0.75 feet per year. There were only five wells that had increases in groundwater elevation, with the most being 1.17 feet per year. This data set had

very accurate and timely data up to 2000 and every year after, fewer and fewer wells were measured. By 2008, there were only two wells being measured. This basin touches into a few counties, but the one that is most represented is Tarrant County. Irrigated agriculture is by far the largest user of water in the county, using as much as ~59,605 AF in 2010. With reliable data only reaching till 2000, additional monitoring should be conducted within this basin.



Southeastern New Mexico

Fort Sumner is one of the more interesting Basins in the state, for the reason that there is a lot of observed depth to water measurements and as you will see, there is little change in groundwater elevation. An average change per year was calculated for the years of 1980-2012 for this basin (Figure 40). Of the 75 wells, 41 wells were measured over this time period. Of these 41 wells, 28 had decreases in groundwater elevation and 13 had increases in groundwater elevation. As the hydrograph suggest there was very little change (decrease in groundwater elevation of 0.05 feet per year, average). Not one well had an average change of more than 0.75 feet per year. Thirty-eight of the wells had less than 0.25 feet change in either direction. It is interesting to see this trend as the neighboring basins groundwater is decreasing in elevation at some of the highest rates in the State. This area receives a majority of its water from surface sources (Pecos River). In 2010 they used a total of ~57,200 AF of water in agriculture. Of the 57,200 AF, only ~12,000 AF was pumped from the groundwater supply. Total groundwater used was only 12,845 AF in 2010.

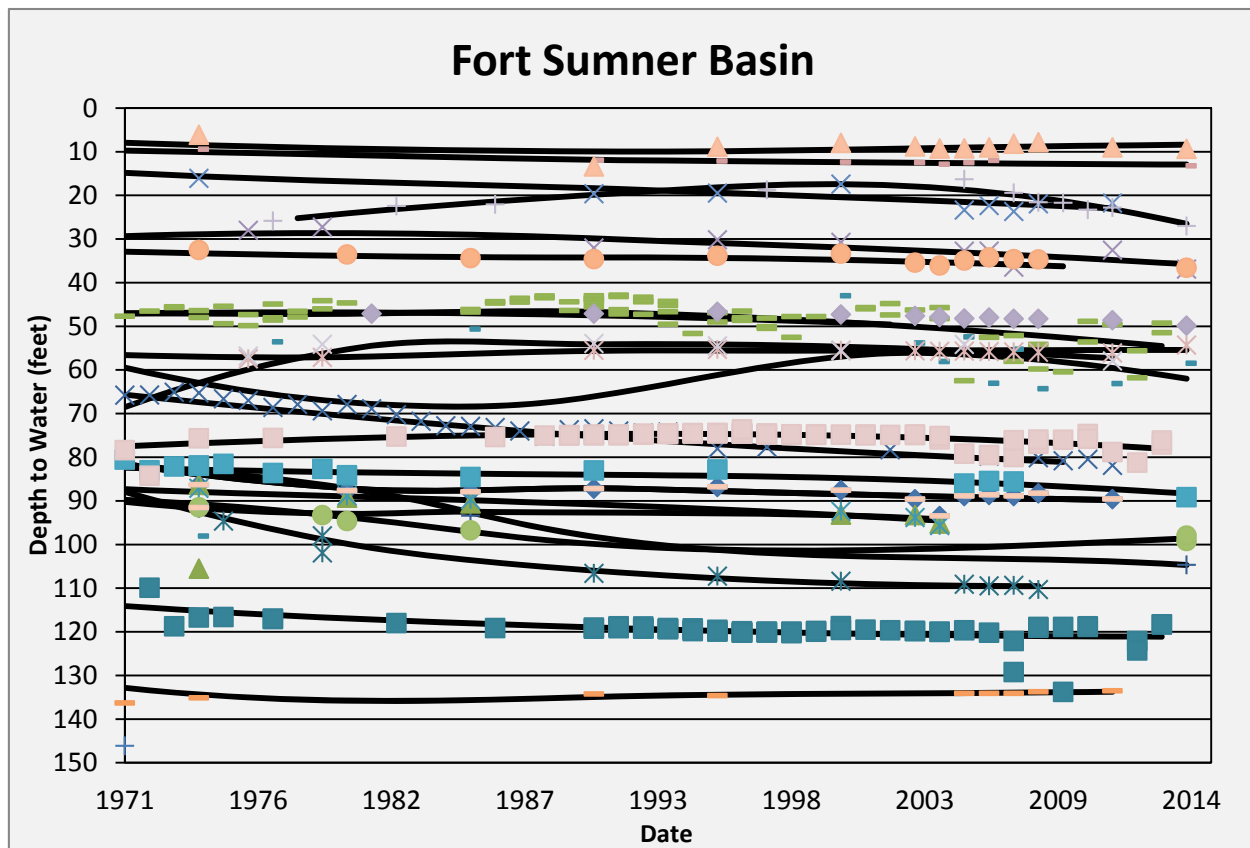


Figure 40: The above graphic illustrates the trend of water levels of wells in the Fort Sumner Basin. Hydrograph depict the observed change in water level for single wells and the respective loess curve for each of the representative wells.

An average change per year was calculated for the years of 1980-2005 in the Causey Lingo Basin (Figure 41). Of the 51 wells, 47 were measured over this time period. Of these 47 wells, 18 wells had decreases in groundwater elevation and 29 that had increases or no change in groundwater elevation. As the hydrograph suggest there was very little decrease or increase in groundwater levels. The well with the most decrease had 0.61 feet of change per year and the two with the most increases had 1.17 and 1.12 feet of change per year respectively. The rest of the wells showed little change; ranging from 0.42 feet per year of decreases in groundwater elevation and 0.74 feet per year of increase in groundwater elevation. 40% of wells had less than 0.20 feet of change in either direction. Average change per well was 0.12 feet of increase in groundwater elevation per year. This is surprising considering the amount of agriculture in the area.

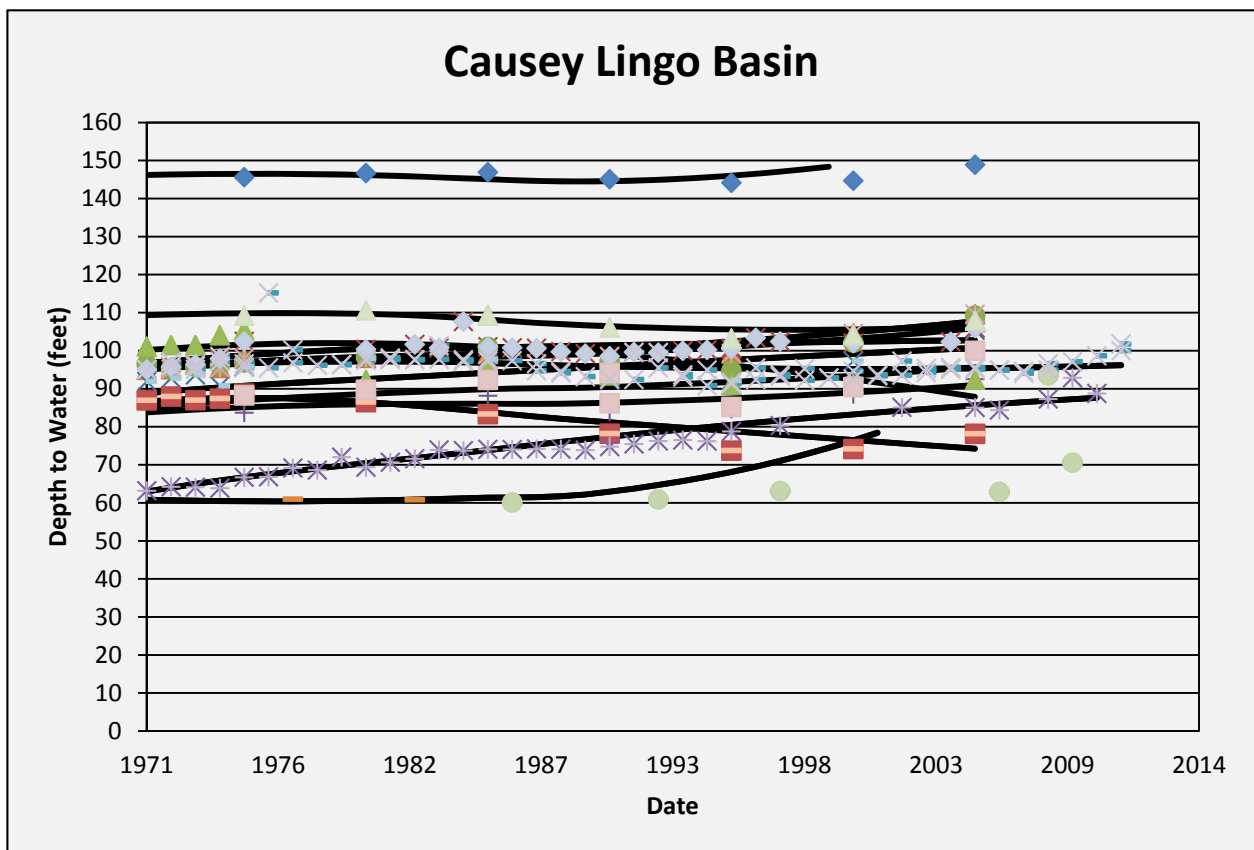


Figure 41: The above graphic illustrates the trend of water levels of wells in Causey Lingo Basin. Hydrograph depict the observed change in water level for single wells and the respective loess curve for each of the representative wells.

The Roswell Basin could also be considered the lower Pecos River Basin. Unlike the Upper Pecos Basin, there was no shortage of data. For shallow wells, an average change per year was calculated for the years of 1980-2013 (Figure 42). Of the 84 shallow wells, 72 were measured over this time period. Of these 72 wells, 40 had decreases in groundwater elevation, changes were relatively low however. Only two wells had decreases of over 1 foot per year, 1.24 and 1.06 feet per year respectively. 10 wells had decreases in groundwater elevation of between 1 and 0.5 foot per year. The remaining 32 wells had decreases of less than a 0.50 of change per year; with 22 of those having 0.25 or less feet of change per year. The remaining 32 wells had increases in groundwater elevation. No well had over 1 foot of increase however. Eight wells had increases between 1 foot and half a foot a year. Five wells had increases of between 0.50 and 0.25 feet per year. The remaining 19 wells had increases of less than 0.25 feet per year. When analyzing the most recent 10 year trend (2003-2013) much different results appear. 20% of wells had decreases of more than a foot a year. The number of wells that had increases in groundwater elevation between 1980 and 2013 was 44% and from 2003 to 2013 that dropped to 26%. One would expect this basin to have increased groundwater level declines due to the amount of groundwater used, 225,758 AF in 2010. There are surface water sources, but it appears usage far outpaces supply.

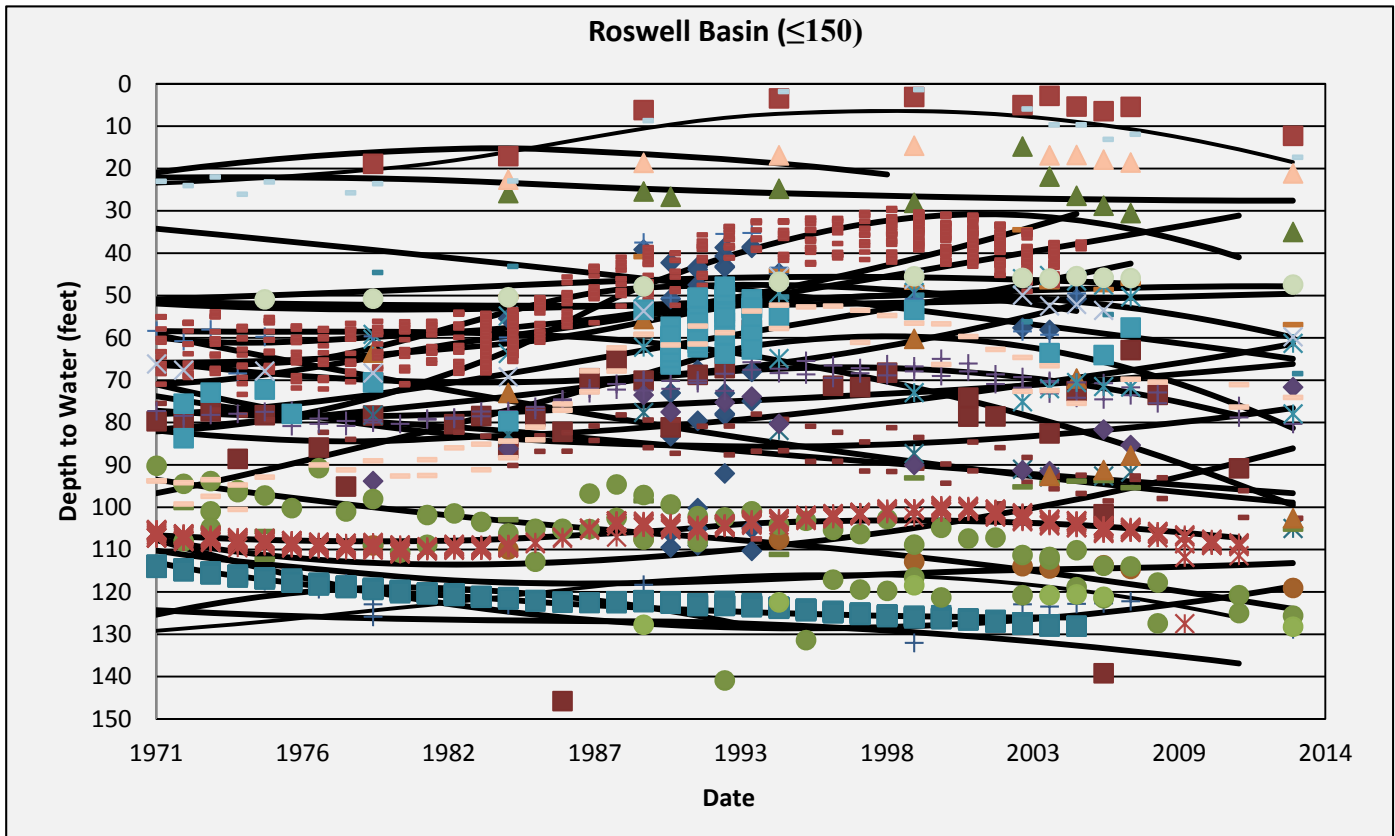


Figure 42: The above graphic illustrates the trend of water levels of wells in Causey Lingo Basin. Hydrograph depict the observed change in water level for single wells and the respective loess curve for each of the representative wells.

An average change per year was calculated for the years of 1980-2013 for deep wells in the Roswell Basin (Figure 43). All 12 wells were sampled, 10 had decreases in groundwater elevation and 2 increased. Only two wells had decreases of more than 1 foot per year, the most being 1.16 feet per year. The remaining 9 wells had decreases of less than a foot per year; with 4 of those having less than 0.5 feet per year of change. The remaining 2 wells had increases in groundwater elevation. No well had over 0.2 feet of change a year however. When analyzing the most recent 10 year trend (2003-2013) much different results appear. 20% of wells had decreases of more than a foot a year. The rate of change between 2003 and 2013 and the original temporal scale (1980-2013) is quite significant for deep wells. Moving from an average decrease of 0.47 per year to an average decrease of 0.72 feet per year, a 52% increase. Two wells had the rate of decrease in groundwater elevation increase by over 1 foot. Five other wells experienced a greater rate of decrease, but not to the same degree (ranging from 0.77 and 0.03 increase in the rate of decline). The remaining five wells experienced an inverse effect and the overall water increases. This is surprising to see, because of the trend of pumping through the 2000s. Pumping hit its peak in 2000 but has been steadily declining reaching 1980 levels.

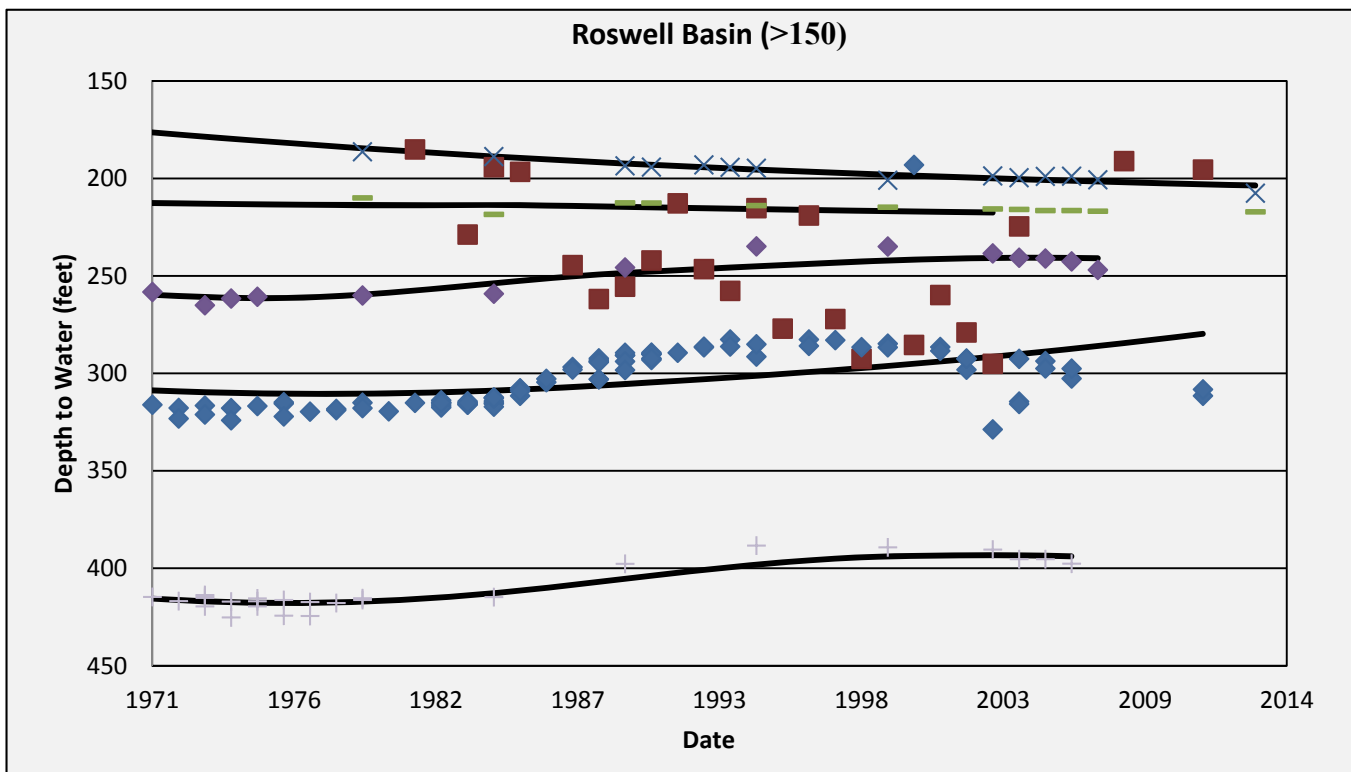


Figure 43: The above graphic illustrates the trend of water levels of deep wells in the Roswell Basin. Hydrograph depict the observed change in water level for single wells and the respective loess curve for each of the representative wells

An average change per year was calculated for the years of 1970 to 2010 in Lea County Basin (Figure 44) for each well. Of the 232 wells, 123 were measured over this time period. Of these 123 wells, 99 wells had decrease in groundwater elevation. Only one had decreases of more than two feet per year, fifteen wells had decreases between 2 and 1 foot per year, 28 wells had decreases between 1 and 0.50 feet per year, 26 wells had decreases between 0.50 and 0.25 feet per year, and 29 wells had decreases between 0.25 and 0.01 feet per year. Twenty-four wells had increases in groundwater elevation. All of which were minimal. Only one well had increases of 0.25 feet per year. The remaining 23 wells had no change or increases of less than 0.25 feet per year. The average decrease in groundwater elevation was 0.45 feet per year from 1970 to 2010. The downward trend of groundwater levels has increased over the last ten years in this basin (2000-2010). The average decrease in groundwater elevation was 0.67 feet per year from 2000 to 2010 for the same wells, a 50% increase. This is not surprising to see, groundwater used in agriculture peaked in 2010, using 32% more groundwater than in 2000 and almost twice as much as in 1980. In mining, which includes oil and gas, water use peaked in 2000, but even then it used less than 30,000 AF which was only 15% of total groundwater used that year.

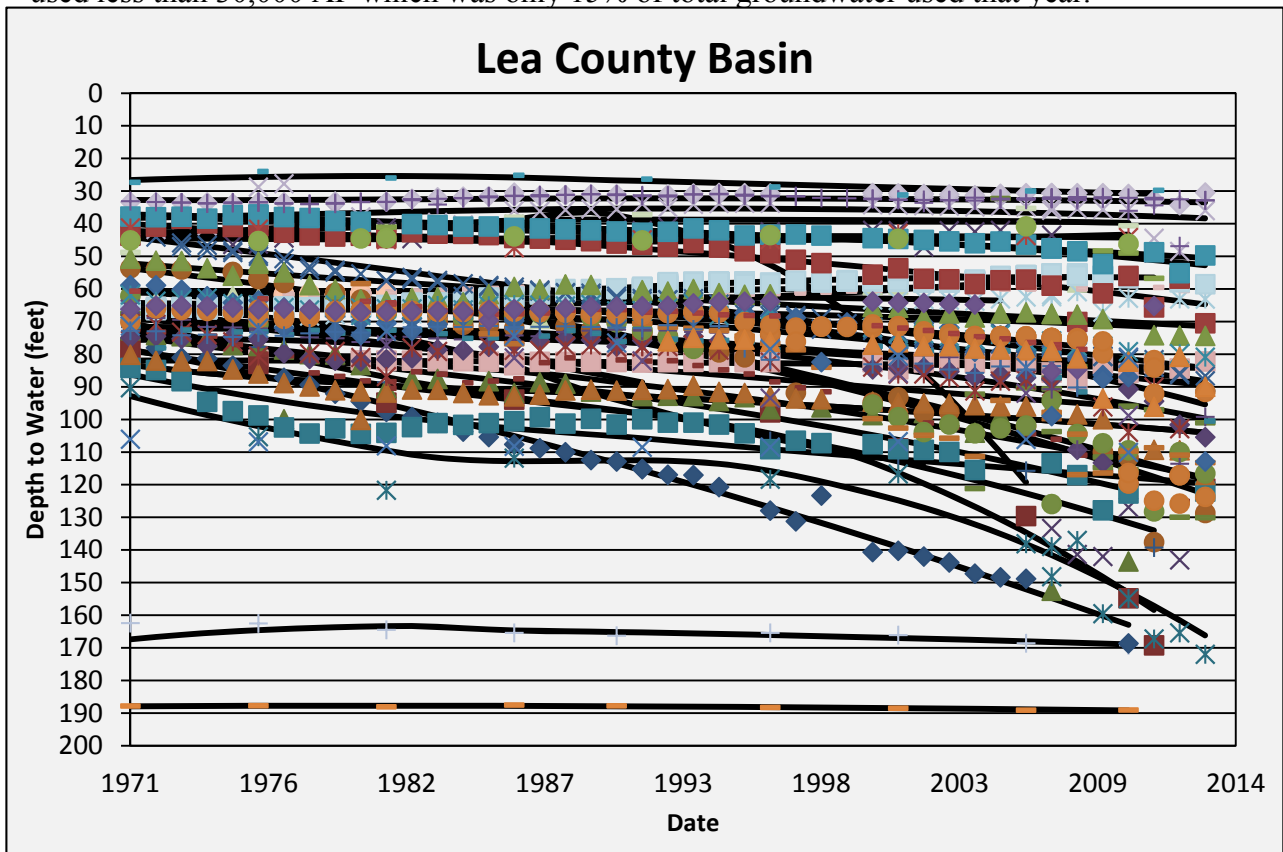


Figure 44: The above graphic illustrates the trend of water levels of wells in the Lea County Basin. Hydrograph depict the observed change in water level for single wells and the respective loess curve for each of the representative wells.

An average change in groundwater elevation per year for each well was calculated for the years between 1970 and 2010 for the Capitan Basin, which is also located in Lea County (Figure 45). Of the 50 shallow wells, 20 were measured over this time period. Of these 20 wells, 16 wells had decreases in groundwater elevation. Only one well had decreases of more than 0.5 feet per year, three wells had decreases between 0.5 and 0.25 feet per year, and 12 wells experienced decreases between 0.25 and 0.01 feet per year. Four wells had increases in groundwater elevation, ranging from 0.05 to 0.34 feet per year. The average decrease per year for these wells was 0.08 feet per year. The downward trend of groundwater levels has increased over the last ten years in the study area (2000-2010). The above wells groundwater elevation decreased 187% more over this time period. The average decrease in groundwater elevation between 2000 and 2010 was 0.23 feet per year. The above mentioned agriculture water uses could be a cause of these faster declines in groundwater levels.

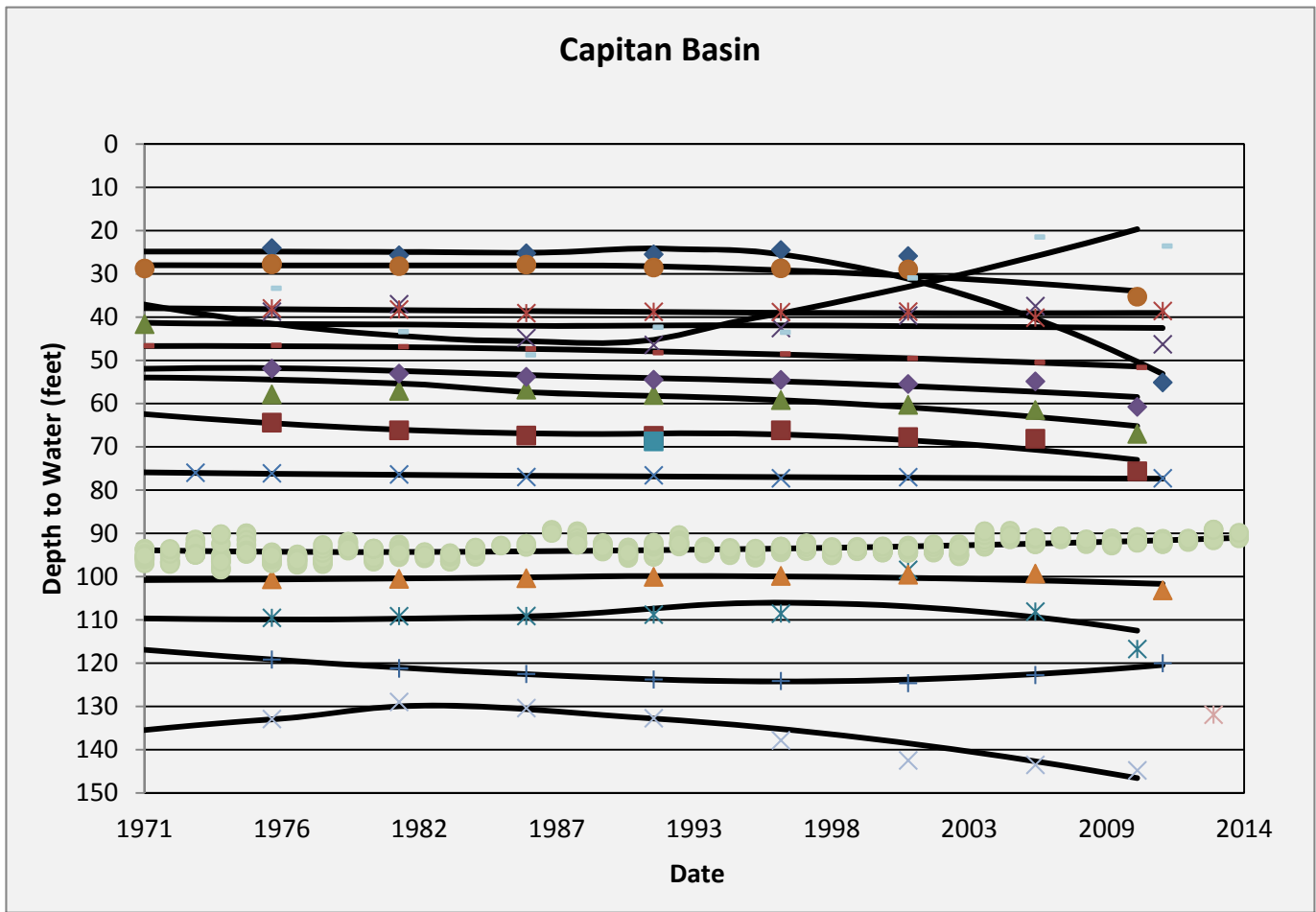


Figure 45: The above graphic illustrates the trend of water levels of shallow wells in the Capitan Basin. Hydrograph depict the observed change in water level for single wells and the respective loess curve for each of the representative wells.

An average change in groundwater elevation per year for each well was calculated for the years between 1980 and 2013 in the Carlsbad Basin (Figure 46). Of the 108 shallow wells, 42 were measured over this time period. Of these 42 wells, 27 wells had decreases in groundwater elevation. Only two wells, had decreases of more than 1 foot per year (1.88 and 1.41 respectively), one well had decreases between 1 and 0.50 foot per year, 3 had between 0.50 and 0.25 feet of change, and 21 wells had decreases between 0.25 and 0.01 feet per year. Fifteen wells had increases in groundwater elevation (nine were less than 0.25 feet per year, 3 between 0.26 and 0.50 feet per year, 2 between 0.50 and a foot, and one increased 1.23 feet per year). From 2003 to 2013, the rate of change increased; the average decrease in groundwater elevation for all the wells from 1980 to 2013 was 0.08 feet per year and from 2003-2013 the change in groundwater elevation increased up to 0.53 feet per year. Thirty-three wells had decreases in groundwater elevation (2 more than 3 feet per year, 2 between 3 and 2 feet of change per year, 67 between 2 and 1 foot per year, and nineteen between a foot and 0.01 feet per year). Twelve wells had increases in groundwater elevation, ranging from 0.003 and 0.45 feet per year. The majority of the Basin is in Eddy County but it extends into Lea County. Both counties are significant users of groundwater for irrigated agriculture with the mining industry making withdrawals as well.

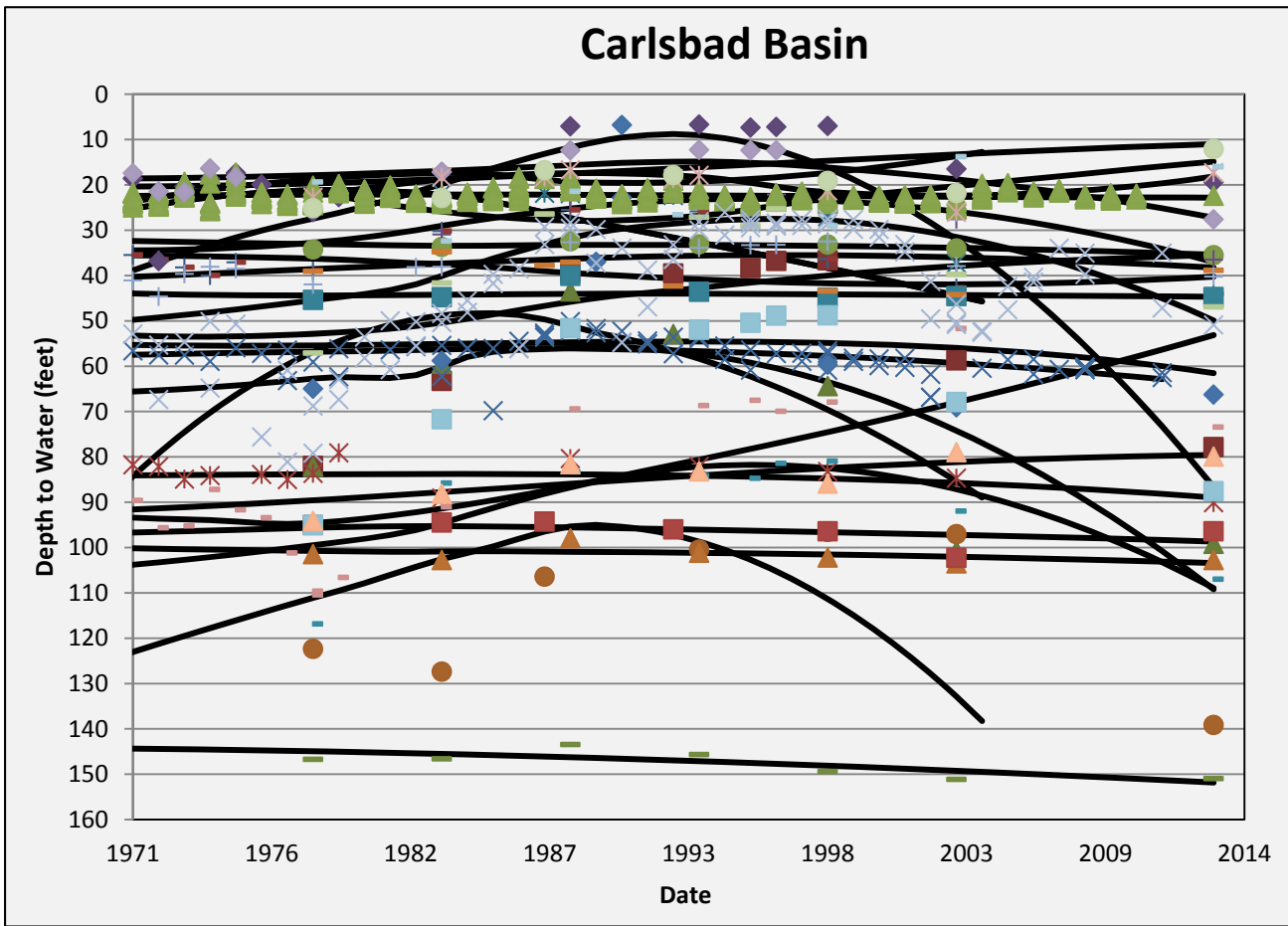


Figure 46: The above graphic illustrates the trend of water levels wells in the Carlsbad Basin. Hydrograph depict the observed change in water level for single wells and the respective loess curve for each of the representative wells.

An average change in groundwater elevation per year for each well was calculated for the years of 1970-2013 in the Salt Basin (Figure 47). Of the 26 shallow wells, 5 were measured over this time period. Of these 5 wells, all showed decreases in groundwater elevation. The one that showed the greatest change, decreased at a rate of 0.87 feet per year. The other four decreased at a rate of between 0.5 and 0.39 feet per year. The downward trend in water levels did not increase at a substantial rate between 2003 and 2013. Average rate of change between 1970 and 2013 was 0.53, between 2003 and 2013 that increased only to 0.58 feet per year. However, water use in this basin is relatively low. Since 1980 groundwater used in irrigated agriculture never went above 30,000 AF.

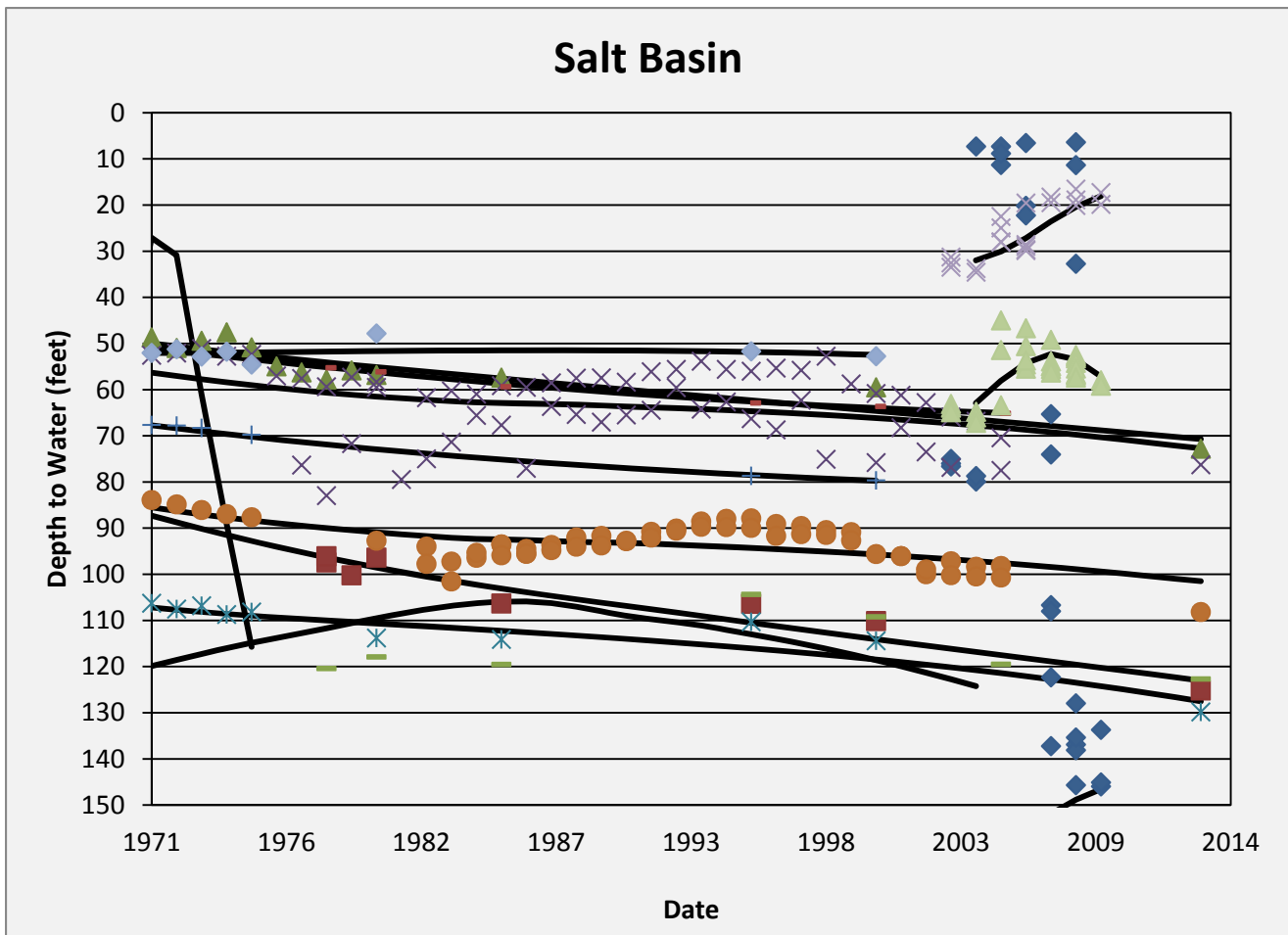


Figure 47: The above graphic illustrates the trend of water levels wells in the Salt Basin. Hydrograph depict the observed change in water level for single wells and the respective loess curve for each of the representative wells.

An average change in groundwater elevation per year for each well was calculated for the years of 1979-2004 in the Penasco Basin (Figure 48). Even though there were 62 wells in this basin, usable data was sparse. Temporal ranges of groundwater elevation changes did vary greatly. However, there were 14 wells that met the criteria of being shallow and having a temporal scale ranging from 1979-2004. The well that had the greatest decline in groundwater elevation had steady decrease throughout the time series; resulting in the yearly decrease of 1.4 feet. All other wells decreased less than 0.75 feet per year. Six wells had increases in groundwater elevation. Three of the six had small increases (between 0.03 and 0.09 feet of change per year), one had 0.29 feet of increase per year, and the one that had the most was determined to be 0.54 feet per year. For the years of 2004 and 2013, six wells were able to be analyzed. All wells, except one experienced decreases in groundwater elevation. The average decline per year from 2004 to 2013

was 0.78 feet. Deep wells experienced little change over the same time period; average decrease was 0.02 feet per year. The majority of the Penasco Basin is in Otero County, but also extends into Chavez. Groundwater use between the two counties varies greatly.

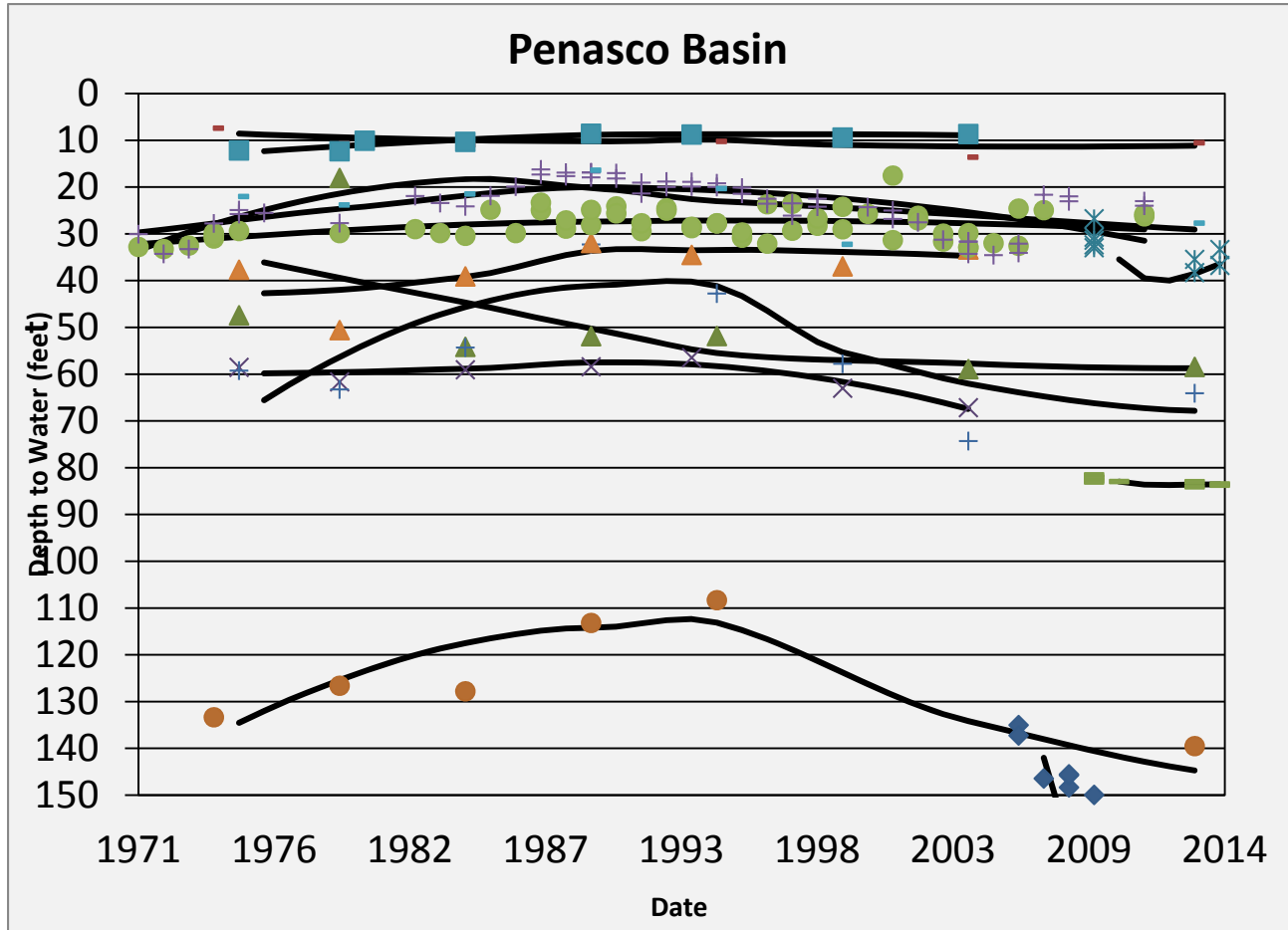


Figure 48: The above graphic illustrates the trend of water levels of shallow wells in the Penasco Basin. Hydrograph depict the observed change in water level for single wells and the respective loess curve for each of the representative wells.

An average change in groundwater elevation per year for each well was calculated for the years between 1980 and 2014 in the Hondo Basin (Figure 49). There were a total of 94 wells in the study area. Nineteen of them met the criteria of being measured between 1980 and 2014. This is one of the only Basins in the state that had enough data in the 2014 that allowed for analysis. Honda Basin showed little change overall. Only one well had decreases in groundwater elevation of more than 0.50 feet per year. There were a total of 12 wells that had decreases between 0.50

and 0.01 feet per year and one over 0.60 feet per year. There were 7 wells that had increases in groundwater elevation (4 of the 7 wells had increases between 0.01 and 0.08, 2 between 0.12 and 0.21, and only one over 0.30 feet per year). The average decrease in groundwater elevation for all 19 was 0.09 feet per year. Much like the other basins, the rate at which water levels are decreasing has increased in the last 10 years. From 2004 to 2014 the average decrease in groundwater elevation was 0.49 feet per year as opposed to 0.09 from 1980 to 2014. The Basin is equally represented in both Lincoln and Otero County. All wells however were located in Lincoln County. Lincoln County relies on both surface and groundwater for irrigation. Total water use has been consistently decreasing since its peak in 1995, returning to 1980 levels by 2010; the increase in the rate at which water levels are decreasing is surprising due to this.

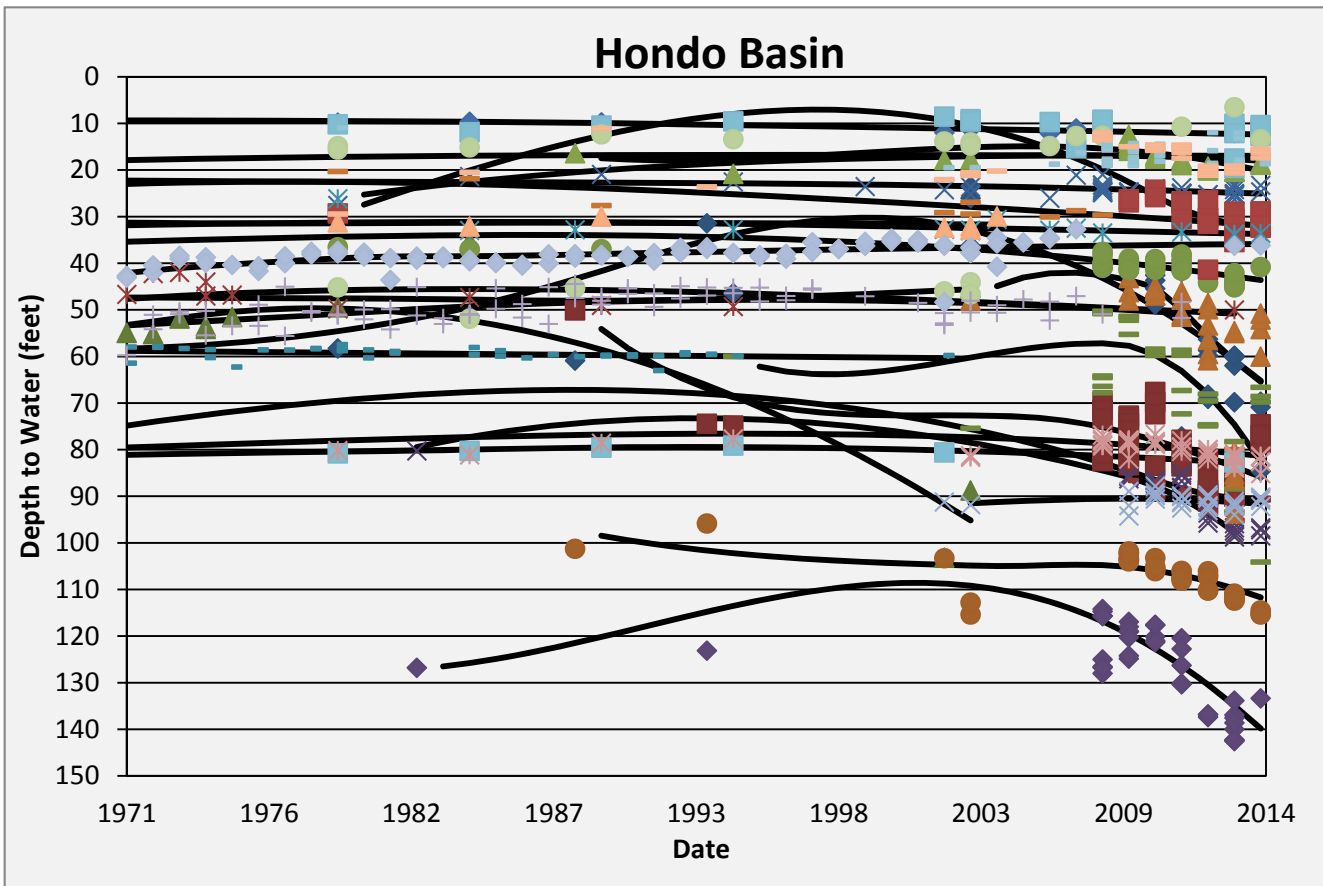


Figure 49: The above graphic illustrates the trend of water levels of shallow wells in the Hondo Basin. Hydrograph depict the observed change in water level for single wells and the respective loess curve for each of the representative wells.

An average change per year was calculated for the years of 1980-2001 in Tularosa Basin (Figure 50). There were a total of 147 wells in the study area, 39 of which were measured between 1980 and 2001. Twenty-one had decreases in groundwater elevation. Only one well had decreases greater than 1 foot per year. Six wells had decreases between 1 and 0.50 feet per year. The remaining 14 had decreases between 0.50 feet and 0.01 feet of change. Eighteen wells had increases in groundwater elevation. Two wells had more than 2 feet of change per year, four between 2 and 1 foot of change, two between 1 and 0.50 feet per year, and 10 that had between 0.50 and 0.00 feet of change. The basin experienced an increase of 0.15 feet per year per well over this timer period. From 2001 to 2013 the basin experienced a decrease of 0.21 feet per well. This is a relatively large basin, extending into Lincoln, Dona Ana, Otero, Sierra, and Torrance Counties. There are significant wells in Lincoln, Dona Ana, and Otero. The wells which had the largest increases and decrease in groundwater elevation were both located in Lincoln. The well with the second most decrease and the well with the third most increase were both located in Dona Ana. The wells which had the 3rd, 4th, and 5th most decrease were all located in Otero County.

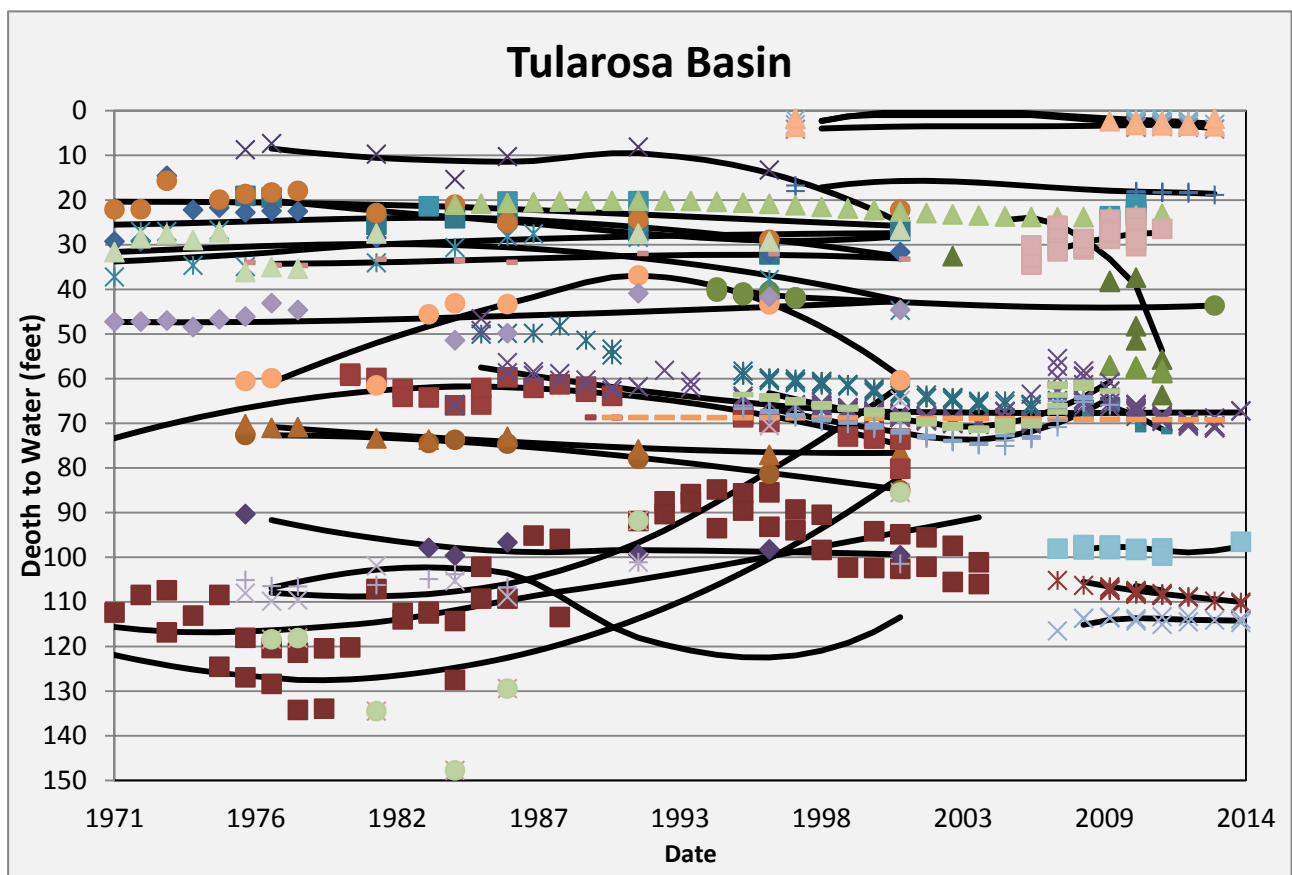
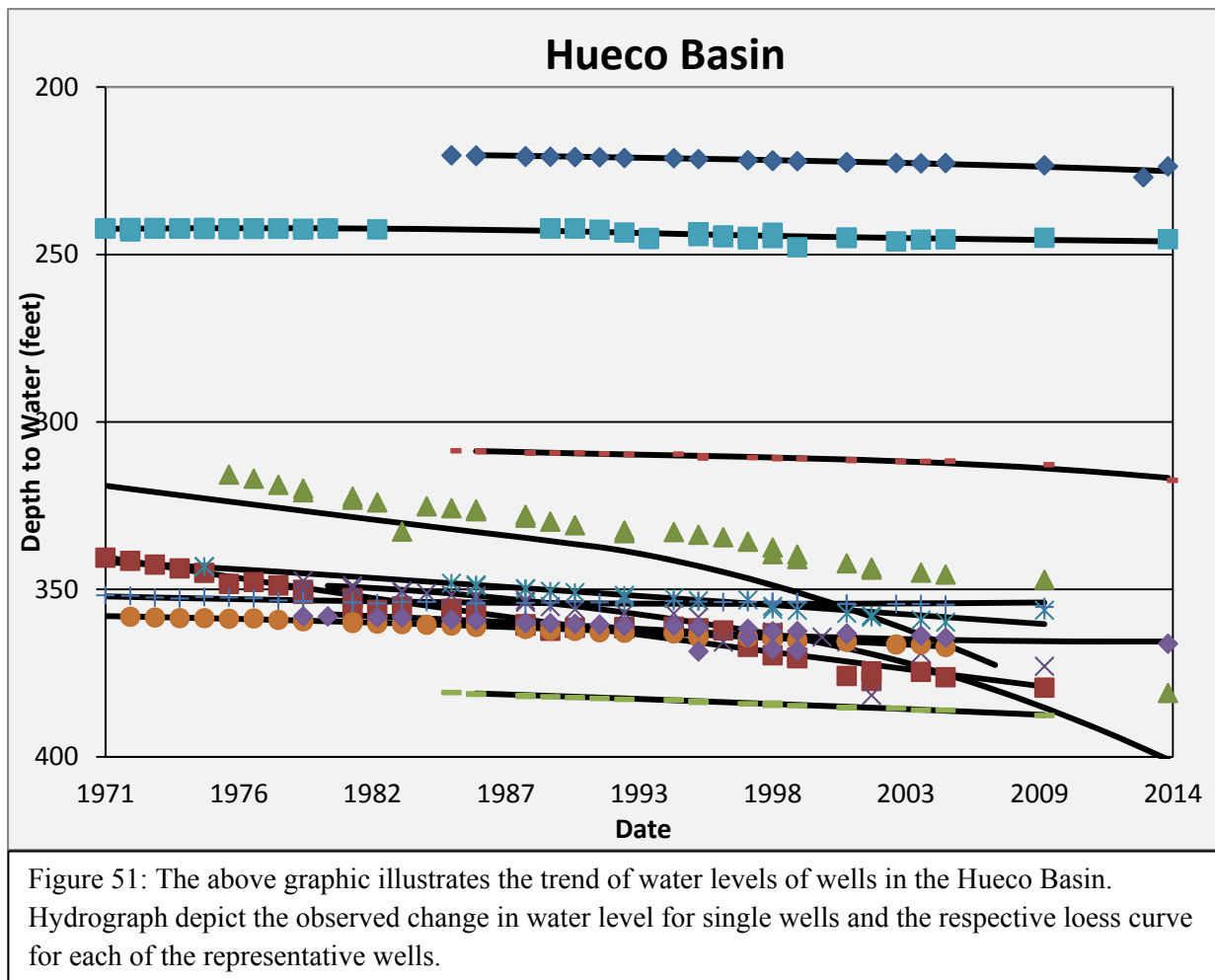


Figure 50: The above graphic illustrates the trend of water levels of shallow wells in the Hondo Basin. Hydrograph depict the observed change in water level for single wells and the respective loess curve for each of the representative wells

An average change per year was calculated for the years of 1980-2009 (Figure 51) in Hueco Basin. There were a total of 14 wells in the study area. Seven of which were measured between 1980 and 2009. All of the wells sampled, had a decrease in water elevation. Decreases ranged from 1.28 feet per year to 0.02 feet per year. Average decrease per well from 1980 to 2009 was 0.63 feet per year. From 2009 to 2014 the rate of change increased to an average decrease in water level of 1.15 feet per year. All of these wells are located in Dona Ana but it is unclear if they have access to surface water.



A majority of wells located near rivers showed little to no change, this is due to increased recharge as well as less groundwater demand. These findings correspond with the finds of the Columbia Plateau assessment (Burn et al., 2012).

Conclusion

Groundwater level measurement data and well information for 5,622 of wells and 129,487 well measurements collected over time were consolidated into one database and analyzed. Data was sourced from a variety of governmental organizations. The New Mexico Aquifer system covers around 121,000 square miles. The primary basins in New Mexico run along the Rio Grande and the Pecos River. The Rio Grande has been relied upon heavily by farmers as well as New Mexico’s two largest cities, Albuquerque and Las Cruces. For the purpose of clarity, the Rio Grande basin was separated into two different subsets, the upper Rio Grande and the lower Rio Grande. Analysis results presented herein also included the evaluation of 27 other basins and sub-basins. Groundwater level changes over 5 year periods were plotted on state-wide maps spanning 1970-2014, which allowed quantification and comparison of changes in groundwater levels over time across the entire state. Loess nonlinear regression was used to predict the groundwater levels and changes in groundwater levels over time for each individual well with greater than 6 measurements, and the measurements and predictions were plotted over time for wells within individual basins to evaluate the general transient trends for changes in groundwater elevation over time in each basin across NM. Tables 1 and 2 provide summaries of the results discussed throughout the report for the spatial and temporal analyses, respectively.

Table 1: Summary of spatial analysis for each of the 5 year time periods.

Date	# of Wells	# of Wells Decreasing Water Elevation	% of Wells Decreasing Water Elevation	# of Wells Increasing Water Elevation	% of Wells Increasing Water Elevation	Mean Water Elevation Change (Ft/five years)	% Change from Prior Period
1970-1975	1357	843	62%	512	38%	-1.84	---
1975-1980	1626	953	59%	674	41%	-1.34	37%
1980-1985	1858	1005	54%	853	46%	-1.72	-22%
1985-1990	2093	1125	54%	968	46%	-2.40	-28%
1990-1995	1989	1235	62%	754	38%	-1.54	56%
1995-2000	2065	1443	70%	622	30%	-2.08	-26%
2000-2005	1622	1212	75%	411	25%	-2.12	-2%
2005-2010	1203	911	76%	293	24%	-3.04	-30%
2010-2014	434	296	68%	138	32%	-1.90	60%
1970-2012	452	307	68%	145	32%	-1.39	37%

Table 2: Summary of temporal analysis for each of the basins.

Basin	# of Wells in the Basin	Date range	# of Wells Used	# Wells Decreasing Water Elevation	# Wells Increasing Water Elevation	# Wells Changed Less Than/Equal to 1 Ft/year	Average Change (Ft/per year)
Lower Rio Grande (shallow)	165	1970-2013	31	28	9	31	-0.07
Lower Rio Grande (deep)	165	1970-2013	6	4	2	6	0.10
Mimbres (shallow)	213	1980-2012	66	34	32	56	0.09
Mimbres (deep)	213	1980-2012	11	8	3	7	-0.88
Lordsburg	43	1980-2008	19	14	5	14	0.40
Bootheal	101	1975-2008	33	27	5	31	-0.20
Gila San Fransico	22	1983-2005	14	3	11	14	0.04
Gallup (shallow)	21	1980-2013	4	4	0	2	-1.04
Gallup (deep)	21	2003-2013	5	3	2	2	-0.46
San Juan (shallow)	42	1983-2013	9	6	3	6	-0.63
San Juan (deep)	42	1983-2013	8	4	4	1	-0.37
Bluewater	27	1970-2010	13	8	5	12	-0.20
Upper Rio Grande (shallow)	106	1989-2014	56	48	8	51	-0.03
Upper Rio Grande (deep)	274	1994-2014	17	15	2	9	-1.00
Canadian River	13	1983-2010	8	5	3	8	-0.05
Clayton (shallow)	106	1982-2010	32	26	6	16	-0.90
Clayton (deep)	106	1982-2012	23	21	2	8	-1.52
Tucumcari	60	1980-2012	20	12	8	20	-0.01
Upper Pecos	7	2000-2013	3	1	2	0	-12.50
Curry County (shallow)	156	1970-2012	11	5	6	11	-0.03
Curry county (deep)	156	1980-2012	47	35	12	35	-0.69
Portales (shallow)	68	1980-2008	21	18	3	13	-0.83
Portales (deep)	68	1980-2008	5	5	0	0	-3.93
Estancia	80	1970-2000	47	42	5	26	-0.75
Fort Sumner	75	1980-2012	41	28	13	41	-0.05
Causey Lingo	51	1980-2005	47	18	29	44	0.12
Roswell (shallow)	219	1980-2013	72	40	32	70	-0.08
Roswell (deep)	219	1980-2013	12	10	2	12	-0.48
Lea County	232	1970-2010	123	99	24	109	-0.45
Capitan (shallow)	50	1970-2010	20	16	4	20	-0.08
Capitan (deep)	6	1970-2010	6	1	5	6	0.01
Carlsbad	108	1980-2013	42	27	15	39	-0.08
Salt Basin	26	1970-2013	5	5	0	5	-0.53
Penasco (shallow)	62	1979-2004	14	8	6	13	-0.15
Penasco (deep)	62	1979-2004	4	2	2	4	-0.02
Hondo	94	1980-2014	19	12	7	19	-0.08
Tularosa (shallow)	147	1980-2001	39	21	18	32	0.15
Tularosa (deep)	147	1980-2001	6	3	3	5	0.19
Hueco	14	1980-2009	7	7	0	5	-0.63

A significant subset of the provided data consistently showed a downward water level trend, throughout New Mexico. The largest declines in water level had similar characteristics. Wells located further from major surface water bodies tended to experience the largest declines. Some

of the most notable are in Figures 1, 3, and 5. This can be partially explained by the share of the water use allocated to the groundwater system. In wells located near major rivers, depth to water was affected by both lower pumping as well as increased potential recharge. When surface water was accessible, the demand on groundwater for water supply was decreased due to the availability of surface water to mitigate demands. Additionally, areas with surface water, when it acts as a losing stream, may have exchange from surface water to the groundwater system that acts to locally recharge the groundwater, which may at least partially mitigate impacts of groundwater pumping on groundwater level changes. These observed effects have been confirmed by earlier studies that have found that in areas like the low Rio Grande valley, water table levels have been historically stable (Ahadi, et al. 2013). We have found that in most cases across the state, as surface water sources decrease, groundwater levels will also decline. As drought conditions emerged in New Mexico in the 2000s, the rate at which groundwater levels were declining increased in almost every case. We would recommend that the collection of data continue into the future, particularly in those areas of significant agricultural production.

Additionally, impacts of the largest use sectors (i.e., agriculture and domestic use) on declines in groundwater levels were evident, and impacts were more significant when both use sectors were collocated. The agricultural water use is approximately 80% of total water usage in NM, and it has been the majority water user since before the 1970s. Areas with significant agricultural production located in the eastern part of the state with little to no surface water have shown the greatest long term declines in water level. Curry County and Portales Basin (Figure 36-38) are clear examples of this. The impacts of water use on groundwater level changes were even more pronounced where both agriculture and major population centers are collocated. If drought conditions continue and water use practices are not modified accordingly, groundwater elevations will likely continue to see decrease. As groundwater sources become more and more valuable and scarce, farmers and city planners will be forced to manage current supplies more efficiently. We would purpose that legislators follow a similar plan of action taken by Ogallala Aquifer managers. In a report conducted (Perterson et al. 2003) in response to sharply declining groundwater levels, managers argued that future equity in the aquifer should not be forfeited for current gains.

All in all, this report set out to evaluate available data and develop analyses to assess the change in groundwater levels in the state of New Mexico. Evaluating different uses of surface and groundwater allowed us to compare areas of high water use to changes in groundwater levels. The results of these analyses suggest that a spatiotemporal approach can advance our ability to observe and contextualize groundwater level changes. It seems that both approaches, spatial analysis over time and temporal analysis over basins, were useful in examining where and when groundwater changes were significant, and comparing these data to water use data supported examination of potential causes of groundwater level changes. However, uncertainty remains in potential causes and impacts of these groundwater level changes on groundwater resource sustainability.

References

- Ackerman, F. Stanton E. A., (2011) The last drop: climate change and the Southwest water crisis. Stockholm Environmental Institute: 4-31
- Ahmed, I., A. A. Al-Othman, R. Umar. 2014. Is shrinking groundwater resources leading to socioeconomic and environmental degradation in Central Ganga Plain, India? *Arabian Journal of Geosciences*. 7 (10): 4377-4385
- Andrade, M. (1992). Actualización geohidrológica del Valle de Guadalupe, Municipio de Ensenada, Baja California. Ensenada: Secretaria de Asentamientos Humanos y Obras Publicas de Ensenada (SAHOPE) and CESPE. 69 pp
- Andrade, M. (1997). Actualización geohidrológica del Valle de Guadalupe, Municipio de Ensenada, Baja California. Ensenada: Grupo Agroindustrial del Valle de Guadalupe. 60 pp.
- Beltrán, L. (1998). Balance de los recursos hidráulicos subterráneos, Acuífero BC-07, Guadalupe, Municipio de Ensenada, Baja California. Ensenada, México. CONAGU A. Gerencia Regional de la Península de Baja California. Subgerencia Técnica Regional. Aguas subterráneas. 17 pp.
- Buchwald, C. A., C. L. Luukkonen, and C. M. Rachol. (2010). Estimation of groundwater use for a groundwater- flow model of the Lake Michigan Basin and adjacent areas, 1864–2005. U.S. Geological Survey Scientific Investigations Report 2010-5068. Middleton, WI.
- Burns, E. R., D. T. Snyder, J. V. Haynes, and M. S. Waibel. (2012) Groundwater status and trends for the Columbia Plateau Regional Aquifer System, Washington, Oregon, and Idaho. USGS Scientific Investigation, 5261: 1-49
- Campos-Gaytan J. R., Kretzschmar T., Herrera-Oliva C. S. (2014) Future groundwater extraction scenarios for an aquifer in a semiarid environment: case study of Guadalupe Valley Aquifer, Baja California, Northwestern Mexico. *Environmental Monitoring Assess*, 186: 7961-7985
- Cayan, D. R., T. Das, D. W. Pierce, T. P. Barnett, M. Tyree, and A. Gershunov (2010) Future dryness in the southwest US and the hydrology of the early 21st century drought. *Proceedings of the National Academy of Science of the United States of America*. 107: (50) 21271-21276
- Chew, C. C., E. E. Small. 2014. Terrestrial water storage response to the 2012 drought estimated from GPS vertical position anomalies. *Geophysical Research Letter*. 41: (17) 6145-6151
- Choi, J. Y., B. A. Engle, S. Muthukrishnan, and J. Habor (2003). GIS based long term hydrologic impact evaluation for watershed urbanization. *Journal of American water resources association*. 623-635

- Choi, W., Galasinski, U., Cho, S. J., Hwang C. S. 2012. A spatiotemporal Analysis of groundwater level changes in relation to urban growth and groundwater recharge potential for Waukesha County, Wisconsin. *Geographical Analysis*, 44: 219-234
- Chust, G., DuCrot, D., Riera, J.L.L., Pretus, J.L.L., 1999. Characterizing human modelled landscapes at a stationary state: a case study of Minorca, Spain. *Environmental Conservation* 26, 322–331
- CONAGUA (1998). Censo de aprovechamientos para extracción de aguas subterráneas. Acuífero BC-07 Valle de Guadalupe, B.C., Gerencia Regional de la Península de Baja California. Subgerencia Regional Técnica. Reporte técnico. 8 pp.
- (CONAGUA) Comisión Nacional del Agua (1990). Estudio de actividades piezometría en el Valle de Guadalupe, Municipio de Ensenada, Baja California. Gerencia Regional de la Península de Baja California. Jefatura de proyecto de aguas subterráneas. 34 pp.
- CONAGUA (2010). Estadísticas del Agua en México, Edición 2010. Edited by: SEMARNAT. 249 pp. http://www.siagua.org/archivos_adjuntos/documentos/estadisticas_mexico.pdf.
- Dourte, D. R., S. Shukla, D. Z., Haman, M D. Reddy, M. U. Devi, A. Mani. 2014. Agrucialtr management impacts on groundwater: simulations of existing and alternative management options in Peninsular India.
- Economic Research Service (ERS), U.S. Department of Agriculture (USDA). Food Environment Atlas
- Egbert, S. L., R. Lee, K. P. Price, and R. Boyce. 1998. Mapping Conservation Reserve Program (CRP) grasslands using multi-seasonal Thematic Mapper imagery. *Geocarto International* 13:17–24.
- Gleick, P. H. 2003. Water use. *Annual Review of Environment and Resources* 28:275–314.
- GLWI. (2007). Q & A: Water Issues in Waukesha. Great Lakes Water Institute database. Available at <http://www.glwi.uwm.edu/ourwaters/documents/WaukeshaHandoutBWeb.pdf> (accessed January 19, 2011).
- Hall, G. E. 2002. High and dry: the Texas-New Mexico struggle for the Pecos River.
- Hall, R. I., Leavitt, P. R., R. Quinlan, A. S. Dixit, and J. P. Smol. 199. Effects of agricultural, urbanization, and climate on water quality in the northern Great Plains. *Limnology and Oceanography* 44: (3) 739-756
- Hobbs, R., 1997. Future landscape and the future of landscape ecology. *Landscape and Urban Planning* 37, (1) 1–9.

(INEGI) Instituto Nacional de Estadística, Geografía e Informática (1976). Carta geológica Francisco Zarco (I11D82).

Ingram, H. M. 1990. Water policy: Continuity and change. University of New Mexico Press 31: 703-705

Jacob, B., 2007. Hydrolics of groundwater. McGraw-Hill Pg. 5

Jaiswal, R. K., S. Mukherjee, J. Krishnamurthy, and R. Saxena. (2003). Role of Remote Sensing and GIS Techniques for Generation of Groundwater Prospect Zones towards Rural Development: An Approach. *International Journal of Remote Sensing* 24, 993–1008

Jury, W. A., and H. Vaux Jr. 2005. The role of science in solving the world's emerging water problems. *Proceedings of the National Academy of Sciences* 102 (44): 15715–20.

Kettle, N., Harrington L., Harrington J. (2007) Groundwater depletion and agricultural land use change in the High Plains: a case study from Wichita County, Kansas. *The Professional Geographer*, 59: (2) 222-235

Konikow, L. F., E. Kendy. 2005. Groundwater depletion: A global problem. *Journal of Hydrology*, 13:317-320

Liverman, D. M. 1999. Geography and the global environment. *Annals of the Association of American Geographers* 89: 107–20.

Longworth, J. W., Valdez J. M., Magnuson M. L., Richard K. 2011. New Mexico water use report 2010. New Mexico Office of the State Engineer Technical Report 54.

McGarigal, K., Marks, B.J., 1995. FRAGSTATS: Spatial pattern Analysis Program for Quantifying Landscape Structure, PNW-GTR_351, United States Department of Agriculture, Pacific Northwest Research Station, Oregon, USA.

National Research Council Committee on Human Dimensions of Global Change. 1999. Human Dimensions of Global Change. In *Global environmental change*, ed. Committee on Global Change Research, 293–375. Washington, DC: The National Academies Press.

Nellis, M. D., K. Price, S. Egbert, and J. Wu. 1996. Natural resource capability of CRP lands as grasslands in southwest Kansas: A remote sensing and GIS perspective. *Geocarto International* 11 (3): 23–28.

Pederson G.T., Gray S.T., Woodhouse C.A., Betancourt J.L., Fage D.B., Littell J.S., Watson E, Luckman B.H. and Graumlich L.J. (2011) The unusual nature of recent snowpack declines in the North American Cordillera. *Science*, 15: 332-335.

- Peterson, J. M., T. L. Marsh, and J. R. Williams. 2003. Conserving the Ogallala Aquifer: efficiency, equity, and moral motives. American Agricultural Economics Association. 15-18
- Philip, T. G. and S. T. Franklin, 1996. Comparison of derivative topographic surfaces of a DEM generated from stereoscopic SPOT images with field measurements. American Society for Photogrammetry and Remote Sensing, 62(10): 1165-1171
- Postel, S. L. (1999). Water for food production: will there be enough in 2025? *Bioscience* 48: (8) 629-637
- Pike, R. J., 1988. The geometric signature: Quantifying landslide-terrain types from digital elevation models, *Mathematical Geology*, 20(5):491-511.
- Qi, S. L., A. Konduris, D. W. Litke, and J. Dupree. 2002. Classification of irrigated land using satellite imagery, the High Plains aquifer, nominal date 1992. Water-Resources Investigations Report 02-4236. Denver, CO: U.S. Geological Survey.
- Randhir, T. O., 2003. Watershed-scale effects of urbanization on sediment export: assessment and policy. *Water Resources Research* 39 (6), 1–13. doi:10.1029/2002WR001913.
- Randhir, T. O., Tsvetkova, O., 2009. Watershed-scale tradeoffs in water quantity and quality attributes for conservation policy'. *Water, Soil and Air Pollution* 201 (1–4), 347–363. doi:10.1007/s11270-008-9949-8.
- Randhir, T. O., O. Tsvetkova. 2011. Spatiotemporal dynamics of landscape pattern and hydrologic process in watershed systems. *Journal of Hydrology*, 404: 1-12
- Ren, W., Y. Zhong, J. Meligrana, b. Anderson. W. E. Watt, J. Chen, H. L. Leung. 2003. Urbanization, land use, and water quality in Shanghai: 1947-1996. *Environment International* 29: 5 649-659
- Rindfuss, R. R., S. J. Walsh, B. L. Turner II, J. Fox, and V. Mishra. 2004. Developing a science of land change: Challenges and methodological issues. *Proceedings of the National Academy of Sciences* 101 (39): 13976–81
- SARH (1967). Inventario de aprovechamientos superficiales y subterráneos para riego. Baja California Norte. Tomo único. Jefatura de irrigación y control de ríos. Dirección de pequeña irrigación.
- (SARH) Secretaría de Agricultura y Recursos Hidráulicos (1982). Dictamen geohidrológico del Valle de Guadalupe. 20 pp.
- Scibek, J. and D. M. Allen. 2006. Modeled impact of predicted climate change on recharge and groundwater levels. *Water Resources Research*. 42: (11) 1-18

Skole, D. L. 2004. Geography as a great intellectual melting pot and the preeminent interdisciplinary environmental discipline. *Annals of the Association of American Geographers* 94: 739–43

Snyder, D.T. 2008. Estimated depth to groundwater and configuration of water table in the Portland, Oregon area. U.S. Geological Survey Scientific Investigations Report 2008-5059, 40 p.

Sophocleous, M. (2010) Review: groundwater management practices, challenges, and innovations in the High Plains aquifer, USA-lessons and recommended actions. *Journal of Hydrology*, 18: (3) 559-575

Vazquez-Sune, E., X. Sanchez-Vila, and J. Carrera. (2005). “Introductory Review of Specific Factors Influencing Urban Groundwater, an Emerging Branch of Hydrogeology, with Reference to Barcelona, Spain.” *Hydrogeology Journal* 13, 522–33.

Wagner, T., D. P. Boyle, M. J. Lees, H. S. Wheater, H. V. Gupta, and S. Sorooshian. 2001. A framework for development and application of hydrological models. *Hydrology and Earth System Science* 5 (1): 13-26

Wakode, H. B., K. Baier, R. Jha, S. Ahmed, and R. Azzam. 2014. Assessment of impact of urbanization on groundwater resources using GIS techniques- case study of Hyderabad, India. *International Journal of Environmental Research*. 8: (4) 1145-1158

Wichelns, D. (2010). *Agricultural water pricing: United States*. OECD. 1-26

Xu, C. Y., Singh V. P. 2002. Cross comparison of empirical equation for calculating potential evapotranspiration with data from Switzerland. *Water Resources Management* 16: 197-219

Zellner, M. L. (2007). “Generating policies for sustainable water use in complex scenarios: an integrated land-use and water-use model of Monroe County, Michigan.” *Environment and Planning B—Planning and Design* 34, 664–86.