2017

Mapping the Albuquerque Aquifer's Potentiometric Surface in 2016

Lucas Curry

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By

Lucas Taylor Sebastian Curry

Dr. William Fleming, Committee Chair

Mr. John Fleck, Committee Member

Dr. Caroline Scruggs, Committee Member

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of the requirements for the Master of Community and Regional Planning
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This professional project will examine and map the water levels in Albuquerque for the year 2016 using ArcGIS. The potentiometric surface of Albuquerque's aquifer will be estimated using data from the USGS, the City of Albuquerque, Sandia National Labs, and Rio Rancho.

Problem Statement:

The aquifer underlying the city of Albuquerque is a complex system that continues to be studied, and its capacity was vastly overestimated until the 1990s when local water levels began to drastically decrease. Following the implementation of water conservation measures in the city, Albuquerque further changed its approach to water management in 2008 by incorporating surface water imported from the San Juan River. This allowed the city and its water utility, the Albuquerque Bernalillo County Water Utility Authority (ABCWUA), to not only depend less on the Albuquerque aquifer groundwater but also to develop programs that would recharge the aquifer and use it as a safety reserve in dry years. By mapping this water level at various time intervals and quantifying the change in the volume of water, the impacts of these management strategies can be measured and further conservation can be planned. The United States Geological Survey (USGS) in cooperation with the ABCWUA has developed a series of these maps in 2002, 2008, and 2012. This professional project's client is the USGS and the project involves contributing to the production of the 2016 Albuquerque aquifer water level map, creating a detailed description of the methods performed, and developing a variety of analyses that verify the accuracy of the maps and demonstrate their utility. This will serve as a guide for the future production of Albuquerque water level maps and will aid in the continuation of this map series. The map itself will be used by the ABCWUA in evaluating its water resource management strategies and in planning for current and future management.

Acknowledgements

I am sincerely grateful to my three committee members who guided, encouraged, and pushed me to complete this project in a relatively short time frame. Bill Fleming, who expertly advised me on the writing process and made me get started earlier rather than later. John Fleck, whose excitement for this project kept me motivated, interested and focused on the outcome. Caroline Scruggs, who persuaded me that it was in fact possible to finish in time I was given and to not delay any longer than was necessary.

I'd also like to thank the United States Geological Survey's New Mexico Water Science Center for giving me the opportunity to work on this project. Thank you Anne-Marie Matherne, who hired me and assigned me to the project; Amy Galanter and Andre Ritchie, who I worked alongside and mentored me through the work; and Laura Bexfield and Nathan Myers, who served as valuable references.

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Introduction

Sustainable water resources are a necessity in the arid Southwest and the water utilities in Albuquerque, New Mexico, have planned to ensure continuous supplies for present and future residents. The ABCWUA has outlined enormous commitments in their water resources management strategy, "Water 2120: Securing Our Water Future," to replenish the historically stressed aquifer underlying the city and to plan for sustainable groundwater extraction on a one hundred year time scale. The implementation of these strategies has resulted in immediate improvements to local and regional water levels.

History of Water Use in Albuquerque

The impetus for the ABCWUA's water resources management strategy is based on Albuquerque's steadily increasing population and the continued increase in water use. The population of Albuquerque has grown rapidly in the past several decades from fewer than 30,000 residents in 1930 to almost 546,000 in 2010 (Figure 1). The city historically acquired its entire water supply from the underlying aquifer, so the increase in population, which naturally led to an increase in water use, implied pumping more and more groundwater. This had a minimal impact on the aquifer water levels until the 1960s when withdrawal rates from the aquifer exceeded the aquifer's natural recharge rate and regional declines of five feet were measured (Kelly, 1982). By 1994, Albuquerque's continued growth had intensified the decline in water levels by more than 100 feet from predevelopment levels measured in the 1950s (Kernodle, McAda, & Thorn, 1995). This drastic change in water level had serious implications for the city, with respect to sustainability, including risks of irreversible land subsidence, increased groundwater pumping and treatment costs, increased leakage from the Rio Grande due to its interconnectedness with the groundwater, and a requirement to find other, more sustainable water resource supplies for the projected population (Glennon, 2002).

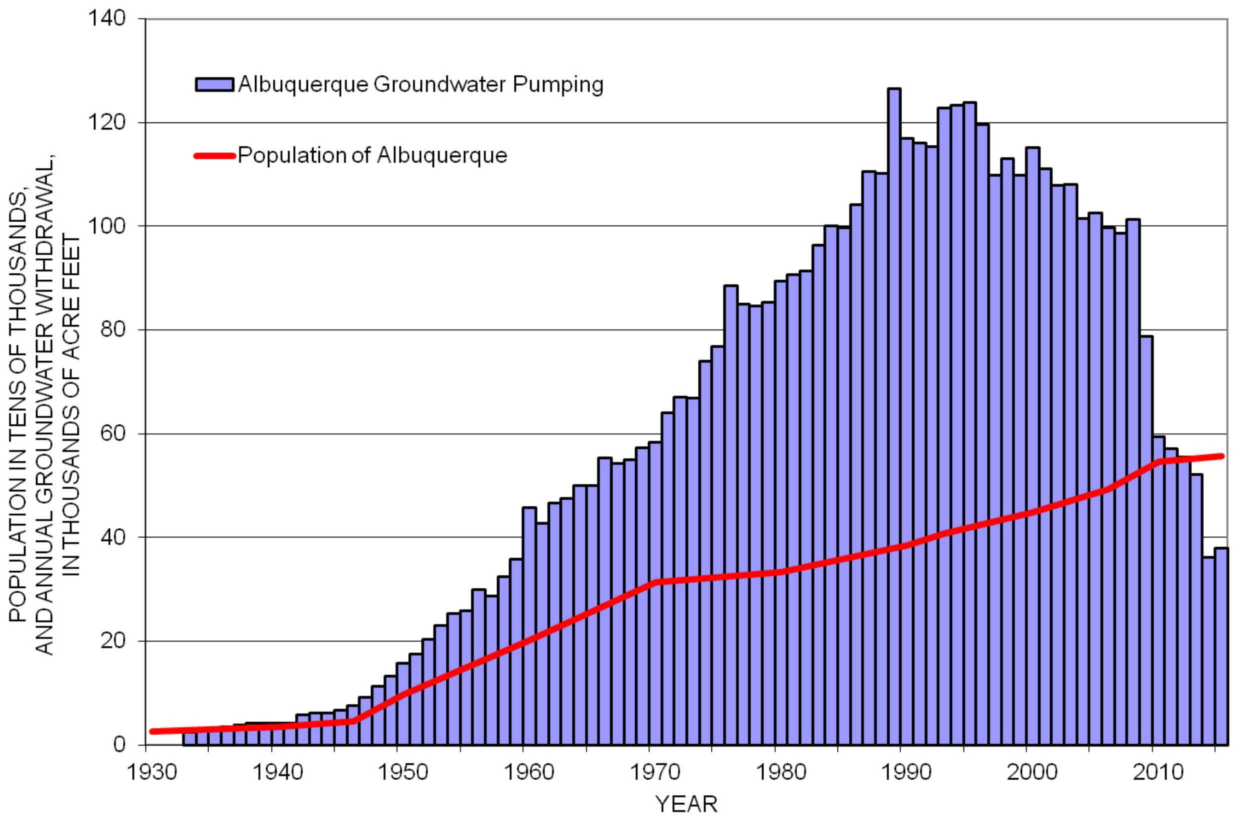


Figure 1. Historical groundwater pumping and population growth in Albuquerque, NM. (Adapted from Thiros, Bexfield, Anning, & Huntington, 2010).

The growth of Albuquerque, like many other metropolitan cities, has included the development of suburban towns like Rio Rancho on the outskirts of the city. Founded in 1961 and incorporated as a city in 1981, Rio Rancho is located northwest of Albuquerque and grew in population to almost 92,000 by 2013 (U.S. Census Bureau, 2016). The town is not serviced by the ABCWUA but instead operates its own water utilities. Rio Rancho has also relied solely on groundwater pumping for its water supply and while the town has a much smaller total demand for water than the City of Albuquerque, it has witnessed similar decreases in water level. While

Rio Rancho and Albuquerque have borders that define the extent of each municipality, the underlying aquifer is hydrologically connected and each city experiences effects from the other's water resource management.

Water Conservation

In 1995, the City of Albuquerque recognized the dangers that a severely decreasing regional aquifer level posed and began implementing water conservation measures including public education programs, increased water rates, restrictions and incentives to decrease outdoor water use, and water conservation plan requirements for industrial users (U.S. EPA, 2006). These conservation strategies were regularly updated and improved as goals were met and led to a successful decrease in per capita water use from 251 gallons per capita per day (gpcd) in 1995 to 127 gpcd in 2015 (ABCWUA, 2016). This reduction in daily water use per person equated to a decrease in Albuquerque's total water use from 125,150 acre-feet in 1995 to 89,570 acre-feet in 2015 (Stansifer, 2016). The impact that these reductions had on groundwater withdrawals was amplified starting in 2008 when Albuquerque began receiving surface water from the San Juan – Chama Project. The City of Albuquerque has rights to 48,200 acre-feet per year of water diverted from the San Juan River, a tributary to the Colorado River, into the Chama River, a tributary to the Rio Grande (Flanigan & Haas, 2008). Gradually shifting to a surface water supply allowed the city to further reduce its groundwater pumping from about 101,300 acre-feet in 2008 to less than 41,000 acre-feet in 2015 (Figure 1) (Stansifer, 2016). In addition to decreased pumping rates, the ABCWUA has attempted to recharge the aquifer using a strategy called aquifer storage and recovery (ASR). Since 2008, the ABCWUA has been sending extra, unused surface water in the winter months to the Bear Canyon Arroyo in Northeast Albuquerque where it naturally infiltrates through the permeable soil layers and replenishes the aquifer.

Rio Rancho has implemented water conservation strategies similar to those implemented by the ABCWUA; however, it does not own the rights nor have the infrastructure to use any surface water like the San Juan – Chama Project water in Albuquerque. Additionally, Rio Rancho has plans to reuse water as a non-potable source and recharge the aquifer by injecting treated wastewater into deep wells (City of Rio Rancho, 2014). Rio Rancho has decreased its daily water use from 188 gpcd in 2000 to 112 gpcd in 2015 but due to its rapidly increasing population has actually increased total water use from 10,460 acre-feet in 2000 to 10,610 acre-feet in 2015 (Wrage, 2016). This increased water use implies that while 15 years of water conservation efforts have been effective, they have been insufficient in decreasing groundwater pumping and drawdown levels would not be expected to have experienced any improvement.

United States Geological Survey (USGS) Estimated Potentiometric Surface and Drawdown Maps

Regional drawdown can be measured by first examining the current potentiometric surface of an aquifer, defined as the "level to which water rises in a well. In a confined aquifer this surface is above the top of the aquifer unit; whereas, in an unconfined aquifer, it is the same as the water table" (Fetter, 1994). The USGS has produced, in cooperation with the ABCWUA, a series of maps depicting the potentiometric surface and drawdown levels from the estimated predevelopment potentiometric surface to 2002, 2008, and 2012 in the Albuquerque metropolitan area. These maps function as regular updates on the status of Albuquerque's groundwater supply and serve to evaluate the water resource management strategies executed by the ABCWUA and Rio Rancho.

The boundary of each map is consistent in its extent covering approximately 437 square miles of Albuquerque's metropolitan area. The borders of the map extend from Isleta Pueblo in the South to include parts of Rio Rancho, Corrales, and Sandia Pueblo in the North and from the Sandia Mountains in the East to Albuquerque's city limits in the West.

Several important considerations were made in determining which water level data points could be used to estimate the potentiometric surface of these maps. Time of year that the measurement was recorded, time since water had been pumped from the well, depth of the screened interval of the well, and location of the well were investigated for each measurement during the data collection phase of map production. The intended purpose of the maps is to show static water levels in Albuquerque. Groundwater pumping, especially at the high volume and duration that municipalities engage in, significantly affects discrete water level measurements by drawing the local aquifer level down. Since water consumption is considerably lower in the winter months due to plants going dormant and requiring less outdoor water use, water level measurements used were mostly within the winter months when groundwater pumping is at its lowest. If pumps had recently been active at a well's location, measurements collected required a time buffer of fourteen days in order to allow the aquifer to rise to static levels. Albuquerque's aquifer has three "zones" (shallow, middle, and deep), each of which has somewhat different water levels at any given point. These maps are created in order to illustrate the water level of Albuquerque's production zone, in the middle zone, between 200 and 900 feet below the water table (Thiros, Bexfield, Anning, & Huntington, 2010). Water level measurements used in the maps, therefore, generally were taken from wells that had a screened interval within that range.

Although the vast majority of the water levels used were measured in the actual year of each map's production, the first map of this series, produced in 2002, used water levels measured during the winters of the 1999 water year to the 2002 water year. A water year is defined as the twelve months from the preceding calendar year's October 1 through September 30 of the designated year. While the water levels represented the 2002 groundwater surface, the range of years was assumed to provide data that would fall within the margin of error for each measurement. This allowed a more extensive and accurate map to be created, using well locations that may not have been measured in 2002. Similarly, the 2008 map used water levels measured in the 2006 water year through 2009 and the 2012 map used water levels from 2010 to 2013. Again, this provided a more extensive network of wells to use in interpolating the groundwater contours.

Water level data was provided by four sources including City of Albuquerque municipal supply wells measured by the USGS using electric tapes and steel tapes; City of Rio Rancho water supply wells measured by the City of Rio Rancho (some of which were measured with a less accurate airline); piezometers from a network installed by the City of Albuquerque, Bernalillo County, the New Mexico Office of the State Engineer, and the USGS that were measured hourly with pressure transducers; and wells on the Kirtland Air Force Base (KAFB) measured by either the KAFB or Sandia National Labs using electric tapes or steel tapes.

In order to account for the groundwater level of the production zone along the Rio Grande, it was assumed that the elevation of the riverbed corresponded to the elevation of the water table. The difference between the water table measurement and production zone measurement within individual nested well groups near the river were used to linearly interpolate the elevation of the production zone under the river. Data points were produced at approximately one mile intervals along the Rio Grande through Albuquerque.

All data points were plotted on a geographic information system (GIS) map and contours were hand-drawn using the water level elevation at each well’s location to guide the contours. These contours were then converted to a gridded area with points spaced at 1,640 foot intervals using a spline interpolation. The change in water level from predevelopment to the year of each map's production was calculated using the difference between these gridded points and similar gridded points interpolated from the Albuquerque aquifer's predevelopment contours estimated in Bexfield and Anderholm's "Predevelopment water-level map of the Santa Fe Group aquifer system in the middle Rio Grande basin between Cochiti Lake and San Acacia, New Mexico." A spline interpolation technique was again used to convert the gridded change in water level points to a surface. The extent of the drawdown maps was defined by the absence of data points in certain areas as well as the presence of fault lines to the East indicating potential hydraulic discontinuities. Drawdown was divided into ranges including, approximately no drawdown, 0 to 20 feet, 20 to 40 feet, 40 to 60 feet, 60 to 80 feet, 80 to 100 feet, 100 to 120 feet, and more than 120 feet. The color schemes and ranges changed slightly from the 2002 map (Figure 2) to the 2008 map but remained consistent from 2008 to 2012 (Figure 4, Figure 6).

2002 Map

The map depicting 2002 water levels and change from predevelopment water levels in Figure 3 shows a cone of depression in eastern Albuquerque with areas of more than 120 feet of drawdown from predevelopment levels, a cone of depression west of the Rio Grande but still within Albuquerque that shows 60 to 80 feet of drawdown, and one more cone of depression in Rio Rancho with 80 to 100 feet of drawdown. One of the implications of these cones of depression is a major shift in general groundwater flow direction from, during the predevelopment time period, north of Albuquerque to the southwest to the current flow towards the three areas of high pumping rates. Limited to no drawdown was measured in southwest Albuquerque as well as in areas along the Rio Grande. These areas experience minimal pumping and immediate recharge from the river.

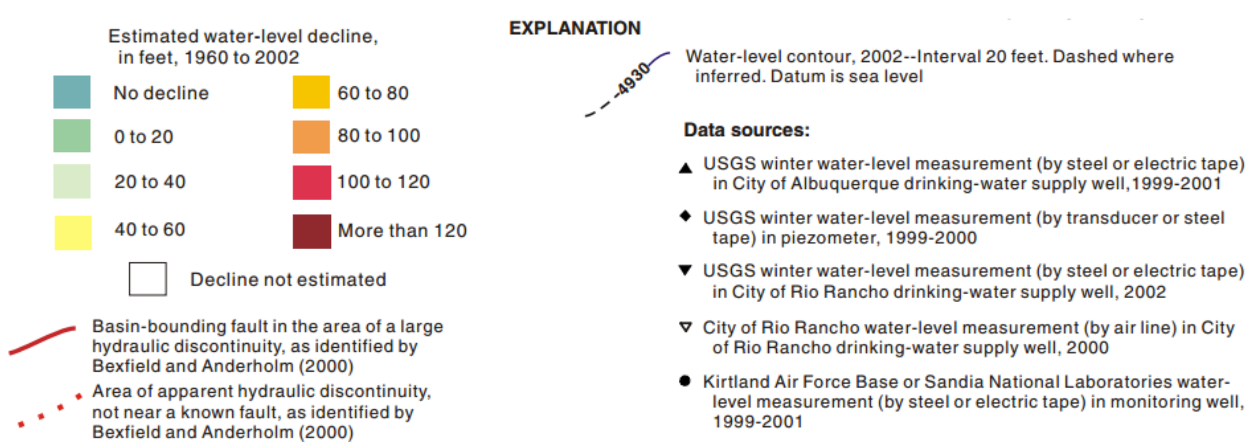


Figure 2. Legend for the "Estimated water-level declines in the Santa Fe Group aquifer system in the Albuquerque area, central New Mexico, predevelopment to 2002" (Bexfield & Anderholm, 2002a)

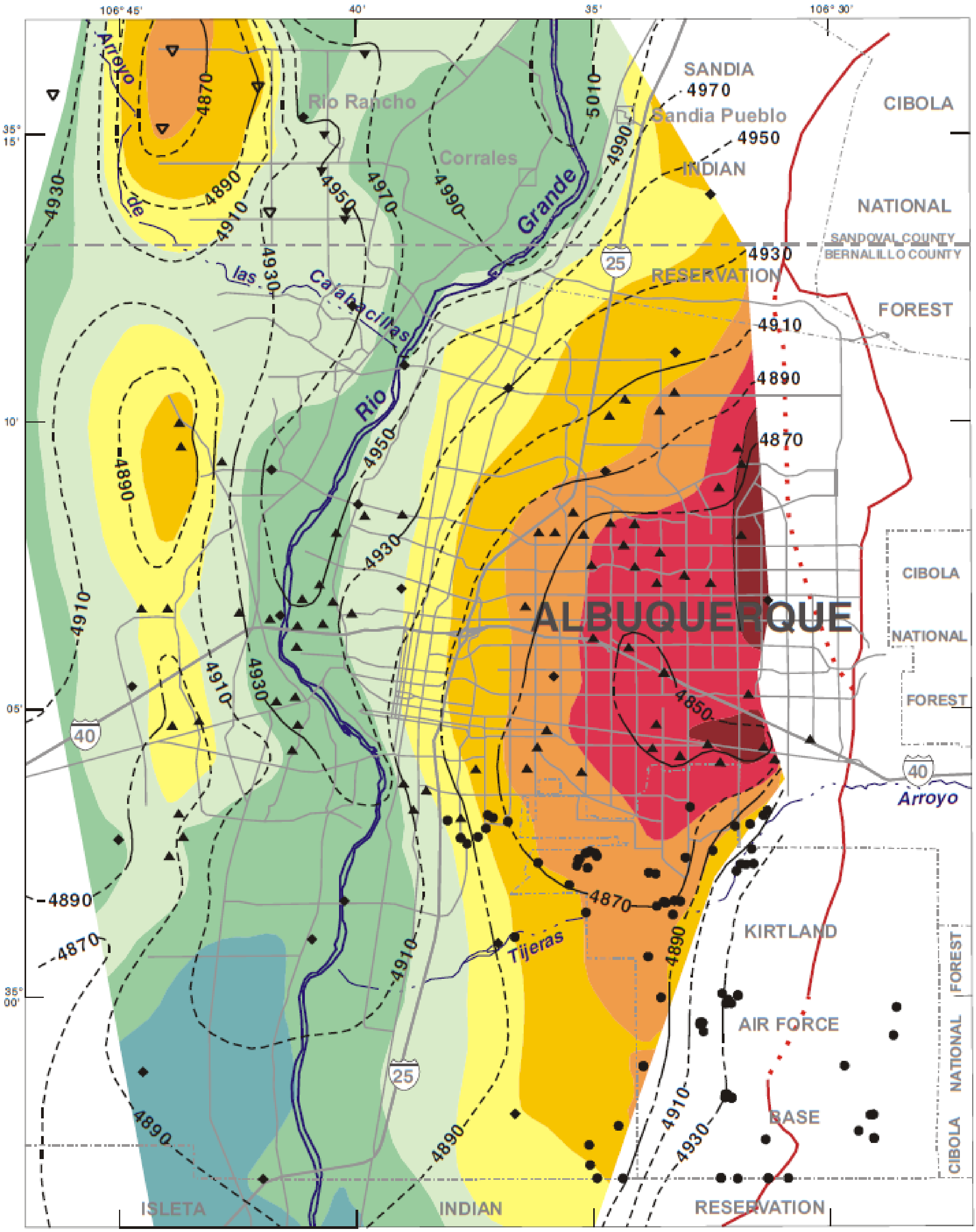


Figure 3. Estimated water-level declines in the Santa Fe Group aquifer system in the Albuquerque area, central New Mexico, predevelopment to 2002 (Bexfield & Anderholm, 2002a)

2008 Map

Figure 5 shows similar trends seen in the 2002 map including deeper and more expansive water level declines from predevelopment conditions in the three locations previously identified. The area along the Rio Grande and southwestern Albuquerque continues to show relatively stable groundwater levels that have not experienced dramatic drawdown.

A fourth cone of depression east of Rio Rancho appears to have formed between 2002 and 2008 with over 120 feet of drawdown from predevelopment. This drawdown, however, has, since the map's publication, been revisited due to its reliance on one data point from a questionable source, the lack of such a magnitude of drawdown in the 2002 and 2012 maps, and the later discovery of an air leak in the measuring equipment (Galanter, 2017).

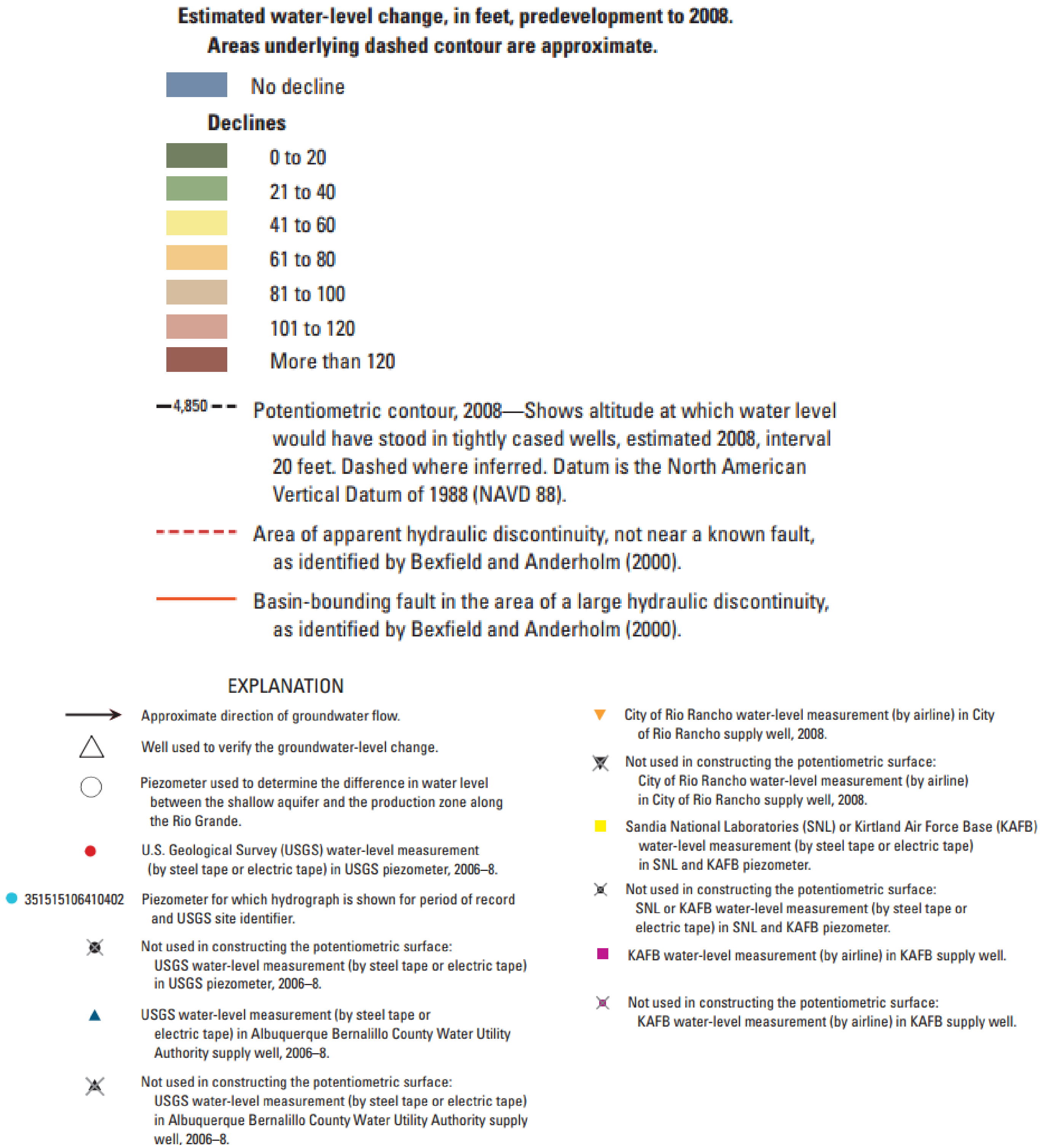


Figure 4. Legend for "Estimated 2008 groundwater potentiometric surface and predevelopment to 2008 water-level change in the Santa Fe Group aquifer system in the Albuquerque area, central New Mexico" (Falk, Bexfield, & Anderholm, 2011)

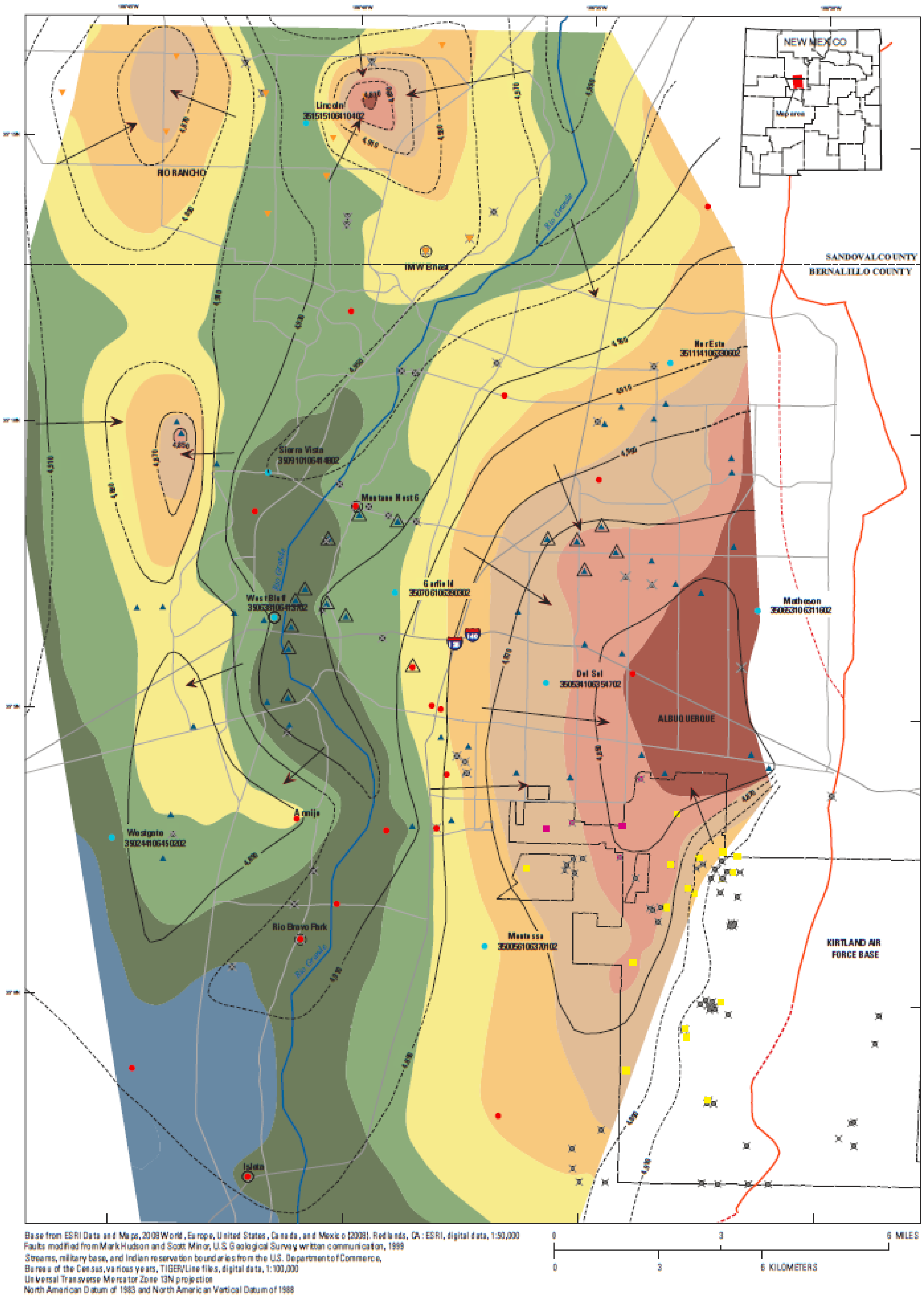


Figure 5. Estimated 2008 groundwater potentiometric surface and predevelopment to 2008 water-level change in the Santa Fe Group aquifer system in the Albuquerque area, central New Mexico (Falk, Bexfield, & Anderholm, 2011)

2012 Map

Figure 7 shows that the severe drawdown in eastern Albuquerque is still present but receding, and the two cones of depression west of the Rio Grande have connected but their drawdown seems to have improved. The fourth area mentioned on the 2008 map shows 40 to 60 feet of drawdown but no sign of severe pumping that would have previously induced over 120 feet of drawdown.

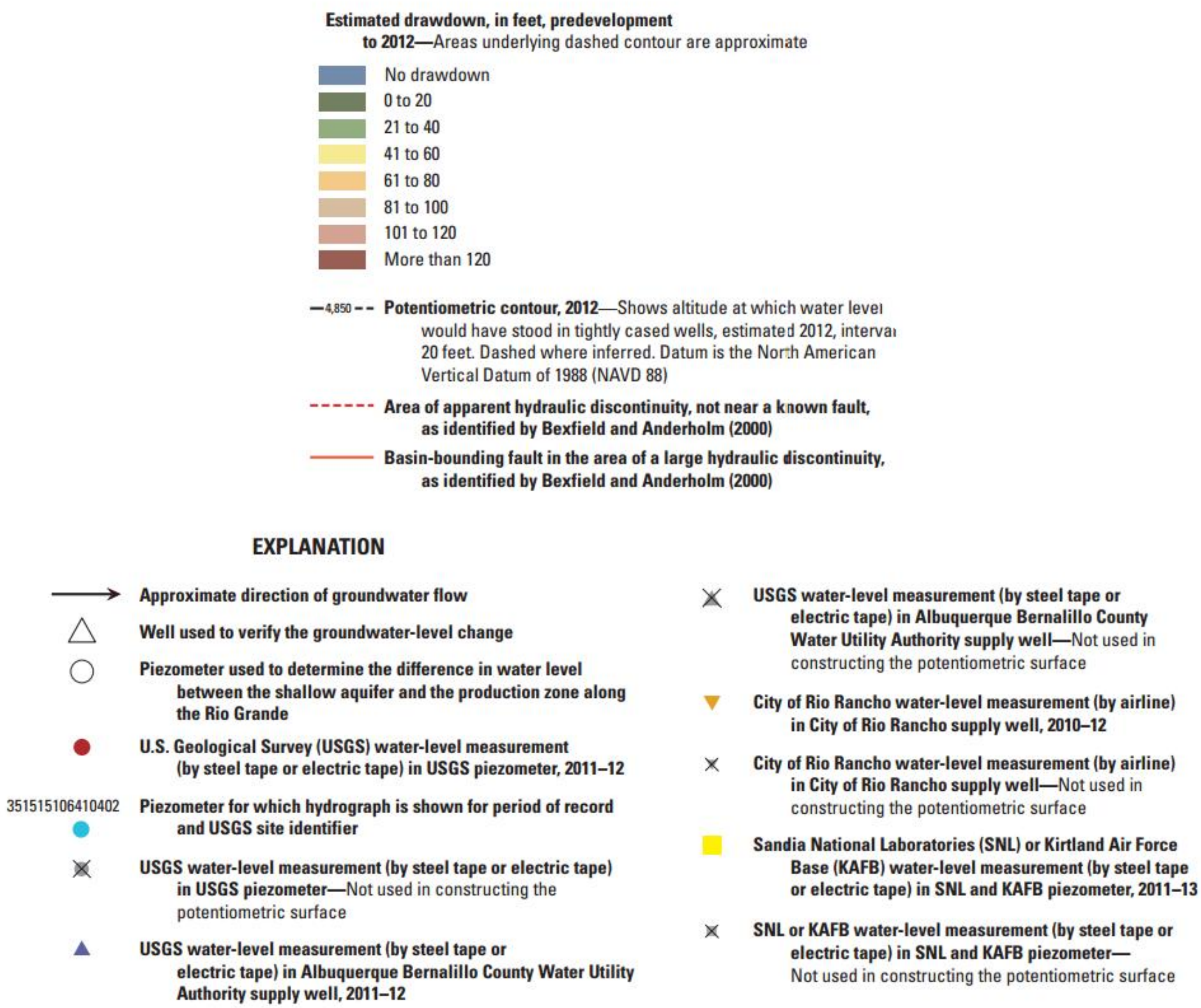
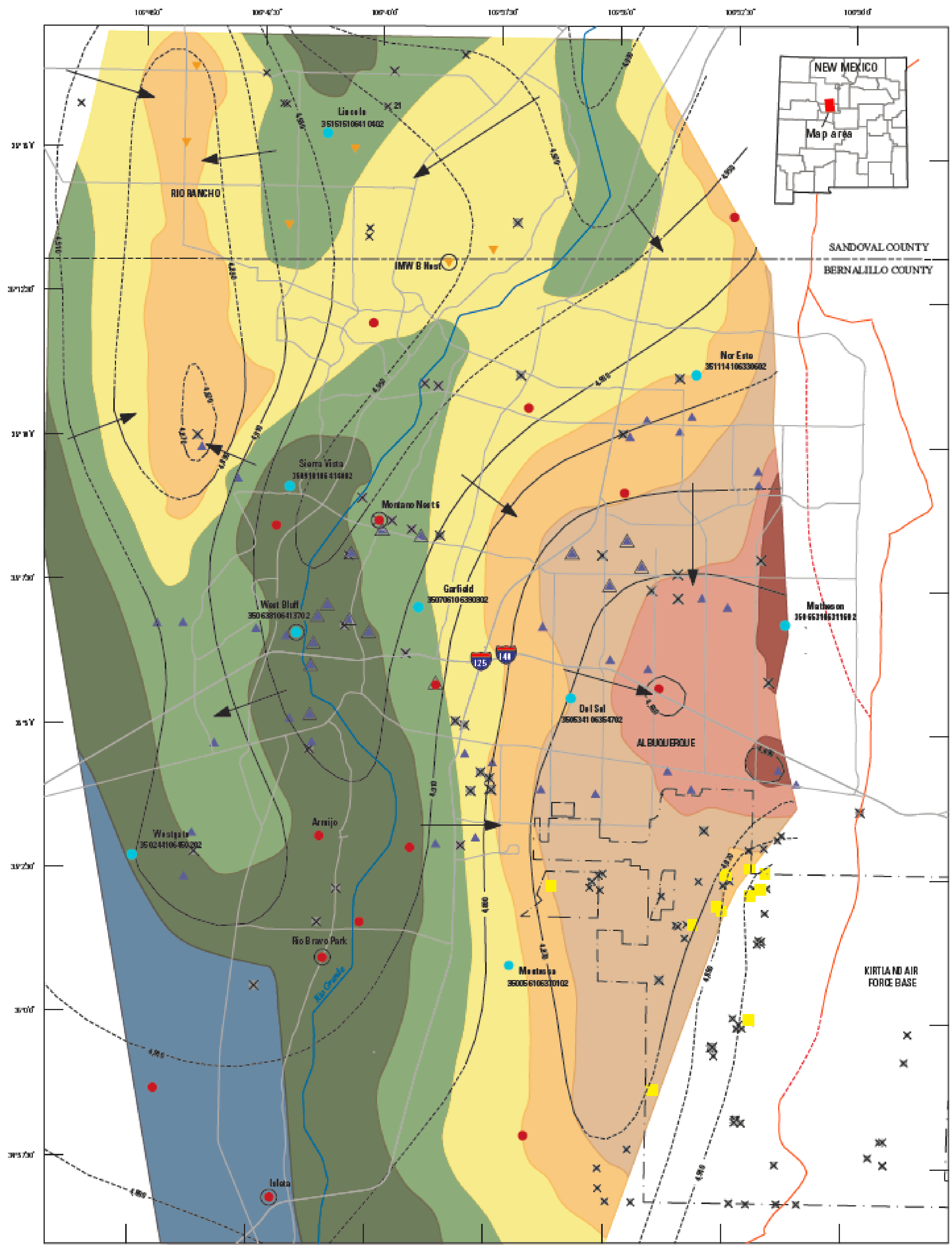


Figure 6. Legend for "Estimated 2012 groundwater potentiometric surface and drawdown from predevelopment to 2012 in the Santa Fe Group aquifer system in the Albuquerque metropolitan area, central New Mexico" (Powell & McKean, 2014)



Base from ESRI Data and Maps, 2006 World, Europe, United States, Canada, and Mexico (2006). Redlands, Calif., ESRI, digital data, 1:50,000
Faults modified from Mark Hudson and Scott Minor, U.S. Geological Survey, written commun., 1999
Streams, military base, and Indian reservation boundaries from the U.S. Department of Commerce,
Bureau of the Census, various years, TIGER/Line files, digital data, 1:100,000
Universal Transverse Mercator Zone 13N projection
North American Datum of 1983 and North American Vertical Datum of 1988

0 3 6 MILES
0 3 6 KILOMETERS

Figure 7. Estimated 2012 groundwater potentiometric surface and drawdown from predevelopment to 2012 in the Santa Fe Group aquifer system in the Albuquerque metropolitan area, central New Mexico (Powell & McKean, 2014)

Methodology

Producing the 2016 map began with an analysis of the three previous potentiometric surface maps and the processes that went into their creation. In order to maintain consistency, the methods were mimicked when possible while also experimenting with and incorporating new processes and methods that may not have been available during the other maps' publications.

Collecting Data

The first step in developing the 2016 map was to collect existing data from a variety of sources. It was assumed that the wells examined in the past provided reliable data, provided water levels from the production zone, and were in spatially varied locations conducive to creating an accurate contour. Therefore, data collection began with a search for water year 2016 water level data in those same wells. Water levels from the USGS and the City of Albuquerque wells that were used in the 2012 map were easily compiled without much doubt as to their reliability due to the thorough data collection and verification process employed by the USGS. Due to the extensive monitoring of the Kirtland Air Force Base jet fuel plume, an abundant supply of water level data was available and obtained from the Sandia National Labs and a private consulting firm, AECOM. Finally, there were several wells periodically monitored by the public works department in the City of Rio Rancho.

These water level measurements were reviewed extensively to ensure that only the most reliable data set would be used to interpolate the potentiometric surface contours. This began by filtering the water level data by date. The final map is intended to depict the static, recovered water level of Albuquerque's aquifer without any drawdown effects from pumping. Municipal water demand is drastically lower in the winter months so less groundwater pumping is required and a more accurate “static” water level can be acquired. Most water levels used were measured in the 2016 water year between November 2015 and March 2016. However, several City of Albuquerque wells that had been used in the 2012 map were measured in the winter of 2015 and/or 2017 but not within the 2016 water year time frame, so the temporal range was expanded to include those water levels. Additionally, three wells measured by the USGS, screened in the production zone, and located in Rio Rancho were measured in the winter of 2015 and added to the collection of data in order to increase density of measurements in that area.

The purpose of this map is to illustrate the state of the groundwater supply in the production zone so wells were required to be screened between approximately 200 and 900 feet below the water table.

Interpolating Contours

All wells were mapped on ArcGIS using well coordinates in the North American Datum of 1983 with a Universal Transverse Mercator Zone 13 projection. Each well point was accompanied by well and water level data including well names, coordinates, land surface elevation, water level elevation and date of measurement, and well construction information. Water levels were all converted to an elevation in the North American Vertical Datum of 1988 (NAVD88). All of the previous maps involved some degree of manual contouring, but, at least for the preliminary 2016 map, a computerized interpolation technique was implemented. A variety of interpolation methods were researched and experimented with, including kriging, inverse distance weighted, and spline techniques; however, the “topo to raster” tool in ArcGIS resulted in the most accurate interpolated potentiometric surface contours. This tool is “specifically designed for the creation of hydrologically correct digital elevation models (DEMs)” (“How Topo to Raster works,” 2017). “Topo to raster” utilizes a thin plate spline technique, which creates a smooth surface that acts as a thin metal sheet prevented from bending in erratic ways. While its primary purpose is to develop a land surface raster, the surface's connected drainage structure serves to accurately depict a groundwater surface. A preliminary map was created using the "topo to raster" tool in order to assess the validity and accuracy of the selected water levels. This tool produced a raster, which was then converted to a groundwater contour using the ArcGIS "contour" tool. These isolines clearly indicated outlying water levels that could be further examined by investigating other water level measurements in that specific well, water levels in nearby wells, the well's screened interval, the water level measurement time since pumps were shut off, and the method of measuring the water level.

The high density of water level measurements obtained in the KAFB region of the map required professional judgment in eliminating repetitive and unnecessary data points. This was accomplished by selecting individual wells within clusters that best represented the production zone (screened interval between 200 and 900 feet below the water table) and removing nearby wells that had measured water levels that differed by no more than 0 to 8 feet from the selected wells.

Water levels acquired from the City of Rio Rancho were closely scrutinized because they have historically been inaccurate for a variety of reasons. Many of Rio Rancho's wells were measured with airlines. This method is useful in wells that contain pumping equipment and cannot be accessed with electric or steel tapes (Cunningham & Schalk, 2011); however, airlines provide a less accurate reading and, in the case of several of Rio Rancho's airlines, can fail and do not provide any reading at all. Additionally, calculation errors were found in the data acquired when comparing the land surface altitude minus the depth to water to the water level elevation.

Ultimately, professional judgment was invoked in determining whether apparently erroneous data points were in fact accurate enough to remain or eliminated.

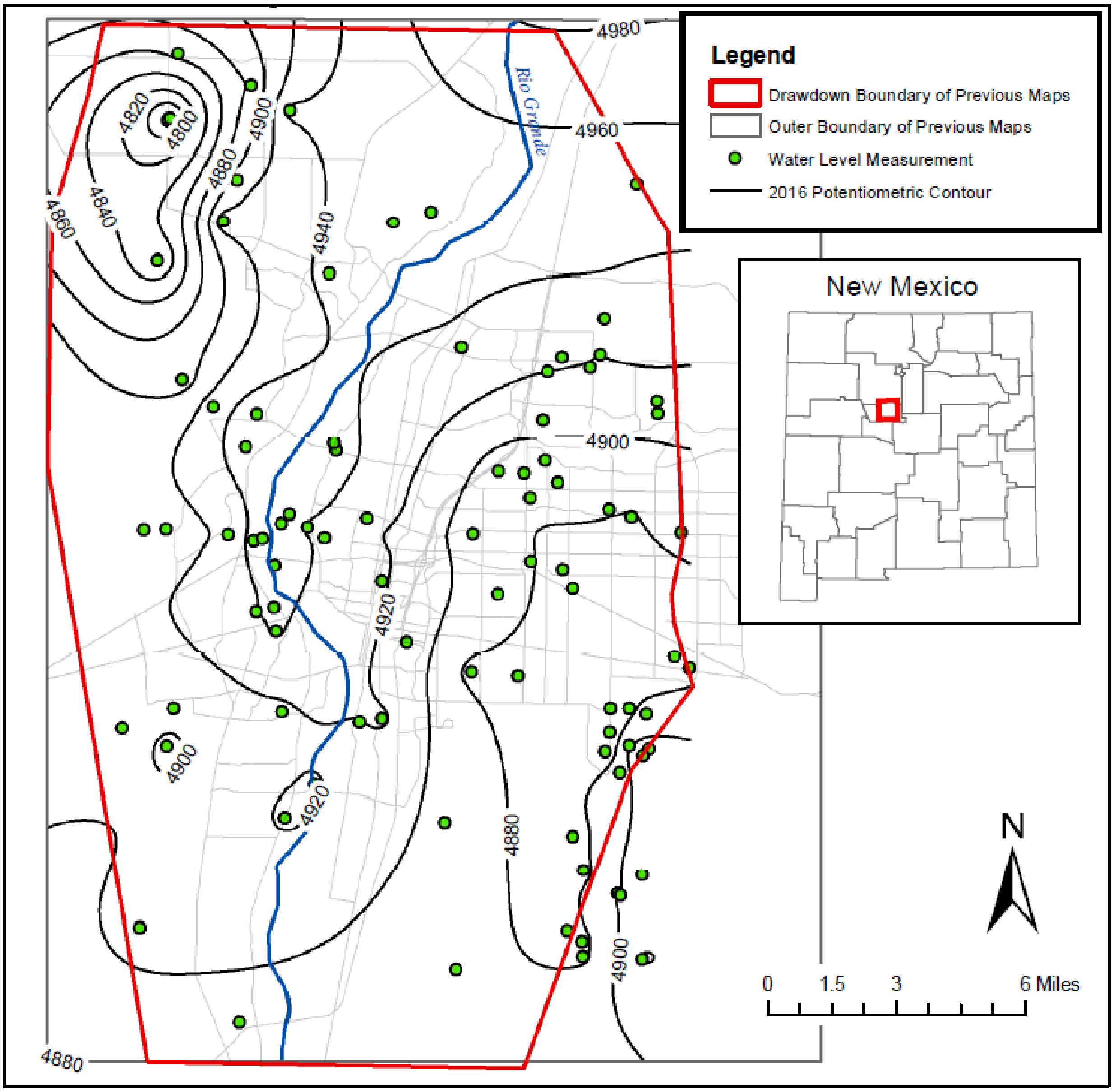
After a thorough and continuous examination, a final set of water levels was selected to create the 2016 potentiometric surface map. The same "topo to raster" interpolation conducted previously was utilized to create the final 2016 groundwater level raster and the conversion to contours was again completed.

Calculating Volume

The change in volume of water between 2012 and 2016 was calculated using a series of ArcGIS tools. Because a different method of contouring was conducted in 2002, 2008, and 2012, a raster of each year's potentiometric surface did not exist. The same "topo to raster" tool that was used to interpolate a raster from water level points in 2016 was used to interpolate a raster from the published, hand-contoured shapefile created for the 2012 map. To calculate the change in water level from 2012 to 2016, each year's potentiometric surface raster was confined to the extent of the previous maps' drawdown boundary using the ArcGIS "clip" tool. With identical extents, the change in water level was calculated by subtracting the 2012 raster contour's water elevation values from the 2016 raster contour's water elevation values using the "minus" ArcGIS tool. This produced a third raster with values representing the change in water level in feet. This raster was converted to a vector format using the "raster to polygon" tool. An attribute field was added to the change in water level polygon layer and the "calculate geometry" function was performed to provide a value for the area of each individual feature in square feet. This attribute table was exported to excel using the "table to excel" tool. Using excel, each feature's area was multiplied by the change in water level to calculate the total change in volume within each feature. These volume changes were summed to produce a total change in volume for the entire extent of the map boundary. This total change in volume also included the volume of soil. As water infiltrates into the ground, it fills in the pore spaces within the soil. The change in volume of water alone was calculated by multiplying this total volume by the porosity of the soil, which in Albuquerque is estimated at 20% (Thiros et al., 2010). This produced a total change in volume of water in cubic feet.

Results and Discussion

The 2016 potentiometric surface contours of Albuquerque's aquifer are presented in Figure 8. These isolines were produced by interpolating the verified set of 2016 water levels into a raster using the "topo to raster" tool and converting this raster into a contoured surface with 20 foot intervals. A preliminary assessment of the contours reveals the same general trends of previous maps where the area surrounding the Rio Grande maintains high water levels, groundwater pumping in East Albuquerque has lowered the water elevation, and Rio Rancho shows signs of extensive pumping and deep cones of depression.



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Subject to Revision
Not for Distribution

Figure 8. Albuquerque aquifer 2016 groundwater surface contours

While a decline in water level can be anticipated, the depression in Rio Rancho must be thoroughly investigated. Due to a comparatively low density of data points in that region, the contours are more likely to be interpolated inaccurately. They rely heavily on individual points, which, when obtained from a questionable source, can cast doubt on large sections of the map. The data point at the center of the severe drawdown in Figure 9 is Supply Well 19 from Rio Rancho. The well's water level elevation has been consistently measured between 4,730 and 4,870 feet since January 2015 but this has rarely occurred after the pump has been shut off for an appropriate duration of time. The water level that was ultimately used was historically low (4,763.54 ft) but was the only measurement that met all of the data requirements including being measured in a winter month, December, approximately fourteen days after the pump had been shut off. It is likely that this data point was affected by long term pumping and does not accurately reflect the static water level; however, it is the only useable measurement in the area and cannot be removed without entirely altering the results of the map.

Additionally there are two points in the Rio Rancho area that cause inaccuracies in the contours and appear to conflict with the surrounding water level measurements. This is not surprising since these contours are created at an interface where a variety of water level measurement sources and measurement dates exist. These points will have to be further examined to see if other measurements from these wells create more accurate contours and if refinement by hand to represent a hydrogeologically accurate surface will be necessary.

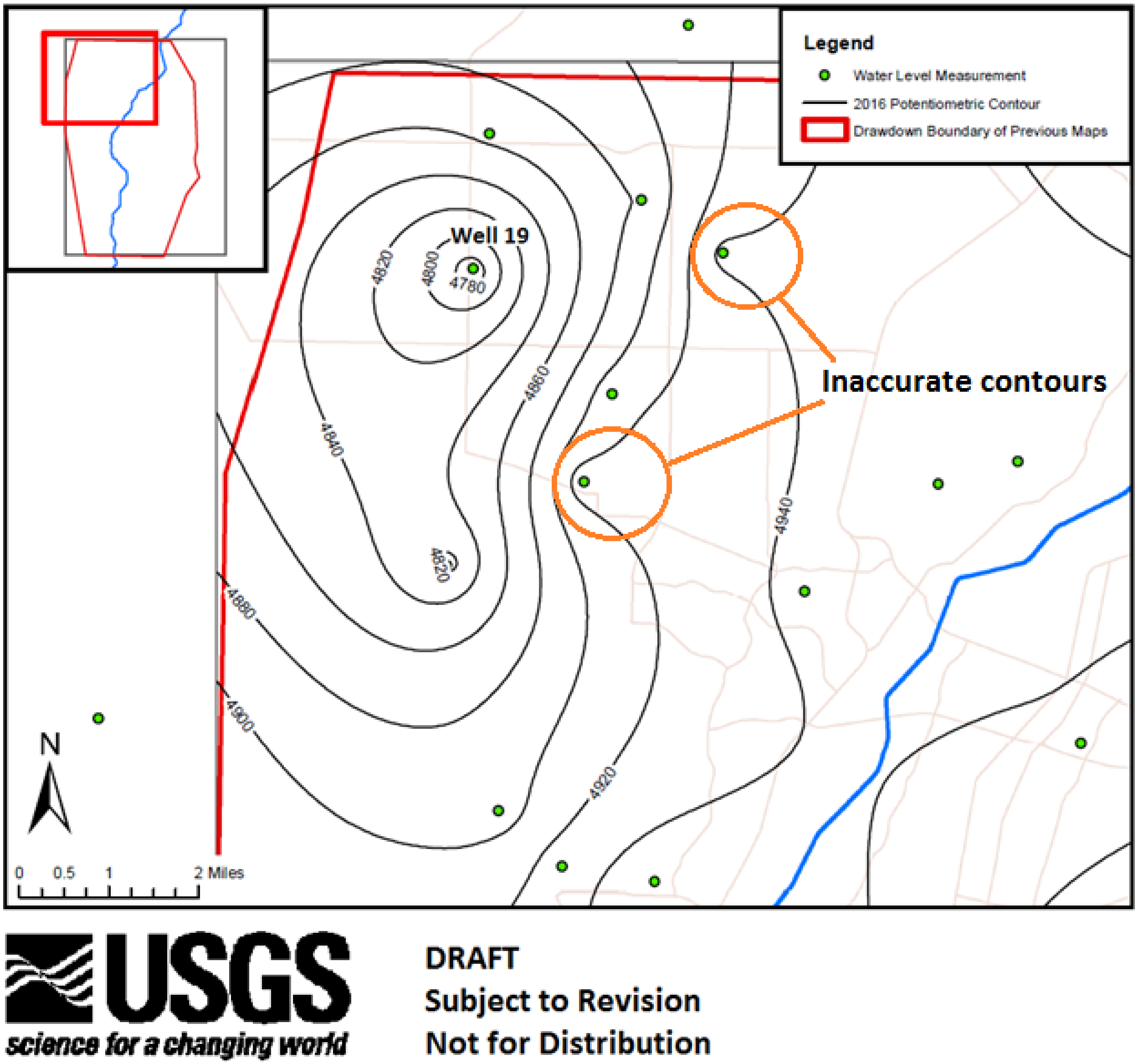

Figure 9. 2016 Groundwater surface contours in Rio Rancho

The interaction between surface water and groundwater is a crucial element of groundwater contouring that must be incorporated into an interpolation. A gaining stream that is recharged from the groundwater will demonstrate contours that point upstream in the shape of a V while a losing stream that loses water to the underlying aquifer, on the other hand, will be characterized by contours pointing downstream (Figure 10).

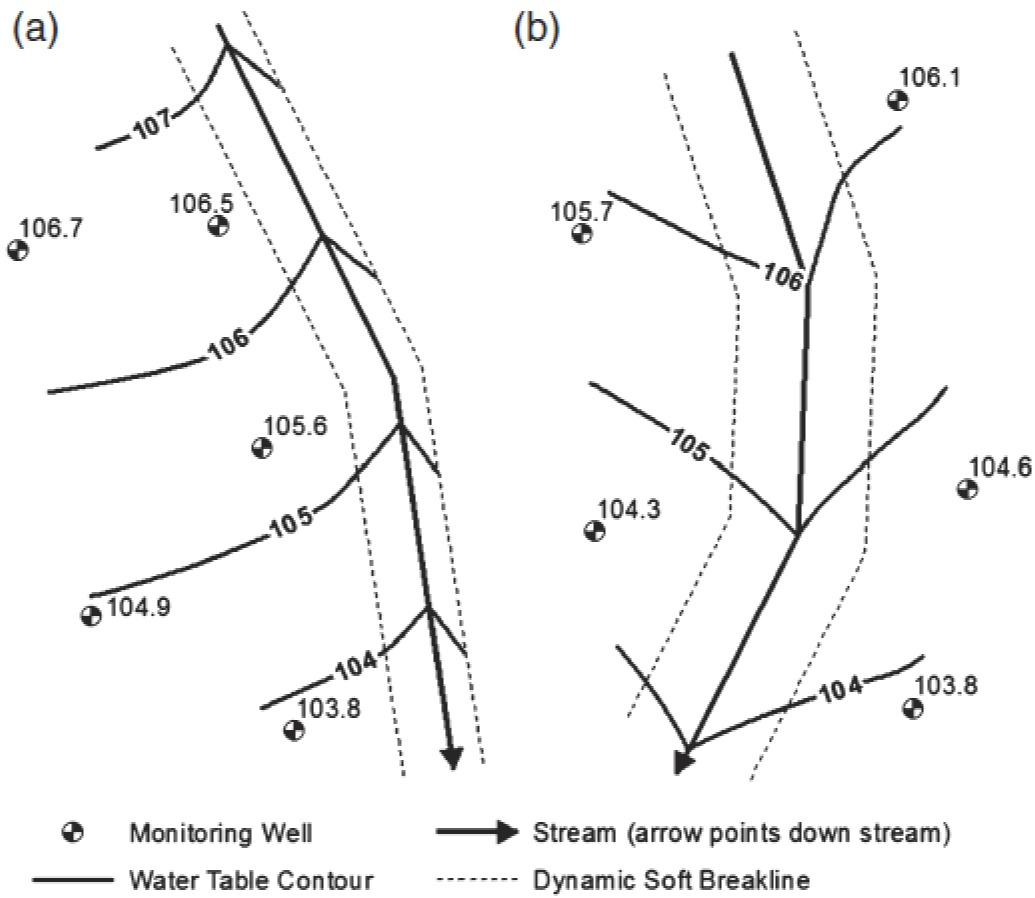

Figure 10. a) Contours of a gaining stream b) Contours of a losing stream (Bannister & Kennelly, 2016)

Hand contouring acknowledges this interaction and creates appropriate isolines, whereas a computer generated interpolation may overlook the surface-groundwater relationship and form incorrect closed loop contours around the stream (Figure 11).

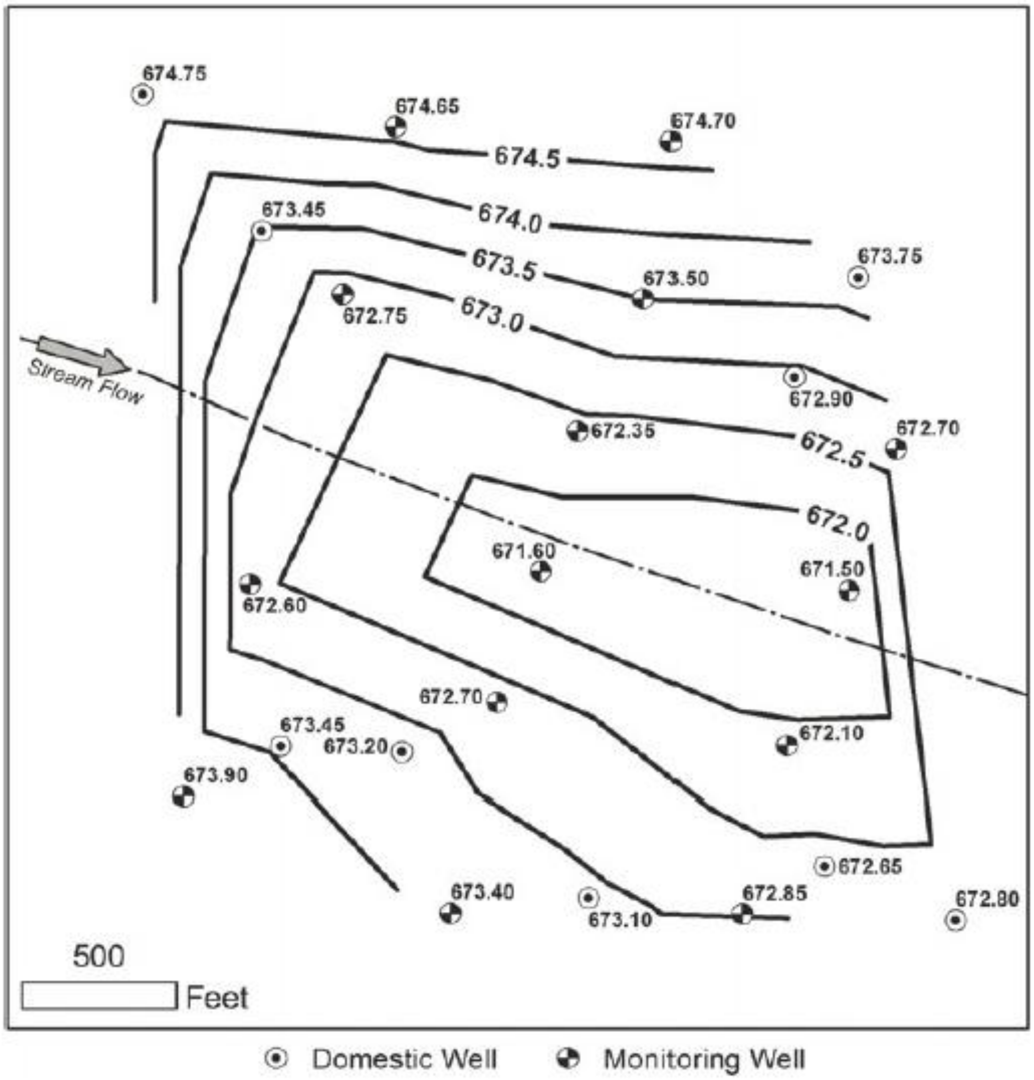

Figure 11. Example of a linear interpolation in GIS (Bannister & Kennelly, 2016)

The Rio Grande was not incorporated as an input to the “topo to raster” tool; however, the contour results, in some cases, correctly display the downstream bending contours of a losing stream (Figure 12). Other areas, however, exemplify the closed loop contours indicative of a non-human influenced, computer generated interpolation.

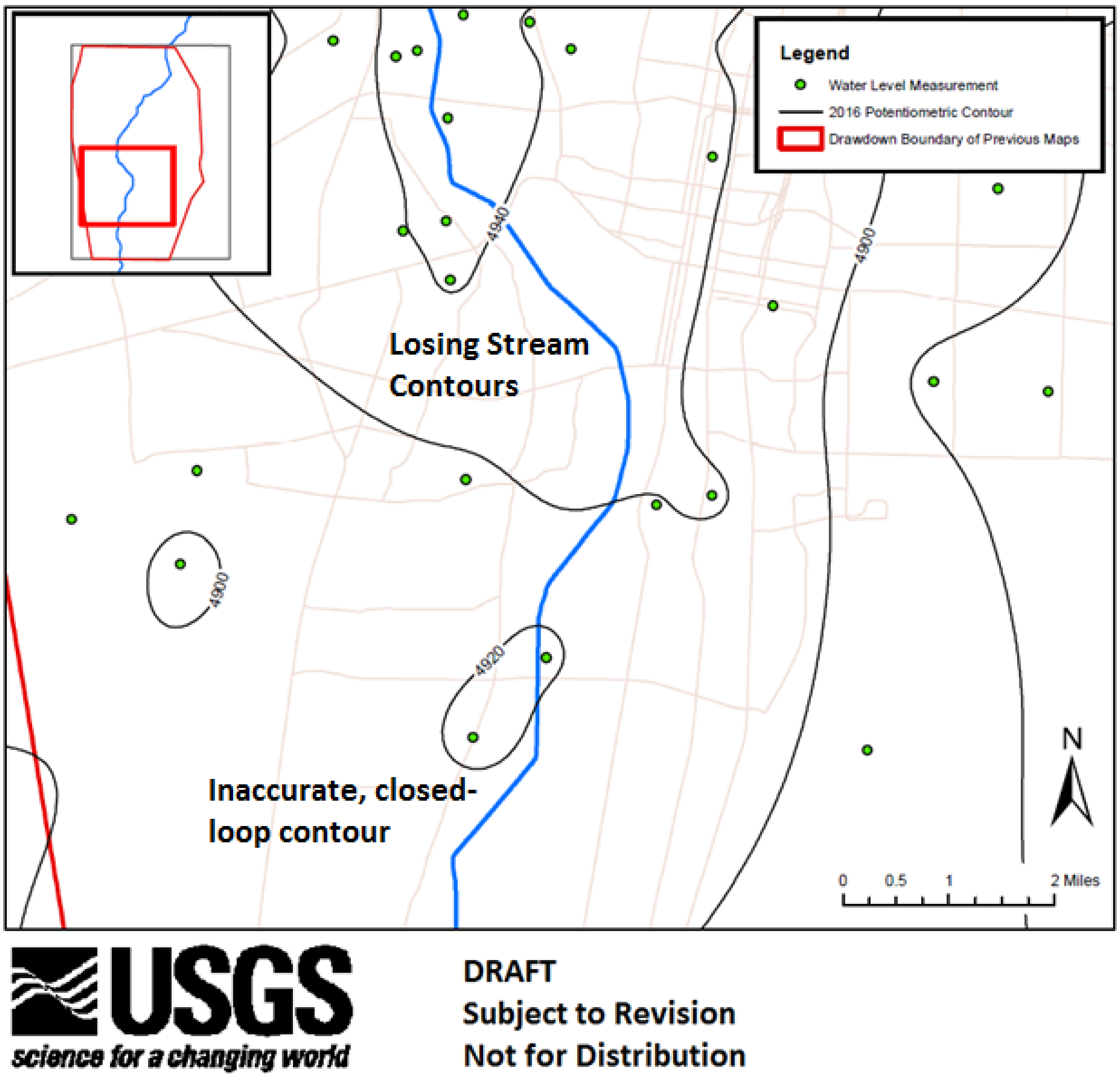

Figure 12. 2016 groundwater surface contours along the Rio Grande

Drawdown from Predevelopment

The preliminary drawdown map of Albuquerque's aquifer from predevelopment to 2016 (Figure 13) also reveals several points of interest along the river, in East Albuquerque, and in Rio Rancho. The area surrounding the Rio Grande, especially in Southwest Albuquerque, shows similar trends to previous maps where no more than 20 feet of drawdown was recorded . Rio Rancho continues to show signs of excessive pumping with severe cones of depression reaching more than 120 feet of depth, and East Albuquerque shows extensive, regional declines ranging from 60 to 80 feet of drawdown to more than 120 feet of drawdown.

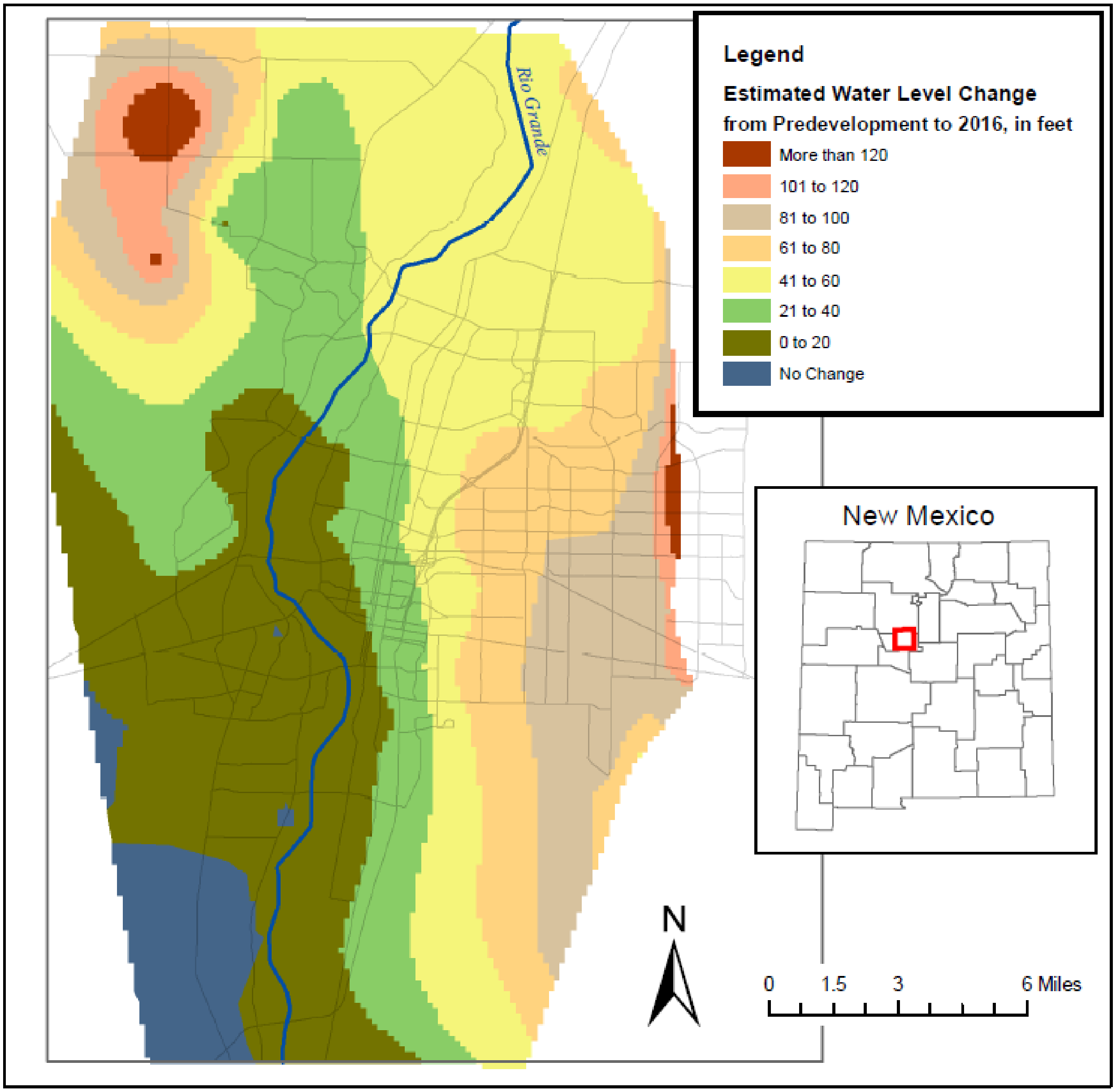

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Figure 13. Estimated water level drawdown from predevelopment to 2016 in the Albuquerque aquifer

A valuable function that this map series serves is in comparing specific regions through time. The boundary demarcated in Figures 14, 15, 16, and 17 roughly encompasses the ABCWUA pumping wells in East Albuquerque. From 2002 to 2008, extensive groundwater withdrawals expanded the already existing cone of depression in East Albuquerque and the area of more than 120 feet of drawdown grew by 219%. After the drastic decrease in groundwater pumping due to Albuquerque’s use of San Juan-Chama Project water starting in 2008, the local aquifer’s recovery can be monitored by comparing the subsequent maps. From 2008 to 2012, the area of more than 120 feet of drawdown shrank by 79%, to a smaller size than existed even in 2002. From 2012 to 2016, the area of more than 120 feet of drawdown witnessed a further 60% reduction while the area of 100 to 120 feet of drawdown greatly decreased by 86%.

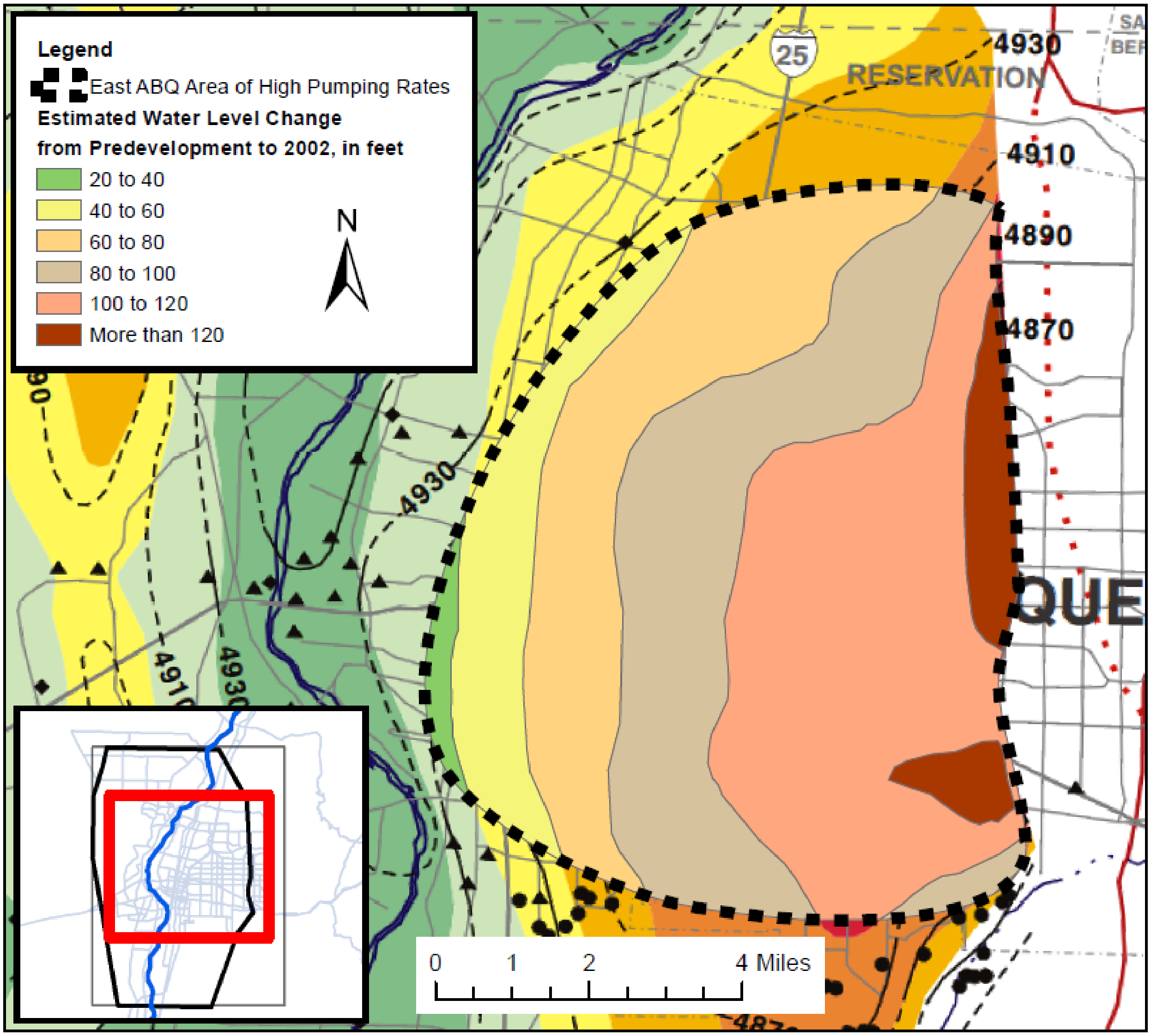

Figure 14. Water level drawdown in East Albuquerque's area of high pumping rates from predevelopment to 2002

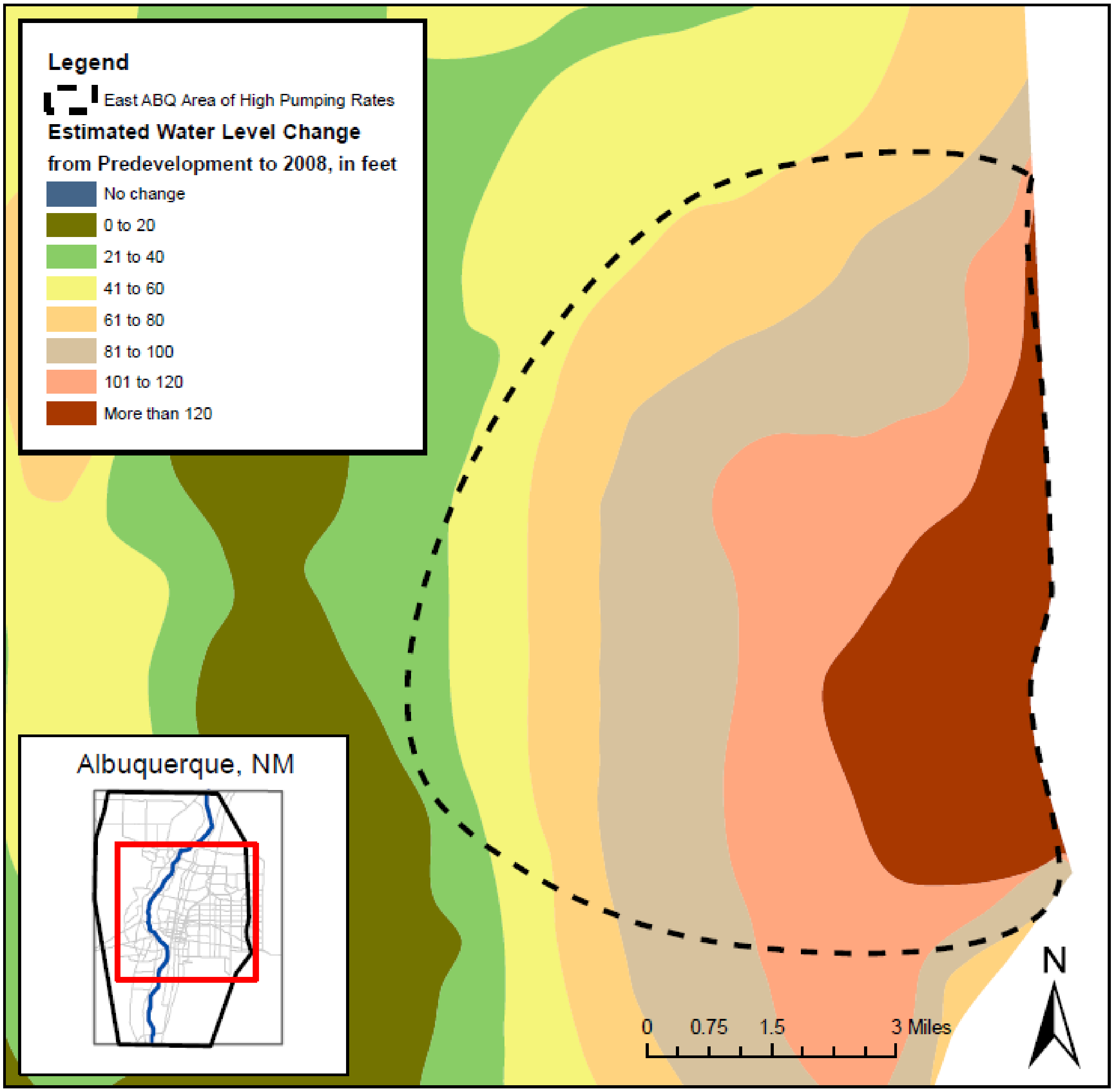

Figure 15. Water level drawdown in East Albuquerque's area of high pumping rates from predevelopment to 2008

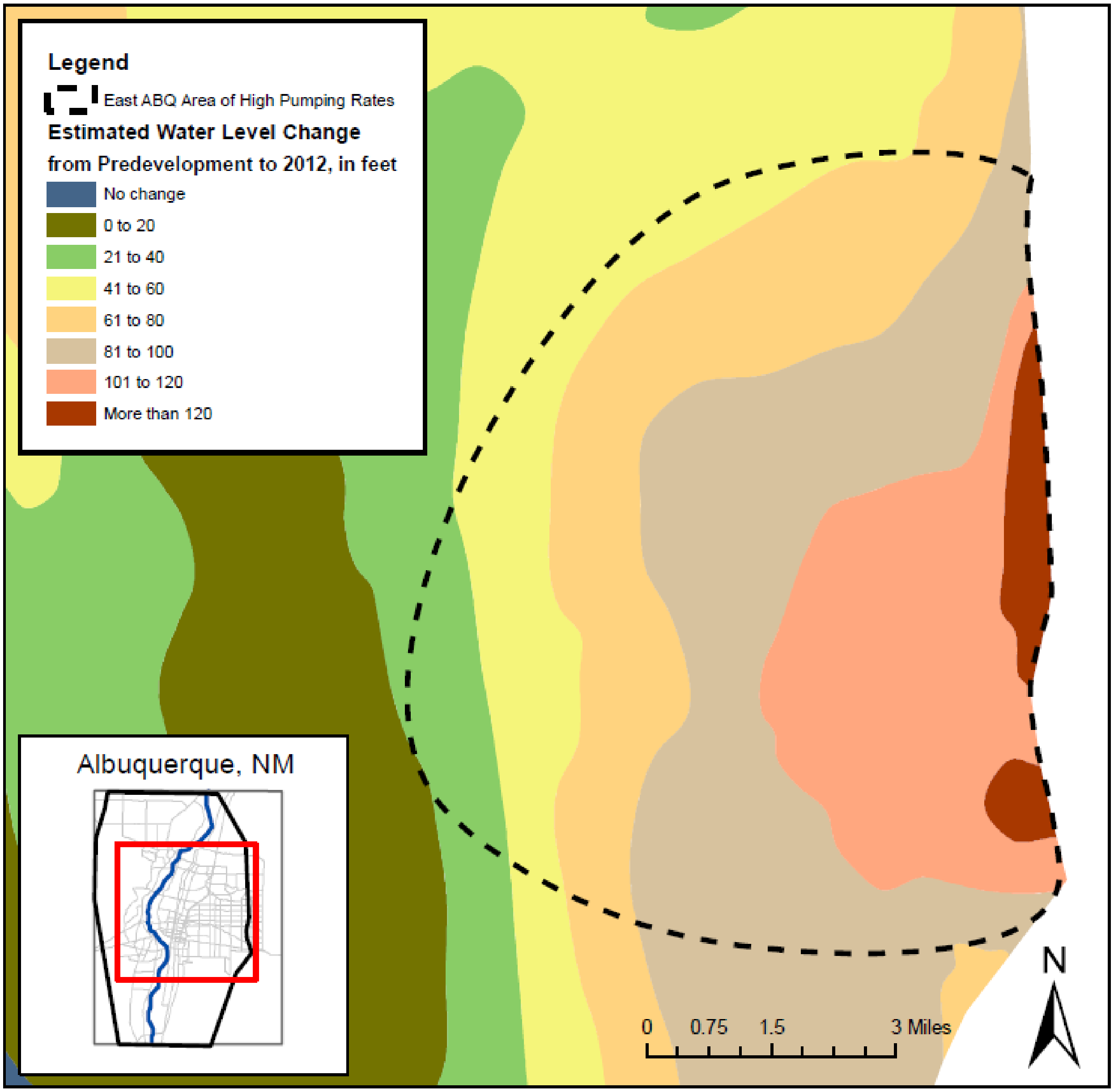

Figure 16. Water level drawdown in East Albuquerque's area of high pumping rates from predevelopment to 2012

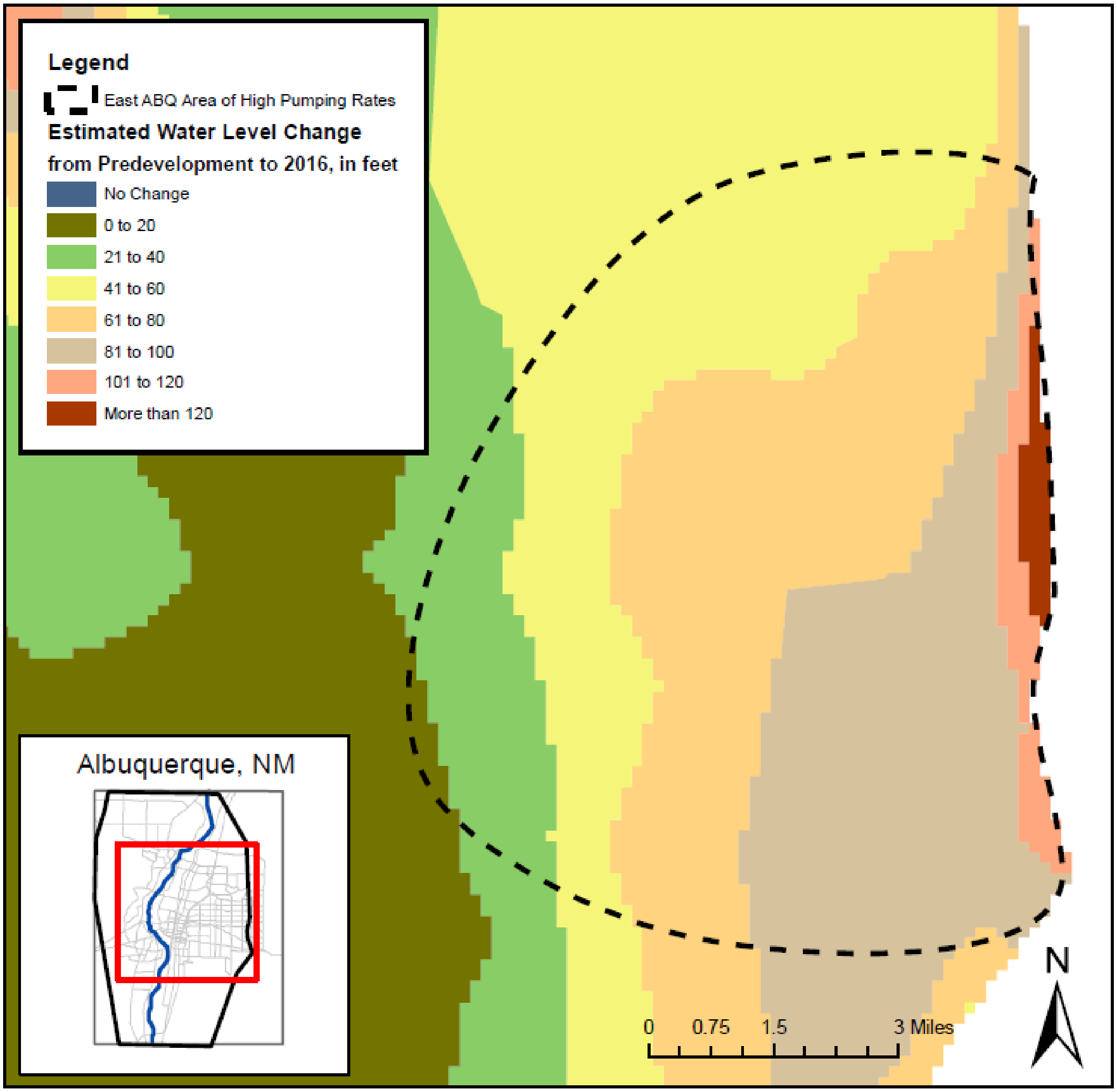

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Figure 17. Water level drawdown in East Albuquerque's area of high pumping rates from predevelopment to 2016

These changes in drawdown level are quantified by calculating the area in square miles of each category of drawdown in each year's map (Figure 18). Clear trends emerge following the switch to surface water, showing areas with both categories of 100 to 120 and more than 120 feet of drawdown declining steadily, areas in the category of 80 to 100 feet of drawdown remaining relatively constant, and areas of all categories below 80 feet reliably increasing.

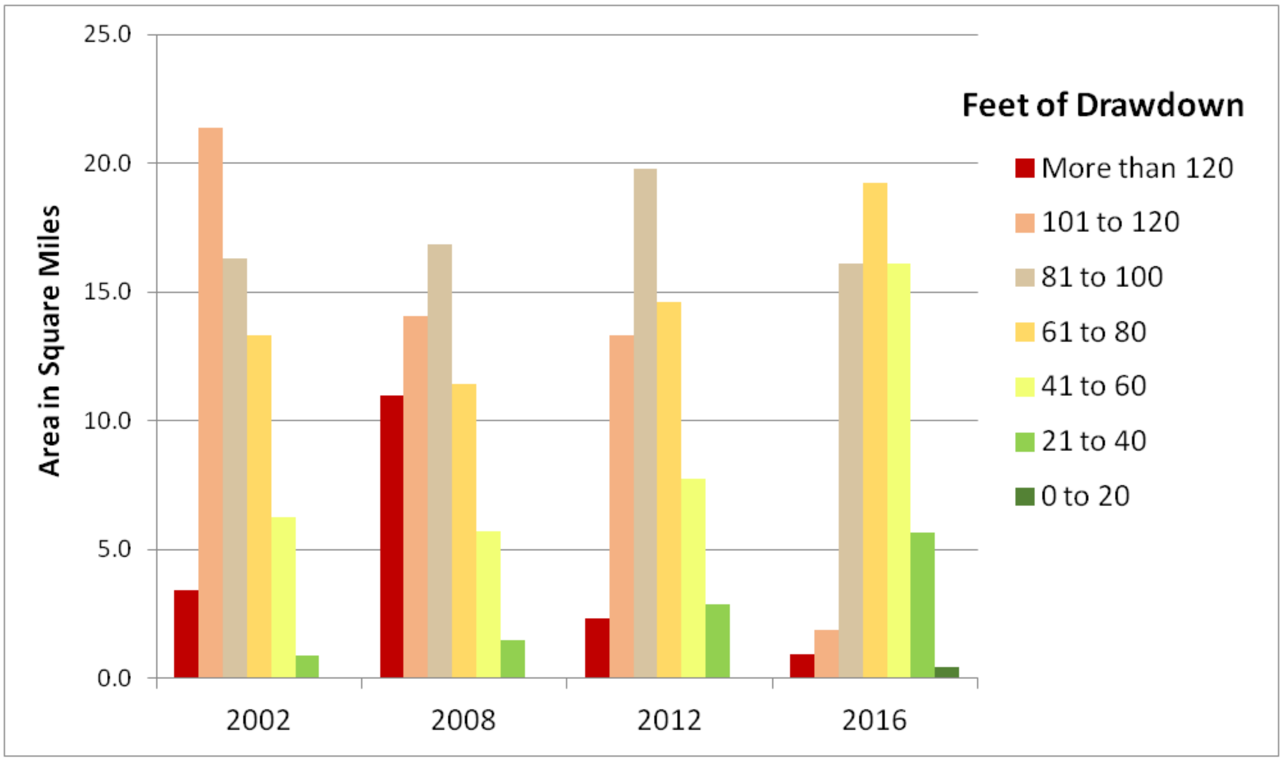

Figure 18. Square miles of drawdown within East Albuquerque's area of high pumping rates

The boundary indicating the area of high pumping rates in Rio Rancho surrounds all of Rio Rancho's supply wells and is examined in Figures 19, 20, 21 and 22. As previously mentioned, this region is notorious for lacking high quality and high density data. This is a valid reason for the absence of consistent trends. The cone of depression in the northwest corner of the map appears to remain mostly unchanged from 2002 to 2008 but the water levels in this area rise from 2008 to 2012. The water levels then lower considerably by 2016 to over 120 feet of drawdown. Again, a deep cone of depression in eastern Rio Rancho is apparent in 2008 that can now be attributed to an inaccurate data point. The severe cone of depression in 2016 results from the single water level measurement in well 19 that we may begin to conclude is also an inaccurate value when comparing drawdown in 2016 to drawdown in 2012, 2008, and 2002.

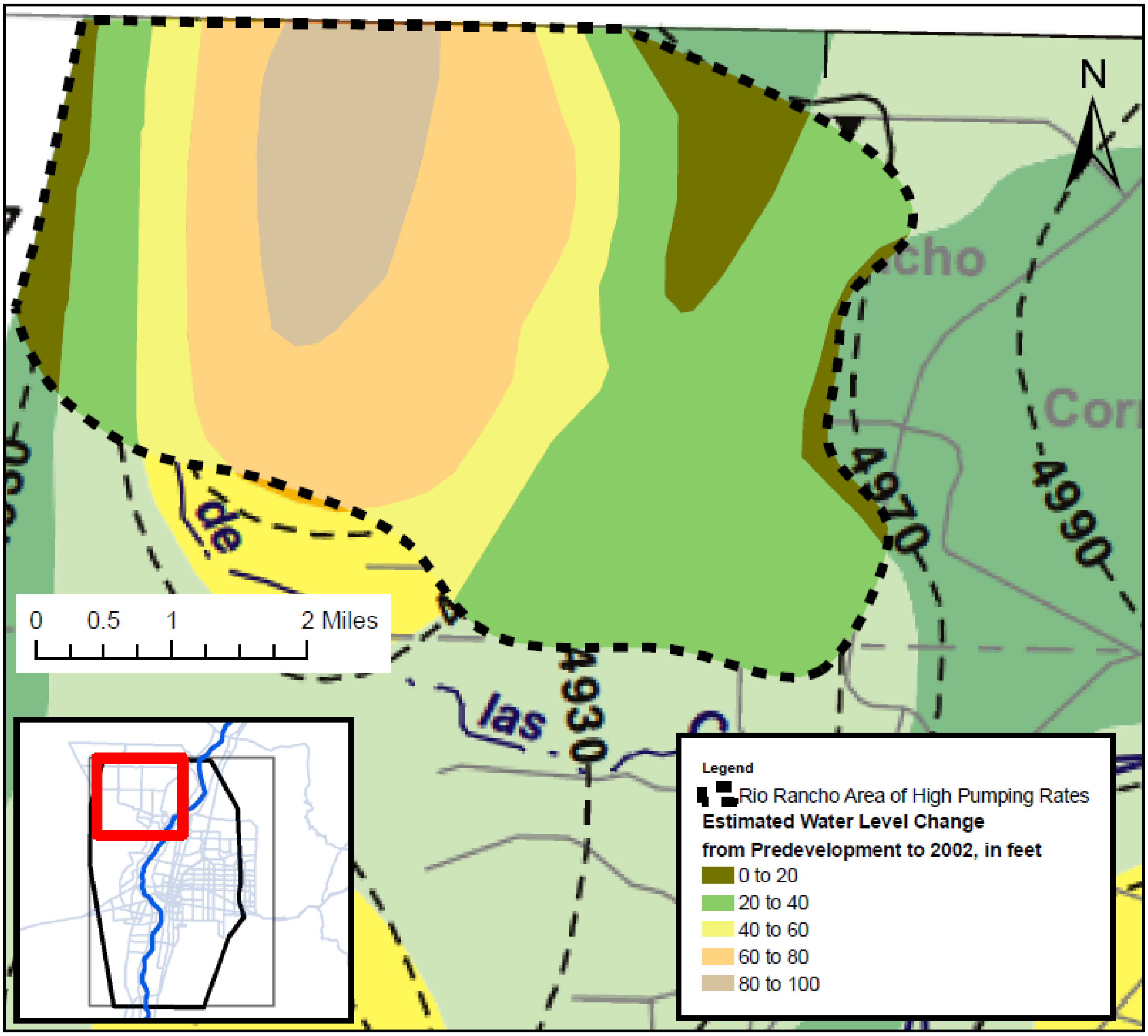

Figure 19. Water level drawdown in Rio Rancho's area of high pumping rates from predevelopment to 2002

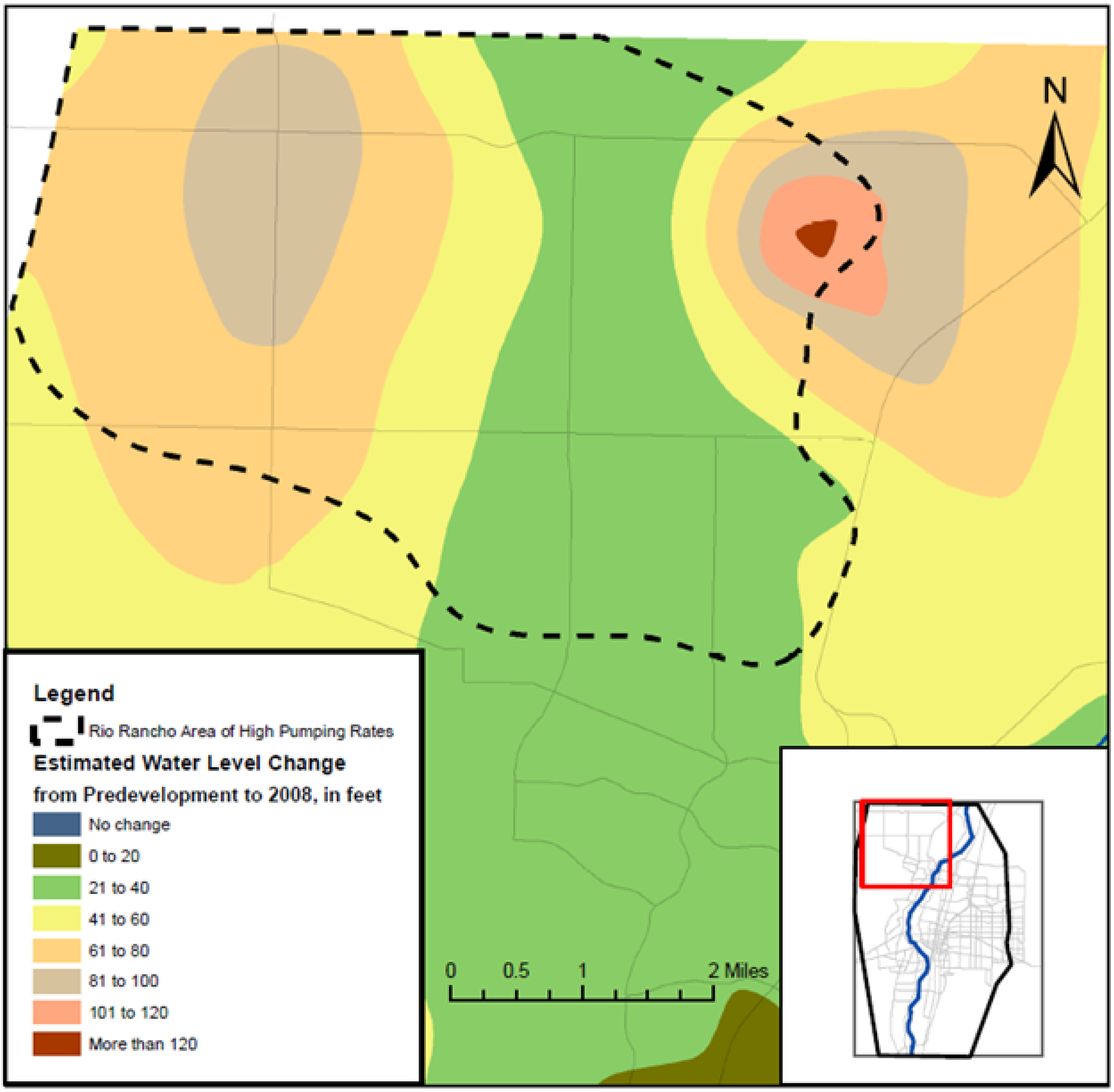

Figure 20. Water level drawdown in Rio Rancho's area of high pumping rates from predevelopment to 2008

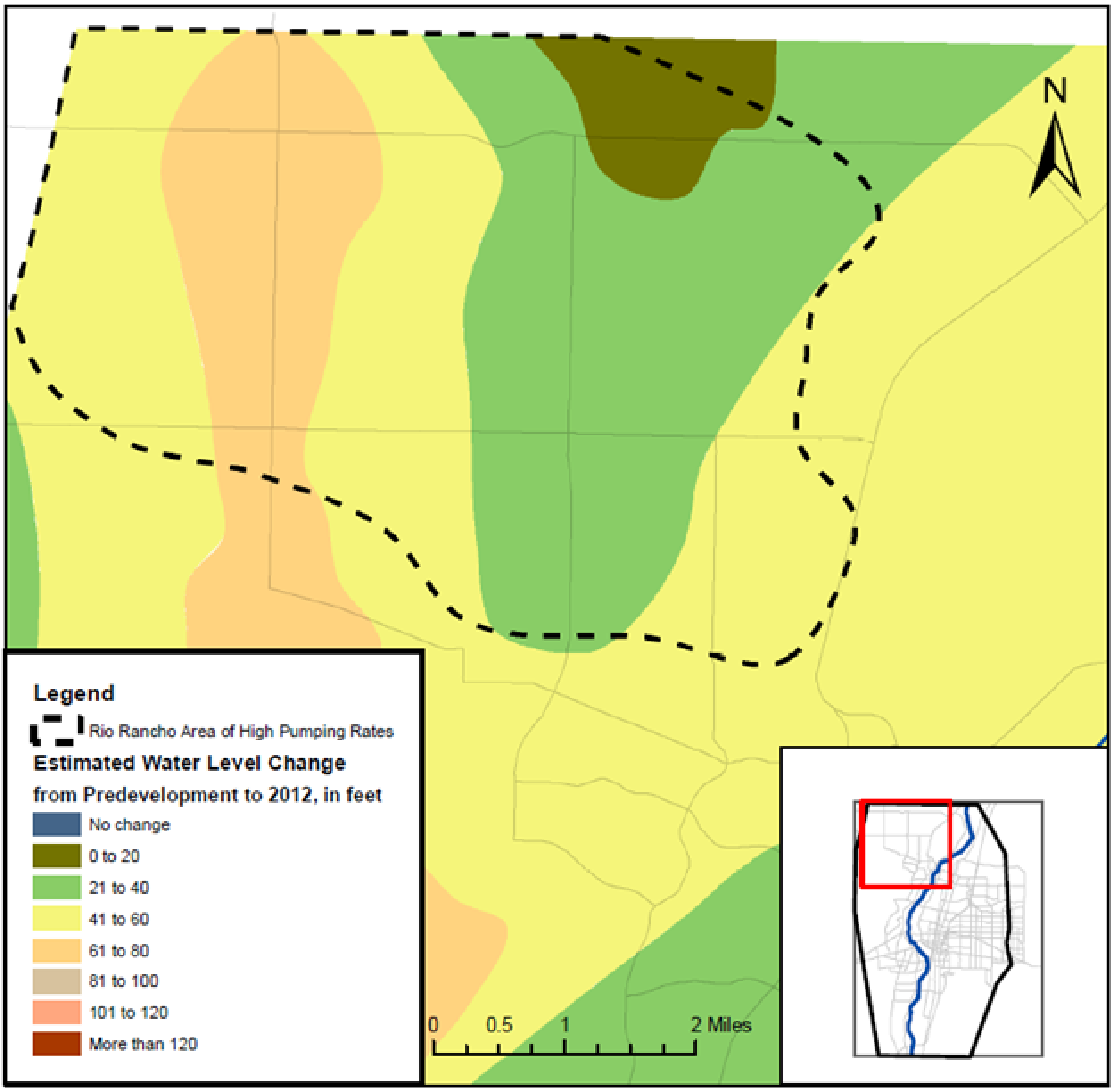

Figure 21. Water level drawdown in Rio Rancho's area of high pumping rates from predevelopment to 2012

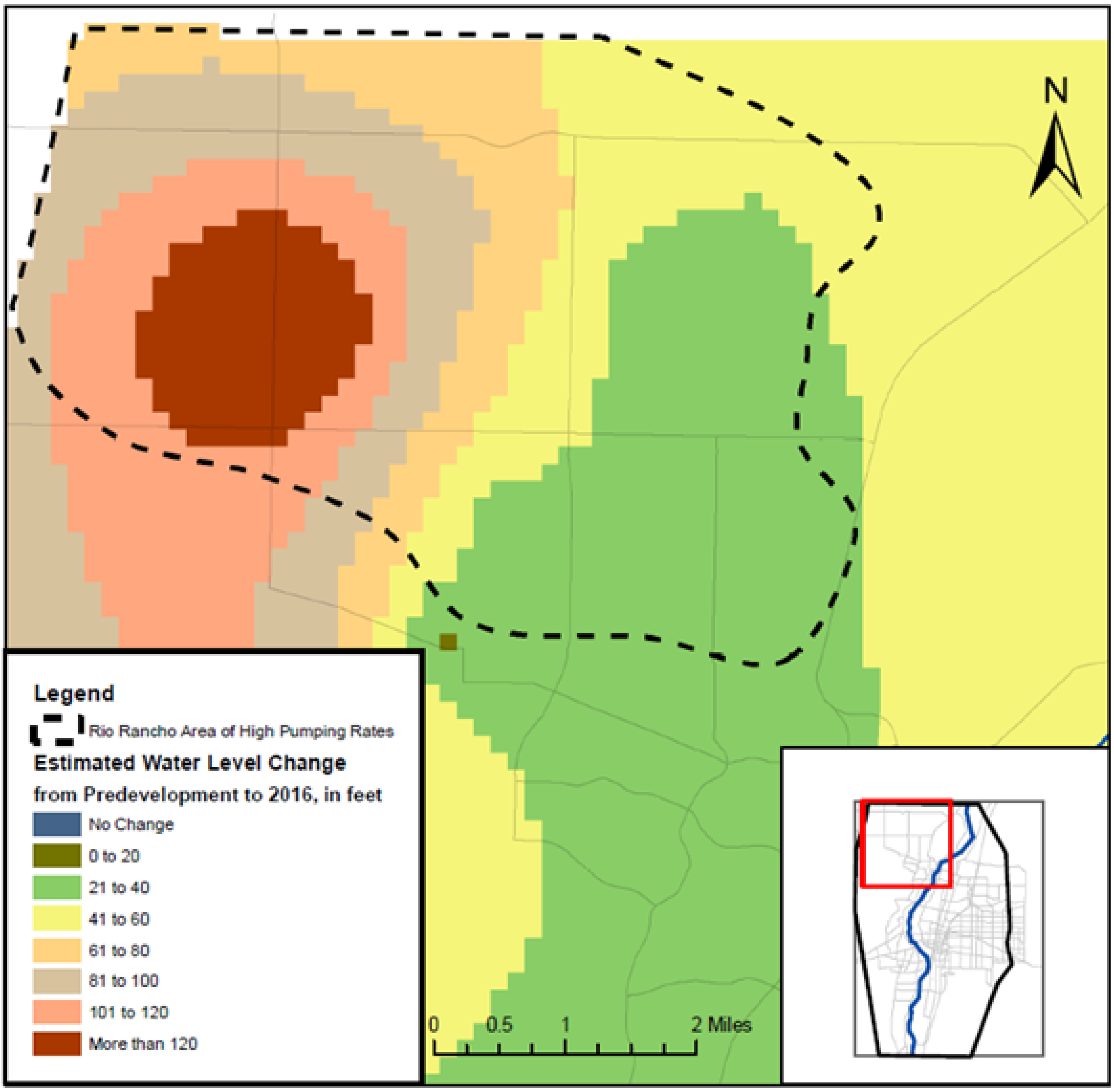

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Figure 22. Water level drawdown in Rio Rancho's area of high pumping rates from predevelopment to 2016

USGS Piezometer Hydrographs

The USGS has a series of piezometer monitoring wells throughout Albuquerque that continuously measure the water level using pressure transducers. The trends identified in the map series can be further verified by examining data retrieved from these piezometer wells. Two of these wells, Del Sol and Matheson, are located in the East Albuquerque pumping area. Another well, West Bluff, is located along the Rio Grande, west of the East Albuquerque pumping area. A third well, Lincoln, is located within Rio Rancho's pumping area (Figure 23).

The hydrographs of the two wells in East Albuquerque (Figures 24 and 25) show the water level elevation in the NAVD88 and tell an analogous story to the drawdown maps. The water level elevations in the Del Sol and the Matheson wells decline between 2002 and 2008, but then, with the introduction of surface water to the ABCWUA's water portfolio, can be seen to immediately increase and recover by almost 30 feet in both wells by 2016.

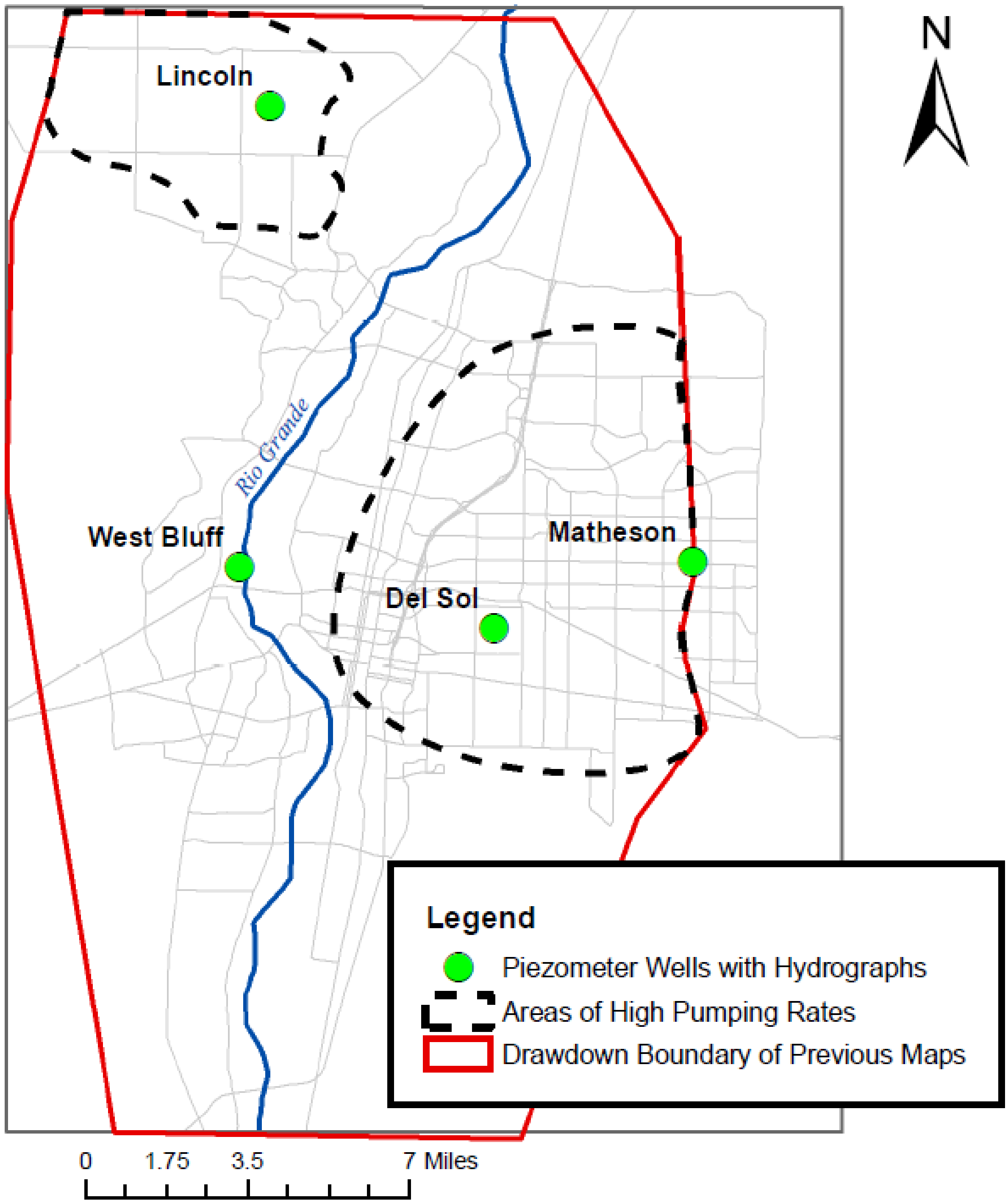

Figure 23. USGS piezometer wells used to create hydrographs

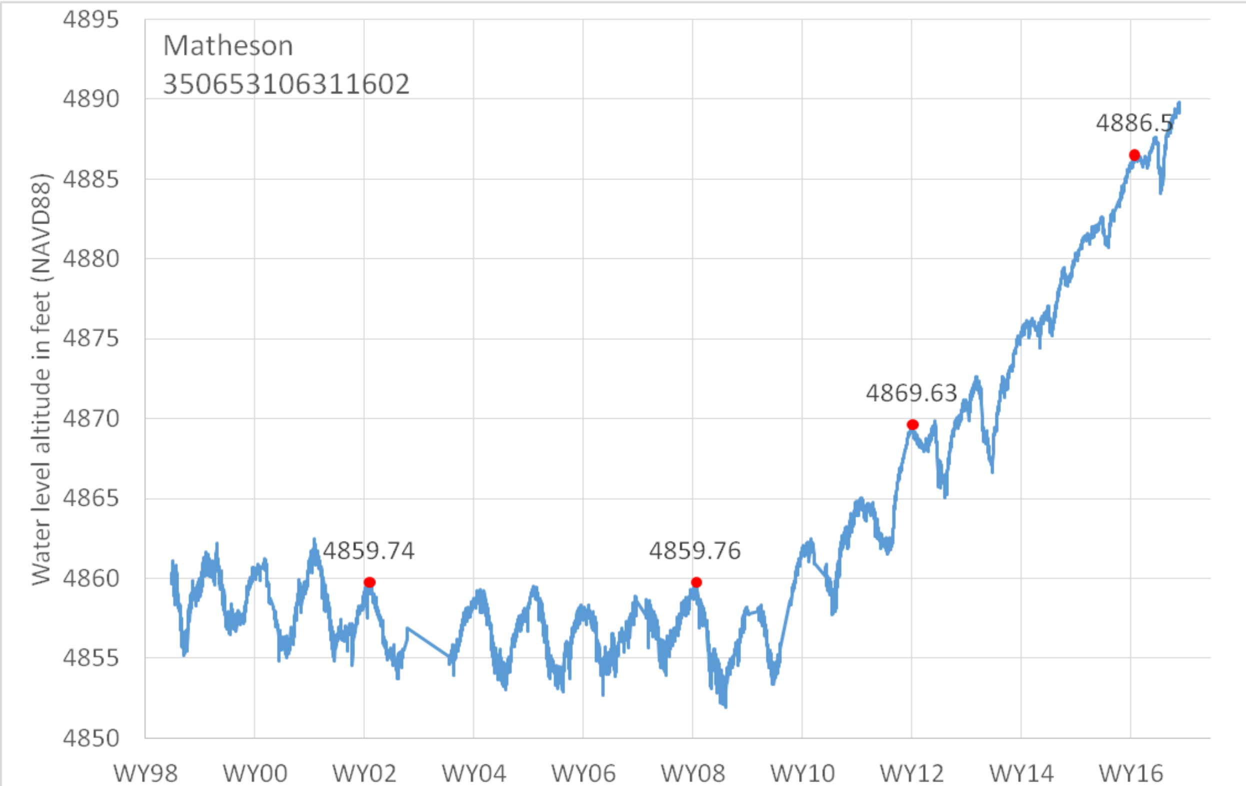

Figure 25. Water level elevation at the Matheson piezometer with USGS site ID 350653106311602 screened in the production zone

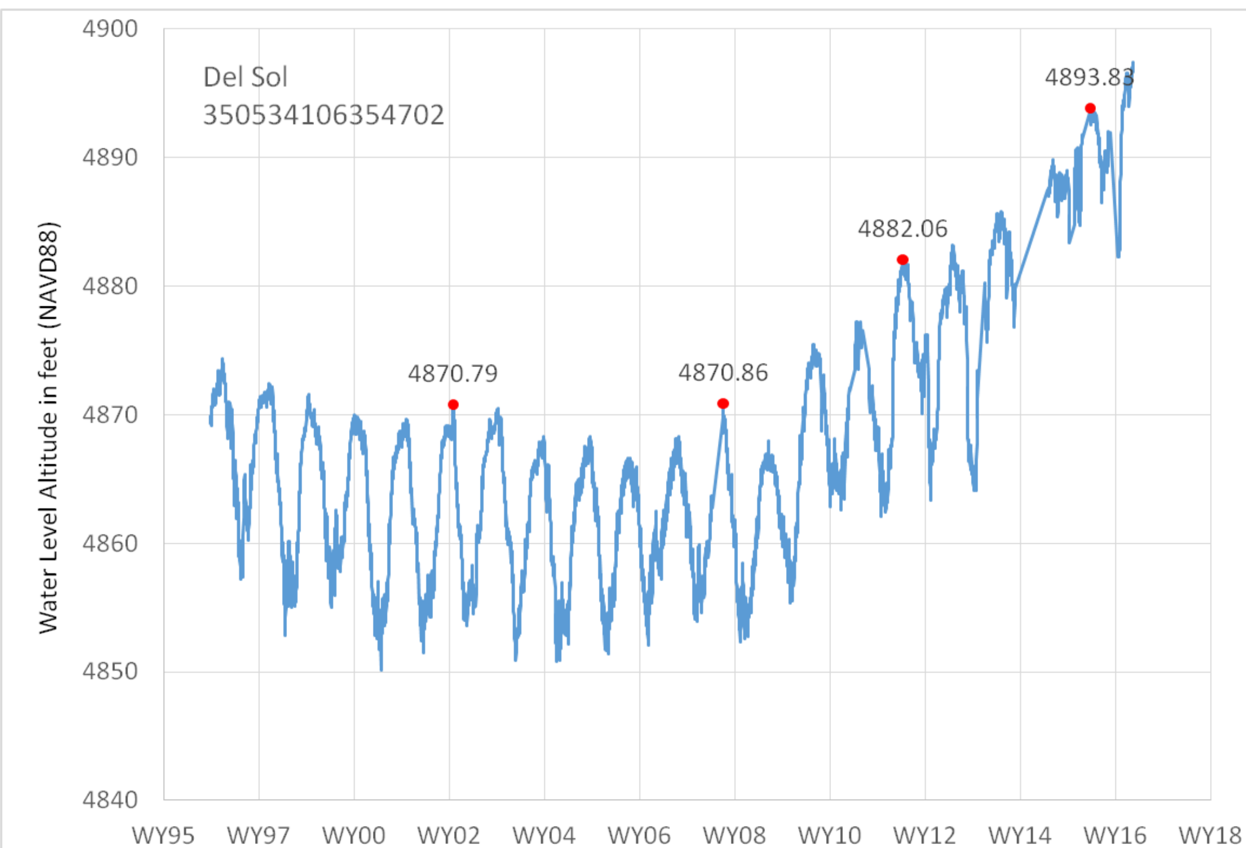

Figure 24. Water level elevation at the Del Sol piezometer with USGS site ID 350534106354702 screened in the production zone

As previously predicted, the groundwater along the river maintains a relatively stable water level elevation due to direct and immediate recharge from the Rio Grande. The piezometer readings at the West Bluff well (Figure 26) indicate extreme seasonal variation in water levels and a minor increase in water level elevation from 2008 to 2012 and from 2012 to 2016.

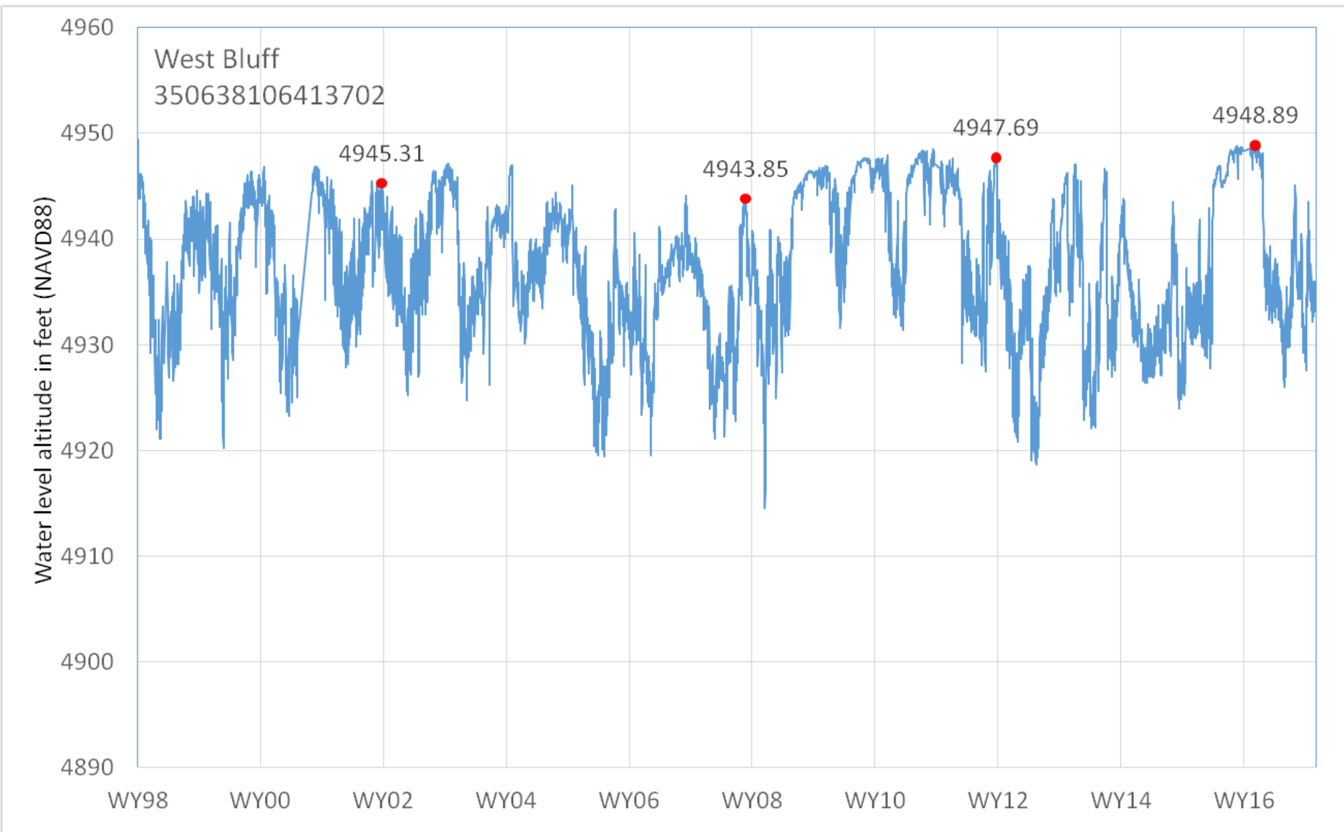

Figure 26. Water level elevation at the West Bluff piezometer with USGS site ID 350638106413702 screened in the production zone

The hydrograph of the Lincoln well (Figure 27), in the heart of Rio Rancho, indicates a consistently decreasing water level elevation until 2013 when the trend is reversed. This could signify a reaction to the implementation of the ABCWUA's reduction in groundwater pumping that was delayed by several years due to the distance from Albuquerque's pumping wells. This piezometer and its trend seem to entirely contradict the drawdown maps in figures 19, 20, 21, and 22 that indicate a recovering cone of depression until 2012, followed by a severe drop in water level in 2016. This piezometer's hydrograph may be useful in informing a necessary manipulation of the 2016 contours to estimate the area's water levels where data points are sparse.

Figure 27. Water level elevation at the Lincoln piezometer with USGS site ID 351515106410402 screened in the production zone

2012 to 2016 Change in Volume of Water

An additional method of verifying the accuracy of the estimated 2016 potentiometric surface contours in Figure 8 involves a calculation of the change in volume of water within the system and a comparison with another established change in volume calculated by the Office of the State Engineer using the current Middle Rio Grande Basin's administrative groundwater model. The subtraction of the raster depicting the Albuquerque aquifer's groundwater elevation in 2012 from that of 2016 resulted in the map shown in Figure 28. This illustrates the change in water level between those years. The change in volume of water between 2012 and 2016 for the isolated area of high pumping rates in East Albuquerque was calculated as a gain of 106,045 acre-feet. Since the change in volume calculated from the map only includes the area within the established pumping boundary and since all other groundwater users besides the ABCWUA were excluded in the administrative groundwater model, the map's change in volume would not be expected to precisely reflect the administrative model's results.

Nevertheless, these numbers should be comparable and within the same order of magnitude. The administrative model estimates cumulative stream depletions resulting from the ABCWUA's groundwater pumping for 2012, 2013, 2014, and 2015 of 253,113 acre-feet (Stansifer, 2016). Total groundwater withdrawals by the ABCWUA for those same years equal 184,754 acre-feet (Stansifer, 2016). While natural, mountain-front recharge can be only roughly estimated with a range of values, approximately 7,000 to 12,000 acre-feet per year would result in 28,000 to 48,000 acre-feet between 2012 and 2016 (Bartolino, Anderholm, & Myers, 2011). Rio Grande stream depletions from ABCWUA pumping plus natural recharge minus ABCWUA groundwater pumping results in a gain of 96,359 to 116,359 acre-feet, a range that encompasses the map's calculated change in volume.

According to the map, the aquifer in the area of high pumping rates in Rio Rancho experienced a loss of about 83,300 acre-feet. With annual pumping rates less than 11,000 acre-feet, there is no possibility that the City of Rio Rancho withdrew that quantity of water in four years. This is further evidence that the Rio Rancho area of the 2016 (and/or 2012) estimated potentiometric surface map(s) is inaccurate and requires further investigation.

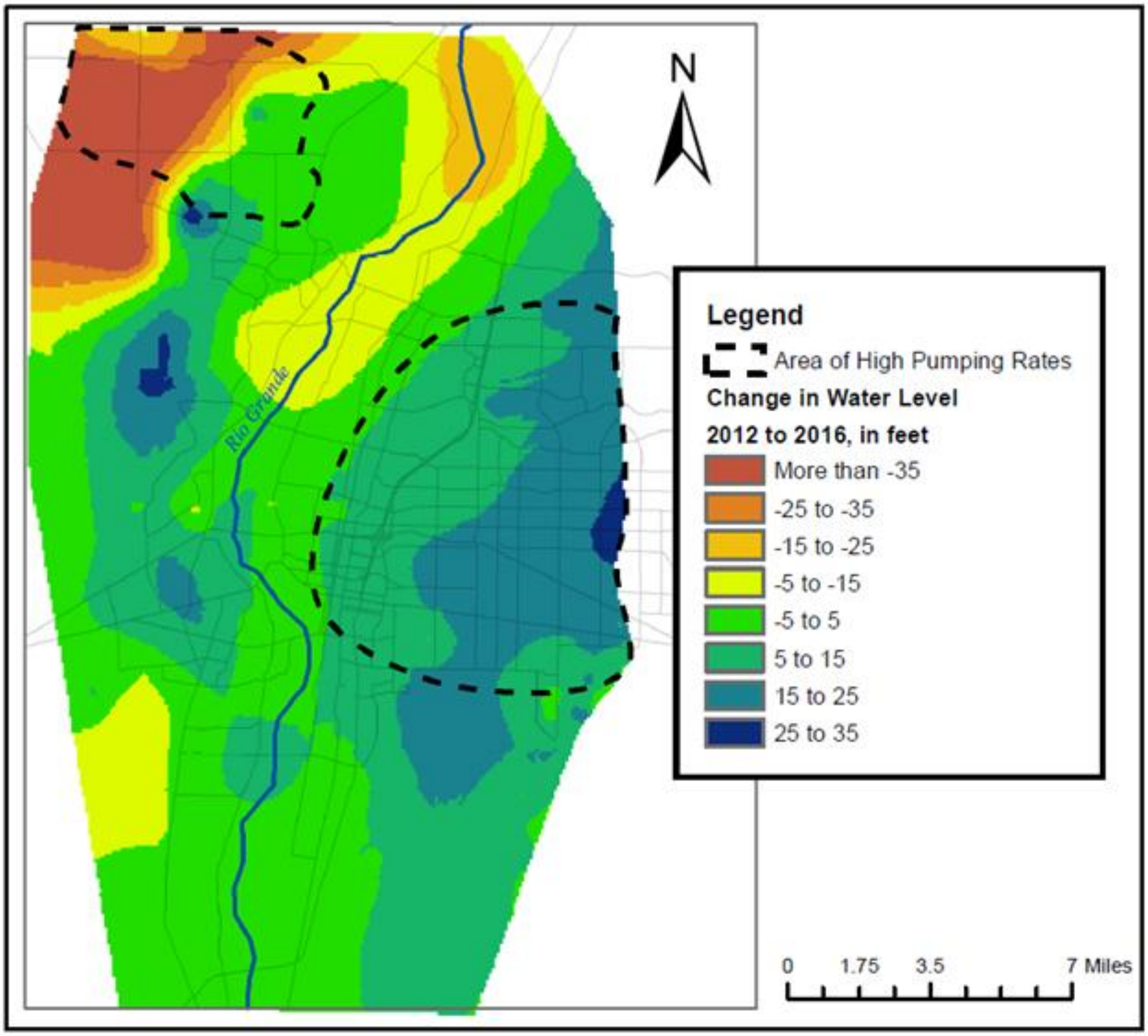

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Figure 28. Water level drawdown in Albuquerque's aquifer from 2012 to 2016

Future Work and Recommendations

All results are preliminary and will continue to be revised as the data points used to create the 2016 maps are reviewed further to ensure accuracy. Additional data points will be investigated in order to improve the interpolation of the groundwater surface, especially in areas of low reliability. Ultimately, the "topo to raster" spline interpolation can serve as a starting point that informs the production of a hand-contoured map. Each method has its advantages: computerized contours eliminate any contouring bias and human error while manually contouring allows the inclusion of an aquifer's heterogeneities, and ideally, both will be employed. This will allow the final contours to correctly interpret individual water levels according to the computerized interpolation while also incorporating professional judgment and knowledge of the area's geological features to maintain hydrogeologic integrity.

Most of the computer generated contours may suffice with only a small amount of interpretation to remove irregularities. However, the interpolation adjacent to the Rio Grande will require a more significant intervention to account for the surface water-groundwater interactions. As previously discussed, the Rio Grande is a losing stream and the estimation of the surrounding groundwater surface should reflect that fact. The downstream-bending "V's" should be included and will alter parts of the contour map along the river where drawdowns are expected to be negligible. This refinement should be informed by a similar process implemented in previous maps: water level elevations of the production zone will be estimated at one mile intervals along the river. These water level elevations will be linearly interpolated from water levels measured in nested piezometers near the Rio Grande. The difference measured between the water level at the water table and the water level in the production zone is assumed to equal the difference between the bottom of the river bed (the groundwater surface) and the production zone under the river.

Groundwater level maps will continue to be a necessity in Albuquerque to continue monitoring the growing population's effect on the region's aquifer. 2016 will not be the last year that this map is created and the ABCWUA has already expressed an interest in a 2020 version. In order to greatly facilitate the production of future maps, a thorough organization and proper labeling will be completed of all relevant 2016 files. This will ease the future map production process if individuals who contributed to the 2016 version are no longer present or are unable to recall the details of creating these maps.

Interpolated contours rely heavily on high quality and high density data points and suffer when either or both are missing. There is little doubt that data obtained from Rio Rancho have a negative influence on the quality of these maps. As previously stated, this is an interconnected aquifer where water management in the City of Albuquerque affects water supplies in Rio Rancho and vice versa. Accurately mapping the Rio Rancho area is crucial to better understanding these impacts. It would be worthwhile for the USGS to obtain measurements in the Rio Rancho area, specifically to inform the interpolation of future maps. Ideally, the USGS could seek independence from other data sources altogether and only utilize data that it has directly measured and verified.

The purpose of this report was initially to create a detailed documentation of the methodology implemented in creating the 2016 contours that may inform and guide future map production. This purpose has evolved to include a set of valuable recommendations that highlight weaknesses in the maps and the mapping procedure as well as a series of analyses that could be pursued further by the USGS to seek funding from its cooperator, the ABCWUA, as the Authority seeks a full understanding of its water supply.

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