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Evaluating the Influence of High-Production Pumping Wells on Impacted Groundwater at the Bluewater, New Mexico, Disposal Site

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Abbreviations

ACL	alternate concentration limit
ADAMS	Agency Documents Access and Management System
amsl	above mean sea level
ARCO	Atlantic Richfield Company
COC	constituent of concern
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
ft	feet
gpm	gallons per minute
HMC	Homestake Mining Company
LM	Office of Legacy Management
LOESS	locally estimated scatterplot smoothing (line)
mg/L	milligrams per liter
mi	miles
NMED	New Mexico Environment Department
NRC	U.S. Nuclear Regulatory Commission
OSE	New Mexico Office of State Engineer
POC	point of compliance
POE	point of exposure
SAG	San Andres-Glorieta (aquifer)
TDS	total dissolved solids
USGS	U.S. Geological Survey

Executive Summary

The U.S. Department of Energy (DOE) Office of Legacy Management (LM) Bluewater, New Mexico, Disposal Site is the location of a former uranium mill that operated between 1953 and 1982. Former milling operations resulted in contamination of the underlying aquifers. The aquifers contaminated by the mill include the San Andres-Glorieta (SAG) aquifer and the ancestral Rio San Jose alluvial aquifer (alluvial aquifer). Groundwater contamination in the SAG aquifer from the Bluewater site has historically been defined by various constituents including nitrate, molybdenum, uranium, and selenium. Dissolved chloride, sulfate, and total dissolved solids (TDS) have also been used as general indicators of mill-related groundwater contamination. As of recent, groundwater contamination in the SAG aquifer from the Bluewater site has been illustrated mainly by concentrations of uranium in groundwater. Uranium is used as the main constituent of concern because it potentially poses a risk to drinking water users, and it is mobile and widespread in regional groundwater. Concentrations of uranium leaving the site however are below the U.S. Nuclear Regulatory Commission- approved site-specific human health based standard applicable at the site boundary and the site is in compliance with the alternate concentration limits approved in the *Long-Term Surveillance Plan for the DOE Bluewater (UMTRCA Title II) Disposal Site, Near Grants, New Mexico*.

The SAG and alluvial aquifers are a valuable resource in the Grants-Bluewater Valley. The SAG aquifer is a primary water source for high-production uses such as municipal and industrial that may pump >15 gallons per minute for long periods (several hours to months) and lower-production uses such as domestic and livestock watering that may pump small quantities of water of between 2 and 15 gallons per minute for short, intermittent periods, in comparison. The alluvial aquifer is used primarily for lower-production uses such as domestic and livestock watering by residences that are not connected to municipal water-supply systems. Previous investigations have indicated local and regional drawdown effects in the SAG aquifer from high-production pumping wells. These drawdown effects have the potential to alter groundwater flow directions in the aquifer, ultimately affecting the fate of the contaminated groundwater.

The objective of this report is to evaluate the influence of the high-production pumping wells on the flow and transport of the contaminated groundwater in the SAG aquifer. LM initiated this action in response to (1) uncertainties of pumping well influences on the contaminated groundwater raised in the *2014 Site Status Report* and (2) and concern of potential movement of the plume expressed by stakeholders in the Grants-Bluewater Valley. This work expands on LM's previous work titled *2017 Uranium Plumes in the San Andres-Glorieta and Alluvial Aquifers at the Bluewater, New Mexico, Disposal Site*—which provided an updated characterization of the groundwater contamination beneath the site and in offsite areas east and southeast of the site. The intentions of this evaluation are not to definitively determine the quantitative effects from pumping; rather, they are to evaluate existing data and identify correlations between the pumping and observed groundwater level, flow, and transport behavior.

Evaluation of high-production pumping impacts included the review of groundwater-level monitoring data to evaluate pumping influences and changes in flow directions. Available water chemistry data were then used to assess the transport of indicator species. Data for 42 wells within the study area were reviewed for this study, 10 Bluewater site wells and 32 offsite wells.

Continuous groundwater-level monitoring data collected at the Bluewater site (from 2012 through most of 2018) were used to evaluate groundwater-level patterns and calculate flow directions and gradients. Several distinct groundwater-level patterns were observed in the continuous groundwater data including long-term trends (typically over 1 year), seasonal trends, and shorter-term trends of various lengths (typically less than 1 month). The seasonal trends show that groundwater levels decline as much as 5 feet in some wells in the spring, summer, and fall. Temporal flow directions show that the seasonal shift in flow direction correlates with the seasonal decline in water levels. Flow directions shift to the south, toward the location where most pumping occurs, during late spring, summer, and early fall. During this period, calculated gradients typically show more variability than non-pumping periods.

Pumping records were tabulated for the period 2012–2018 for the industrial and municipal high-production pumping wells. Pumping records indicate that the timing of higher pumping correlates with the local seasonal drawdown of the water levels, shift in flow directions, and change in hydraulic gradient within areas of the Bluewater site.

Statistical trend analysis was conducted for uranium, sulfate, and TDS. Uranium and sulfate are both good indicators of mill-related contamination. TDS was used instead of chloride because it is a measure of all dissolved constituents in groundwater (including chloride) and is a good indicator of the presence of contaminants in general.

The trend analysis was conducted with the Mann-Kendall statistical test in both Bluewater site and offsite wells for wells with eight or more samples. In total, 8 Bluewater site wells and 7 out of 32 offsite wells had more than 8 valid data points. The analysis identified increasing trends in three Bluewater site wells; this includes well 14(SG) (for uranium and sulfate), 15(SG) (for sulfate and TDS), and 18(SG) (for uranium, sulfate, and TDS). Increasing trends were identified in one offsite well (951). An increasing trend for all analytes was calculated in well 951 using data from 1984 through 2018; however, no trend was calculated for well 951 using data from 2012 through 2018. Well 951 operated as an extraction well from 1999 through 2012.

The use of current datasets for this evaluation made it clear that data limitations exist. A reduction in these limitations would improve confidence in the evaluation of influences of high-production wells. Several data limitations identified include:

- Sparse groundwater-level datasets.
- Sparse water chemistry datasets.
- Limited resolution and availability of pumping records.
- Limited well network.

Because of the complexity of the hydrogeology in the study area and sparseness of data, uncertainties associated with the analyses and conclusions of this evaluation are inherent and unavoidable. The following are the major uncertainties relevant to this evaluation:

- Groundwater flow directions in offsite areas are not well defined.
- Influences of faults on groundwater flow are not well understood.

- Several potential anthropogenic sources of contamination exist within the study area, and several potential pathways to transmit water from these different sources to the SAG aquifer also exist but are not well understood. Little is known about the specific signatures of the different contaminant sources or the connectivity of the aquifers. If increasing concentration trends are identified in certain areas, the actual source of the contamination might be inconclusive, and further investigation would be needed.
- Correlations that exist between seasonal groundwater-level fluctuations, flow directions and gradients, and periods of increased pumping do not definitively imply the fluctuations in groundwater levels are caused by high-production pumping.
- The horizontal and vertical extent of the contamination is not fully delineated. As a result, expansion or reduction in the size of the plume may go undetected.

The conclusions from this evaluation are as follows:

- Groundwater levels and flow directions at the Bluewater site suggest that high-production pumping southeast of the site seasonally influences site groundwater levels and flow directions.
- Contaminant trend data suggests there is no clear evidence that high-production pumping is impacting groundwater quality at wells outside of the 2017 uranium plume; from the available data, geochemical conditions appear to be stable.
- The data used for this evaluation are temporally and spatially sparse. Routine, comprehensive sampling would better inform long-term contaminant concentration trends at nearby, high-production pumping wells.

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1.0 Introduction and Objective

This report is an evaluation from the U.S. Department of Energy (DOE) Office of Legacy Management (LM) of the influences of high-production pumping wells on the contaminated groundwater beneath the Bluewater, New Mexico, Disposal Site (the Bluewater site) located in the Grants-Bluewater Valley in Cibola County, New Mexico (Figure 1). LM initiated this action in response to (1) uncertainties of pumping well influences on the contaminated groundwater raised in the *Site Status Report: Groundwater Flow and Contaminant Transport in the Vicinity of the Bluewater, New Mexico, Disposal Site* (herein referred to as the 2014 Site Status Report) (DOE 2014), (2) and concern of potential movement of the plume expressed by stakeholders in the Grants-Bluewater Valley. This work expands on LM's previous work *Uranium Plumes in the San Andres-Glorieta and Alluvial Aquifers at the Bluewater, New Mexico, Disposal Site* (herein referred to as the 2017 Plume Update Report) (DOE 2019), which provided an updated characterization of the groundwater contamination beneath the site and in offsite areas east and southeast of the site.

The Bluewater site is the location of a former uranium mill (mill) that operated between 1953 and 1982. Former operations resulted in contamination to the underlying aquifers. Groundwater contaminants have included nitrate, molybdenum, selenium, uranium, chloride, and sulfate (DOE 2014). The site was transitioned to DOE under the U.S. Nuclear Regulatory Commission (NRC) general license in 1997, after NRC accepted site reclamation as complete and terminated its specific license with the former licensee, Atlantic Richfield Company (ARCO). DOE is the long-term steward of the site with responsibilities that include monitoring of groundwater contamination in the underlying aquifers resulting from operations at the mill.

The aquifers contaminated by the mill include the San Andres-Glorieta (SAG) aquifer and the ancestral Rio San Jose alluvial aquifer (alluvial aquifer). Both the SAG and alluvial aquifers are valuable resources in the Grants-Bluewater Valley. The SAG aquifer is a primary water source for high-production uses such as municipal, industrial, and irrigation, and lower-production uses such as domestic and livestock watering. The alluvial aquifer is used primarily for lower-production uses by residences that are not connected to municipal water-supply systems (DOE 2014). Previous investigations have indicated local and regional drawdown effects in the SAG aquifer from high-production pumping wells (Baldwin and Anderholm 1992; Frenzel 1992). These drawdown effects have the potential to alter groundwater flow directions in the aquifer, ultimately affecting the fate of the contaminated groundwater.

The objective of this report is to evaluate the recent influence of the high-production pumping wells in the study area on the flow and transport of the contaminated groundwater in the SAG aquifer. The focus is limited to the SAG aquifer because it is the main aquifer in the Grants-Bluewater Valley used by high-production wells.

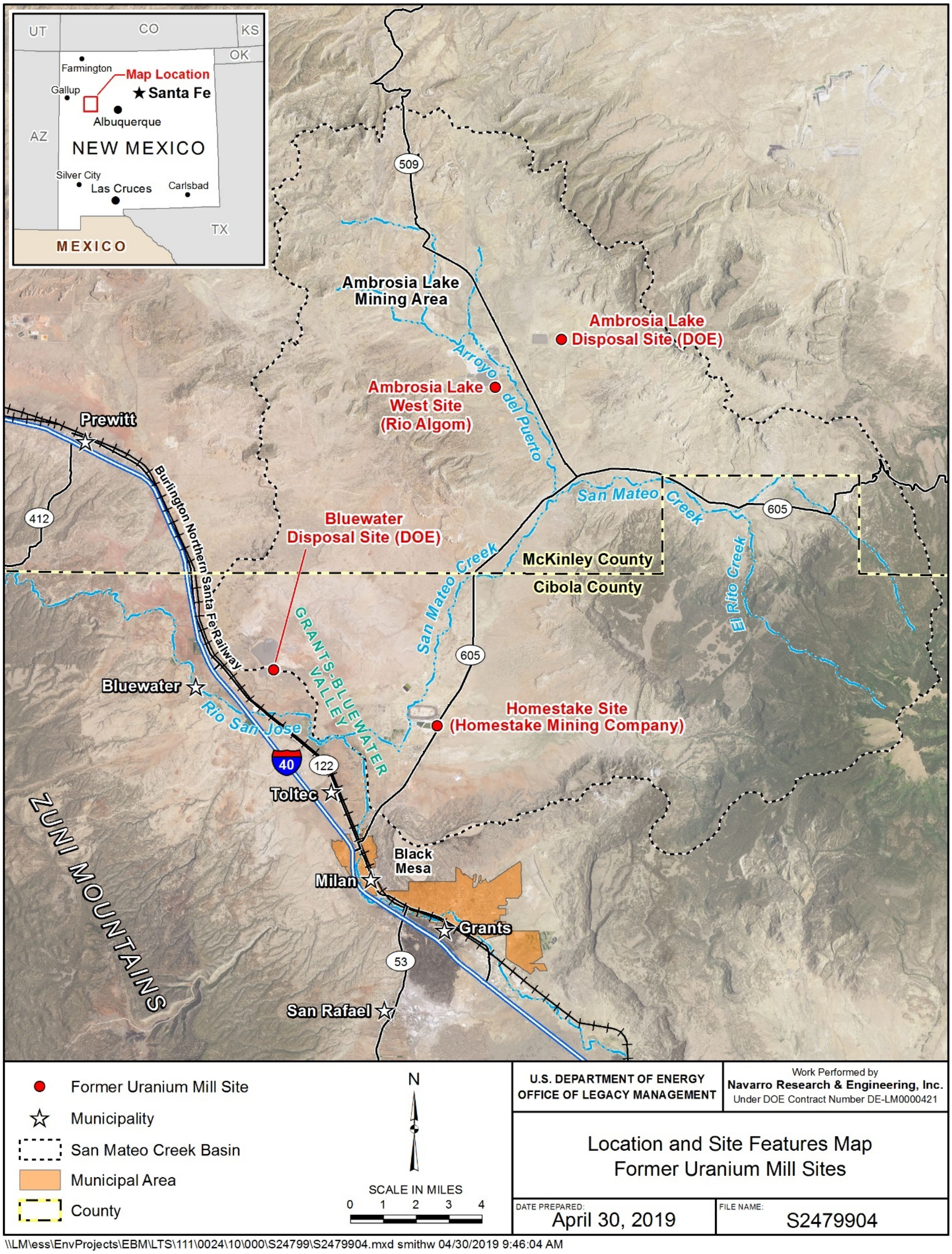

Figure 1. Former Uranium Mill and Disposal Sites in the Grants-Bluewater Valley in Cibola County, New Mexico

This report presents a brief site history with respect to groundwater contamination, the hydrogeology of the SAG aquifer including a summary of the relevant stratigraphy and structure, groundwater flow, current extent of contamination as defined using uranium concentrations, and the groundwater-level and chemistry monitoring programs. Evaluation of high-production pumping impacts includes review of groundwater-level monitoring data to evaluate pumping influences and changes in flow directions and gradients at Bluewater site wells. Water chemistry data collected at the Bluewater site and offsite wells are then used to assess the transport of indicator species by evaluating concentration trends. The scope of work for this evaluation was limited to the use of existing groundwater-level and water quality data. Much of the evaluation was performed using recent data collected from 2012 to 2018. Previous investigations most relied on for this evaluation include those of Baldwin and Anderholm (1992); Frenzel (1992); Applied Hydrology Associates (AHA 1995); DOE (2014); and NMED (2010). Analytical flow modeling to assess drawdown and capture zone from high-production wells was initially considered as part of this evaluation but was deemed too simplistic due to the complexity of the groundwater flow system and transient nature of the pumping.

1.1 Study Area Description

The Bluewater site is in northwest New Mexico, in Cibola County in the western part of the northwest to southeast trending Grants-Bluewater Valley at the base of the Zuni Mountains (Figure 1). The village of Bluewater is about 1.5 miles (mi) to the southwest, the village of Milan is about 6 mi to the southeast, and the town of Grants is about 9 mi to the southeast. The general study area encompasses the Grants-Bluewater Valley, which is defined in this study as the area that extends from the Bluewater site 4 mi to the east and 9 mi to the southeast to Grants. The major features within the study area are shown in Figure 2.

The two main drainages within the Grants-Bluewater Valley are the Rio San Jose and San Mateo Creek (Figure 1). The Rio San Jose is an ephemeral drainage that flows from the northwest to the southeast along the southwest side of the Grants-Bluewater Valley. The San Mateo Creek is also an ephemeral drainage that flows from the northeast to the southwest and joins the Rio San Jose approximately 1 mi south of the site. The San Mateo Creek basin is part of the larger Rio San Jose drainage basin.

1.2 Bluewater Site Background

Processing of uranium ore at the Bluewater mill produced radioactive tailings. The radioactive tailings were stored onsite at two locations, the carbonate tailings pile and the main tailings impoundment, as shown in Figure 2. As early as the late 1950s, seepage from the tailings had been identified as a source of contamination to the underlying alluvial and SAG aquifers (West 1972). To reduce the seepage, in 1960 the Anaconda Copper Company (the predecessor to ARCO) began pumping tailings fluid ponded on the main tailings impoundment to a gravity injection well into a formation below the SAG aquifer, the Yeso Formation. Contamination resultant from tailings fluid injection was identified in the SAG aquifer, and injection was terminated in 1977. Production wells located south of the current Bluewater site boundary were used for a water supply to support milling operations. During the milling operations, uranium and nitrate concentrations above background levels were detected in a SAG water-supply well (Anaconda #2) used as a production well for milling. Pumping was ceased and the last year of uranium ore milling at the site was 1982; mill operations to recover uranium from leachate fluids continued for several more years.

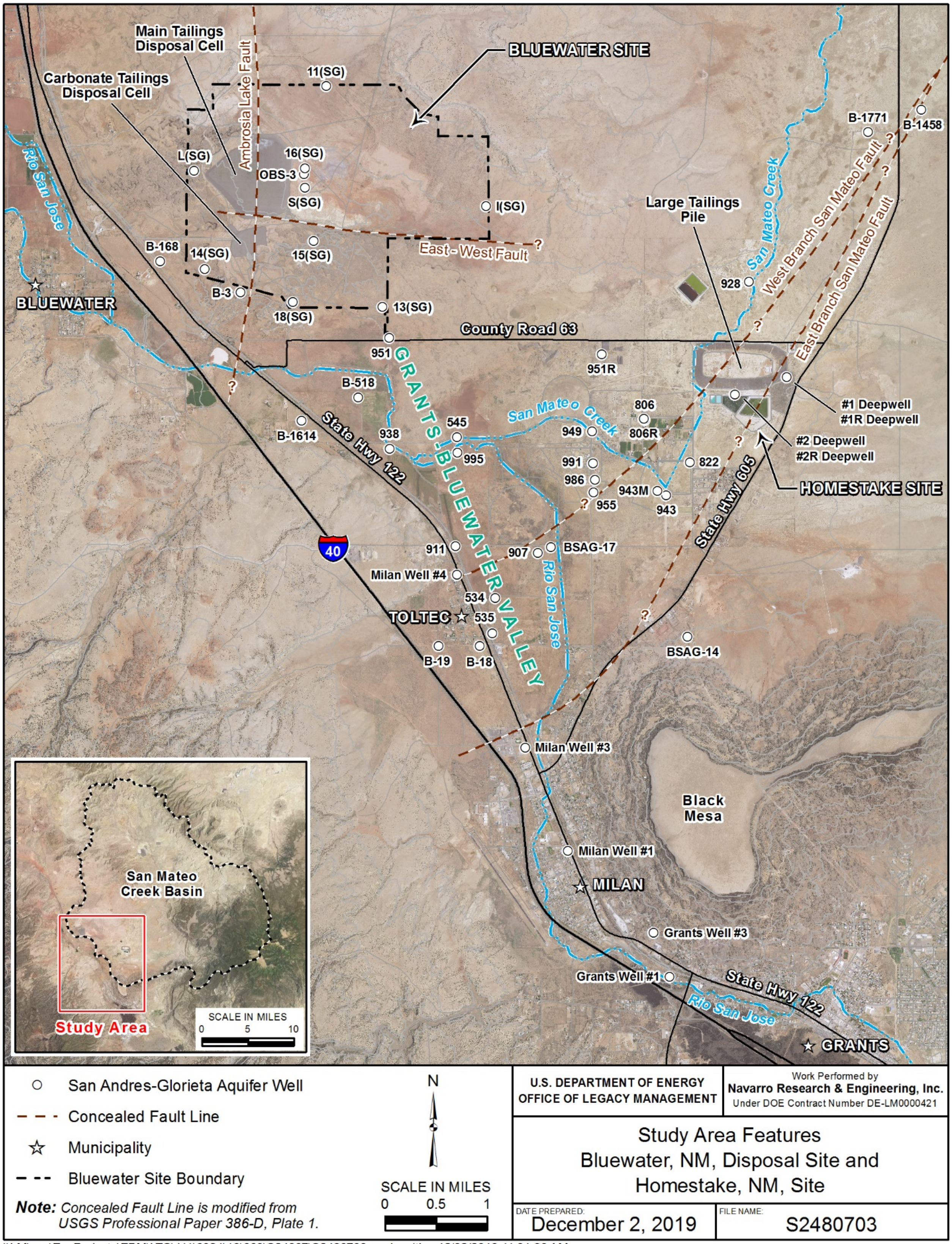

Figure 2. Study Area Features, Bluewater and Homestake Sites

In the early 1980s, ARCO began a series of corrective actions focused on reclamation of the former mill site and minimizing the groundwater contamination stemming from mill operations. The corrective actions included dewatering the main tailings impoundment to the extent practicable via pumping and wick drains to reduce seepage from the impoundment. It was estimated that the wick drains reduced the potential seepage volume of tailings fluid by approximately 40 million gallons (AHA 1993). Another remedial measure was attempted by ARCO that included pumping of contaminated subsurface water from both aquifers (extracted water was piped to the evaporation ponds). Pumping was conducted for a period of less than 1 year, and it was concluded that it did not reduce contaminant levels in water samples collected from wells in either aquifer. Reclamation of the site was completed in 1995 and included encapsulating the tailings piles (known as the Carbonate Tailings Disposal Cell and the Main Tailings Disposal Cell (Figure 2).

In 1996, NRC approved alternate concentration limits (ACLs) for the alluvial and SAG aquifers for point of compliance (POC) wells and identified point of exposure (POE) wells (NRC 1996). POE and POC wells are shown in Figure 3. Currently, well 16(SG) is used as a surrogate for SAG POC wells S(SG) and OBS-3 because the latter wells no longer provide representative chemistry data due to the degraded condition of the well casings (DOE 2014). ACLs were established in the alluvial aquifer for selenium (0.05 milligrams per liter [mg/L]), molybdenum (0.10 mg/L), and uranium (0.44 mg/L) and in the SAG aquifer for selenium (0.05 mg/L) and uranium (2.15 mg/L). These ACLs were based on a health-based concentration limit (0.44 mg/L for uranium) in POE wells for both aquifers at the site's east boundary. The established ACLs formed the basis for groundwater monitoring and other provisions established in DOE's Long-Term Surveillance Plan for the site (DOE 1997). In 2004, New Mexico revised its groundwater standard for uranium from 5 to 0.03 mg/L, consistent with a revised drinking water standard established by the U.S. Environmental Protection Agency (EPA) in 2000.

1.3 Other Uranium Mills and Mines

The study area is located in the San Mateo Creek Basin in which three other former uranium mills and disposal sites, the Homestake Site, the Ambrosia Lake West Site (Rio Algom), and the Ambrosia Lake Disposal Site (DOE) are located (Figure 1). Additionally, 85 legacy uranium mines have been identified in the San Mateo Creek basin (Figure 1) (EPA 2018). The significance of these other uranium mills and mines is that they have adversely affected water quality in the San Mateo Creek Basin. Identifying the source of water quality impacts in select areas within the San Mateo Creek Basin is complicated by the various number of sources. Impact on water quality from the different mills and mines is still under investigation (EPA 2018).

The Homestake site, owned by the Homestake Mining Company (HMC), is a former uranium mill that lies within the study area in the Grants-Bluewater Valley. The Homestake site has contributed to contamination in the Grants-Bluewater Valley primarily in the San Mateo Creek alluvial aquifer (which joins with the ancestral Rio San Jose alluvial aquifer) and Chinle Formation aquifers. HMC is conducting active remediation of the San Mateo Creek alluvial aquifer and Chinle Formation aquifers and has a long-term goal to restore the alluvial aquifer and the Chinle Formation aquifers by reducing the concentrations of contaminants to background concentrations. HMC's remediation effort currently extracts SAG aquifer groundwater and injects this groundwater into the alluvial aquifer to help flush that aquifer and reduce remediation time. Alluvial groundwater entering the Homestake site from the north has elevated levels of uranium and other constituents. Anthropogenic sources of elevated constituents include contributions from historical contaminant releases from the former uranium mines and mills in the San Mateo Creek basin (DOE 2014). This incoming contaminated groundwater complicates efforts to distinguish Homestake-related contamination from offsite sources. Contaminant sources and background levels of alluvial groundwater entering the Homestake site from the north are currently being studied by HMC and others (HMC 2018; EPA 2018; Harte et al. 2019).

The Ambrosia Lake West site and Ambrosia Lake disposal site are in the northern part of the San Mateo Creek basin well outside the study area. Both sites have contributed to elevated constituents in groundwater within the San Mateo Creek basin. Groundwater contamination at the Ambrosia Lake West site is currently present in the alluvium, Tres Hermanos Sandstone Members of the Mancos Shale, and the Dakota Sandstone (EPA 2018). Groundwater contamination at the Ambrosia Lake disposal site is present in the alluvium and Tres Hermanos Sandstone members of the Mancos Shale (EPA 2018). These sites are near the Ambrosia Lake mining area, a significant mining area within the San Mateo Creek basin.

1.4 Geology

The geology of the study area is complex and highlighted by the structural dip to the northeast and faulting. The sedimentary bedrock generally dips 2° to 5° to the northeast as a result of the Zuni uplift, a northwest-trending elliptical dome. Successively younger stratigraphic beds are exposed from southwest to northeast. Figure 4 presents a geologic map of the site, showing locations of the faults in the study area and two cross sections (A–A′ and B–B′), detailed in Figure 5 and Figure 6, respectively. Two main faults identified at the Bluewater site are the Ambrosia Lake Fault and the East-West Fault. Two other main faults located within the study area to the southeast of the Bluewater Site are the West Branch and East Branch of the San Mateo Fault. Cross section A–A′, extending from the Main Tailings Disposal Cell east to the site boundary, shows the offset from the Ambrosia Lake Fault, the structural dip to the northeast, and the general stratigraphic sequence in the northeast area of the site. Cross section B–B′, extending from the Main Tailings Disposal Cell to the southeast corner of the site boundary, shows the offset from both the East-West and the West Branch of the San Mateo Fault.
The relevant geologic formations in the study area range in age from Lower Permian (oldest in age), to the Upper Triassic era, to the Quaternary era (youngest in age). The Lower Permian-era deposits include the Yeso Formation, the Glorieta Sandstone and the San Andres Limestone, the Upper Triassic-era deposits include the Chinle Formation, and the Quaternary-era deposits include the ancestral Rio San Jose alluvium, the Bluewater Basalt flow, and the surficial alluvium. The cross sections shown in Figure 5 and Figure 6 highlight the general stratigraphic sequence below the Bluewater site and extending to the south.

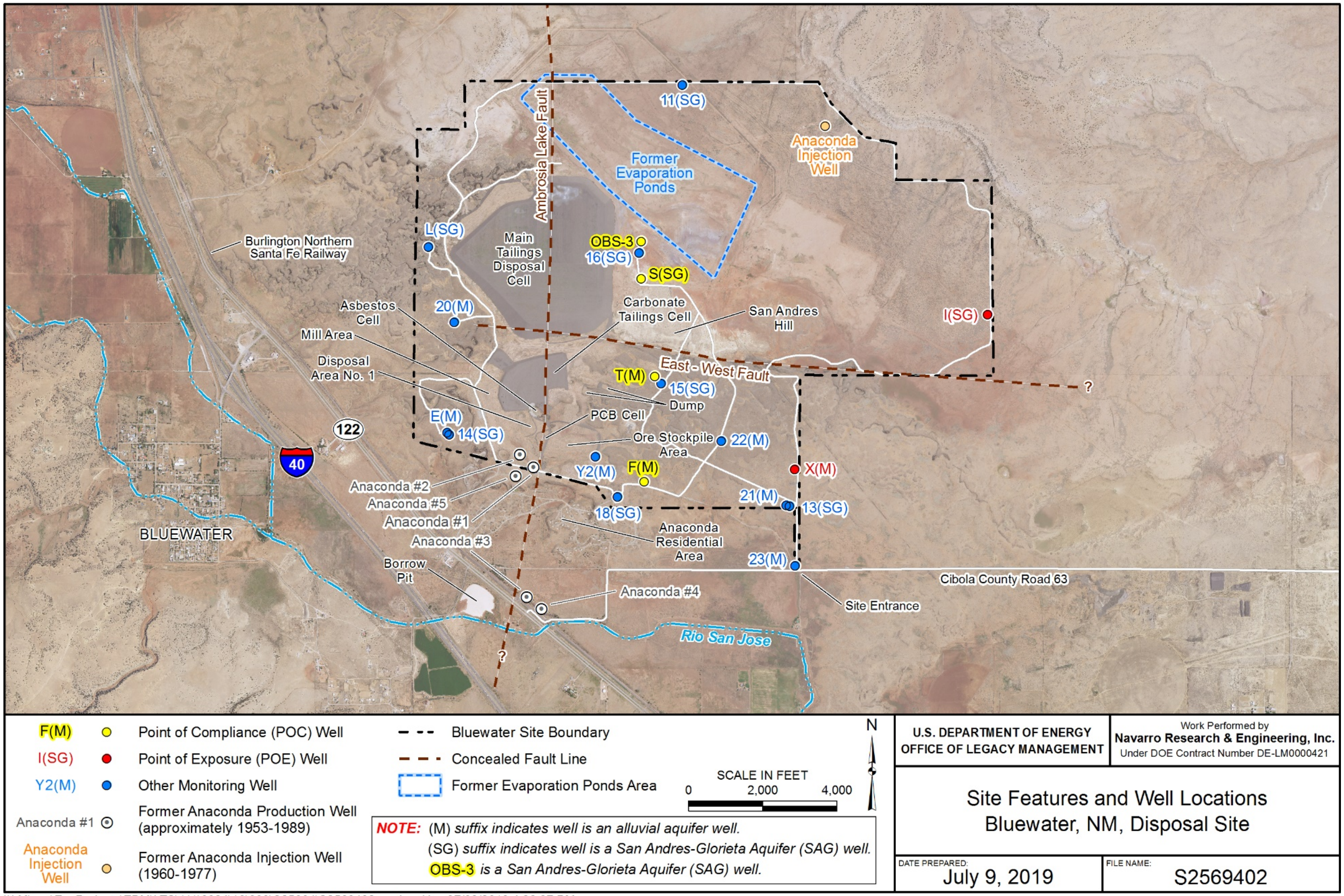

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Figure 3. Site Features and Well Locations, Bluewater Site

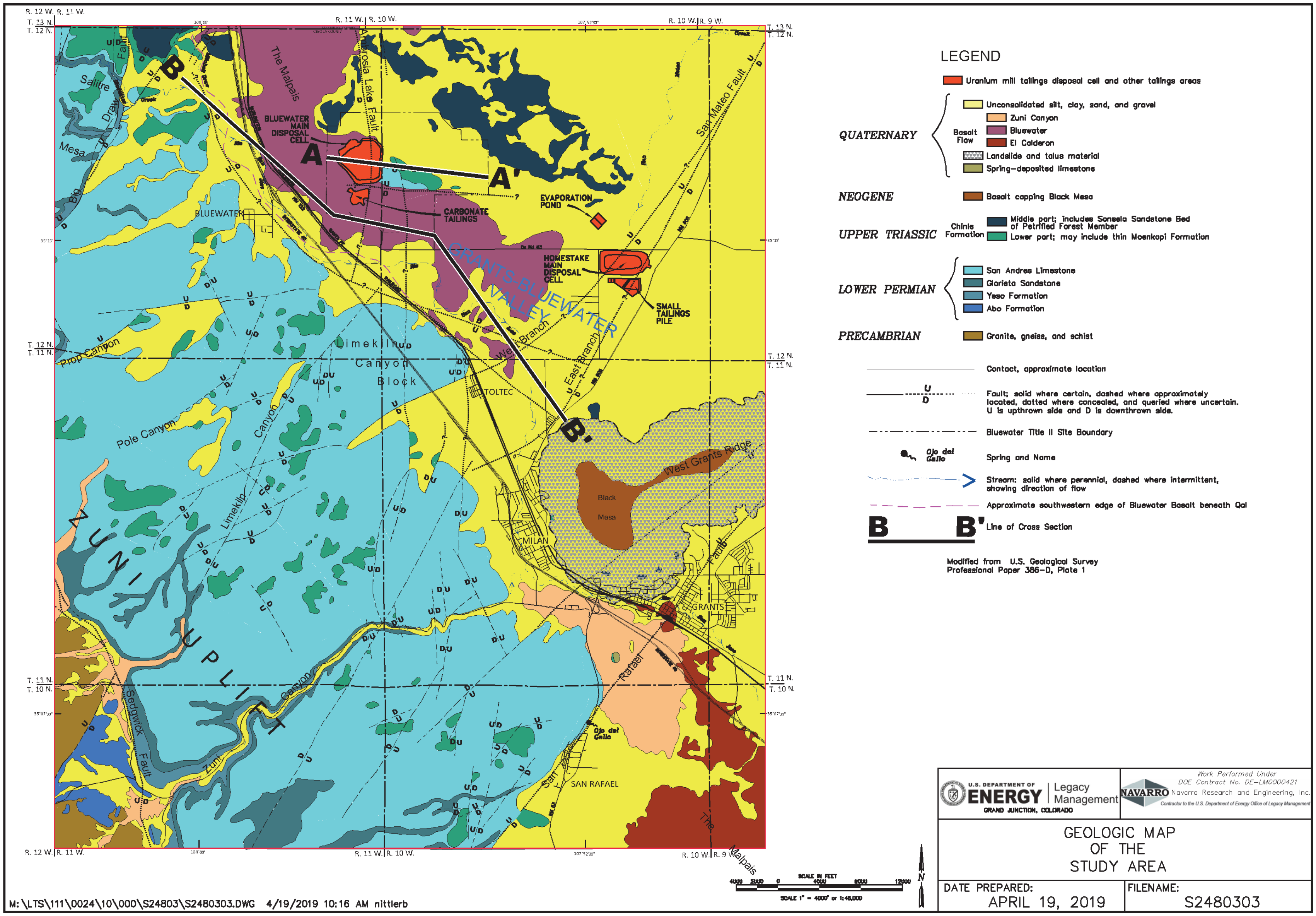

Figure 4. Geologic Map of the Grants-Bluewater Valley Area and East Flank of the Zuni Uplift

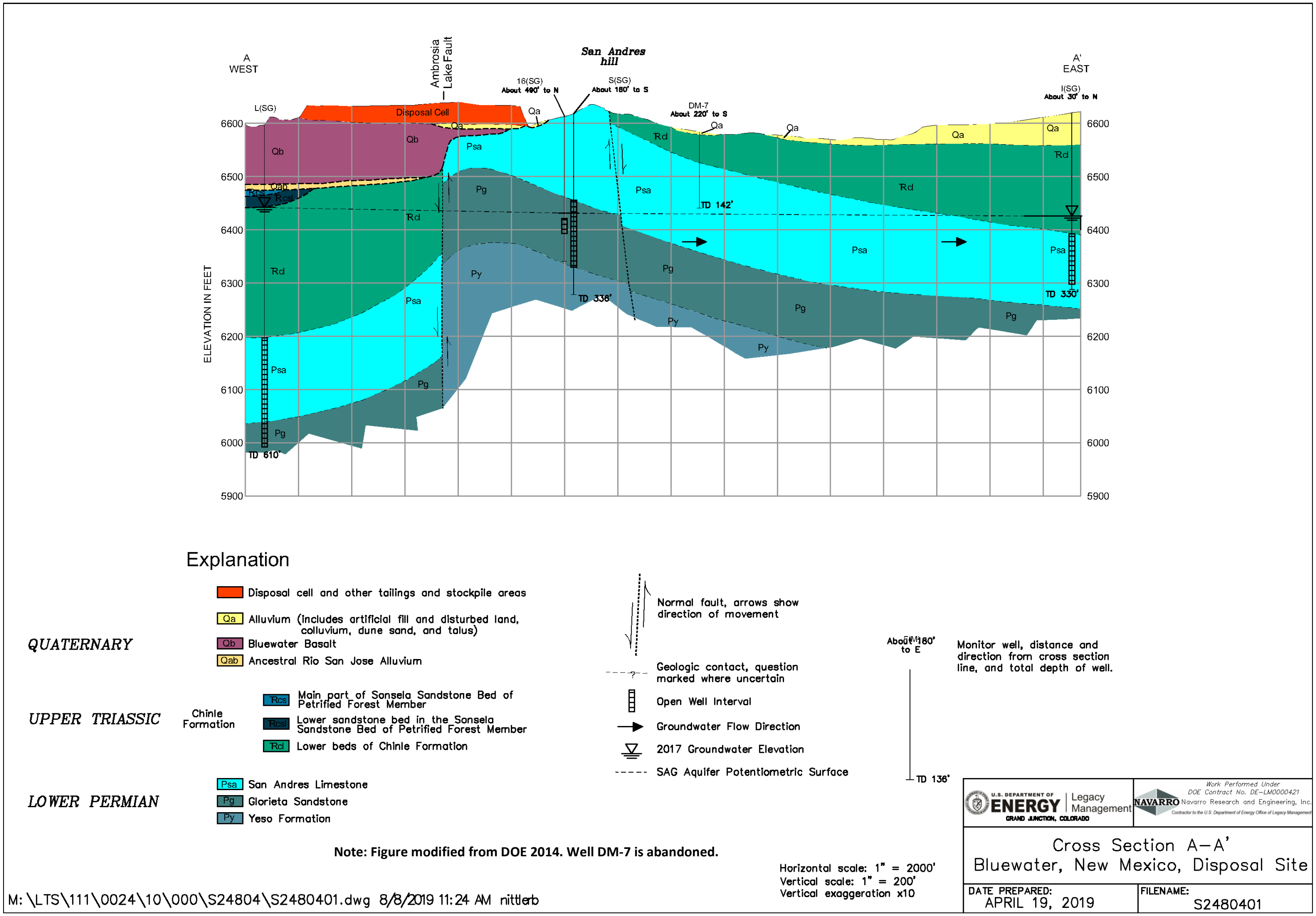

Figure 5. Geologic Cross Section A–A', Bluewater Site

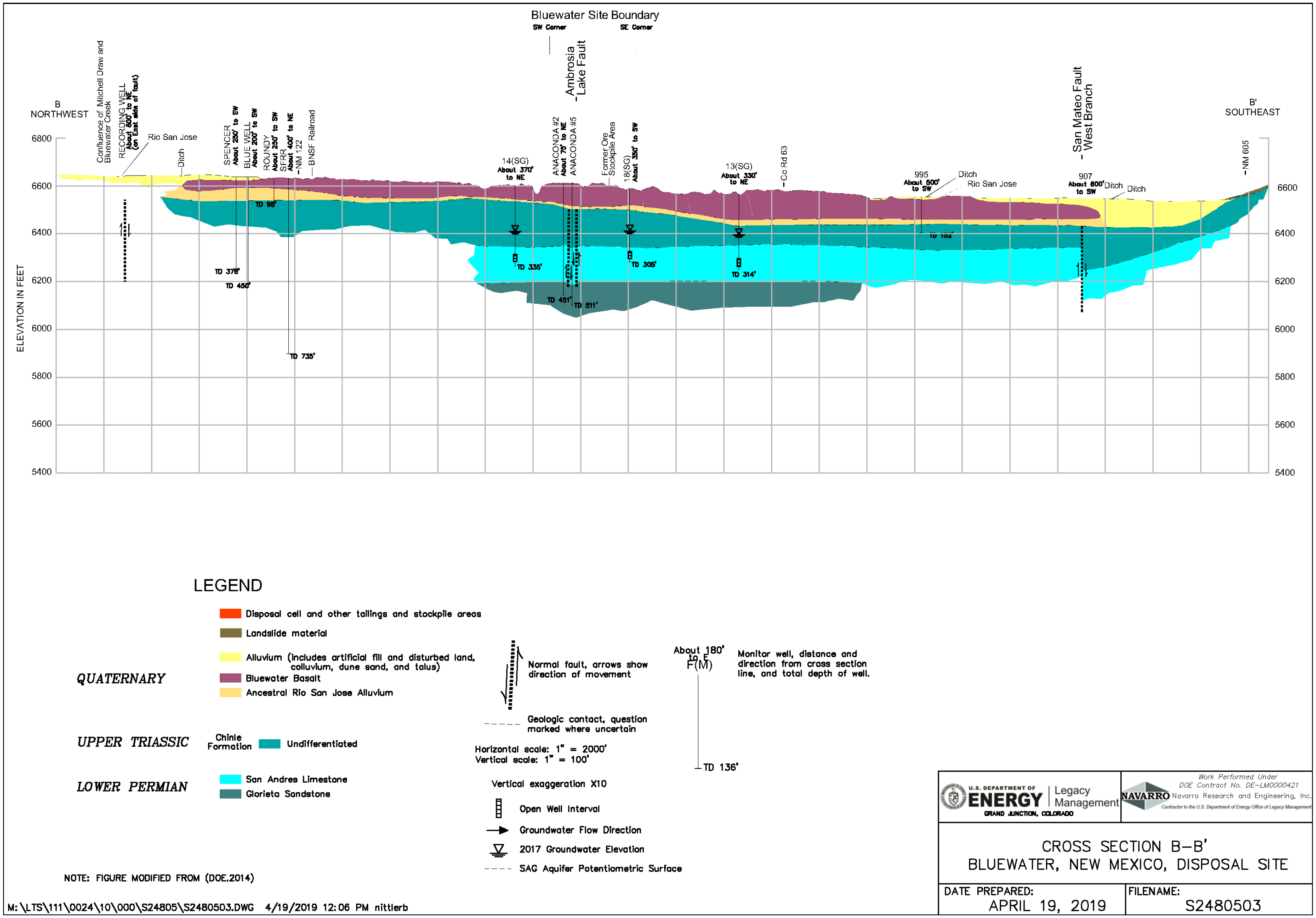

Figure 6. Geologic Cross Section B–B', Bluewater Site

1.5 Hydrogeology

The SAG aquifer is the most productive aquifer in the study area, the primary water source for municipal, commercial, and irrigation water, and a source for domestic use (indoor and outdoor household purpose) and livestock watering on a limited basis. This aquifer includes two geologic formations, the San Andres Limestone and the Glorieta Sandstone, which are treated as one hydrogeologic unit because the contact between them is gradational and difficult to identify and because there is good hydraulic connection between the formations (White and Kelly 1989). The San Andres Limestone is typically a mixture of limestone and fractured limy sandstone, and the Glorieta Sandstone comprises a fine- to medium-grained sandstone (DOE 2014).

The San Andres Limestone is the uppermost formation to the west of the Bluewater site and is exposed along the southwest margin of the valley at the base of the Zuni uplift (Figure 4). The SAG formations dip to the east and northeast beneath the Bluewater site and Grants-Bluewater Valley. Due to faulting, the San Andres Limestone is also exposed at the Bluewater site east of the Ambrosia Lake Fault and north of the East-West Fault (Figure 4). The SAG aquifer is approximately 100–300 feet (ft) below the base of the alluvial aquifer in the area west of the Ambrosia Lake Fault and south of the East-West Fault (Figure 5). In the Grants-Bluewater Valley, the thickness of the SAG unit is about 200–250 ft.

Groundwater moves through the SAG aquifer through both the bedrock matrix and through well-connected fractures, solution cavities, solution channels, and cavernous zones where the limestone has dissolved (White and Kelly 1989; DOE 2014). Transmissivity of the SAG aquifer around the Bluewater site is high and has been reported between 1700 and 414,000 feet^2/day (DOE 2014). The higher transmissivities are attributed to the karstic features of the bedrock.

The Chinle Formation overlies the San Andres Limestone across most of the study area where the SAG unit dips below the ground surface, and the Chinle Formation has not been removed by erosion. This formation is less permeable than the underlying SAG aquifer and is generally regarded as the confining unit near the Bluewater site. Because of faulting and erosion, the Chinle Formation is absent in an area directly beneath the eastern half of the Main Tailings Disposal Cell to approximately 0.25 mi to the east of the Main Tailings Disposal Cell (Figure 4). In the areas where the Chinle Formation overlies the SAG aquifer, the formation acts as a confining layer and SAG aquifer groundwater occurs under confined conditions (DOE 2014).

Despite the Chinle Formation being regarded as an aquitard at the Bluewater site, it has three fine-grained sandstone units that are regarded as aquifers beneath the Homestake site. From youngest to oldest, these intervals are referred to as the Upper Chinle, Middle Chinle, and Lower Chinle aquifers (HMC 2018). The Chinle aquifers present beneath the Homestake site are not present beneath the Bluewater site. Operations at the Homestake site have led to contamination of groundwater within areas of the Upper Chinle, Middle Chinle, and Lower Chinle aquifers.

The extent of the alluvial aquifer in the study area is several miles and goes from upgradient of the Bluewater site to the east end of Grants and generally follows the path of the Rio San Jose and San Mateo Creeks (Figure 6). Throughout most of the study area the alluvial aquifer rests on the Chinle Formation, which acts as an aquitard between the alluvial and SAG aquifer. As a result, the alluvial aquifer and SAG aquifer are not in direct hydraulic communication. In two areas, however, the alluvial aquifer directly overlies the SAG aquifer, which allows for the aquifers to be in direct hydraulic communication. The areas where the alluvial aquifer and SAG aquifer are in contact are in the eastern half of the Main Tailings Disposal Cell (Figure 5) and in an area from that extends about 1 mi north of Toltec to about 1 mi south of Milan.

The Yeso Formation underlies the Glorieta Sandstone and is a relatively less-permeable unit compared with the overlying SAG unit (Hydro-Search 1977). A low-permeable layer in the upper part of the Yeso Formation separates the lower Yeso Formation from the SAG aquifer at the Bluewater site (West 1972).

1.5.1 SAG Aquifer Groundwater Recharge and Discharge

Recharge to the SAG aquifer occurs primarily from infiltration of precipitation where the San Andres Limestone is exposed along the base of the Zuni mountains, seepage from streamflow, deep percolation from irrigation, and seepage from the alluvial aquifer (AHA 1995). Discharge of groundwater from the SAG aquifer occurs to wells, leakage to alluvium, and spring discharge (AHA 1995). The closest identified spring is the Ojo del Gallo spring approximately 12 mi southeast of the Bluewater site; however, no flow has been observed at Ojo del Gallo during the past two decades (DOE 2014).

1.5.2 SAG Aquifer Flow Directions

Groundwater flow directions in the SAG aquifer are controlled by the stratigraphy and structure, transmissivity, and locations of aquifer recharge and discharge. As presented in the 2014 Site Status Report, the ambient flow directions (absence of high-production pumping) in the SAG aquifer are generally from northwest to southeast. The flow direction arrows shown in Figure 7, representing ambient groundwater flow directions in the SAG aquifer, were originally developed by Applied Hydrology Associates (AHA 1995) using hydraulic head data and modified in the 2014 Site Status Report. These ambient flow directions are generally consistent with SAG aquifer flow directions presented by others across the study area (Baldwin and Anderholm 1992; Hydro-Search 1981; and DOE 2014). Groundwater that originates northwest of the Bluewater site flows southeast to the areas north of Milan and Grants. However, groundwater that originates along the base of the Zuni Mountains west and southwest of the Bluewater site generally flows east and then to the southeast toward areas of Milan and Grants. Groundwater flowing in the SAG aquifer underneath the Bluewater site south of the East-West Fault appears to bypass the municipal wells for Milan and heads under Black Mesa in the direction of Grants. The flow path taken by groundwater migrating east across the Bluewater site north of the East-West Fault intersects the Homestake site both north and south of the Large Tailings Pile.

Mapped ambient regional groundwater flow directions in the SAG aquifer in the vicinity of the Bluewater site have historically been consistent over the past 30 years or more (DOE 2014), but it has been recognized that high-production pumping wells can have an influence on localized flow directions. Figure 8 presents a potentiometric surface of the SAG aquifer in 1978 during a period in which multiple high-production pumping wells (Anaconda #1, Anaconda #3, and Anaconda #4) were operated by the ARCO mill just south of the current Bluewater site. Pumping rates from Anaconda pumping wells (#1 through #5), as shown in Figure 3, are estimated to have ranged between 600 and 2000 gallons per minute (gpm) during milling years at the Bluewater site (DOE 2014). As shown, the high-production pumping wells created a cone of depression (spanning at least 1 mi wide) that altered ambient flow directions. Specifically, the pumping appears to have changed groundwater flow at the Bluewater site south of the East-West Fault from southeast to south and reversed local flow directions to the northwest between Toltec and the pumping wells.

Figure 9 presents a potentiometric map developed for the 2017 Plume Update Report (DOE 2019), which represents a more recent depiction of groundwater flow at the Bluewater site. The 2017 potentiometric surface was created using December 2017 groundwater levels. Groundwater-level data from offsite wells were not used to develop the 2017 potentiometric map because offsite groundwater levels are measured in production wells or near production wells and the data are not well constrained. In other words, the sparse distribution of wells makes it difficult to identify true flow directions in offsite areas. As shown in Figure 9, there is a predominant groundwater-flow direction to the east-southeast in the SAG aquifer across the Bluewater site. The effects of the Ambrosia Lake Fault and East-West Fault groundwater elevations and gradients and flow are also discernible. The most noticeable impact is observed along the East-West Fault, west of the Ambrosia Lake Fault (Figure 4), where heads north of the East-West Fault are as much as 14 ft higher than corresponding heads south of the fault. In the east area of the Bluewater site, near well I(SG), the heads north of the East-West Fault are approximately 2–3 ft higher than the corresponding heads on the south side of the fault. This head difference could reflect the East-West Fault's capacity to act as a partial barrier to groundwater flow in the SAG (DOE 2014). In contrast, the Ambrosia Lake Fault, trending south to north beneath the Main Tailings Disposal Cell, appears less of a barrier to groundwater flow. However, the groundwater contours across the Ambrosia Lake Fault show a steeper horizontal gradient occurs north of the East-West Fault relative to the gradient south of the East-West Fault. The steeper horizontal gradient across the Ambrosia Lake Fault coincides with the region where approximately 300 ft of vertical offset between the SAG units occurs (Figure 5).

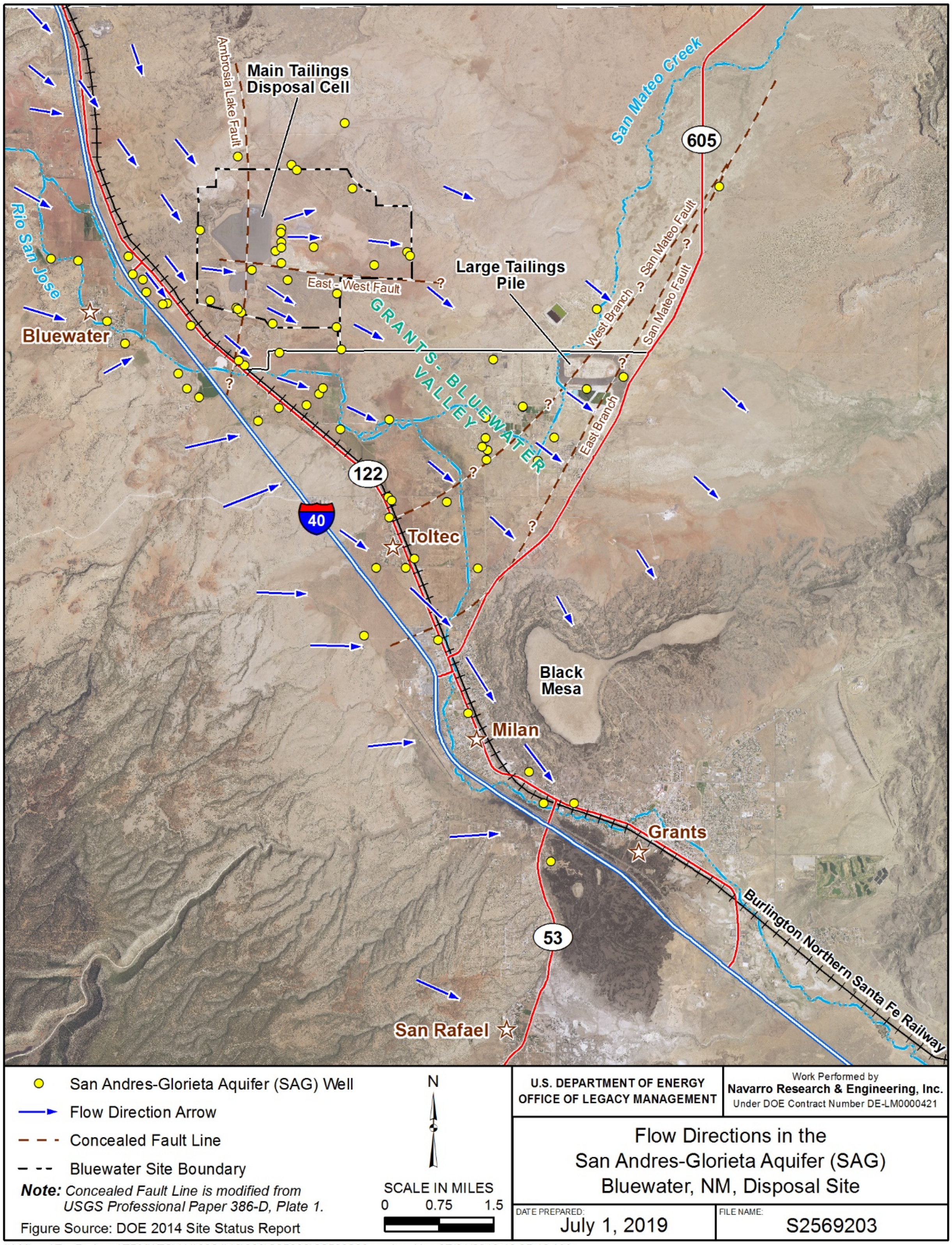

Figure 7. Flow Directions in the San Andres-Glorieta Aquifer, Bluewater Site

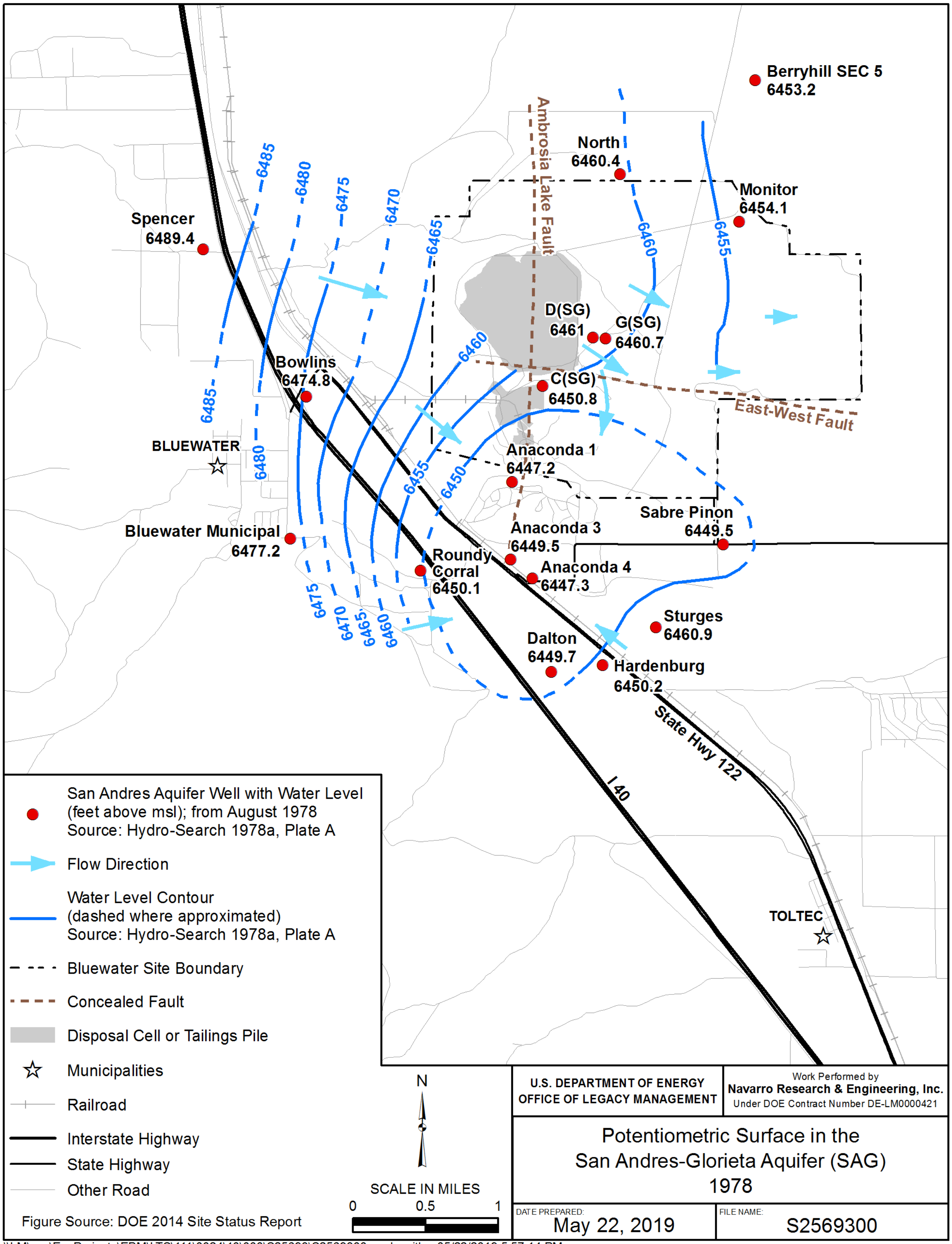

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Figure 8. Potentiometric Surface in the San Andres-Glorieta Aquifer 1978

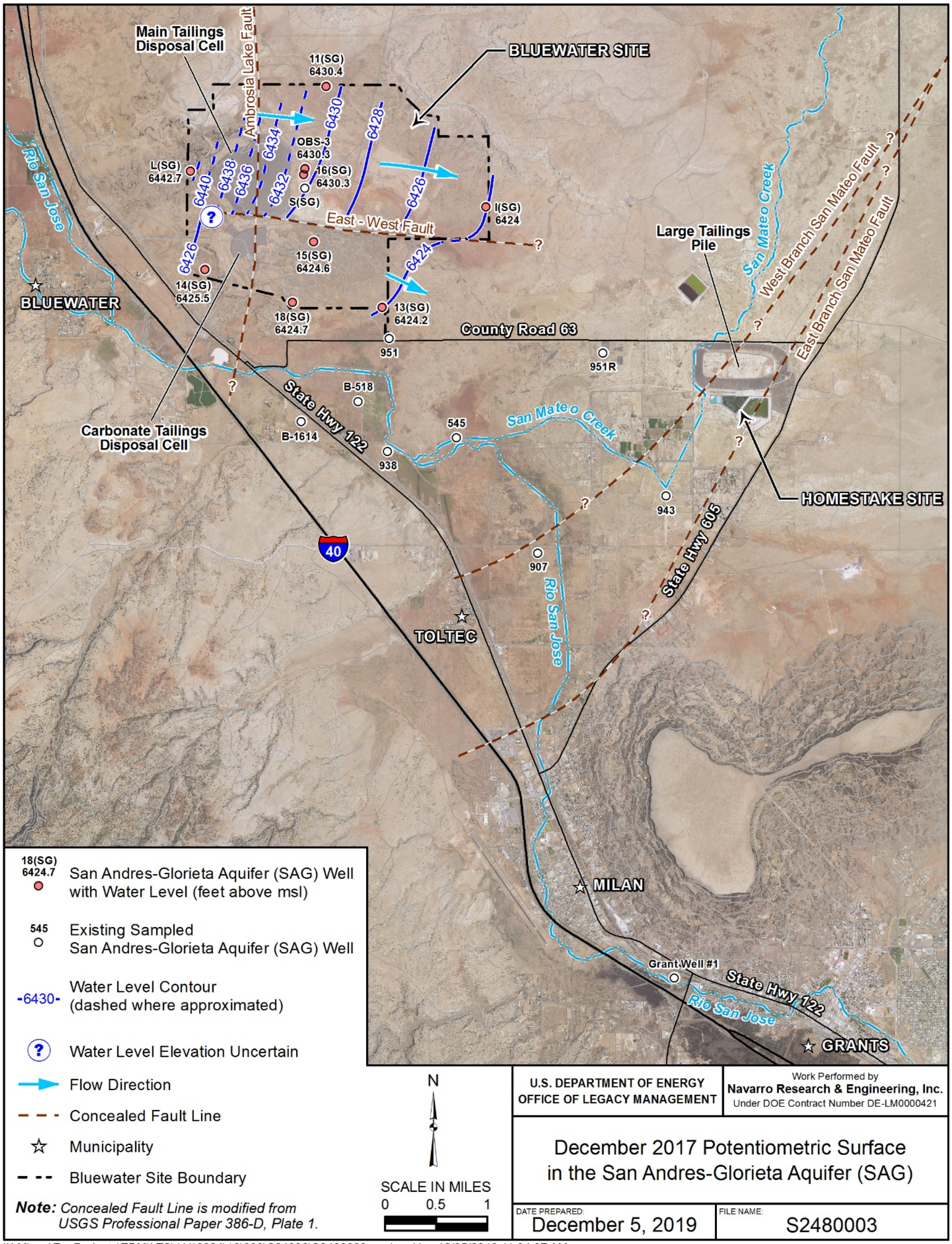

Figure 9. December 2017 Potentiometric Surface in the San Andres-Glorieta Aquifer at the Bluewater Site

2.0 SAG Aquifer Wells Addressed in This Study

This section presents the SAG aquifer wells in the study area and a summary of the monitoring programs.

2.1 SAG Aquifer Wells and Permitted Uses

The SAG aquifer in the study area supports high-production wells used for industrial, irrigation, and municipal supply and lower-production wells used for domestic and livestock watering supply. For the purposes of this study, high-production wells are defined by permitted uses of industrial, irrigation, and municipal water that may pump >15 gpm for long periods (several hours to months); domestic and stock water wells pump small quantities of water between 2 and 15 gpm for short, intermittent periods, in comparison (AHA 1995).

The use of the SAG aquifer has changed over time. As reported by Baldwin and Anderholm (1992), the SAG aquifer began to be used for irrigation in 1944, and by 1954 twenty-eight wells were used for irrigation in the Grants-Bluewater area. Large-scale industrial use started in 1951, and by 1955 irrigation use started to decline. Changes in groundwater use over time have resulted in changes in locations of groundwater-level declines (Baldwin and Anderholm 1992).

In the 2017 Plume Update Report, DOE provided a crosswalk of SAG aquifer wells, their uses, and an inventory of applicable names and identifiers. This crosswalk was not a full inventory, but was assumed to include all current high-production wells, recently abandoned wells, and other wells historically used to monitor SAG groundwater in the study region and downgradient of the Bluewater site. It should be noted that the geology in the study area is complex and well completion details are sometimes incomplete; as a result, not all offsite wells have been confirmed as completed in the SAG aquifer. Ongoing work will continue to evaluate well completion intervals, and the crosswalk will continue to be updated with new information. The crosswalk was developed because there had been little consistency in nomenclature for many of the SAG wells, especially those not owned by DOE or HMC. The SAG wells located in the study area for this evaluation include the wells identified in the recent crosswalk (DOE 2019) and one additional irrigation well (BSAG-17) recently located by the New Mexico Environment Department (NMED) (NMED 2019). Figure 10 shows the locations of these SAG aquifer wells and their permitted uses per the New Mexico Office of State Engineer (OSE). A total of 42 wells are completed in the SAG aquifer within the study area, 10 Bluewater site wells and 32 offsite wells. Two of these offsite wells (B-1771 and B-1458) may be completed in Chinle aquifer but are assumed to be SAG wells until additional investigation is completed. A summary of these SAG aquifer wells and their alternate aliases is provided in Table 1.

A total of 10 SAG wells are permitted for industrial use in the study area. Four of these industrial wells are owned and operated by HMC (#1R Deepwell, #2 Deepwell, #2R Deepwell, and 951R), and five are owned and operated by Tri-State Generation & Transmission Association, Inc. (Tri-State), wells 822, 949, 995, B-18, and B-19. Well B-3 is permitted for industrial use and was formerly used by the Bluewater mill (Anaconda #1) but is currently only used for stock watering (DOE 2019). Industrial supply well 995 is also permitted for irrigation use. Well 951 was historically used for industrial supply by HMC, but is now only used for monitoring. Multiple industrial supply wells have also been recently abandoned by HMC. HMC abandoned #1 Deepwell in 2019 and replaced it with #1R Deepwell, and well 943 was abandoned in 2018. The abandonment of #2 Deepwell is planned to occur in the near future; it will be replaced by #2R Deepwell. The industrial supply wells are located approximately 1.5 to 3 mi south and southeast of the Bluewater site boundary and are in an area within the boundary of the plume to 2.8 mi south of the 2017 uranium plume.

Four wells are permitted for irrigation use in the study area, not including well 995. The irrigation supply wells are 938, 545, BSAG-17, and 806R and are privately owned. Well 806R, operated by the Murray Acres Irrigation Association, was drilled to replace well 806, which was recently abandoned in 2014. Irrigation supply wells identified in Figure 10 are located between 1 and 2.75 mi from the Bluewater site boundary and are between 0.6 and 2.8 mi south of the 2017 uranium plume.

Five wells are permitted for municipal uses (Milan Well #1, Milan Well #3, Milan Well #4, Grants Well #1, Grants Well #3), and one well is permitted for subdivision use (911). According to NMED (2015), well 911 is an inactive well that was historically used for irrigation. These municipal wells range from 2 to 7 mi from the Bluewater site boundary and are between 1.9 and 6.5 mi south of the 2017 uranium plume. The Bluewater Village well is hydraulically upgradient of the Bluewater site and was not included in this study.

Eight wells are permitted for domestic supply (B-168, B-1614, B-518, 955, 986, BSAG-14, B-1771, and B-1458), and three wells (991, 534, and 535) have unknown uses. HMC determined the integrity of well 986 had been compromised and indicated contamination from a shallower aquifer may have been impacting samples from the well prior to 2008 (HMC and Hydro 2009; Hydro 2016).

A total of 13 wells are currently used only for monitoring purposes. Ten of these wells are owned by DOE and are located onsite. One of these monitoring wells (well 951) was converted by HMC in 2012 from a well used for industrial supply to a monitoring well when uranium concentrations became elevated above the 0.03 mg/L groundwater standard. Well 928 (an irrigation well prior to Homestake's milling operations) was used only for monitoring purposes by HMC before being abandoned in 2017 because testing indicated leakage from a shallower aquifer was likely impacting samples from the wells (Hydro 2015).

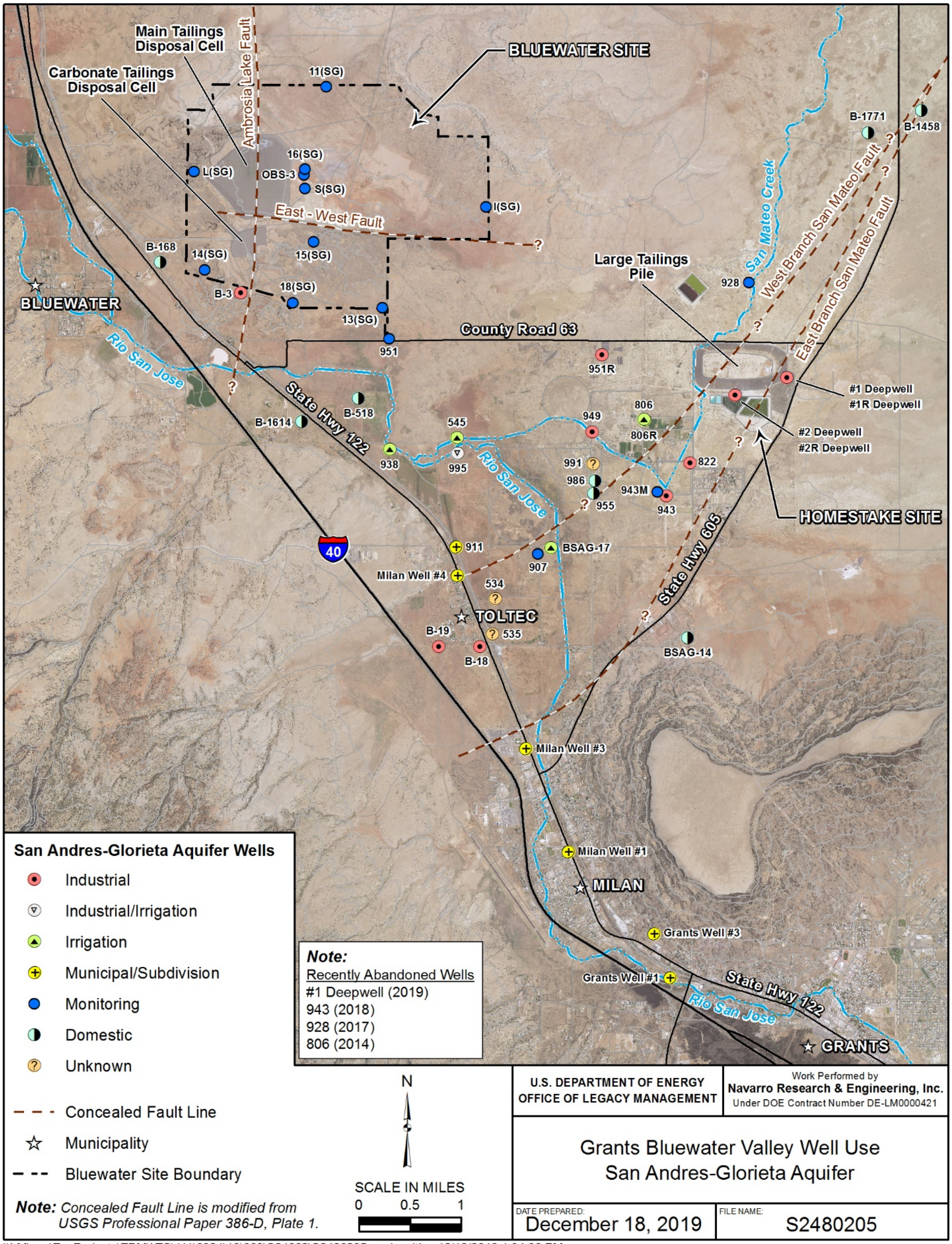

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Figure 10. Grants-Bluewater Valley Well Use, San Andres-Glorieta Aquifer, Bluewater Disposal Site and Homestake Site

Table 1. Summary of Study Area San Andres-Glorieta Wells and Aliases

Study ID	HMC ID	NMED ID	Other Known Aliases	Date Installed	Well Uses	Status as of June 2019
DOE Wells						
11(SG)	--	--	B-410 POD31	7/14/2012	Monitoring	Active
13(SG)	--	--	B-410 POD27	6/27/2012	Monitoring	Active
14(SG)	--	--	B-410 POD28	7/11/2012	Monitoring	Active
15(SG)	--	--	B-410 POD29	6/20/2012	Monitoring	Active
16(SG)	--	--	B-410 POD25	6/14/2012	Monitoring	Active
18(SG)	--	--	B-410 POD30	6/7/2012	Monitoring	Active
I(SG)	0923	BW-28	BW-28, B-410 O-10, HMC-923	7/23/1979	Monitoring	Active
L(SG)	--	BW-25	BW-25, B-410 O-15	1/18/1981	Monitoring	Active
S(SG)	--	BW-26	B 00410 O-14	2/23/1981	Monitoring	Active
OBS-3	--	BW-27	B 00410 O-22	2/23/1981	Monitoring	Active
HMC Wells						
#1R Deepwell	#1R	--	#1R Deep	2018	Industrial	Active
#2R Deepwell	#2R	--	#2R Deep	2018	Industrial	Active
#1 Deepwell	#1 Deepwell	BW-29	UN-HP #1 (HSI No. S-72)	1979	Industrial	Abandoned (2019)
#2 Deepwell	#2 Deepwell	BW-30	UN-HP #2 (HSI No. S-71)	--	Industrial	Active
928	0928	BW-32	Roundy Sec. 23, USGS 351519107513901 (12N.10W.23.233)	Prior to 6/27/1940	Formerly used for irrigation supply, HMC only used for monitoring	Abandoned (2017)
951	0951	BW-34, SMC-01	HMC-951, BW-34, SMC-01, Sabre Piñon, USGS 12N.10W.20.333A = Site No. 351452107552301 (USGS 7 in SSR [DOE 2014])	2/1/1957	Formerly used for industrial supply, now used only for monitoring	Active
951R	0951R	--	B 00028 POD 1340	4/20/2012	Industrial	Active
943M	0943M	New well	B-28, B 00028 POD 1384	12/28/2017	Monitoring	Active
943	0943	BW-33	USGS 351331107523401, USGS 12 in SSR [DOE 2014]*	1/1/1980	Industrial	Abandoned (2018)
Tri-State Wells						
B-18	--	BW-21	B 00018	2/1/1957	Industrial	Active
B-19	--	BW-22	POD B 00019, (B00019 in 2014 SSR)	2/1/1957	Industrial	Active
949	0949	BW-23	B 00044, B-44	2/19/1950 (repaired 7/15/1984)	Industrial	Active
995	0995	--	Tri-State, Plains B-45, B 00045, POD B 00045, B-45	8/1944 (repaired 7/25/1984)	Industrial/ Irrigation	Active
822	0822	--	OSE B-5F, B 00005 F	7/1/1964	Industrial	Active

Table 1. Summary of Study Area San Andres-Glorieta Wells and Aliases (continued)

Study ID	HMC ID	NMED ID	Other Known Aliases	Date Installed	Well Uses	Status as of June 2019
Municipal Wells						
Milan Well #1	0532	BSAG-16, LSM-43	OSE B-23, B 00023, Village of Milan Well #1, HMC-532	6/5/1969 (repaired/ deepened 11/1971)	Municipal	Active
Milan Well #3	0999	BSAG-10, LSM-44	OSE B-35, B 00035, HMC-999, City of Milan Well #3	--	Municipal	Active
Milan Well #4	0998	BSAG-6, BW-16	OSE B-50, B 00050, HMC-998, Village of Milan Well (#4) Golden Acres	1/1/1955	Municipal	Active
Grants Well #1	--	BSAG-11	OSE B-38, B 00038, City of Grants Well #1	8/2/1960	Municipal	Active
Grants Well #3	--	BSAG-12	OSE B-40, B 00040, City of Grants Well #3, HSI Map No. S-66	9/30/1976	Municipal	Active
911	0911	BSAG-5, BW-15	B-49, HMC-911, USGS 351304107541801* (11N.10W.05.212)	4/26/1957	Municipal/ Subdivision Use	Inactive
Irrigation Wells						
806	0806	LSM-41	B-5, B 0005, Murray Acres Irrigation Association	9/1955	Irrigation	Abandoned (2014)
806R	0806R	BSAG-15, LSM-46	B-5 (POD2), B-5R, B-5 CLW, Murray Acres Irrigation Association	3/4/2008	Irrigation	Active
545	0545	BSAG-8, BW-20	B00050A, B-50A, Gutierrez	4/3/1998	Irrigation	Unknown
938	0938	BSAG-4, BW 06	B00196, B-196, USGS 351354107552401 former Cottonwood Well (S-36)	1946	Irrigation	Unknown
BSAG-17	--	--	--	--	Irrigation	Unknown
Domestic Wells						
B-168	--	--	B 00168, B 000168 POD2*	4/12/2011	Domestic	Unknown
B-1614	--	--	B-1614, B 01614	9/21/2004	Domestic	Unknown
B-518	--	BSAG-7, BW-19	B00518 POD2, Smith well, B 00518	6/26/2006	Domestic	Unknown
955	0955	BSAG-1, BW-02	B-510, B00510, HSI Guthrie	3/31/1978	Domestic	Unknown
BSAG-14	--	BSAG-14 LSM-42	--	--	Domestic*	Unknown
B-1771**	--	BSAG-13, LSM-47	Kit South well, B 01771, B 01771 POD1	3/17/2009	Domestic	Unknown
B-1458**	--	BSAG-9, BW-35	B 01458 (Elkins), POD B 01458	3/7/2001	Domestic	Unknown
986	0986	BSAG-2, BW-03	B 00700	4/1/1988	Domestic	Unknown

Table 1. Summary of Study Area San Andres-Glorieta Wells and Aliases (continued)

Study ID	HMC ID	NMED ID	Other Known Aliases	Date Installed	Well Uses	Status as of June 2019
Miscellaneous or Unknown						
B-3	--	--	B 00003 EXPL, B-3-0, Anaconda #1	7/23/1979	Formerly used by Bluewater Mill Site for industrial supply, currently used for stock watering	Unknown
991	0991	BSAG-3, BW 04	B-44*, B 00044*	--	Unknown	Unknown
907	0907	--	B 01827, USGS Site No. 351104107534701 (11N.10W.04.211) (identified as USGS 10 in the SSR [DOE 2014])	Prior to 2/26/1946	Monitoring	Active
534	0534	--	--	7/24/1956	Unknown	Unknown
535	0535	--	Site No. 351216107541701 (11N.10W.04.333), Dow well	7/24/1956	Unknown	Unknown

Notes:
* Information needs to be confirmed.
** Wells may be completed in the Chinle Formation.

Abbreviation:
-- = unknown installation date and/or no aliases

2.2 SAG Aquifer Monitoring

Currently, groundwater monitoring within the study area is conducted by DOE, HMC, NMED, and intermittently by the U.S. Geological Survey (USGS) and EPA. Groundwater characterization and monitoring efforts at the Bluewater and Homestake sites have yielded the largest datasets, with databases maintained by DOE and HMC, respectively. NMED has conducted supplemental monitoring since 2008 at various SAG well locations within this study area and currently partners with DOE to sample offsite private wells. EPA and USGS have recently collected and analyzed data within the San Mateo Creek Basin (and Grants-Bluewater Valley) to evaluate the extent of elevated levels of constituents in groundwater from ambient and anthropogenic sources (EPA 2018; Harte et al. 2019). USGS also continues to periodically measure groundwater elevations at offsite wells around the region and within the Grants-Bluewater Valley. The communities of Bluewater, Milan, and Grants monitor their groundwater supply well networks. Groundwater-level and constituent concentration data for select analytes from these sources are included in the groundwater evaluations in this report.

2.2.1 Bluewater Site

Figure 10 presents the locations of the 10 monitoring wells completed in the SAG aquifer at the Bluewater site. The monitoring network at the Bluewater site has evolved since the site was transferred to DOE in 1997. When the Bluewater site transferred to DOE, the groundwater monitoring network consisted of nine monitoring wells, five monitoring wells in the alluvial aquifer and four monitoring wells in the SAG aquifer (L(SG), 16(SG), OBS-3, and S(SG)).

DOE installed two additional wells in summer 2011, and eight more wells in 2012. SAG aquifer wells 11(SG), 13(SG), 14(SG), 15(SG), 16(SG), and 18(SG) were installed in summer 2012 to gain a better understanding of the hydrogeological characteristics of the SAG aquifer at the site and because a nearby offsite private well (951), just east of the site entrance gate and boundary, had elevated uranium concentrations. Well 16(SG) was installed between wells OBS-3 and S(SG) because their well screens are highly corroded and uranium concentrations were anomalously low. Sample results from wells OBS-3 and S(SG) are not considered to be representative of aquifer conditions. Currently, all Bluewater site wells are sampled semiannually. Since 2012, DOE has employed a continuous water-level monitoring system in monitoring wells using pressure transducers and data loggers (programed to record at 5-minute intervals) connected to the LM System Operation and Analysis at Remote Site (SOARS) system.

2.2.2 Homestake Site

HMC's SAG aquifer monitoring program includes monitoring of five HMC wells (#1R Deepwell, #2 Deepwell, #2R Deepwell, 943M, and 951R) and periodic monitoring of other SAG wells in the study area (806R, 949, 955, and 991). Well 951R replaced well 951 (previously operated as a production well) in July 2012 because DOE suspected that well 951 was pulling the Bluewater SAG aquifer uranium plume to the well. Wells #1R Deepwell and 943M replaced wells #1 Deepwell and 943, respectively, in 2018. Well #2R Deepwell has been drilled to replace #2 Deepwell. Wells #1 Deepwell, #2 Deepwell, and 943 were replaced because testing indicated leakage from a shallower aquifer was likely impacting samples from the wells (HMC and Hydro 2009; Hydro 2015; Hydro 2016; HMC 2017a; HMC 2017b; HMC and Hydro 2018). Some wells may have been compromised due to leakage prior to 2008 (HMC and Hydro 2009). The locations of HMC SAG wells are shown in Figure 10.

3.0 Groundwater Contamination in the SAG Aquifer

Identification of Bluewater site-derived, mill-related groundwater contamination in the SAG aquifer in the Grants-Bluewater Valley is complicated by the variability of constituents in the aquifer. The variability is attributed to several factors such as residence time and flow paths in the aquifer, anthropogenic sources from irrigation and fertilizers, domestic and agricultural waste, various mine and mill-related contamination, downward vertical seepage from the Chinle Formation and alluvial aquifer, and upward seepage from the Yeso Formation (Baldwin and Anderholm 1992; DOE 2014; NMED 2010).

Groundwater contamination in the SAG aquifer from the Bluewater site has historically been defined by various constituents including nitrate, molybdenum, uranium, and selenium (DOE 2014). Dissolved chloride, sulfate, and total dissolved solids (TDS) have also been used as general indicators of mill-related groundwater contamination (DOE 2014). Typically, concentrations of these mill-related indicators are not high enough to definitively imply the source of concentrations. Additional analyses to help define mill-related contamination have included isotopic composition, evaluation of major ions, and radionuclides (DOE 2014; NMED 2010). As of recent, groundwater contamination in the SAG aquifer from the Bluewater site has been illustrated mainly by concentrations of uranium in groundwater (DOE 2014; DOE 2019). Uranium is used as the main constituent of concern because it potentially poses a risk to drinking water users, and it is mobile and widespread in regional groundwater

(DOE 2014). Concentrations of the other constituents (e.g., molybdenum, nitrate, and sulfate) are generally not high enough to be significant threats to human health and the environment. However, for this evaluation, sulfate and TDS are also evaluated.

3.1 2017 Uranium Plume in the SAG Aquifer

The 2017 Plume Update Report (DOE 2019) provided an updated characterization of the groundwater contamination from the Bluewater site. Groundwater contamination in the 2017 Plume Update Report was defined as the areas with uranium concentrations exceeding the EPA drinking water maximum contaminant level and New Mexico groundwater standard of 0.03 mg/L. The extent of contamination although not well defined, has been relatively unchanged (DOE 2014; DOE 2019). As shown in Figure 11, the highest uranium concentrations were detected in well 16(SG) (1.09 mg/L) and well I(SG) (0.29 mg/L) located directly east and hydraulically downgradient from the Main Tailings Disposal Cell. Concentrations of uranium decrease to the east of the Main Tailings Disposal Cell. The north and west boundary of the 2017 SAG uranium plume lies within the Bluewater site, and the south edge of the plume is relatively well-defined using data from non-DOE wells. However, the extent of the plume is not well defined to the east and northeast, due to the lack of wells in this region. Non-DOE wells within the plume boundary include 951, 951R, 928 (abandoned in 2017), and B-3 (well has not been sampled since August 2013). The downgradient extent of the 2017 SAG uranium plume is approximately 2 mi north of the nearest municipal water-supply well in the Grants-Bluewater Valley (Milan Well #4).

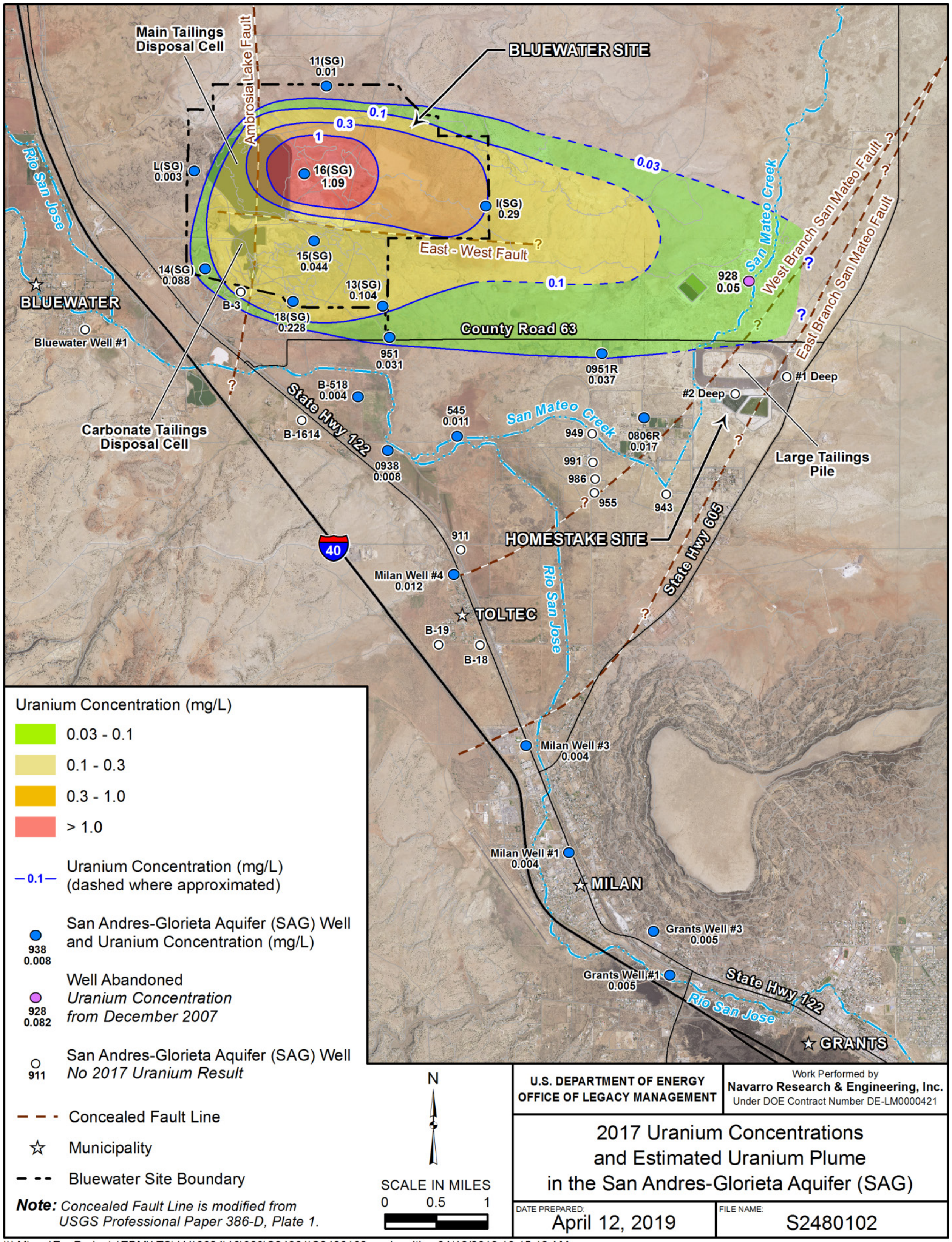

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Figure 11. 2017 Uranium Concentrations and Estimated Uranium Plume in the San Andres-Glorieta Aquifer

3.2 Variability of Mill-Related Contaminant Concentrations in the SAG Aquifer

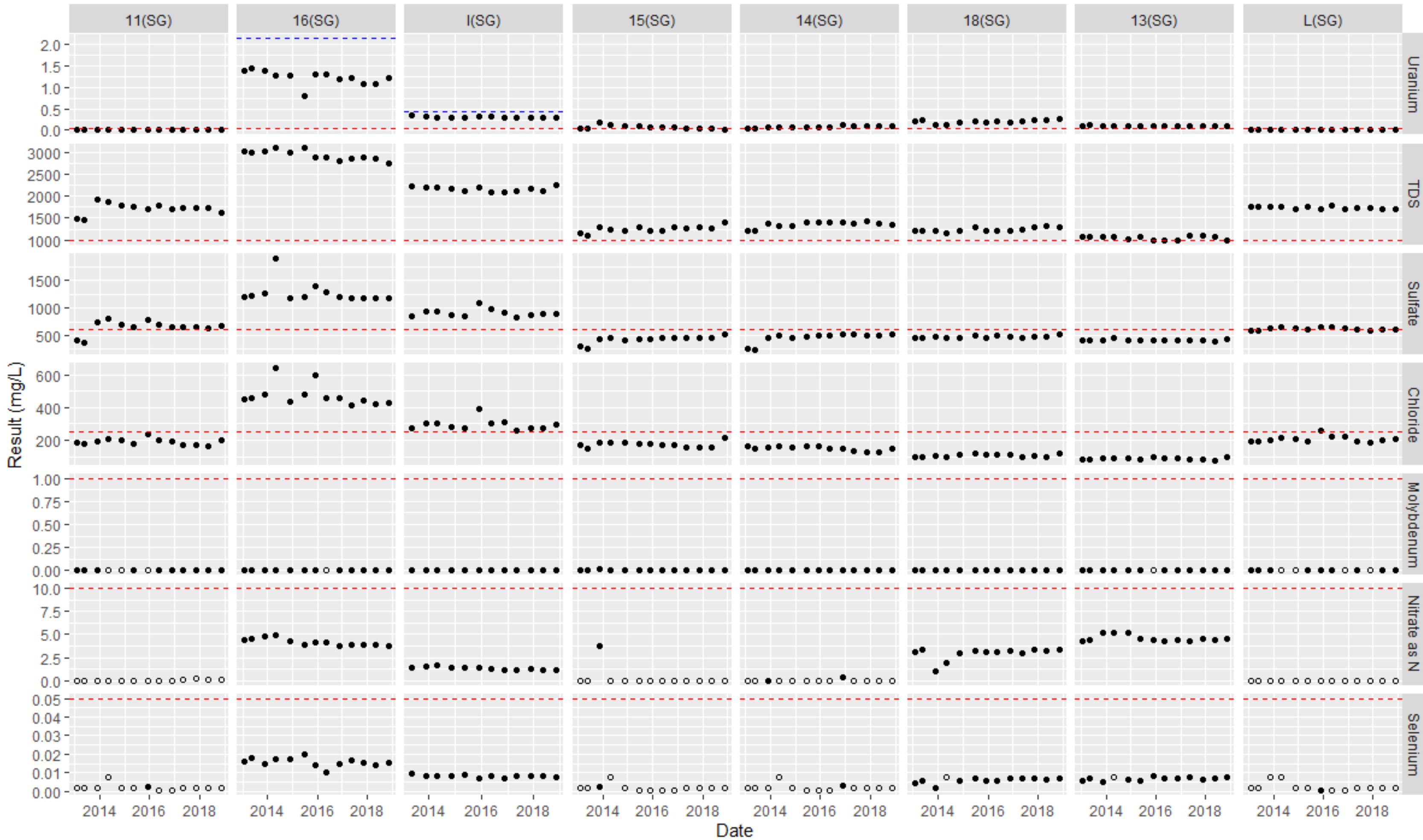
Figure 12 and Figure 13 present time–trend plots of the key indicators of mill-related contamination for Bluewater site and offsite SAG wells, respectively, including the constituents of concern (COCs) uranium, sulfate, chloride, nitrate as nitrogen (N), molybdenum, and selenium (DOE 2014). Although not a COC, TDS is also included as a more general indicator of groundwater quality; elevated levels could also indicate milling-related impacts. Data used to create the plots are from multiple sources including DOE, HMC, NMED, and the New Mexico Drinking Water Bureau (NMDWB). The data presented in Figure 12 for eight Bluewater site SAG wells extends from 2012 through 2018, the period for which most recent data were collected. Datasets for offsite wells are less complete than datasets for Bluewater site wells.

Figure 13 presents data for 13 of the 34 offsite wells. Offsite wells not included in Figure 13 that have fewer than four data points were either not recently sampled or are omitted because testing of the wells indicated leakage from a shallower aquifer was likely impacting samples from the wells. Data presented for the offsite wells extend from 1984 through 2018. It should be noted that Figure 12 and Figure 13 have different *y* scales for each constituent. The dashed red lines on these figures represent the current New Mexico Water Quality Control Commission groundwater standards (New Mexico groundwater standards) for the respective constituents, listed in Table 2.

Table 2. New Mexico Water Quality Control Commission Groundwater Standards (New Mexico Administrative Code 20.6.2.3103)

Constituent	Standard
Uranium	0.03 mg/L
Total dissolved solids	1000 mg/L
Sulfate	600 mg/L
Chloride	250 mg/L
Molybdenum	1.0 mg/L (irrigation use)
Nitrate as N	10 mg/L

The plots presented in Figure 12 and Figure 13 provide insight into concentrations of various constituents at wells with respect to other wells, to New Mexico groundwater standards, and to ACLs established for the Bluewater site. The New Mexico groundwater standards are provided as a reference point and not intended to imply they are contaminant concentrations to which DOE is required to comply. Exceedance of standards does not imply concentrations are higher than background levels or that elevated concentrations are solely the result of milling activities. Furthermore, if a well has higher analyte concentrations than another well, it does not imply the elevated concentrations are the result of milling activities. This is because concentrations can increase along a flow path as more anions and cations are dissolved into groundwater (Freeze and Cherry 1979). This phenomenon was suggested to occur along flow paths within the study area as groundwater flows deeper and deeper to the east (NMED 2010). NMED indicated that TDS, sulfate, sodium, bicarbonate, and selenium concentrations increased in wells along a general transect that extends from the town of Bluewater to the Homestake site. AHA (1995) also reported groundwater quality degrades with distance from the outcrops as more constituents dissolve in groundwater due to leakage from adjacent formations and smaller amounts of recharge.



Notes:

○ Hollow symbol denotes result below detection limit.

⋯ Red dashed line denotes the corresponding New Mexico standard listed in Table 2, included as a reference point, not intended to imply compliance requirement.

⋯ Blue dashed line denotes the ACL limit (2.15 mg/L) for the SAG POC well (16(SG)) and health-based concentration limit (0.44 mg/L) for the SAG POE well (I(SG)).
New Mexico standard is equal to the established ACL for selenium (0.05 mg/L) at well 16(SG).

Figure 12. Time–Concentration Trend Plots for Bluewater Site SAG Wells (2012–2018)

Notes:
○ Hollow symbol denotes result below detection limit.
⋯ Red dashed line denotes the corresponding New Mexico standard listed in Table 1.
* For well 806R, HMC's most recent (5/4/2017) uranium result (0.114 mg/L) is not shown. Value is anomalous and inconsistent with the historical record.

Figure 13. Time–Concentration Trend Plots for Offsite SAG Wells (1984–2018)

As shown in Figure 12, wells 16(SG) and I(SG), located directly downgradient of the Main Tailings Disposal Cell, generally have the highest concentrations for uranium, TDS, sulfate, chloride, nitrate, and selenium. This is a good indication the groundwater in the areas of these wells is impacted by mill-related contaminants. Wells 18(SG) and 13(SG), located along the south edge of the site boundary and south of the East-West Fault and east of the Ambrosia Lake Fault, show elevated levels of nitrate and selenium compared to other wells except 16(SG) and I(SG), but are below the New Mexico groundwater standard. The set of wells that has elevated concentrations of nitrate and selenium is different than the set of wells with elevated TDS. For TDS, Bluewater site wells north of the East-West Fault (11(SG), 16(SG), I(SG), and L(SG), the designated upgradient well at the site) have elevated TDS concentrations compared to those of wells south of the East-West Fault. Concentrations of molybdenum are similar at all wells and, like nitrate and selenium, are well below New Mexico groundwater standards.

Most recent monitoring results from late 2018 show New Mexico groundwater standards for the Bluewater site wells are exceeded for chloride (16(SG) and I(SG)), sulfate (L(SG), 11(SG), 16(SG), and I(SG)), TDS (all wells except 13(SG)), and uranium (all wells except 11(SG) and L(SG)). It should be noted that the ACL for uranium (2.15 mg/L) at SAG POC wells is not exceeded, nor is the health-based concentration limit (0.44 mg/L) upon which it was based exceeded at the POE well. No Bluewater site wells exceed the New Mexico groundwater standards for molybdenum, selenium, and nitrate.

As shown in Figure 13, concentrations of the different constituents in groundwater also vary for offsite wells. A group of wells approximately 1 mi south of the Bluewater site boundary (B-518, 938, and 545) have relatively low concentrations of all constituents, whereas wells 951R and 806R have high concentrations relative to those of other offsite wells. Specifically, uranium concentrations are highest at offsite wells 951, 951R, and B-1771, and wells 951R, 806R, and B-1458 have the highest concentrations for TDS, sulfate, and chloride. The Milan and Grants wells in the southern region of the study area have relatively low concentrations of analytes with respect to those of other offsite wells. However, TDS and sulfate concentrations are typically higher in Milan Well #4 than in the other Milan and Grants wells.

Most recent monitoring results from late 2018 for offsite wells indicate New Mexico groundwater standards are exceeded for uranium (951 and 951R), TDS (951R, 806R, B-1771, and B-1458), sulfate (906R, and B-1458), and chloride (B-1458). Molybdenum, selenium, and nitrate as N concentrations are below the New Mexico groundwater standards for all offsite wells.

4.0 Evaluation of Pumping Influence

Pumping influences on groundwater in the SAG aquifer at the Bluewater site were evaluated by reviewing existing pumping records for high-production wells in the study area, assessing groundwater-level behavior using continuous groundwater-level data, and computing flow directions and gradients over time. If influences of high-production wells occur, it is expected that hydraulic responses in the SAG aquifer can be observed in groundwater-level data. The hydraulic responses will be influenced by the locations of wells and rates, timing, and duration of pumping, but will also be influenced by aquifer properties (transmissivity and storage), structural features of the aquifer (faults or conduits), and conditions of groundwater flow (confined or unconfined).

As discussed in Section 1.5.1, influences from high-production pumping have previously been observed at the Bluewater site during active mill operations when the Anaconda production wells were used between 1960 and 1982 (AHA 1995). Locations of these Anaconda production wells are shown in Figure 3. Previous studies have also demonstrated local and regional drawdown effects in the SAG aquifer from high-production pumping wells (Baldwin and Anderholm 1992; Frenzel 1992). These drawdown effects have the potential to alter groundwater flow directions in the aquifer locally and regionally, ultimately affecting the fate of the contaminated groundwater. Frenzel (1992) evaluated and forecasted pumping responses in the SAG aquifer in the region and estimated a drawdown of 10 ft from pumping would be observed about 3 mi away after 1 year of pumping at a theoretical discharge of 10,000 acre-feet for irrigation. Frenzel also forecasted about 25 ft of drawdown in the Grants-Bluewater area after 35 years of pumping under the theoretical irrigation pumping scenario. Frenzel's study demonstrates that drawdown at the Bluewater site monitoring wells may be possible from pumping from wells within the study area.

4.1 SAG Aquifer Pumping

In order to understand the recent pumping history from high-production wells in the study area, a search was conducted for pumping records for industrial use wells operated by HMC, Tri-State, municipal wells operated by Grants and Milan, and irrigation wells. Pumping records for the industrial and municipal wells were located; however, no pumping records were found for irrigation wells. Irrigators are not required by OSE to submit pumping records, but permitted annual diversion amounts were retrieved.

Monthly pumping records for HMC industrial wells were obtained from NRC Agency Documents Access and Management System (ADAMS) records and a database provided by HMC. For some periods, HMC's pumping was reported for individual wells, and for other periods, HMC's pumping was reported as a combined pumping rate for all wells. Pumping records from Tri-State wells and the Grants and Milan wells were obtained from OSE's New Mexico Water Rights Reporting System. Tri-State also provided pumping records not found in OSE's database, to fill in data gaps.

Pumping records were tabulated for the period of 2012–2018, consistent with the period of record for continuous groundwater-level monitoring at Bluewater site wells. Tabulated pumping records are provided in Appendix A.

Figure 14 presents a bar chart summarizing the monthly pumping records for HMC, Tri-State, and Grants-Milan municipal wells. In some cases, pumping was reported from mid-month to mid-month. If this occurred, an assumption was made that the pumping reported for that period was entirely for the first month. In other cases, pumping was provided for a 2-month period or more. If this occurred, the pumping was divided equally between each month for that period of record.

Figure 14. Pumping Records for Industrial and Municipal Use Wells in the San Andres-Glorieta Aquifer

Since 2012, combined pumping from the HMC wells typically has been less than 200 acre-feet per month (1490 gpm), with an average of 128 acre-feet per month (950 gpm). Pumping from HMC wells dramatically decreased in early 2016. Pumping rates were not available for each individual HMC well for the period of interest, so pumping rates for HMC wells are reported as a total for all wells (#1 Deepwell, #2 Deepwell, 951, 951R, 943). Pumping from well 951 was discontinued in March 2012 and was replaced by that of 951R. The majority of recent pumping (2017 and 2018) was from the #2 Deepwell and 951R wells. The combined average pumping rate from the Tri-State wells was 198 acre-feet per month (1470 gpm). Pumping from Tri-State wells since 2012 has occurred at wells B-18, B-19, and 949, but no reported pumping occurred at wells 822 and 995. Combined pumping from the Grants and Milan municipal wells on average is 243 acre-feet per month (1810 gpm), with pumping rates higher in the spring and summer and lower in the winter. Average combined pumping from both municipal and industrial wells in the study area was approximately 568 acre-feet per month (4220 gpm). Overall pumping trends for combined industrial and municipal use show higher pumping in the spring and summer and lower pumping in the winter.

Although no pumping records for irrigation wells were found, irrigation wells can be expected to operate strictly during the irrigation season (typically March through October) when municipal pumping is highest. Review of OSE records indicates the combined permitted amount for irrigation use from wells 806R, 938, and 545 is approximately 1240 acre-feet per year (1150 gpm over 8 months). No records were found for BSAG-17. Well 995, permitted for both industrial and irrigation use, is assumed to be only used for industrial supply. It is possible that other unidentified wells used for irrigation exist in the study area.

4.2 Groundwater-Level Trends

Groundwater levels in the SAG aquifer fluctuate with changing rates of recharge and discharge. Infiltration from precipitation is a main source of recharge, and pumping from high-production wells is a main source of discharge in the study area. Baldwin and Anderholm (1992) demonstrated how SAG groundwater levels were influenced by both precipitation and pumping. This section evaluates both long- and short-term groundwater-level hydrographs and compares them to precipitation and pumping data.

4.2.1 Long-Term Groundwater-Level Trends

Long-term groundwater trends are best illustrated using groundwater-level data collected by USGS, which has been monitoring groundwater at wells in the Grants-Bluewater Valley dating back to the 1940s. Although the USGS monitoring records can be sparse, they help show long-term groundwater-level trends at various wells in the study area. Two offsite wells monitored by the USGS (wells 951 and 535) were used to illustrate the long-term groundwater-level trends in the study area. Well 951 is located on the southern border of the Bluewater site and has also been monitored by HMC and DOE, and well 535 is located approximately 3 mi to the southeast of the Bluewater site (Figure 10). As shown in Figure 15, groundwater levels in the SAG aquifer in these two wells generally increased from 1957 to 1989 and decreased after 1999 to 2018. The timing and magnitude of these changes were similar until about 1994. Between 1999 and 2018, the groundwater level in well 951 decreased more than 50 ft, whereas the groundwater level in well 535 decreased approximately 8 ft. This difference in drawdown may be attributed to the pumping of well 951 by HMC from 1999 to 2012.

Figure 15 also presents the cumulative departure from average annual precipitation from 1954 through 2016. The cumulative departure from average annual precipitation is helpful in identifying periods when precipitation was less or greater than average. The red line in Figure 15 represents the average annual precipitation (10.3 inches) at the Grants Airport, New Mexico (Station 2973682), for the period of record 1954–2016. As expected, Figure 15 shows that groundwater levels generally increased when the cumulative departure from average annual precipitation was increasing (1964–1999) and generally decreased when cumulative departure from average annual precipitation was decreasing (1999–2018). Further comparison shows that during some periods, the trending between precipitation and groundwater levels is inverse. For example, from 1995 to 1999 groundwater levels in well 951 decreased, but the trend line showing cumulative departure from average annual precipitation increased, which indicates a wetting period. This inverse correlation could reflect changes in pumping in the SAG aquifer.

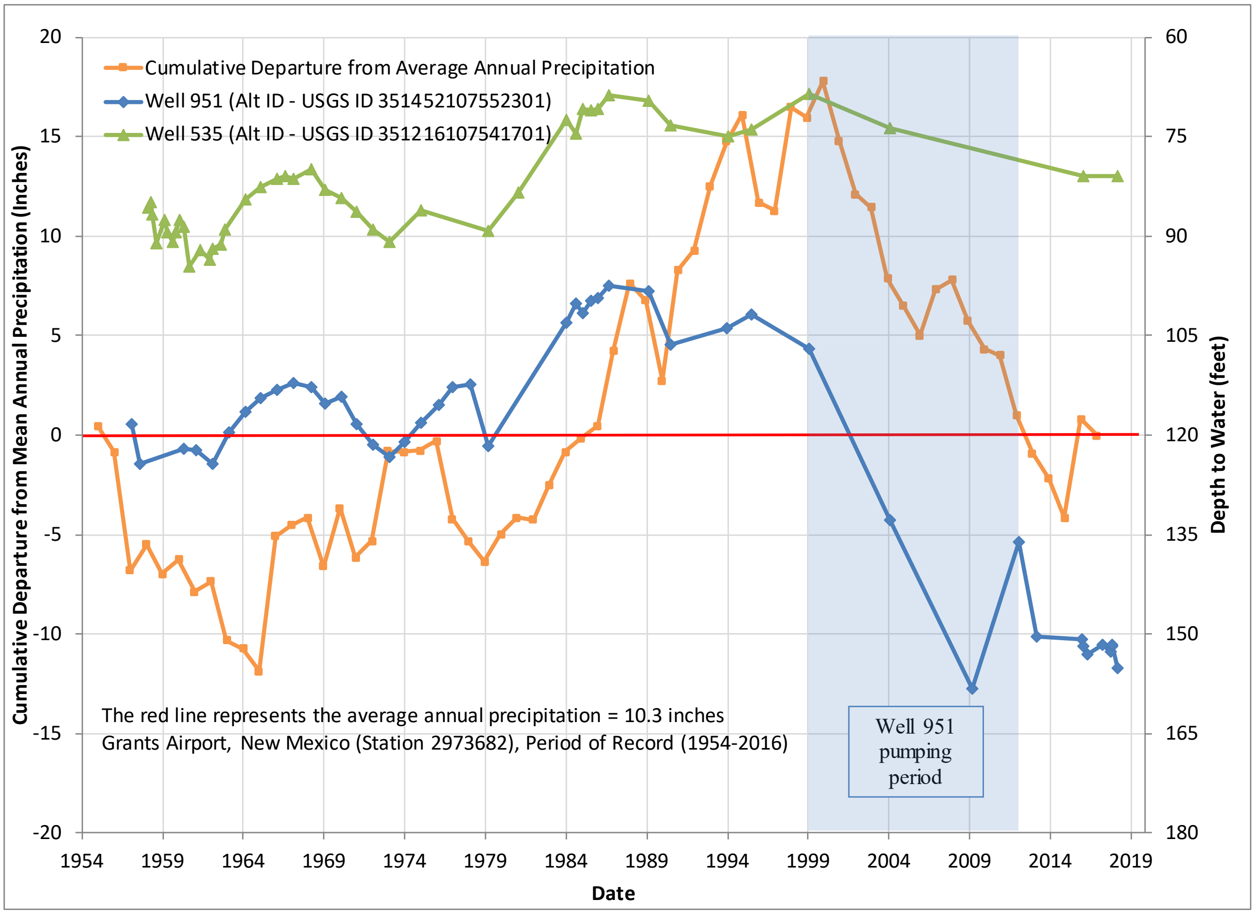
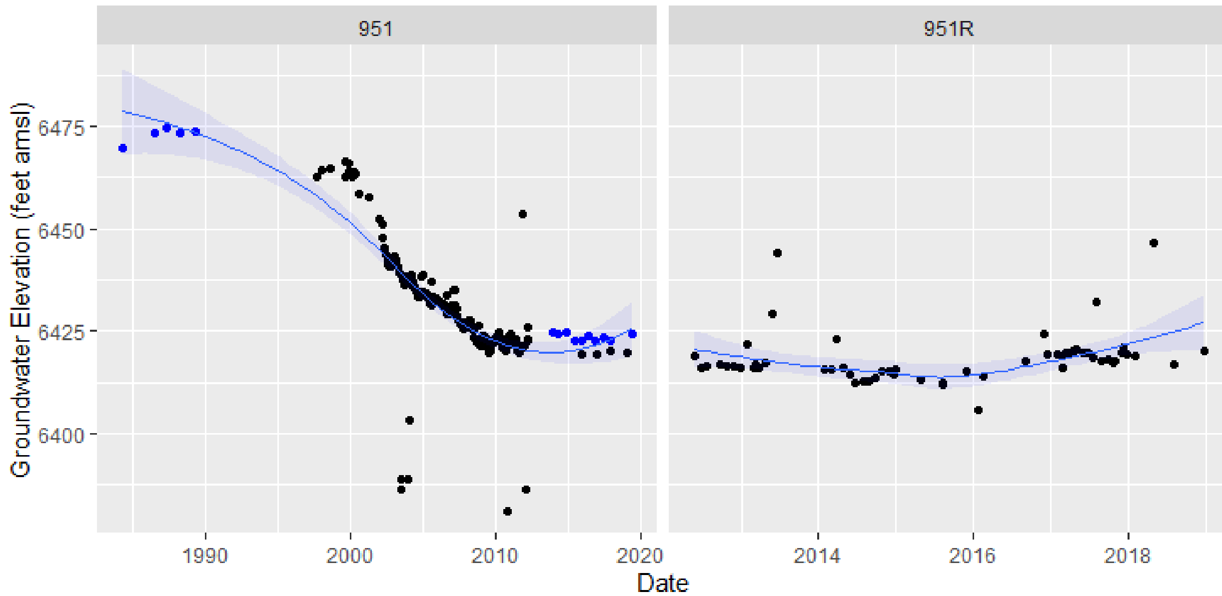


Figure 15. Cumulative Departure for Annual Average Precipitation (1954–2018) and Groundwater Elevations in the SAG Aquifer

4.2.2 Offsite SAG Aquifer Well Hydrographs

Groundwater levels in some offsite wells have been more routinely collected by HMC. Although the monitoring records of offsite wells by HMC does not extend as far back as the USGS records, HMC datasets contain groundwater levels collected at more frequent intervals. Figure 16 shows hydrographs for two HMC wells (951 and 951R). These wells contain some of the more complete groundwater-level datasets for offsite wells and are within the boundary of the 2017 uranium plume. The hydrograph for well 951 uses data from both HMC (black dots) and DOE (blue dots) for a period of record of 1984–2018 and shows the groundwater level decreased by over 50 ft between 1999 and 2018, consistent with the observed response from the USGS dataset in Figure 15. HMC began pumping well 951 in 1999 and discontinued pumping the well in 2012 when 951R was installed as a replacement. The hydrograph for well 951R extends from 2012 through 2018 and shows that groundwater levels in well 951R generally decline between 2012 and early 2016 and increase from 2016 to 2018. This response relates well with the pumping record reported by HMC. HMC began pumping well 951R in 2012; pumping from all HMC pumping wells decreased in 2016.



Notes: Blue dots are groundwater levels measured by DOE, and black dots are groundwater levels measured by HMC. Groundwater elevations for 951R above 6450 and below 6400 are considered outliers and were omitted from the evaluation.

Figure 16. Groundwater Levels at Select Offsite Wells 951 and 951R

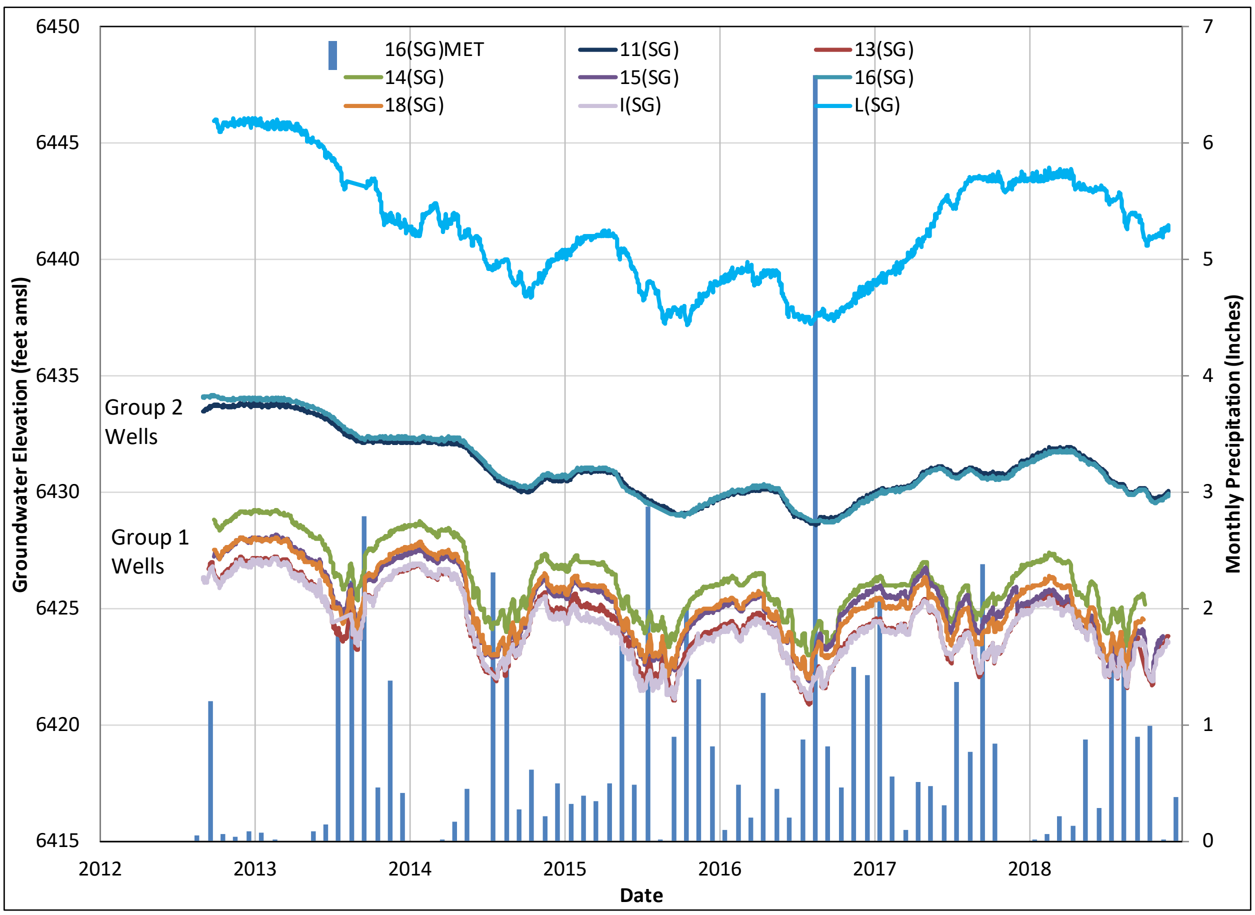
4.2.3 Bluewater Site SAG Aquifer Well Hydrographs

As discussed above, since 2012, DOE has employed a continuous water-level monitoring system in eight monitoring wells recording at 5-minute intervals. Figure 17 presents these continuous groundwater-level records for the period of late 2012 through late 2018. The high-frequency, continuous groundwater-level monitoring detects shorter-term trends and patterns. As shown, groundwater levels generally decreased from the end of 2012 to mid-2016 and have increased from mid-2016 to mid-2018. However, groundwater levels in wells in different areas across the site show different seasonal and shorter-term (monthly) trends. For example, wells 13(SG), 14(SG), 15(SG), 18(SG), and I(SG) (Group 1 wells) all show similar trends where groundwater levels are typically 4 to 5 ft higher in the fall, winter, and early spring and decrease in late spring, summer, and early fall when pumping in the SAG aquifer is highest. For the purposes of this discussion, spring is assumed to begin on March 1, summer on June 1, fall on September 1, and winter on December 1. These wells also show patterns of shorter-term fluctuations (approximately 1 month in duration) that typically occur in the summer months. Group 1 wells 13(SG), 14(SG), 15(SG), and 18(SG) are all located south of the East-West Fault, and Group 1 well I(SG) is located north of the East-West Fault but far enough east to where the groundwater levels in the SAG are under confined conditions (Figure 5). The similar groundwater-level trends reflected in well I(SG) and wells 13(SG), 14(SG), 15(SG), and 18(SG) may indicate the influence of the East-West Fault on groundwater flow may not extend much further east than the Bluewater site boundary.

Wells 16(SG) and 11(SG) (Group 2 wells), both north of the East-West Fault and east of the Ambrosia Lake Fault, also show a similar groundwater-level trend. Groundwater levels in these wells fluctuate less (typically less than 2 ft) seasonally, and the shorter-term (monthly) groundwater-level fluctuations are not observed in these wells.

Well L(SG) is the site background well upgradient of the Main Tailings Disposal Cell (north of the East-West Fault and west of the Ambrosia Lake Fault). Groundwater-level trends in well L(SG) are unique in comparison to those of the other well groups. Seasonal groundwater levels in L(SG) fluctuate as much as 4 ft in a given year, similar to groundwater-level fluctuations in Group 1 wells; however, these wells show a dampened response to these seasonal fluctuations.

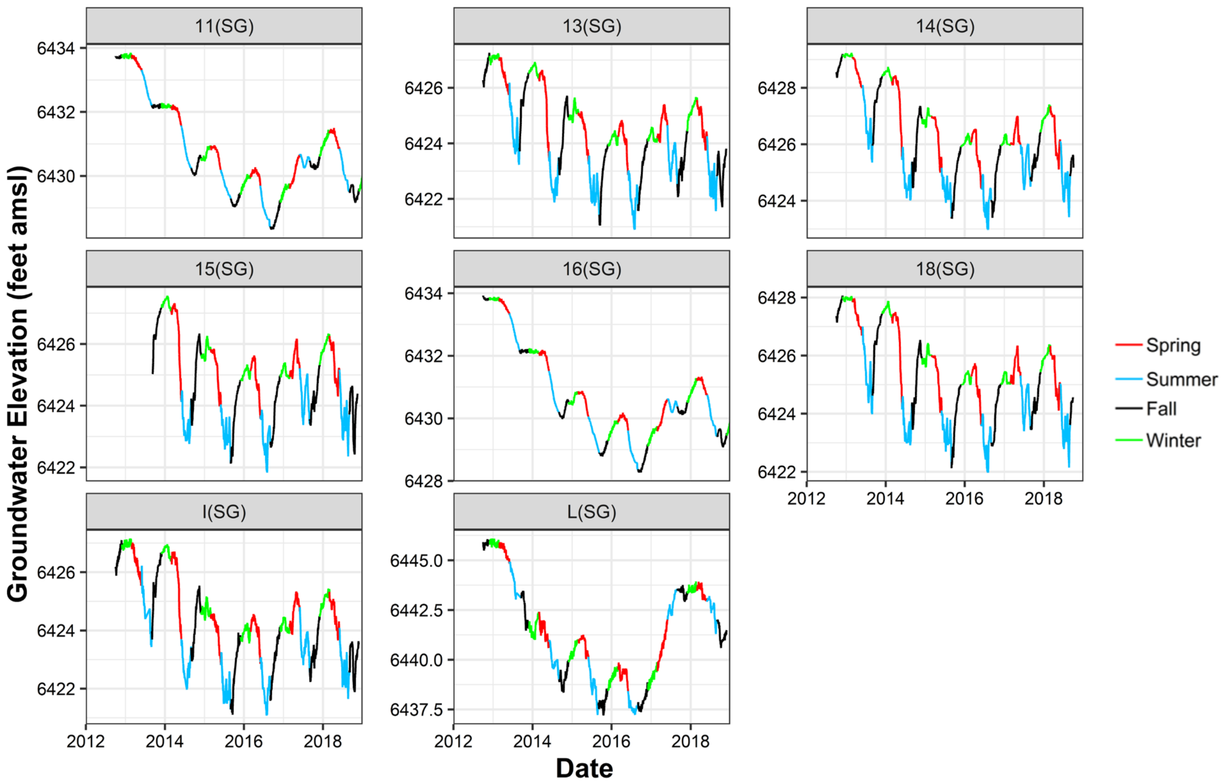
Figure 17 also presents monthly precipitation totals measured at a meteorological weather station (16(SG)MET) at the Bluewater site. Monthly precipitation has ranged between 0 and 6.5 inches since 2012 and is typically highest in the summer months when groundwater levels are lowest, and pumping is highest. Monthly precipitation totals show an inverse correlation to groundwater levels (when seasonal declines in groundwater levels correlate to periods when precipitation is typically highest). It is expected that higher precipitation would lead to an increase in groundwater levels. A delayed aquifer response to precipitation infiltration is possible, and if this were the case, groundwater levels would be expected to rise several months after a precipitation event.



Abbreviation: amsl = above mean sea level

Figure 17. Continuous Groundwater Levels and Total Monthly Precipitation at the Bluewater Site

Figure 18 more clearly depicts the seasonality of the groundwater levels across the Bluewater site area. As shown, groundwater levels typically begin to decrease in the spring and are lowest in the summer and fall, at which point they begin to increase. Groundwater levels are typically highest in late fall, winter, or early spring. The seasonal decline in late spring and summer directly correlates to the periods of higher pumping.



Note: In this figure, fall is assumed to begin on September 1, winter on December 1, spring on March 1, and summer on June 1.

Abbreviation: amsl = above mean sea level

Figure 18. Seasonality of Groundwater Levels at Bluewater Site Wells

4.3 Groundwater Flow Directions and Rose Diagrams

Variability in flow directions was evaluated using average daily groundwater levels from continuous groundwater-level data measured in the Bluewater site wells and periodic hand-measured groundwater-level data in well 951R. The continuous record allows for daily flow directions to be calculated for the period of record. Flow directions were calculated by solving three-point problems in which a plane was fit to groundwater elevations at three well locations that form the vertices of a triangle. Calculations were performed with the Python scripting language using the NumPy and Pandas libraries (Oliphant 2006; McKinney 2010).

Equilateral triangles, or even roughly equilateral triangles, are preferable to irregularly shaped triangles for this calculation: the closer the triangle is to being equilateral, the more valid the results will be. The method also assumes that there is no disturbance, such as pumping, a barrier to groundwater flow such as a fault, or interaction with surface water, within the well triangle. If either of these assumptions is violated, then the calculated flow direction can be in error. The results are represented as rose diagrams. A rose diagram is like a histogram, except the bars are represented in a radial pattern from 0° to 360°. The bars are divided into 5° increments, and the size of the bar representing each increment is relative to the proportion of dates that have a calculated flow direction within the increment.

Figure 19 presents the five well triangle pairs and associated groundwater flow rose diagrams. The assumptions are generally honored for all well triangles except for well triangle 3 that includes a section of the East-West Fault. The well triangle pairs are summarized in Table 3.

Table 3. Bluewater Site Area Well Triangle Pairs

Triangle ID	Well Triangle
Triangle 1	14(SG), 15(SG), 18(SG)
Triangle 2	18(SG), 15(SG), 13(SG)
Triangle 3	15(SG), 13(SG), I(SG)
Triangle 4	16(SG), 11(SG), I(SG)
Triangle 5	13(SG), I(SG), 951R

Overall, the rose diagrams generally indicate calculated groundwater flow directions are to the east at the Bluewater site and more to the southeast at well triangles 3 and 5 located south and east of the site. This is consistent with flow directions historically mapped for the Bluewater site. Groundwater flow directions are somewhat variable, with the directions for well triangles 1 and 2 varying approximately 20°, well triangle 3 varying approximately 30°, and directions for well triangles 4 and 5 varying 10°. Well triangles that showed the greatest variation in flow direction include three wells with hydrographs included in Group 1 (as discussed in Section 4.2.3). Seasonal and shorter-term groundwater-level fluctuations were more prevalent in the Group 1 wells. Well triangles that showed the least variation in flow direction included wells with hydrographs included in Group 2 (as discussed in Section 4.2.3) or included well 951R, which did not have a continuous water-level record. Seasonal and shorter-term groundwater-level fluctuations were less prevalent in the Group 2 wells.

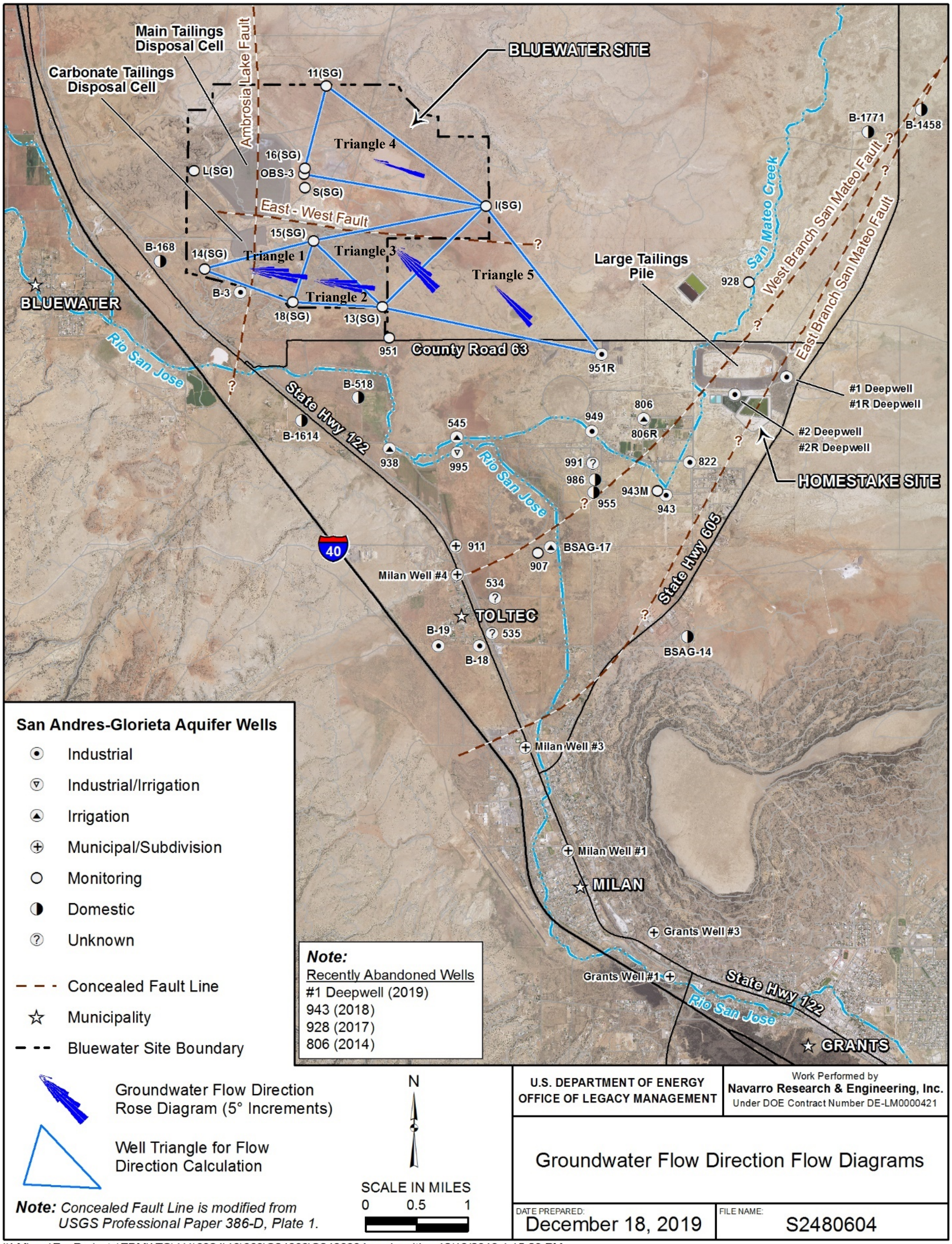


Figure 19. Groundwater Flow Direction Flow Rose Diagrams

Flow direction time plots for each well triangle are presented in Figure 20. Flow direction time plots indicate that flow direction patterns for well triangles 1 and 2 are similar. The groundwater flow directions for these well pairs trend more to the southeast, toward the area of high-production wells, during the spring, and summer when pumping is highest. Well triangle 3 also shows a similar seasonal trend with a direction more to the south in the summer months. This also correlates to the period in which groundwater levels are the lowest in these wells. A deviation in flow direction different from the seasonal fluctuations is observed in well triangles 1 and 2 beginning in 2018, at which point the flow directions shift more to the south. A deviation in flow direction different from the seasonal fluctuations is also observed in well triangle 3 from mid-2014 to mid-2015.

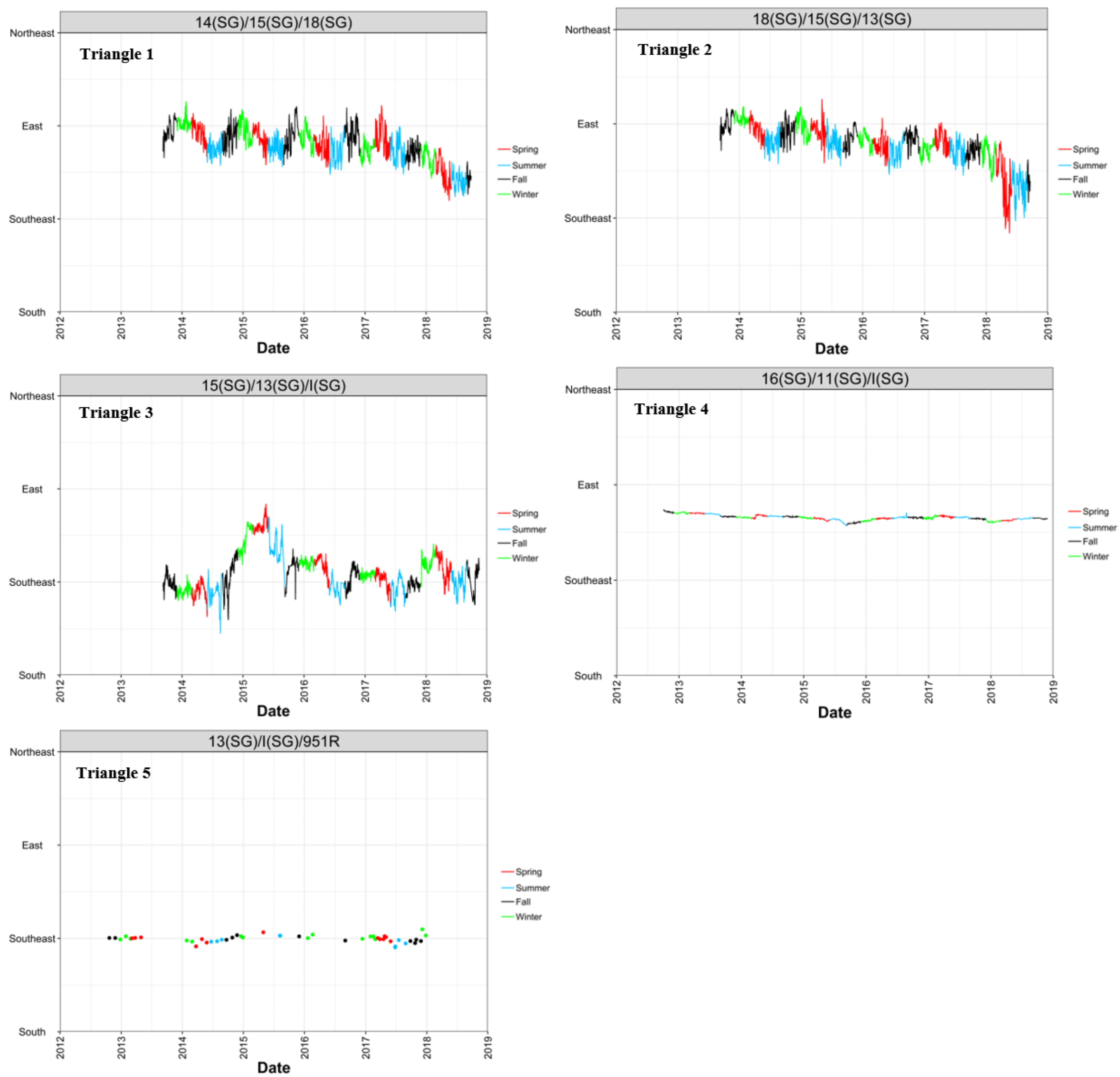


Figure 20. Calculated Flow Directions Time Plots

Contrary to those in well triangles 1, 2, and 3, flow directions calculated for well triangle 4 show no seasonal fluctuations and a relatively constant flow direction with time. This is consistent with the groundwater-level trends observed in Group 2 wells (Figure 16 and Figure 17), which were fairly stable with little to no seasonality. The flow direction time plot for well triangle 5 indicates a relatively constant flow direction to the southeast, toward HMC well 951R. It is possible the seasonality is not illustrated because of the limited groundwater-level data available for well 951R.

4.4 Horizontal Gradients

Variability in horizontal gradients was also evaluated using average daily groundwater levels from continuous groundwater-level data measured in the Bluewater site wells and periodic hand-measured groundwater-level data in well 951R. Similar to flow directions, gradients were calculated by solving the three-point problems in which a plane was fit to groundwater elevations at three well locations that form the vertices of a triangle. Gradients were calculated for the same well pairs used to calculate the flow directions.

Figure 21 presents gradient time plots for the five well triangle pairs discussed above and shown in Figure 19. In general, gradients for triangles 1, 2, and 3 are similar. Gradients for well triangles 1, 2, and 3 are typically more variable in the spring, fall, and summer. This correlates to the period in which groundwater flow directions are more to the south and when pumping from high-production wells is highest. Fewer fluctuations in gradients occur in the winter. For well triangle 4, gradients are typically highest in the summer and lowest in the winter. The time plot for well triangle 5 does not show a seasonal pattern, which may be because of the lack of data for well 951R. However, the well triangle 5 gradient time plot shows a distinct reduction in gradient in early 2016, the time at which pumping from HMC wells was reduced.

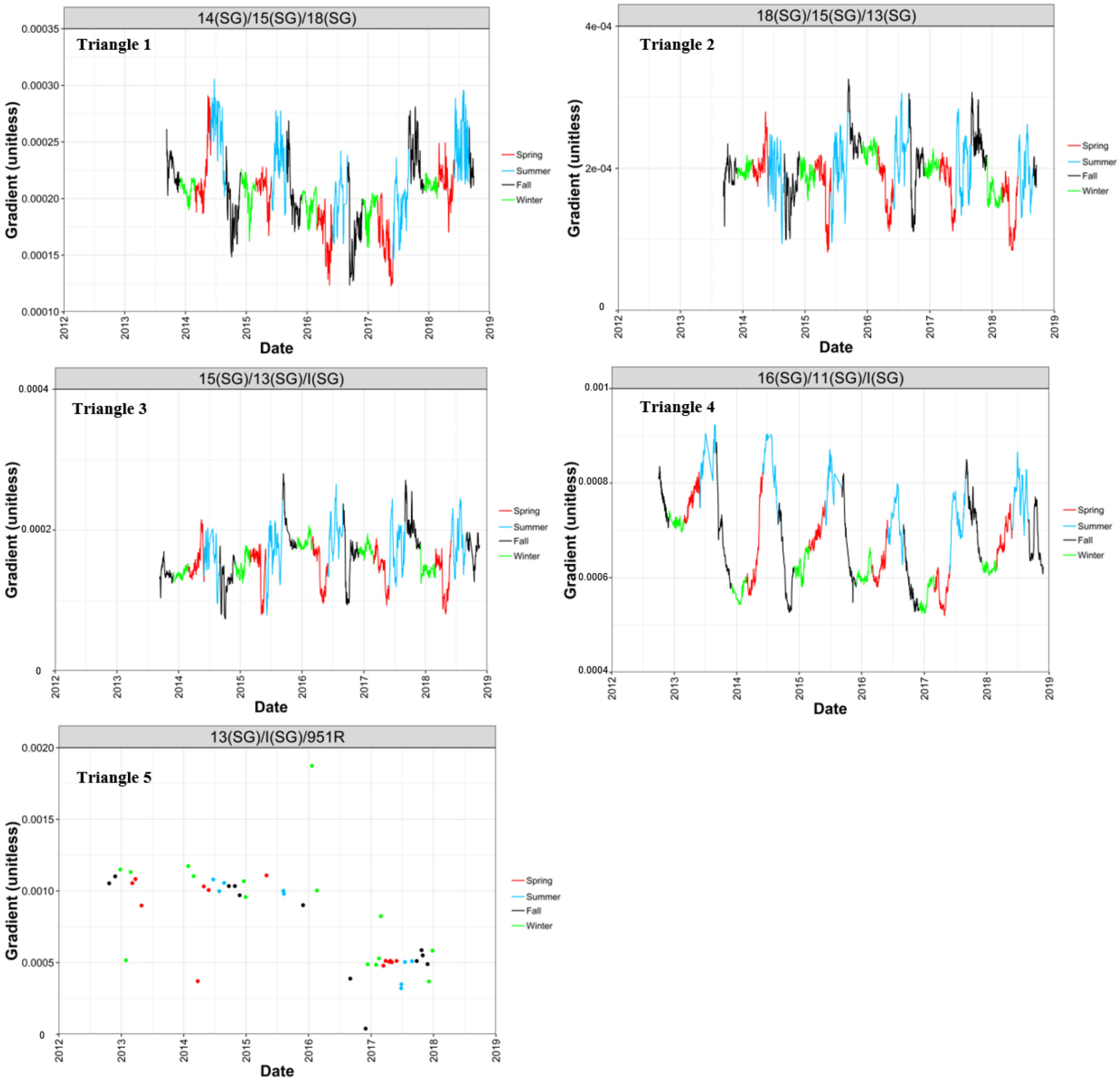


Figure 21. Calculated Gradient Time Plots

4.5 Summary of Pumping Influences

Two offsite wells (HMC wells 951 and 951R) are located within the boundary of the 2017 uranium plume (DOE 2019). The hydrographs for these wells show water levels have been influenced by pumping. Except for well 951R, flow directions were not calculated using offsite well data because the sparse distribution of wells makes it difficult to identify true flow directions in offsite areas. Water-level data from well 951R were paired with continuous water-level data from onsite wells and groundwater flow directions, and hydraulic gradients were calculated. Flow directions calculated using 951R (well triangle 5) indicated flow was generally toward the southeast, and the direction remained relatively constant. No discernible trends were observed in the gradient time plot using 951R; however, there was a sudden decrease in gradient in 2016 that correlates to the time when HMC pumping decreased.

Continuous water-level data collected at Bluewater site wells were also evaluated for pumping influences. The evaluation indicated that Group 1 wells, 13(SG), 14(SG), 15(SG), and 18(SG), in the region south of the East-West Fault, and well I(SG) on the east boundary of the Bluewater site, had the greatest seasonal fluctuations in groundwater levels. Groundwater levels in these Group 1 wells are typically 4 to 5 ft higher in the fall, winter, and early spring and decrease in late spring, summer, and early fall when pumping in the SAG aquifer is highest. Groundwater flow directions also fluctuate more around Group 1 wells and shift more to the south during the period when pumping is highest. Calculated hydraulic gradients also fluctuation around Group 1 wells more so when pumping is highest. The correlations of periods of higher pumping to greater declines in groundwater levels and shift of flow directions toward the pumping well areas suggest that Group 1 wells are most influenced by pumping. Group 2 wells (16(SG) and 11(SG)) north of the East-West Fault showed less seasonal fluctuations in groundwater levels, and groundwater around the Group 2 wells showed little to no change in flow directions. This suggests groundwater around Group 2 wells is less influenced by high-production pumping wells than that around Group 1 area wells. Although seasonal groundwater-level fluctuation in well L(SG) is at times comparable to that of Group 1 wells, flow directions were not calculated around this well because L(SG) could not be paired with other wells to construct a well triangle unobstructed by fault lines.

Continuous groundwater-level data also show an inverse correlation to precipitation, and although it is possible groundwater levels could be responding to delayed recharge to the aquifer from precipitation, the consistent patterns seasonal patterns reflect more of a pumping response.

5.0 Water Chemistry Trends

An analysis was also conducted to evaluate if current concentration trends of mill-related contamination are increasing, decreasing, or remaining relatively constant at wells in the study area. Trends were evaluated with respect to the influences of high-production wells on the contaminated groundwater at the Bluewater site.

Historically, in a few cases, concentrations have been observed to increase during the pumping of high-production wells near the Bluewater site. For example, during active milling operations, elevated uranium concentrations were observed in Anaconda well #2 following pumping of the well. Also, elevated uranium concentrations were observed in well 951 after pumping it from 1999 to 2012. It is likely that pumping of these wells increased hydraulic gradients and diverted flow directions toward them, resulting in increased uranium concentrations. If this were the case, it can be expected that pumping in wells near the current plume could also result in increased uranium (or other analyte) concentrations in these wells. Concentration trends were evaluated to assess this hypothesis for both Bluewater site and offsite wells in the study region.

In general, the direction of transport of contaminants will be consistent with flow directions. If flow directions change, the configuration of the plume will change. If flow directions are variable, the average flow direction is the anticipated direction of contaminant movement, assuming a constant gradient. Concentrations of contaminants in wells located both within and downgradient of the plume can be used to detect and/or monitor for increasing trends. If the plume is being pulled by pumping wells, the pumping well or wells located between the pumping well and the areas with higher concentrations should be expected to show increasing trends. It should be noted that increasing trends do not indicate the plume is moving as a strict result of the influences of the high-production pumping wells. Other potential causes for increasing concentration trends may include plume movement not induced by pumping, leakage from aquifers above or below the pumped interval, change in geochemical conditions in the aquifer resulting in release of contaminants in the mineralized zone in the Ambrosia Lake Fault Zone and the formation of materials (including in the SAG) adjacent to the fault zone (DOE 2014), or increasing seepage from the Main Tailings Disposal Cell.

Based in part on the time–concentration plots in Figure 12 and Figure 13, uranium, sulfate, and TDS were selected for trend analysis. Uranium and sulfate are both good indicators of mill-related contamination, and both have been measured at concentrations that exceed the State of New Mexico groundwater standards. Sulfate is present in the tailing fluids well above concentrations in native groundwater (AHA 1995). TDS was used instead of chloride because it is a measure of all dissolved constituents in groundwater (including chloride) and is a good indicator of the presence of contaminants in general.

The use of uranium, sulfate, and TDS in trend analysis is also suitable because the transport of uranium in the SAG aquifer is considerably different than the transport of sulfate and TDS. In general, sulfate and TDS are more conservative (less retarded) and travel with the general velocity of groundwater flow, whereas uranium is less conservative (more retarded). As a result, it would be expected that uranium would be less responsive to fluctuations in flow directions caused by pumping and its response expected to lag behind any observed increase of sulfate and TDS.

Molybdenum, nitrate (as N), and selenium were not included in the trend analysis because, as shown in Figure 12 and Figure 13 concentrations have been generally stable and well below the corresponding New Mexico groundwater standard in all Bluewater site and offsite wells evaluated in this study. Many of the molybdenum and selenium results have also been below the detection limit (Figure 13).

The trend analysis was conducted with the Mann-Kendall statistical test using a 0.05 significance level, a nonparametric test for monotonic trend. Trend tests were performed for both Bluewater site and offsite wells for wells with eight or more samples. Offsite wells were not used in the analysis if it was known the wells were impacted from vertical leakage from overlying aquifers (#1 Deepwell, #2 Deepwell, 943, 986), as discussed in Section 2.2.2. In total, 8 Bluewater site wells and 7 offsite wells had more than 8 data points. Data and plots for offsite-wells B-518, 545, Grants Well #1, Grants Well #3, B-1771, and B-1458 are presented, but Mann-Kendall analysis was not conducted for these wells due to the limited number of samples. The dataset for Bluewater site wells extends from 2012 through 2018. The full monitoring records were not evaluated for wells I(SG) and L(SG) because a portion of the data for both wells were deemed not representative due to issues with sample collection. The full monitoring record was typically used in the trend analysis for offsite wells, except for well 951. Trend analysis was conducted for well 951 for the entire monitoring record (1984 to present) and from 2012 to present because the pumping of well 951 for industrial use ceased in 2012. If both dissolved and total concentrations were available, total concentrations were used.

Mann-Kendall trend analysis results are summarized and general statistics for the dataset are provided in Table 4. For each well with sufficient chemistry data, supplementary time–concentration plots of uranium, sulfate, TDS, and (where available) groundwater levels are provided in Appendix B.

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Table 4. Mann-Kendall Trend Analysis Results Summary and General Statistics

Onsite Wells											
General Statistics									Mann-Kendall Statistical Trend Results		
Analyte	**Location**	**Initial Date**	**Final Date**	**Number of Samples**	**Minimum**	**Maximum**	**Mean**	**Standard Deviation**	**tau**	***p* value**	**Significant Trend**
Uranium	11(SG)	2012-11-14	2018-11-15	14	0.00739	0.0239	0.012	0.0039	–0.02	0.96	None
Uranium	13(SG)	2012-11-15	2018-11-14	14	0.0906	0.123	0.104	0.0086	–0.33	0.11	None
Uranium	14(SG)	2012-11-14	2018-11-15	14	0.0308	0.12	0.070	0.0274	0.57	0.01	Increasing
Uranium	15(SG)	2012-11-13	2018-11-15	14	0.0209	0.174	0.074	0.0396	–0.54	0.01	Decreasing
Uranium	16(SG)	2012-11-13	2018-11-14	14	0.8	1.45	1.246	0.1708	–0.57	0.01	Decreasing
Uranium	18(SG)	2012-11-14	2018-11-15	14	0.127	0.271	0.205	0.0385	0.37	0.08	None
Uranium	I(SG)	2013-05-15	2018-11-14	12	0.282	0.35	0.308	0.0202	–0.37	0.11	None
Uranium	L(SG)	2012-11-14	2018-11-15	14	0.00278	0.0035	0.003	0.0002	–0.30	0.16	None
Sulfate	11(SG)	2012-11-14	2018-11-15	14	371	815	635.2	132.8	–0.03	0.91	None
Sulfate	13(SG)	2012-11-15	2018-11-14	14	395	459	415.6	16.3	0.06	0.83	None
Sulfate	14(SG)	2012-11-14	2018-11-15	14	229	530	450.4	98.0	0.63	0.00	Increasing
Sulfate	15(SG)	2012-11-13	2018-11-15	14	265	512	419.6	67.8	0.58	0.00	Increasing
Sulfate	16(SG)	2012-11-13	2018-11-14	14	1170	1910	1270.7	194.6	–0.31	0.15	None
Sulfate	18(SG)	2012-11-14	2018-11-15	14	445	516	473.1	21.1	0.46	0.03	Increasing
Sulfate	I(SG)	2013-05-15	2018-11-14	12	828	1100	910.3	74.1	–0.06	0.84	None
Sulfate	L(SG)	2012-11-14	2018-11-15	14	580	660	618.9	26.0	0.01	1.00	None
TDS	11(SG)	2012-11-14	2018-11-15	14	1470	1930	1701.4	134.1	–0.06	0.83	None
TDS	13(SG)	2012-11-15	2018-11-14	14	994	1110	1050.3	38.2	–0.20	0.37	None
TDS	14(SG)	2012-11-14	2018-11-15	14	1200	1430	1345.7	71.5	0.41	0.05	None
TDS	15(SG)	2012-11-13	2018-11-15	14	1090	1390	1240.7	76.6	0.42	0.05	Increasing
TDS	16(SG)	2012-11-13	2018-11-14	14	2760	3100	2951.4	110.6	–0.67	0.00	Decreasing
TDS	18(SG)	2012-11-14	2018-11-15	14	1150	1320	1230.0	51.6	0.54	0.01	Increasing
TDS	I(SG)	2013-05-15	2018-11-14	12	2100	2270	2167.5	55.6	–0.26	0.27	None
TDS	L(SG)	2012-11-14	2018-11-15	14	1700	1800	1740.7	31.5	–0.40	0.06	None
Uranium	545	2004-05-06	2017-07-25	5	0.007	0.026	0.013	0.0076	N/A	N/A	N/A
Uranium	806R*	2008-09-24	2018-10-05	13	0.017	0.027	0.021	0.0034	0.14	0.54	None
Uranium	938	2008-08-25	2018-10-04	8	0.005	0.021	0.010	0.0049	0.50	0.11	None
Uranium	951	1984-04-26	2017-11-15	47	0.003	0.048	0.029	0.0104	0.42	0.00	Increasing
Uranium	951	2012-03-09	2017-11-15	10	----	----	----	----	–0.42	0.11	None
Uranium	951R	2012-04-24	2018-11-27	23	0.020	0.080	0.035	0.0116	0.01	0.96	None
Uranium	B-1458	2015-06-23	2018-10-03	4	0.001	0.010	0.003	0.0046	N/A	N/A	N/A
Uranium	B-1771	2014-10-07	2018-10-03	5	0.022	0.032	0.027	0.0045	N/A	N/A	N/A
Uranium	B-518	2008-08-28	2018-10-04	6	0.004	0.025	0.010	0.0082	N/A	N/A	N/A
Uranium	Grants Well #1	2004-10-27	2018-10-05	4	0.005	0.011	0.007	0.0027	N/A	N/A	N/A
Uranium	Grants Well #3	2004-10-27	2018-10-05	5	0.005	0.010	0.006	0.0020	N/A	N/A	N/A
Uranium	Milan Well #1	1997-03-19	2018-10-02	24	0.004	0.010	0.006	0.0016	–0.45	0.00	Decreasing
Uranium	Milan Well #3	1997-03-19	2018-10-02	30	0.003	0.021	0.006	0.0046	–0.50	0.00	Decreasing
Uranium	Milan Well #4	2008-08-27	2018-10-02	9	0.005	0.019	0.013	0.0040	–0.20	0.53	None

Table 4. Mann-Kendall Trend Analysis Results Summary and General Statistics (continued)

Onsite Wells											
General Statistics									Mann-Kendall Statistical Trend Results		
Analyte	**Location**	**Initial Date**	**Final Date**	**Number of Samples**	**Minimum**	**Maximum**	**Mean**	**Standard Deviation**	**tau**	***p* value**	**Significant Trend**
Sulfate	545	2004-05-06	2017-07-25	5	327	460	408.2	48.97	N/A	N/A	N/A
Sulfate	806R	2008-09-24	2018-10-05	14	577	674	639.1	28.24	0.14	0.51	None
Sulfate	938	2008-08-25	2018-10-04	8	249	330	296.6	28.77	0.57	0.06	None
Sulfate	951	1984-04-26	2017-11-15	48	270	426	345.8	27.59	0.33	0.00	Increasing
Sulfate	951	2012-03-09	2017-11-15	10	----	----	----	----	–0.24	0.37	None
Sulfate	951R	2012-04-24	2018-11-27	23	520	637	575.4	26.35	0.19	0.20	None
Sulfate	B-1458	2015-06-23	2018-10-03	4	601	720	680.3	54.29	N/A	N/A	N/A
Sulfate	B-1771	2014-10-07	2018-10-03	5	390	460	422.6	25.57	N/A	N/A	N/A
Sulfate	B-518	2008-08-28	2018-10-04	6	256	295	280.2	17.33	N/A	N/A	N/A
Sulfate	Grants Well #1	2015-06-30	2018-10-05	3	188	340	259.3	76.43	N/A	N/A	N/A
Sulfate	Grants Well #3	2015-06-24	2018-10-05	4	333	390	358.3	23.92	N/A	N/A	N/A
Sulfate	Milan Well #1	1997-03-19	2018-10-02	24	130	203	155.6	21.53	–0.32	0.03	Decreasing
Sulfate	Milan Well #3	1997-03-19	2018-10-02	24	166	409	226.6	56.17	–0.51	0.00	Decreasing
Sulfate	Milan Well #4	2008-08-27	2018-10-02	9	183	480	381.8	81.07	0.28	0.35	None
TDS	545	2004-05-06	2017-07-25	5	857	1020	929.8	70.50	N/A	N/A	N/A
TDS	806R	2008-09-24	2018-10-05	14	1500	1660	1606.4	51.68	–0.25	0.25	None
TDS	938	2008-08-25	2018-10-04	8	664	819	748.1	55.60	0.33	0.32	None
TDS	951	1984-04-26	2017-11-15	47	623	1105	909.2	71.54	0.24	0.02	Increasing
TDS	951	2012-03-09	2017-11-15	10	----	----	----	----	0.02	1	None
TDS	951R	2012-04-24	2018-11-27	23	1360	1530	1465.2	45.81	–0.17	0.27	None
TDS	B-1458	2015-06-23	2018-10-03	4	1900	2170	2067.5	116.44	N/A	N/A	N/A
TDS	B-1771	2014-10-07	2018-10-03	5	920	1300	1092.0	155.47	N/A	N/A	N/A
TDS	B-518	2008-08-28	2018-10-04	6	680	793	740.7	38.62	N/A	N/A	N/A
TDS	Grants Well #1	2015-06-30	2018-10-05	3	564	880	704.7	160.83	N/A	N/A	N/A
TDS	Grants Well #3	2015-06-24	2018-10-05	4	860	954	918.5	43.77	N/A	N/A	N/A
TDS	Milan Well #1	1997-03-19	2018-10-02	24	404	661	494.8	58.42	–0.46	0.00	Decreasing
TDS	Milan Well #3	1997-03-19	2018-10-02	24	500	951	622.3	126.89	–0.65	0.00	Decreasing
TDS	Milan Well #4	2008-08-27	2018-10-02	9	541	1000	891.2	141.95	0.17	0.60	None

Notes:
N/A = not applicable; Mann Kendall tests were not conducted because the number of data points was less than eight.
---- = statistics not generated for this date range.
* For well 806R, HMC's most recent (5/4/2017) uranium result (0.114 mg/L) is not shown. Value is anomalous and inconsistent with the historical record.

Abbreviation:
TDS = total dissolved solids

5.1 Uranium Concentration Trends

Historical uranium concentration trends near the Bluewater site were previously discussed by Applied Hydrology Associates (AHA 1995). They reported that uranium concentrations at POC wells had been declining since the 1980s and that uranium concentrations reached a peak in well I(SG) in about 1989 and declined up to 1995, the time at which this trend was reported.

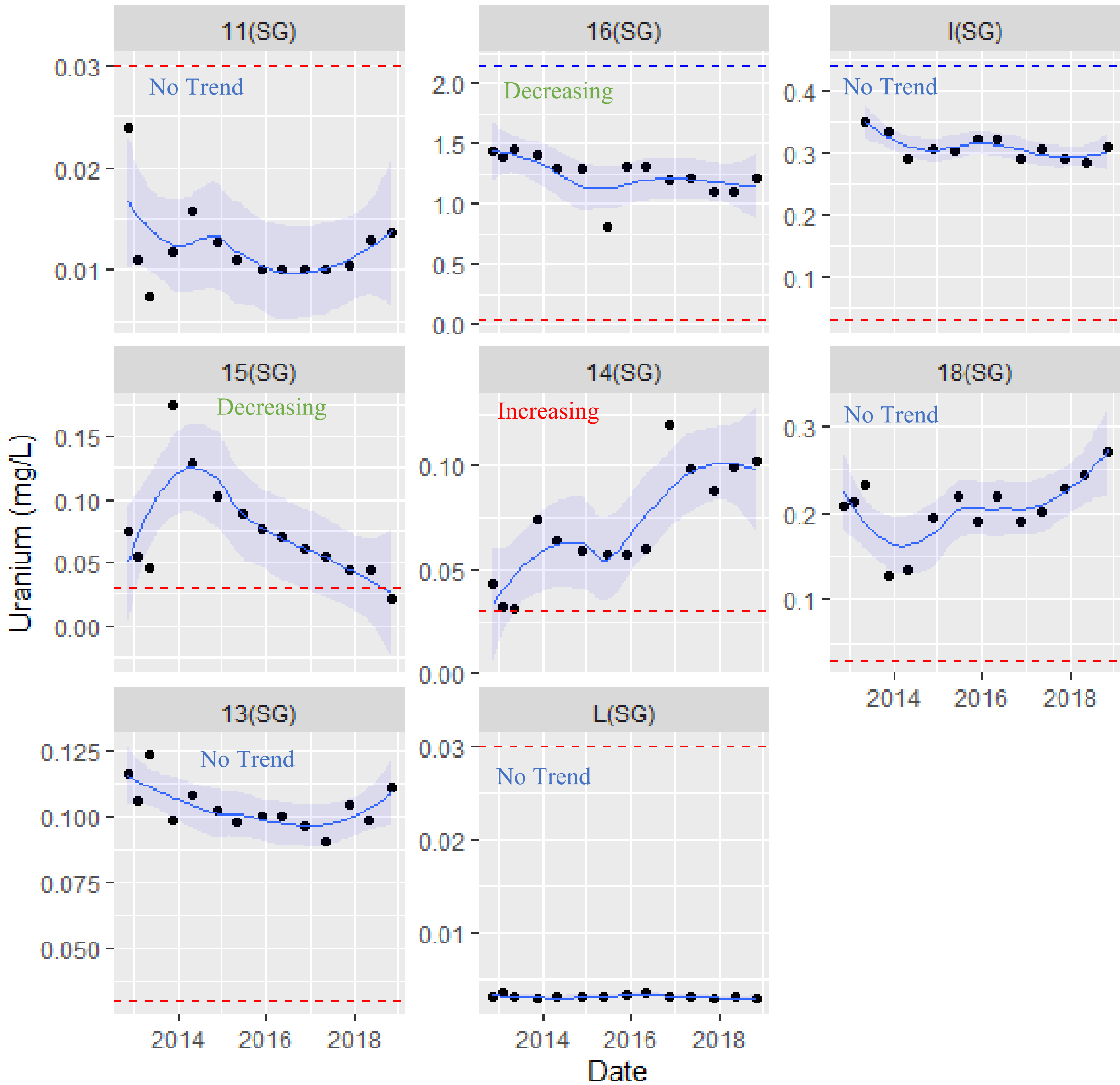
Time-series plots of uranium concentrations for the period of 2012–2018 for eight Bluewater site wells are shown in Figure 22. These wells are all located within the uranium plume except for well 11(SG), north of the plume, and well L(SG), upgradient of the plume. The plots also contain locally estimated scatterplot smoothing (LOESS) lines. LOESS lines show that temporal uranium concentrations patterns are variable in Bluewater site wells. The LOESS tool is a locally weighted regression to estimate local average concentration, which helps to visually identify patterns in the data. Wells 16(SG), located upgradient of I(SG), and I(SG) appear to have the most similar temporal variability patterns; it could also be argued that 13(SG) has a similar pattern. Uranium time–concentration patterns from all other wells are not similar.

Mann-Kendall results for uranium concentration trends for Bluewater site wells are shown in Figure 22 and Table 4. Well 14(SG), in the southwest corner of the Bluewater site, was the only well identified with an increasing trend. Wells 15(SG) and 16(SG), the nearest wells downgradient of the disposal cells, were identified to have a decreasing trend. These wells are on the south and north sides of the East-West Fault, respectively. The complex nature of uranium in groundwater at Bluewater site wells located within the SAG uranium plume is illustrated by the variability of trends. Uranium concentrations in remaining wells (11(SG), 13(SG), 18(SG), I(SG), and L(SG)) exhibit no trend.

Time-series plots with various periods of records of uranium concentrations and LOESS lines for seven offsite wells are shown in Figure 23. LOESS lines show that time–concentration patterns for wells 806R, 938, and 951R are relatively similar. In these wells, highest concentrations appear around 2014 and are lower in preceding and subsequent years. Time–concentration patterns for Milan Well #1 and Well #3 also look similar; concentrations decline in the early 2000s and then appear relatively stable. Concentrations for well 951 peaked in 2010 and have been declining since about 2012. Uranium concentrations for six additional wells (B-518, 545, Grants Well #1, Grants Well #3, B-1771, and B-1458) that did not have enough data for trend analysis are also presented in Figure 23.

Mann-Kendall results for uranium concentration trends for offsite wells are shown in Figure 23 and Table 4. No offsite wells were identified to have increasing trends, two offsite wells (Milan Well #3, and Milan Well #1) have decreasing trends, and five wells (951 since 2012, 951R, 938, 806R, and Milan Well #4) had no trend based on Mann-Kendall analysis. The decreasing trends in Milan Well #1 and Milan Well #3 are prevalent and indicate that uranium concentrations were at one time higher in these wells. Concentrations in Milan Well #1 and Milan Well #3 appear to have been stable since 2005 with the exception of a small concentration spike in 2015 and 2016.

Figure 24 shows the locations of both Bluewater site wells and offsite wells, color codes identifying uranium concentration trends, and start and end dates for the trend analysis. As shown, wells downgradient of the higher uranium concentration areas and downgradient of the plume do not have increasing trends.



Notes:

Mann-Kendall trend results shown on plots as "Increasing," "Decreasing," or "No Trend."

Wells are presented from west to east and from north to south, with the exception of L(SG), which is the upgradient well located west of the Main Tailings Disposal Cell.

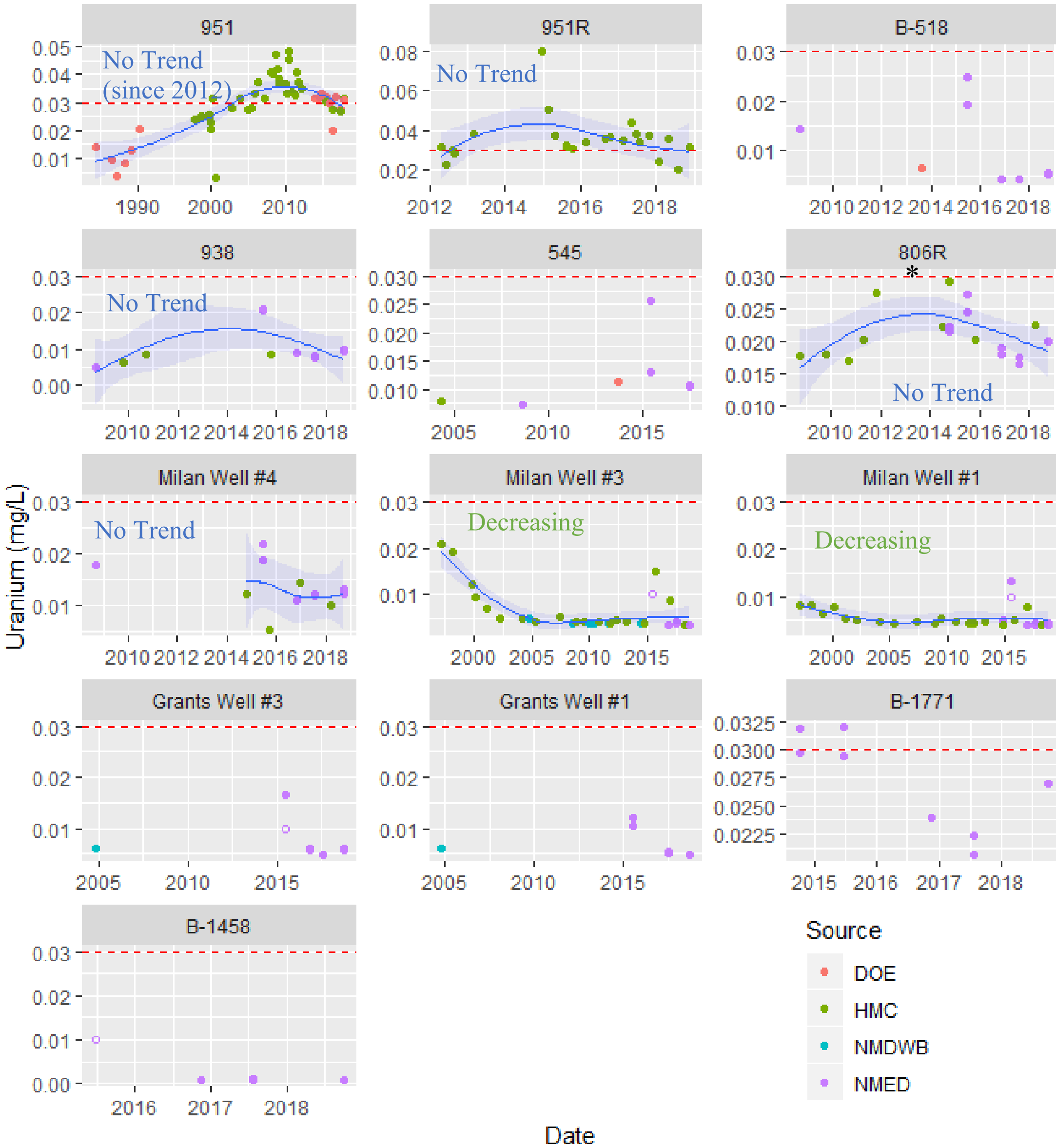
——Blue line is a LOESS locally weighted regression line.

Shaded area is the corresponding 95% pointwise confidence interval.

- - - 0.03 mg/L State of New Mexico groundwater standard for uranium included as a reference point, not intended to imply compliance requirement.

- - - Denotes the ACL limit (2.15 mg/L) for the SAG POC well (16(SG)) and health-based concentration limit (0.44 mg/L) for the SAG POE well (I(SG)).

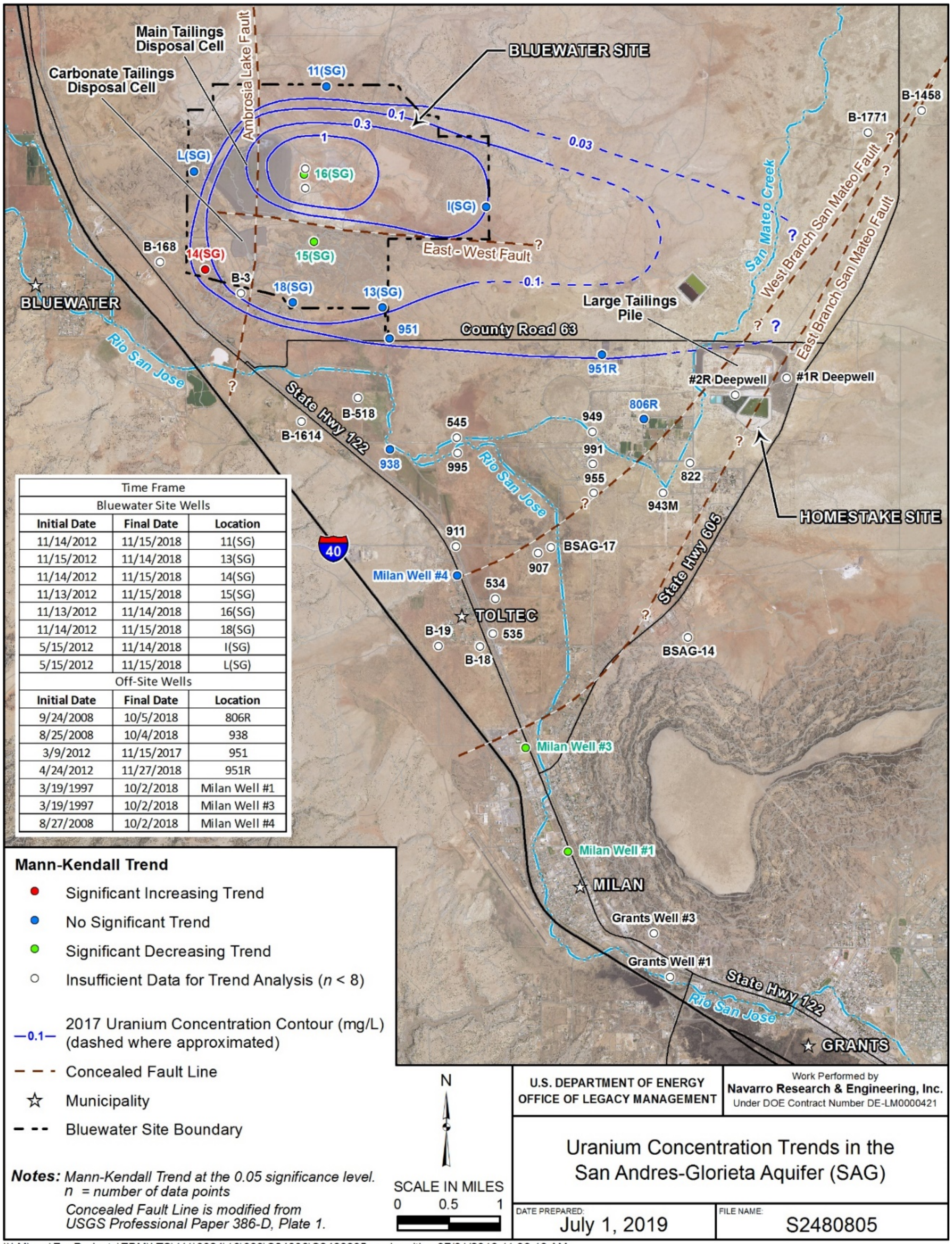
Figure 22. Uranium Concentration Trends in Bluewater Site SAG Wells and Mann-Kendall Results



Notes:
Regression lines and confidence intervals are only shown for wells with ≥8 measurements.
Because of the large (>10-year) gap in data for Milan Well #4, the regression line and corresponding confidence interval is plotted only for the most recent (2014–2018) data.
For wells sampled by NMED since 2015, results are plotted for both total and dissolved fractions.
Mann-Kendall trend results shown on plots as "Increasing," "Decreasing," or "No Trend."
Wells are presented from west to east and from north to south, with the exception of wells B-1771 and B-1458, which are east of the Bluewater site and north of the Homestake site.
——Blue line is a LOESS locally weighted regression line.
Shaded area is the corresponding 95% pointwise confidence interval
- - - 0.03 mg/L State of New Mexico groundwater standard for uranium, included as a reference point, not intended to imply compliance requirement.
○ Hollow symbols denote result below the detection limit.
* For well 806R, HMC's most recent (5/4/2017) uranium result (0.114 mg/L) is not shown. Value is anomalous and inconsistent with the historical record.

Abbreviations: DOE = U.S. Department of Energy; HMC = Homestake Mining Company;
NMDWB = New Mexico Drinking Water Bureau; NMED = New Mexico Environment Department

Figure 23. Uranium Concentration Trends in Offsite SAG wells and Mann-Kendall Results



Time Frame		
Bluewater Site Wells		
Initial Date	Final Date	Location
11/14/2012	11/15/2018	11(SG)
11/15/2012	11/14/2018	13(SG)
11/14/2012	11/15/2018	14(SG)
11/13/2012	11/15/2018	15(SG)
11/13/2012	11/14/2018	16(SG)
11/14/2012	11/15/2018	18(SG)
5/15/2012	11/14/2018	I(SG)
5/15/2012	11/15/2018	L(SG)
Off-Site Wells		
Initial Date	Final Date	Location
9/24/2008	10/5/2018	806R
8/25/2008	10/4/2018	938
3/9/2012	11/15/2017	951
4/24/2012	11/27/2018	951R
3/19/1997	10/2/2018	Milan Well #1
3/19/1997	10/2/2018	Milan Well #3
8/27/2008	10/2/2018	Milan Well #4

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Figure 24. Uranium Concentration Trends in the San Andres-Glorieta Aquifer

5.2 Sulfate Concentration Trends

Like uranium, historical sulfate concentration trends at the Bluewater site were discussed by Applied Hydrology Associates (AHA 1995). It was reported that sulfate concentrations at POC wells had been declining since the 1980s.

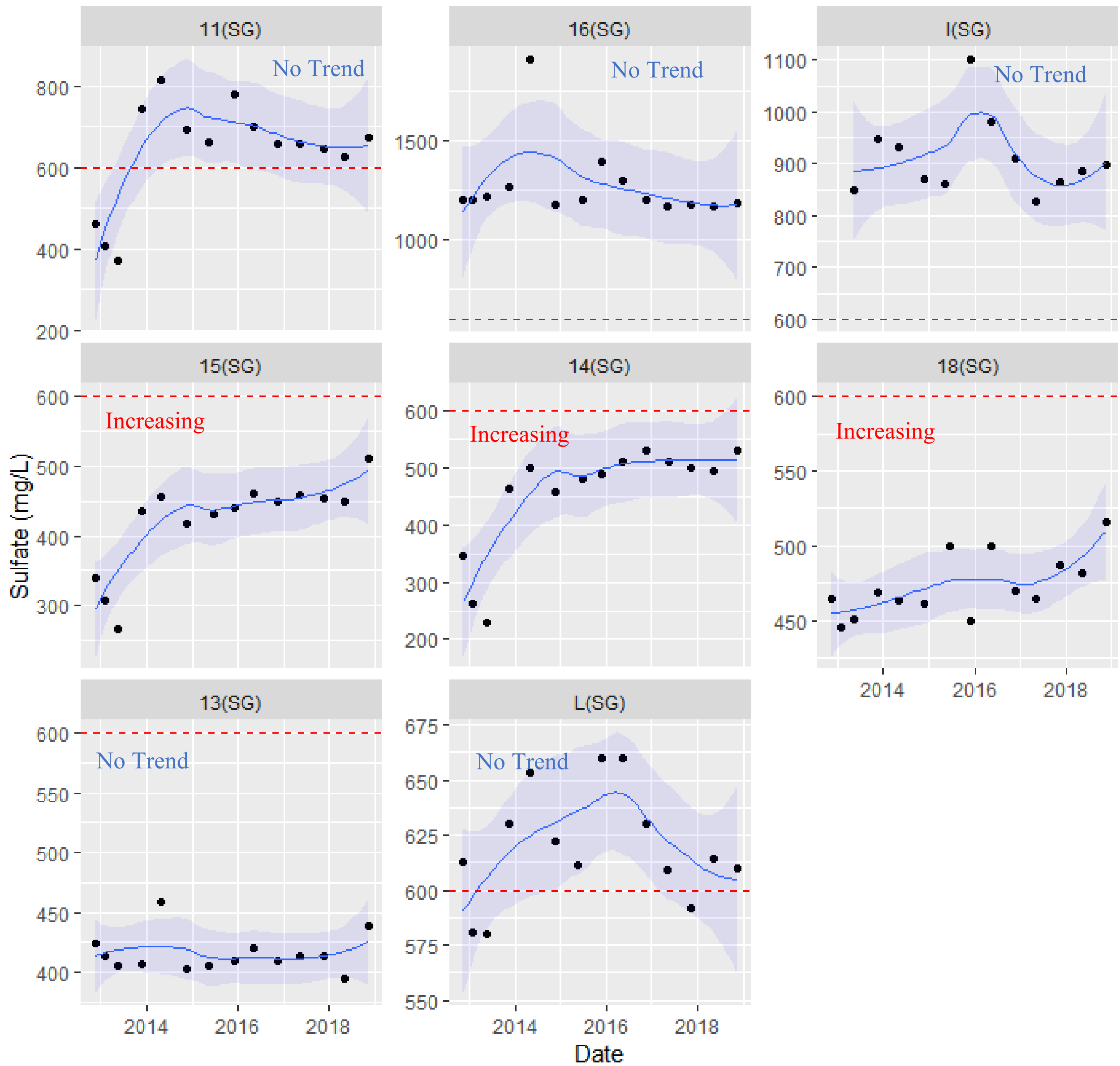
Time-series plots of sulfate concentrations for the period of 2012–2018 and associated LOESS lines for eight Bluewater site wells are shown in Figure 25. Sulfate concentrations in wells 18(SG), 15(SG), 14(SG), and 13(SG) are generally below the New Mexico groundwater standard and those in the other site wells including upgradient well L(SG) are above the standard. LOESS lines show time–concentration patterns for sulfate are variable in Bluewater site wells, but less variable than uranium trends. Wells 11(SG), 14(SG), and 15(SG) all show similar patterns with a sudden increase in sulfate after mid-2013, where concentrations increased as much as 2 times, followed by a period in which concentrations were maintained at that increased level and did not change as significantly. Wells 11(SG), 16(SG), I(SG), and L(SG) all show a spike in concentrations in late 2015/early 2016. These concentration spikes are not always reflected in the LOESS lines.

Mann-Kendall test results for sulfate concentration trends are shown in Figure 25 and Table 4. An increasing trend was found for wells 14(SG), 15(SG), and 18(SG), located in the south half of the Bluewater site, south of the East-West Fault. No decreasing trends were identified in Bluewater site wells. Wells 11(SG), 16(SG), I(S)G, 13(SG), and L(SG) had no significant trends.

Time-series plots of sulfate concentrations and LOESS lines for seven offsite wells are shown in Figure 26. The plots show concentrations for various periods of record. Time–concentration patterns for well 951R, which HMC began using for industrial supply in 2012, show a slight increase from 2012 through 2015 and then remain relatively constant. Sulfate concentrations in wells 951 and 938 remain relatively constant. Concentrations in 806R also remain constant, with a few of the higher concentrations detected more recently in 2015 and 2017. The only well with sulfate concentrations exceeding the New Mexico drinking water standard is 806R, and sulfate concentrations have exceeded the groundwater standard in well 951R only a few times, most recently in 2017 and 2018. It has been reported that sulfate concentrations increase in wells more to the east due to groundwater in this area having a higher residence time (NMED 2010). Milan Well #1 and Milan Well #3 also have similar sulfate concentration trends; concentrations decline in the early 2000s and then appear relatively stable. Sulfate concentrations for six additional wells (B-518, 545, Grants Well #1, Grants Well #3, B-1771, and B-1458) that did not have enough data for analysis are also presented in Figure 26.

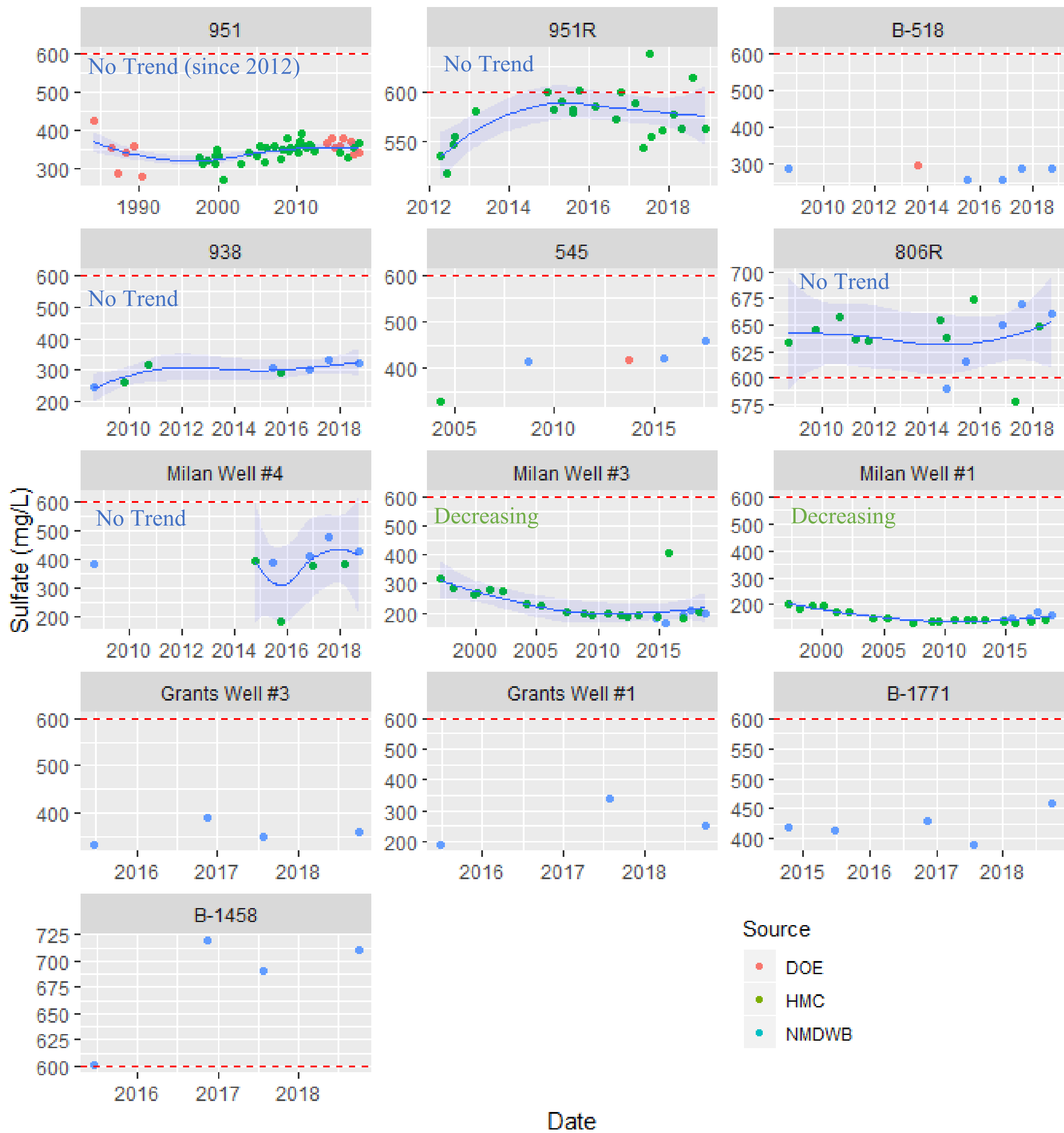
Mann-Kendall results for sulfate concentration trends for offsite wells are shown in Figure 26 and Table 4. Similar to uranium results, no offsite wells were identified to have increasing trends, two offsite wells (Milan Well #3, and Milan Well #1) have decreasing trends, and five wells (951 since 2012, 951R, 938, 806R, and Milan Well #4) had no trend based on the Mann-Kendall analysis.

Figure 27 shows the locations of both Bluewater site and offsite wells, color codes identifying sulfate concentration trends, and start and end dates for the trend analysis. As shown, a cluster of three wells in the south half of the Bluewater site near the Ambrosia Lake Fault has increasing trends. Wells 15(SG) and 18(SG) are between the highest plume concentrations and the area where high-production pumping wells are located to the south and east. No offsite wells downgradient of the uranium plume show increasing trends.



Notes:
Mann-Kendall trend results shown on plots as "Increasing," "Decreasing," or "No Trend."
——Blue line is a LOESS locally weighted regression line.
Shaded area is the corresponding 95% pointwise confidence interval.
- - - 600 mg/L State of New Mexico groundwater standard for sulfate, included as a reference point, not intended to imply compliance requirement.

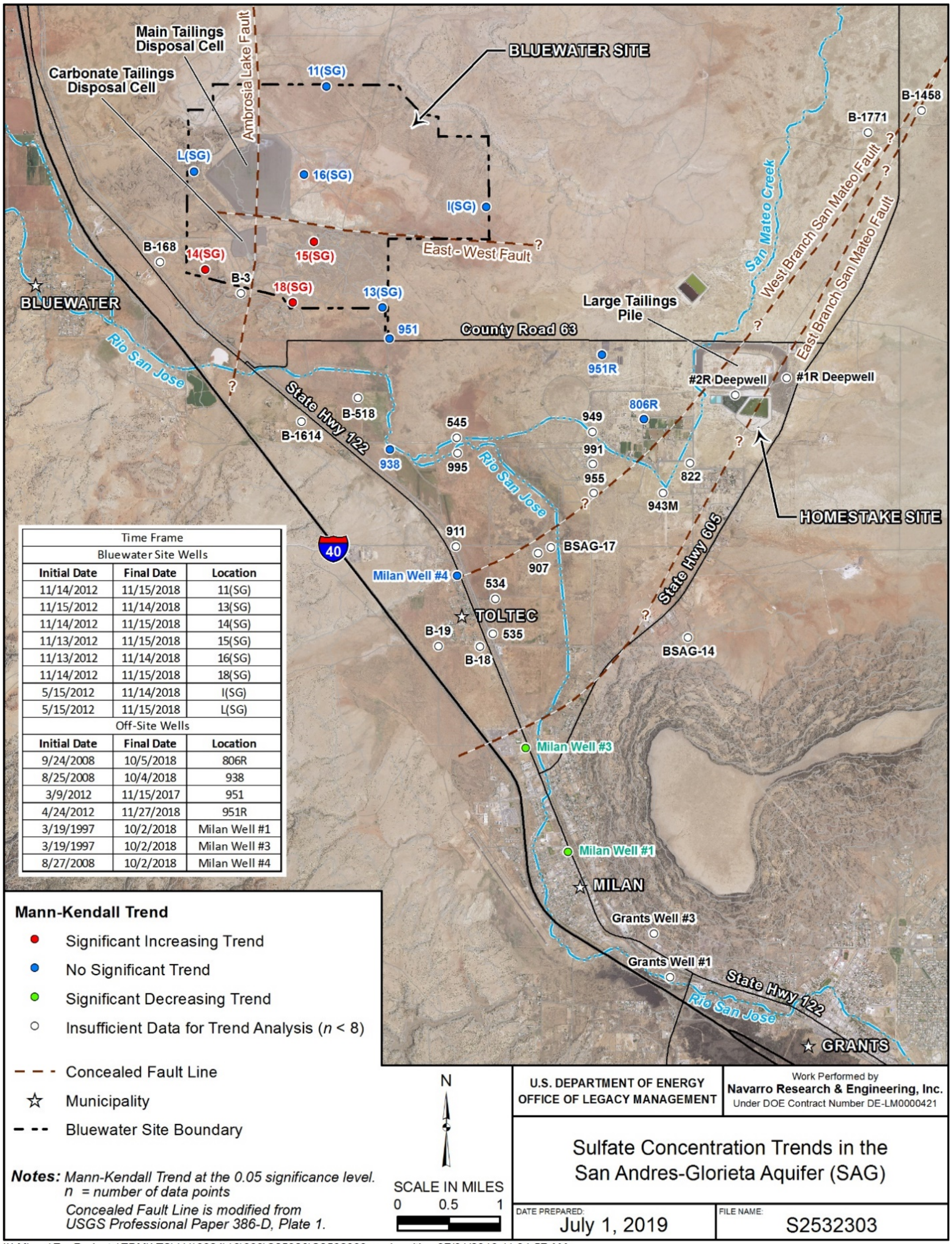
Figure 25. Sulfate Concentration Trends in Bluewater Site SAG Wells and Mann-Kendall Results



Notes:
Regression lines and confidence intervals are only shown for wells with ≥8 measurements.
Because of the large (>10-year) gap in data for Milan Well #4, the regression line and corresponding confidence interval is plotted only for the most recent (2014–2018) data.
Mann-Kendall trend results shown on plots as "Increasing," "Decreasing," or "No Trend."
——Blue line is a LOESS locally weighted regression line.
Shaded area is the corresponding 95% pointwise confidence interval.
- - - 600 mg/L State of New Mexico groundwater standard for sulfate, included as a reference point, not intended to imply compliance requirement.

Abbreviations: DOE = U.S. Department of Energy; HMC = Homestake Mining Company;
NMDWB = New Mexico Drinking Water Bureau

Figure 26. Sulfate Concentration Trends in Offsite SAG Wells and Mann-Kendall Results



Time Frame		
Bluewater Site Wells		
Initial Date	Final Date	Location
11/14/2012	11/15/2018	11(SG)
11/15/2012	11/14/2018	13(SG)
11/14/2012	11/15/2018	14(SG)
11/13/2012	11/15/2018	15(SG)
11/13/2012	11/14/2018	16(SG)
11/14/2012	11/15/2018	18(SG)
5/15/2012	11/14/2018	I(SG)
5/15/2012	11/15/2018	L(SG)
Off-Site Wells		
Initial Date	Final Date	Location
9/24/2008	10/5/2018	806R
8/25/2008	10/4/2018	938
3/9/2012	11/15/2017	951
4/24/2012	11/27/2018	951R
3/19/1997	10/2/2018	Milan Well #1
3/19/1997	10/2/2018	Milan Well #3
8/27/2008	10/2/2018	Milan Well #4

Figure 27. Sulfate Concentration Trends in the San Andres-Glorieta Aquifer

5.3 Total Dissolved Solids (TDS) Concentration Trends

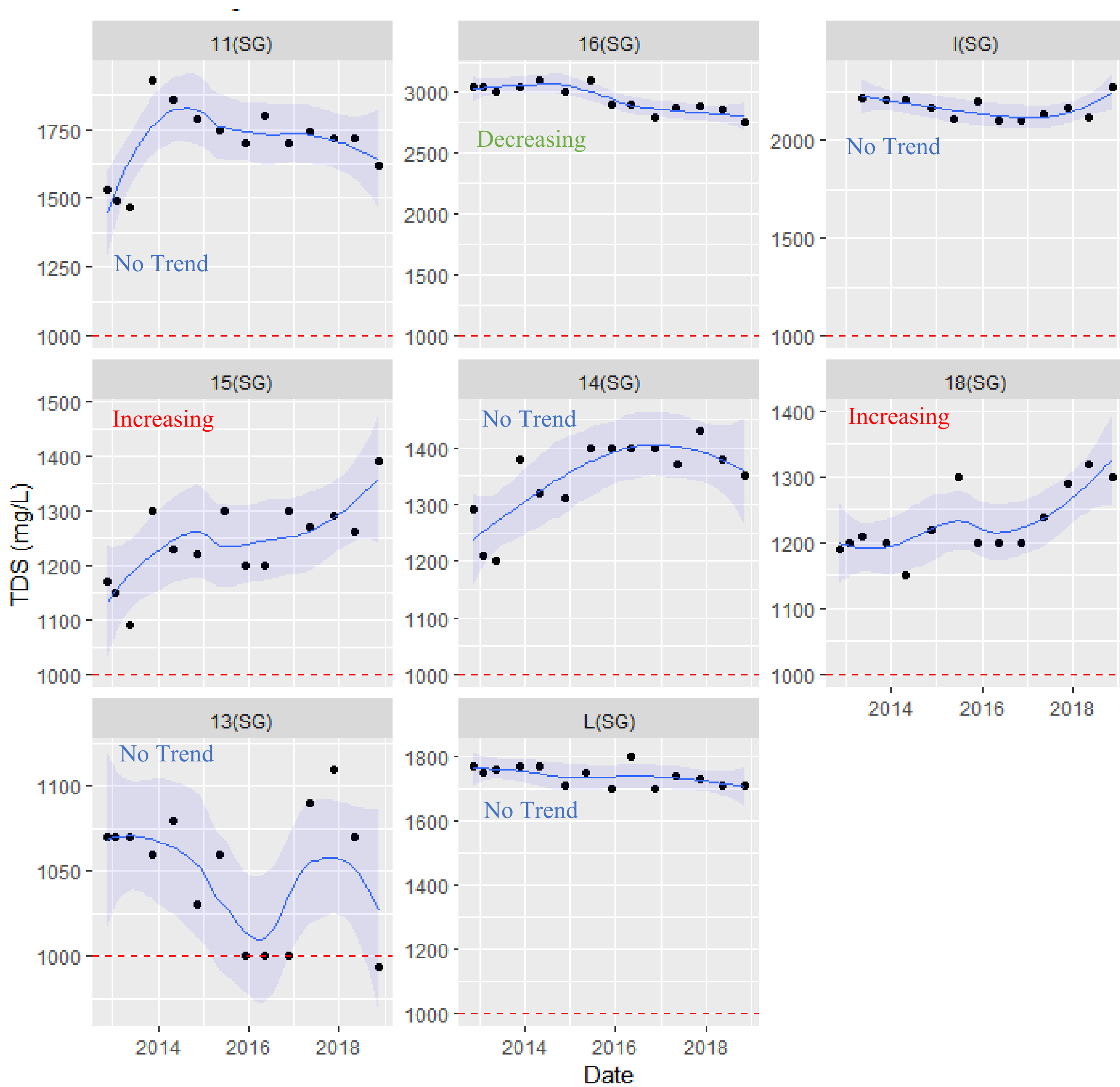
TDS concentrations for the period of 2012–2018 and associated LOESS lines for eight Bluewater site wells are shown in Figure 28. Wells 13(SG), 14(SG), and 15(SG) and 18(SG), south of the East-West Fault, typically have the lowest TDS concentrations (between 1000 and 1400 mg/L). Background concentrations of TDS are reported to be less than 1500 mg/L for the SAG aquifer (AHA 1995). The site background well (L(SG)) has TDS levels generally above 1700 mg/L. LOESS lines in Figure 28 show TDS trends are variable in Bluewater site wells, but less variable than uranium trends. Wells L(SG), 16(SG), and downgradient well I(SG) show a similar flat trend with no sudden increases or decreases in TDS. Wells 11(SG), 14(SG), and 15(SG) show a spike in TDS in late 2013, similar to the spike of sulfate in wells 11(SG), 14(SG), and 15(SG) and uranium concentrations in 15(SG).

Mann-Kendall test results for TDS concentration trends are shown in Figure 28 and Table 4. An increasing trend was found for wells 15(SG) and 18(SG), located in the south half of the Bluewater site, south of the East-West Fault. In contrast, the TDS trend in well 16(SG), north of the East-West Fault, is decreasing. Wells 11(SG), I(S)G, 13(SG), and L(SG) had no significant trend. These Mann-Kendall results are similar to sulfate trends except for well 16(SG), that had a decreasing trend for TDS, and 14(SG), that had no trend for TDS.

Time-series plots of TDS concentrations and LOESS lines for seven offsite wells are shown in Figure 29. Time plots are shown for various periods of record. Concentrations for well 951R show a slight increase from 2012 through 2015 and then remain relatively constant. As previously mentioned, HMC began using well 951R in 2012 for industrial supply and HMC pumping has declined beginning in 2015. Well 806R shows a similar TDS concentration pattern to 951R, but is more subdued. TDS concentration patterns for Milan Well #1 and Well #3 also look similar; concentrations decline in early 2000s and then appear relatively stable. TDS concentrations for six additional wells (B-518, 545, Grants Well #1, Grants Well #3, B-1771, and B-1458) that did not have enough data for analyses are also presented in Figure 29.

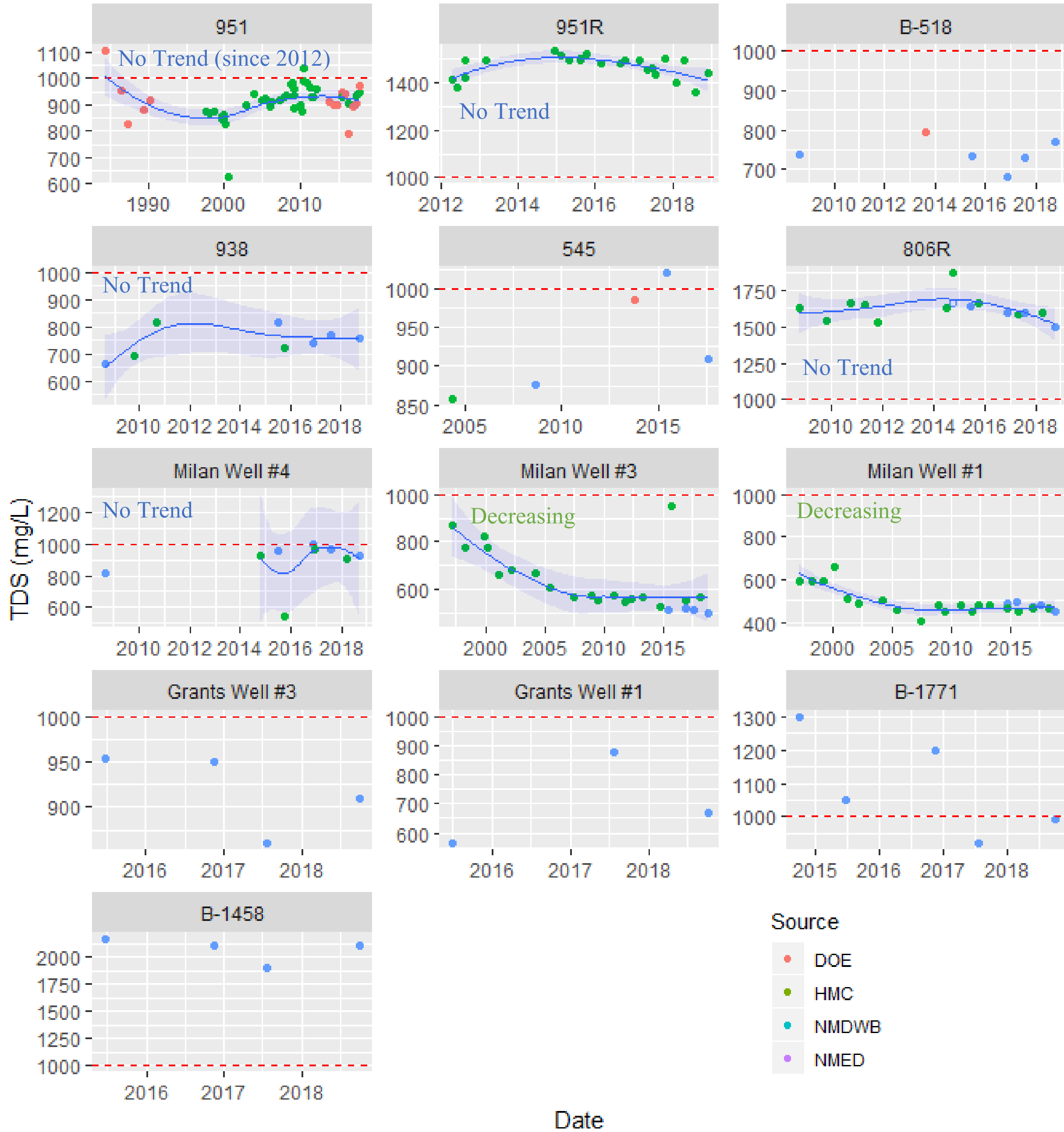
Mann-Kendall analysis results for TDS for offsite wells are shown in each chart in Figure 29 and Table 4. Similar to uranium and sulfate results, no offsite wells were identified to have increasing trends, two offsite wells (Milan Well #3, and Milan Well #1) have decreasing trends, and five wells (951 since 2012, 951R, 938, 806R, and Milan Well #4) had no trend based on Mann-Kendall analysis.

Figure 30 shows the locations of both Bluewater site and offsite wells, color codes identifying TDS concentration trends, and start and end dates for the trend analysis. As shown, the two wells 15(SG) and 18(SG) in the south half of the Bluewater site near the Ambrosia Lake Fault have increasing trends. Wells 15(SG) and 18(SG) are between the highest plume concentrations and the area where high-production pumping wells are located to the south and east. No offsite wells downgradient of the uranium plume show increasing trends.



Notes:
Mann-Kendall trend results shown on plots as "Increasing," "Decreasing," or "No Trend."
——Blue line is a LOESS locally weighted regression line.
Shaded area is the corresponding 95% pointwise confidence interval.
- - - 1000 mg/L State of New Mexico groundwater standard for TDS, included as a reference point, not intended to imply compliance requirement.

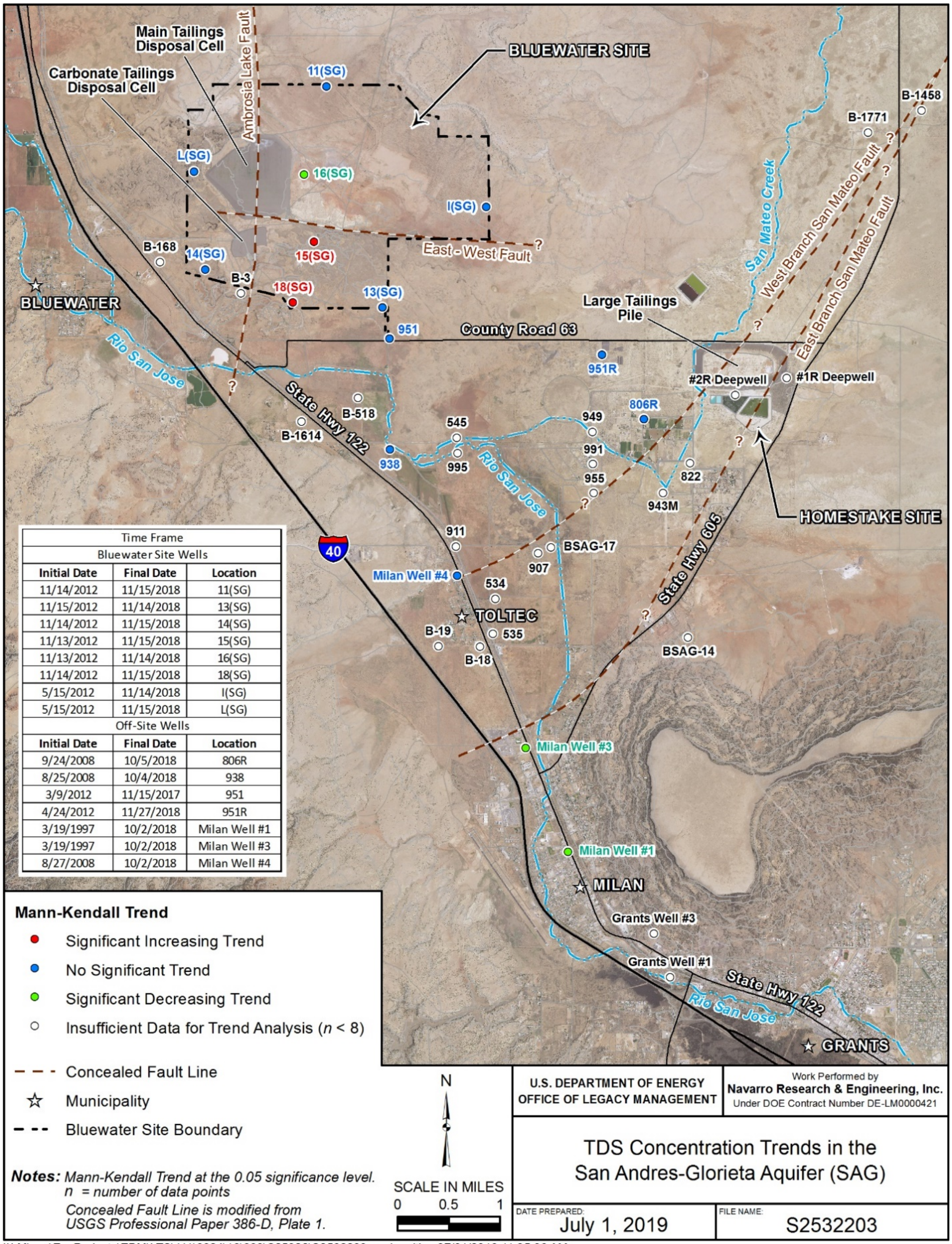
Figure 28. Total Dissolved Solids Concentration Trends in Bluewater Site SAG Wells and Mann-Kendall Results



Notes:
Regression lines and confidence intervals are only shown for wells with ≥8 measurements.
Because of the large (>10-year) gap in data for Milan Well #4, the regression line and corresponding confidence interval is plotted only for the most recent (2014–2018) data.
Mann-Kendall trend results shown on plots as "Increasing," "Decreasing," or "No Trend."
——Blue line is a LOESS locally weighted regression line.
Shaded area is the corresponding 95% pointwise confidence interval.
- - - 1000 mg/L State of New Mexico groundwater standard for TDS, included as a reference point, not intended to imply compliance requirement.

Abbreviations: DOE = U.S. Department of Energy; HMC = Homestake Mining Company; NMDWB = New Mexico Drinking Water Bureau; NMED = New Mexico Environment Department

Figure 29. Total Dissolved Solids Concentration Trends in Offsite SAG Wells and Mann-Kendall Results



Time Frame		
Bluewater Site Wells		
Initial Date	**Final Date**	**Location**
11/14/2012	11/15/2018	11(SG)
11/15/2012	11/14/2018	13(SG)
11/14/2012	11/15/2018	14(SG)
11/13/2012	11/15/2018	15(SG)
11/13/2012	11/14/2018	16(SG)
11/14/2012	11/15/2018	18(SG)
5/15/2012	11/14/2018	I(SG)
5/15/2012	11/15/2018	L(SG)
Off-Site Wells		
Initial Date	**Final Date**	**Location**
9/24/2008	10/5/2018	806R
8/25/2008	10/4/2018	938
3/9/2012	11/15/2017	951
4/24/2012	11/27/2018	951R
3/19/1997	10/2/2018	Milan Well #1
3/19/1997	10/2/2018	Milan Well #3
8/27/2008	10/2/2018	Milan Well #4

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Figure 30. Total Dissolved Solids Concentration Trends in the San Andres-Glorieta Aquifer

6.0 Summary and Discussion

This evaluation included a review of (1) groundwater-level data and pumping data to evaluate hydraulic responses in the SAG aquifer to high-production pumping wells and (2) groundwater chemistry data and trends to assess the potential transport of mill-related contaminants. This section presents a summary and discussion of the evaluation presented above.

6.1 Water-Level Fluctuations and Trends

Patterns of groundwater levels and changes in flow directions were evaluated to see if response from pumping and/or precipitation is observed within the study area. It was anticipated that if groundwater is being influenced by pumping, a hydraulic response would be observed. Previous work in the area has indicated groundwater levels in the SAG aquifer respond to both pumping and precipitation (Baldwin and Anderholm 1992).

Groundwater-level data for offsite wells 535, 951 and 951R were used to evaluate groundwater behavior in offsite areas (Figure 15 and Figure 16). Data in offsite areas are sparse, and only longer-term patterns and trends could be observed. In general, groundwater levels in offsite wells 535, 951 and 951R reflect changes in pumping (in wells 951 and 951R) and precipitation. Groundwater-level measurements for offsite wells are shown in plots in Appendix B.

Average daily groundwater-level data were also used to evaluate patterns and trends at eight Bluewater site wells (Figure 17 and Figure 18). The use of average daily data provided the opportunity to evaluate shorter-term groundwater-level patterns. Seasonal (short-term) water-level fluctuations are apparent in these groundwater-level data, and the influence of the faulting on the water-level patterns is also noticeable. Continuous water levels showed seasonal declines of approximately 4 to 5 ft in the late spring, summer, and early fall in five wells: 13(SG), 14(SG), 15(SG), 18(SG), and I(SG). Short-term (monthly) fluctuations also occur. These wells are south of the East-West Fault, except for I(SG), which is north of the East-West Fault and on the east edge of the site boundary. Similar patterns in I(SG) with wells south of the East-West Fault suggest the influence of the East-West Fault is diminished to the east. Other wells (11(SG) and 16(SG)) north of the East-West Fault and east of the Ambrosia Lake Fault show less of a seasonal fluctuation. This could be because the East-West Fault acts as a flow barrier and the hydraulic responses are reduced through the fault zone. This area around well 16(SG), north of the East-West Fault, contains the highest concentrations of mill-related contaminants. Well L(SG), also north of the East-West Fault but west of the Ambrosia Lake Fault, has a unique water-level pattern that shows greater seasonal fluctuations but also a dampened response at times.

Comparison of calculated average daily flow directions to seasonal decline in water levels shows a correlation with a shift in flow direction. Flow directions shift more to the south in the late spring, summer, and early fall (Figure 20). During this period, calculated gradients for well triangles 1, 2, and 3 (Figure 21) show greater variability. These well triangles are in the south and east areas of the Bluewater site (Figure 19). For well triangle 4, gradients are typically highest in the summer and lowest in the winter. This triangle represents an area of groundwater north of the East-West Fault. The well triangle 5 gradient time plot does not show a seasonal pattern, which may be a result of the lack of data. However, the well triangle 5 gradient time plot shows a distinct reduction in gradient in early 2016, the time when pumping from HMC wells was reduced.

Pumping records were tabulated to compare timing and magnitude of pumping to changes in groundwater levels and flow directions. Pumping records for the industrial and municipal high-production pumping wells (Figure 14) suggest that the timing of higher pumping correlates with the seasonal drawdown of the groundwater levels. Precipitation recorded at the Bluewater site is highest during the summer when groundwater levels are lowest. A delayed aquifer response to infiltration of precipitation is possible, and if this were the case, groundwater levels would be expected to rise several months after a precipitation event. Fluctuations of groundwater levels at the Bluewater site are likely a function of both pumping and precipitation.

These flow direction and gradient trends are consistent with the anticipated effects from pumping. However, this does not fully suggest the groundwater-level declines are from pumping.

6.2 Uranium, Sulfate, and TDS Concentration Trends

Water chemistry trends were also evaluated to assess if pumping is impacting the transport of contaminants. The concept is that pumping could pull contaminated groundwater toward the pumping well or nearby well(s) and an increasing concentration trend would be observed.

As previously discussed, pumping of industrial wells has been observed to influence groundwater levels and contaminant concentrations at the Bluewater site. During active milling operations and associated pumping from the Anaconda wells, uranium concentrations increased in Anaconda well #2. Also, uranium concentrations were reported to increase in well 951 after pumping it from 1999 to 2012 (DOE 2014). This phenomenon (observations of increasing trends) was evaluated by plotting time-series data and performing concentration trend tests for three analytes (uranium, sulfate, and TDS) that are indicators of mill-related contaminants from the Bluewater site.

Time–concentration plots were prepared for Bluewater site wells and offsite wells. In general, diverse trends of the various contaminants are revealed. Several plots show increasing and others show decreasing trends, some plots have both increasing and decreasing trends, and others show no significant change in concentration over time. Trend analysis results are shown in Figure 22 through Figure 30 and summarized in Table 4. Well-specific time–trend plots are provided in Appendix B.

Concentration trends were identified by Mann-Kendall tests for eight Bluewater site wells and seven offsite wells. The eight Bluewater site wells are monitoring wells, and the offsite wells used in the trend analysis are high-production wells, except for well 951, which is now used only for monitoring. The use of irrigation supply wells 938 and 545 is also unknown as is the extent of use of irrigation well 806R.

The wells in the study area that have increasing concentration trends of the selected analytes are as follows:

- Uranium 14(SG)
- Sulfate 14(SG), 15(SG), and 18(SG)
- TDS 15(SG) and 18(SG)

6.2.1 Bluewater Site Wells

Wells 14(SG), 15(SG), and 18(SG) are the only wells identified by the Mann-Kendall test to have increasing trends. These wells are located within the extent of the uranium plume and in the south half of the Bluewater site. The increasing trends indicate an increase in contaminant mass in this area. These wells are near the Ambrosia Lake Fault, which is a potential transport pathway for contaminants (DOE 2014). The specific source of the contaminants has not been verified; however, previous work describes that historical seepage from the main tailings impoundment likely resulted in a mineralized zone in the Ambrosia Lake Fault Zone and the formation of materials (including in the SAG) adjacent to the fault zone (DOE 2014). Wells 14(SG), 15(SG), and 18(SG) also are in an area where seasonal water-level fluctuations are observed that could be caused by pumping.

Two Bluewater site wells showed decreasing trends for uranium (16(SG) and 15(SG)), and one shows a decreasing trend for TDS (16(SG)). Well 16(SG) is downgradient of the Main Tailings Disposal Cell, and well 15(SG) is downgradient of the Carbonate Tailings Disposal Cell.

6.2.2 Municipal Wells

Milan Well #1, Milan Well #3, and Milan Well #4 were the only municipal wells with adequate data for the Mann-Kendall trend analysis. The datasets for Grants Well #1 and Grants Well #3 were not sufficient for the analysis. A decreasing trend was identified for uranium, sulfate, and TDS at Milan Well #1 and Milan Well #3. No trend was identified for Milan Well #4 for uranium, sulfate, and TDS. Evaluation of time–concentration plots of uranium, sulfate, and TDS indicates concentrations in Milan Well #1 and Milan Well #3 began to decline around the early 2000s (Appendix B). Uranium concentrations in these wells have remained relatively constant since 2005, and sulfate and TDS concentrations have remained relatively constant since 2008. It is unknown why concentrations in the aquifer around early 2000 were higher in these wells. Based on the trend analysis presented herein, there is no evidence that pumping is currently drawing contamination into these wells.

6.2.3 Other Offsite Wells

With the exception of the Village of Milan municipal wells, four other offsite wells (951, 951R, 806R, and 938) contained sufficient data to calculate statistical trends. Well 951 is within the current delineated uranium plume, just south of the Bluewater site, and was pumped from 1999 through 2012 by HMC for industrial supply. Time–concentration patterns for this well show uranium, sulfate, and TDS concentrations increased during the pumping period and decreased following the pumping period. The Mann-Kendall test was used for two periods for well 951. The full period of record used included the pre-pumping period (1999–2012), and the other period of record used was for that time following pumping (2012–present). An increasing trend was identified using the full record, and no trend was identified for the time following the pumping period. This suggests pumping of well 951 was pulling contaminated groundwater to the well. Concentrations in this well might revert to where they were before the well was used for as an industrial supply.

Well 951R is also within the current delineated uranium plume and is approximately 2 mi southeast of the Bluewater site. This well replaced well 951 as a pumping well in 2012, and pumping of 951R began in 2012, concurrent with observed concentration increases of uranium, sulfate, and TDS in the well. Pumping of all HMC wells decreased in 2015, also concurrent with the time that concentrations of uranium, sulfate, and TDS began to decrease or remain relatively constant in 951R. Mann-Kendall analysis for the full period of record indicates no trends.

Well 806R is used for irrigation by the Murray Acres Irrigation Association. Time–concentration patterns for this well show concentrations of uranium increased between 2009 and 2015 and have been decreasing since. This pattern is also observed with TDS concentrations, but is more subdued. Observed concentration patterns at well 806R for sulfate indicate concentrations are variable, but stable. With the use of the data since 2009, the Mann-Kendall test indicated there are no statistically identifiable trends for uranium, sulfate, and TDS for well 806R. This well is located approximately 0.75 mi downgradient from well 951R and, unlike 951R, is outside the defined uranium plume. Concentrations of uranium, sulfate, and TDS in these two wells (951R and 806R) are comparable. However, unlike that in wells 951 and 951R, the monitoring and pumping history of well 806R does not currently suggest that pumping this well is increasing its constituent concentrations.

Well 938 is an irrigation well approximately 1 mi south of the Bluewater site and well 951 and for which there are no pumping records. Ambient flow directions from the site do not suggest mill-related contaminants would reach well 938. However, pumping of this well could induce flow to it from an area that would typically not contribute groundwater. Time–concentration plots and LOESS lines and calculated Mann-Kendall trends for this well currently do not suggest concentrations are increasing for uranium, sulfate, or TDS.

7.0 Limitations and Uncertainties

The use of current datasets for this evaluation made it clear that several data limitations exist. These limitations can be described as the shortcomings of the data and datasets, which can include the spatial and temporal resolution and quality of the data. Overcoming some of the limitations would allow for a stronger analysis and set of conclusions with less uncertainty. The main limitations for this evaluation are summarized as follows:

- Groundwater-level datasets are sparse for many offsite wells, which limits use of the data to assess groundwater flow directions and gradients. Groundwater levels are frequently not measured in offsite wells or are often collected at various times during which the aquifer could be under different pumping conditions. Comprehensive, synoptic groundwater-level measurements are needed to better assess groundwater flow directions in offsite areas.
- Water chemistry datasets are sparse for many offsite wells, which limits the number of wells that can be statistically evaluated for concentration trends. A more spatially and temporally robust dataset would assist with the evaluation of concentration trends and sources.
- The accuracy and availability of pumping records limits the correlations that can be made between drawdown and pumping.
- The current well network highlights the limitations for monitoring:
  - The wells do not provide vertical and horizontal delineation of the plume.
  - Temporal limitations exist from limited access to some wells, which means data is not available for all time periods evaluated.

Uncertainties associated with the analyses and conclusions of this evaluation are inherent and unavoidable due to the complexity of the hydrogeology in the study area and sparseness of data. Uncertainty refers to incomplete or unknown information and can pertain to predictions, physical measurements or calculations, and to what is not known. The following provides a summary of the major uncertainties relevant to this evaluation:

- Although groundwater flow directions are relatively well defined within the Bluewater site, flow directions are poorly defined in offsite areas. Currently, this evaluation utilizes a general depiction as reported in 1995 of flow directions in offsite areas to predict where the contaminants will move (DOE 2014). The significance in understanding flow direction in offsite areas is that it is the measure generally used to predict which direction contaminants will move within the aquifer.
- Uncertainty exists with how faults influence groundwater flow within the SAG aquifer and vertical connectivity between the SAG and other aquifers. These features can have a significant effect on groundwater movement and influence of high-production pumping wells on contaminated groundwater. Some faults may act as flow barriers limiting the direction of groundwater flow in the horizontal direction. Other faults may act as conduits that transmit water from aquifers above. Two major faults that have been mapped on the Bluewater site have been hypothesized to influence groundwater flow (DOE 2014). Vertical displacement along portions of the East-West Fault and Ambrosia Lake Fault resulted in the faults acting as partial hydraulic barriers to horizontal groundwater flow in the SAG. These fault zones may also be capable of acting as vertical and horizontal conduits of groundwater flow between the alluvial aquifer and SAG aquifer (DOE 2014). There are also two major faults, the East and West Branch of the San Mateo Creek Fault, southeast of the Bluewater site that can have significant influence on groundwater flow in the study area. It is unknown whether these faults act as hydraulic barriers or conduits to groundwater flow. If these faults act as conduits, it is possible that any contamination found in offsite wells near or downgradient of the faults could be from above aquifers. If these faults act as barriers to horizontal groundwater flow, the influence of high-production pumping wells on contaminated groundwater beneath the Bluewater site would be significantly reduced. Because the influence of the faulting on groundwater flow in the study area is not known, the influence of high-production pumping wells on groundwater flow and potential contribution of contamination from overlying aquifers is uncertain.
- Several potential anthropogenic sources of contamination occur within the study area including mill-related contamination originating from (1) the Bluewater site, (2) the Homestake site, and (3) mill- and mine-related contamination in the alluvial aquifer from other uranium mills and mines within the San Mateo Creek basin. Naturally occurring concentrations of constituents also vary between the different aquifers. Several potential pathways to transmit water from these different sources to the SAG aquifer also exist, including (1) percolation through faults from overlying alluvial and Chinle Formation aquifers, (2) deteriorating well casings that provide a conduit between the overlying aquifers and SAG aquifer, and (3) areas where the alluvial aquifer directly overlies the SAG aquifer (DOE 2014). In general, little is known about the specific signatures of the different contaminant sources or about the connectivity of the aquifers. If increasing concentration trends are identified in certain areas, the actual source of the contamination might be inconclusive and further investigation would need to be conducted.

- Correlations that exist between seasonal groundwater-level fluctuations, flow directions and gradients, and periods of increased pumping do not definitively imply the fluctuations in groundwater levels are caused by high-production pumping. To more definitively understand these relationships, more accurate and complete pumping records from all wells in the area would be needed. Hydraulic testing of individual wells would also be required to isolate impacts from individual pumping wells. Lack of understanding of these direct correlations may lead to inaccurate conclusions of the causes of groundwater-level fluctuations.
- The horizontal and vertical extent of the contamination is not fully delineated. As a result, expansion or reduction in the size of the plume may go undetected.
- A well-by-well statistical trend analysis is a limited tool that can provide insight into plume stability and movement. Results can be misleading without combining them with additional lines of evidence such as bulk plume metrics, which accounts for the spatial integration of concentrations. Additional analyses that account for the spatial integration of concentrations help reduce uncertainties when defining the stability and movement of plumes.

8.0 Conclusions and Recommendations

The objective of this report was to evaluate the influence of the high-production pumping wells in the study area on the flow and transport of the contaminated groundwater in the SAG aquifer. The concern was pumping from high-production pumping wells could cause movement of the plume resulting in the potential degradation of water quality in existing wells. The conclusions from this evaluation are as follows:

- Groundwater levels and flow directions at the Bluewater site suggest that high-production pumping southeast of the site seasonally influences site groundwater levels and flow directions.
- Contaminant trend data suggest there is no clear evidence that high-production pumping is impacting groundwater quality at wells outside of the 2017 uranium plume; geochemical conditions appear to be stable based on the available data.
- The data used for this evaluation are temporally and spatially sparse. Routine, comprehensive sampling would better inform long-term contaminant concentration trends at nearby, high-production pumping wells. To allow for additional collection of data, the next updated assessment of site conditions is suggested for 2024.

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Appendix A

Industrial Use and Municipal Use Pumping Records

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Appendix A

Industrial Use and Municipal Use Pumping Records

	HMC Pumping	Tri-State Pumping						Municipal Pumping						
Date	Total Pumping from HMC Wells (#1 Deep Well, #2 Deep Well, 951, 951R, 943)	B-18	B-19	949	822	995	Total Tri-State Pumping	Milan Well #1	Milan Well #3	Milan Well #4	Grants Well #1	Grants Well #3	Total Municipal Pumping	Grand Total
January-2012	116.4	13.5	6.5	157.6	0.0	0.0	177.6	15.8	25.1	5.7	1.7	115.0	163.3	457.3
February-2012	194.3	9.1	0.0	3.0	0.0	0.0	12.1	11.4	17.2	11.3	3.2	97.5	140.6	347.1
March-2012	119.4	58.7	56.1	43.0	0.0	0.0	157.8	12.4	20.0	14.5	3.3	126.1	176.3	453.4
April-2012	134.4	114.3	106.0	44.3	0.0	0.0	264.7	16.7	27.6	16.6	4.0	153.5	218.5	617.6
May-2012	198.3	114.7	108.7	44.1	0.0	0.0	267.5	17.7	29.0	16.7	5.2	198.1	266.6	732.4
June-2012	160.8	112.2	110.6	60.5	0.0	0.0	283.4	21.9	35.7	19.9	17.9	211.7	307.1	751.2
July-2012	164.4	0.0	0.0	0.0	0.0	0.0	0.0	15.1	26.5	15.7	2.9	187.1	247.3	411.7
August-2012	182.0	126.9	118.4	65.4	0.0	0.0	310.7	14.8	28.7	15.9	0.0	180.3	239.7	732.4
September-2012	177.4	112.5	109.5	47.9	0.0	0.0	269.8	13.3	24.8	14.0	7.8	161.8	221.7	668.9
October-2012	157.3	14.6	117.9	124.1	0.0	0.0	256.6	18.9	29.0	19.5	4.5	150.8	222.7	636.6
November-2012	221.9	0.9	105.9	107.9	0.0	0.0	214.6	12.4	12.1	13.2	0.1	129.3	167.1	603.6
December-2012	175.8	1.1	119.0	117.8	0.0	0.0	237.8	16.1	16.5	14.6	0.0	122.6	169.8	583.4
January-2013	208.4	0.6	113.7	113.6	0.0	0.0	227.9	14.2	23.9	12.4	0.6	131.7	182.9	619.2
February-2013	180.7	0.8	108.6	107.8	0.0	0.0	217.2	18.4	13.3	10.0	0.6	131.7	174.1	571.9
March-2013	178.2	6.3	116.0	144.6	0.0	0.0	266.8	15.1	26.7	3.0	0.0	142.6	187.3	632.4
April-2013	281.1	7.4	53.6	72.2	0.0	0.0	133.1	17.8	29.1	16.9	0.1	175.5	239.5	653.7
May-2013	223.2	20.5	104.7	130.9	0.0	0.0	256.1	15.1	32.4	15.2	0.0	215.2	277.9	757.1
June-2013	200.2	42.6	64.6	167.8	0.0	0.0	275.0	16.8	36.6	12.1	27.4	197.7	290.6	765.7
July-2013	263.2	19.5	37.1	188.5	0.0	0.0	245.1	18.0	43.1	0.0	6.8	204.1	272.0	780.2
August-2013	189.9	29.8	86.9	114.1	0.0	0.0	230.9	18.4	33.5	0.0	0.0	192.3	244.2	664.9
September-2013	246.1	108.5	84.2	39.8	0.0	0.0	232.5	17.6	38.8	0.0	21.2	182.0	259.6	738.2
October-2013	262.5	69.3	69.7	17.5	0.0	0.0	156.4	18.4	27.8	0.0	0.0	159.1	205.3	624.2
November-2013	212.1	53.4	12.1	25.6	0.0	0.0	91.1	19.1	8.7	13.7	0.0	129.5	171.0	474.1
December-2013	234.8	52.5	50.4	4.9	0.0	0.0	107.8	15.7	21.5	9.6	0.0	130.8	177.7	520.2
January-2014	198.5	70.2	70.2	6.6	0.0	0.0	147.0	14.0	16.1	12.1	0.0	145.7	188.0	533.5
February-2014	177.1	96.4	71.7	41.6	0.0	0.0	209.7	12.6	13.3	13.5	0.0	131.6	170.9	557.7
March-2014	114.2	93.4	87.5	24.1	0.0	0.0	205.0	14.9	22.1	15.9	0.0	173.6	226.4	545.7
April-2014	78.1	102.6	99.4	35.5	0.0	0.0	237.5	14.9	22.1	15.9	5.4	196.3	254.5	570.1
May-2014	150.7	102.6	99.4	35.5	0.0	0.0	237.5	23.6	25.1	29.5	5.4	196.3	279.9	668.1
June-2014	148.3	39.0	44.3	202.1	0.0	0.0	285.4	18.2	28.0	3.5	36.1	196.9	282.7	716.4
July-2014	192.3	73.6	77.4	129.9	0.0	0.0	280.9	15.8	22.0	1.4	17.7	192.5	249.4	722.7
August-2014	133.7	113.0	108.7	61.0	0.0	0.0	282.7	10.0	14.9	0.0	2.3	177.5	204.7	621.1
September-2014	151.8	72.0	75.4	38.4	0.0	0.0	185.8	14.7	14.9	0.0	4.5	170.1	204.1	541.7
October-2014	158.3	0.3	1.2	0.0	0.0	0.0	1.5	8.3	14.9	0.0	0.0	164.2	187.4	347.2
November-2014	155.2	29.3	21.4	97.5	0.0	0.0	148.2	6.1	14.9	0.0	0.0	129.3	150.3	453.7
December-2014	198.1	18.4	15.4	182.4	0.0	0.0	216.2	9.3	14.9	1.2	0.0	129.6	155.0	569.2
January-2015	136.7	6.9	6.0	127.6	0.0	0.0	140.5	31.1	0.0	11.2	0.0	129.8	172.0	449.2
February-2015	166.9	4.2	65.4	136.9	0.0	0.0	206.5	32.8	0.0	19.5	0.1	103.6	156.0	529.3
March-2015	208.8	27.4	96.6	84.6	0.0	0.0	208.6	32.8	0.1	19.5	0.0	137.0	189.4	606.8
April-2015	180.9	7.1	73.0	116.9	0.0	0.0	197.0	19.7	4.6	19.8	0.6	157.1	201.8	579.7
May-2015	178.6	44.8	72.5	117.1	0.0	0.0	234.4	21.6	2.3	23.8	0.0	469.2	516.9	929.9
June-2015	194.7	78.8	72.7	78.7	0.0	0.0	230.1	25.3	11.7	23.2	5.2	18.9	84.2	509.1
July-2015	140.5	18.4	25.4	192.9	0.0	0.0	236.7	7.4	13.7	21.4	2.9	27.0	72.4	449.6
August-2015	146.0	25.3	26.3	154.3	0.0	0.0	205.9	3.6	25.6	18.1	0.0	172.0	219.3	571.2
September-2015	215.6	11.3	65.2	123.3	0.0	0.0	199.7	9.5	25.0	14.3	0.0	166.5	215.3	630.7
October-2015	176.9	68.4	106.1	42.7	0.0	0.0	217.1	17.4	10.4	11.0	0.0	147.5	186.3	580.3
November-2015	170.7	71.3	75.5	13.2	0.0	0.0	159.9	15.1	9.1	10.2	0.0	146.2	180.7	511.3
December-2015	181.1	80.2	76.8	16.3	0.0	0.0	173.2	12.5	10.0	11.4	0.0	92.6	126.5	480.8
January-2016	208.2	87.2	79.2	7.1	0.0	0.0	173.6	15.3	12.5	12.1	0.0	122.1	161.9	543.7
February-2016	177.4	30.9	19.4	114.6	0.0	0.0	164.8	16.3	6.7	16.7	0.0	119.1	158.8	501.0
March-2016	47.5	8.9	0.8	167.6	0.0	0.0	177.3	15.9	9.4	16.4	0.0	145.5	187.2	411.9
April-2016	74.4	5.4	3.4	165.4	0.0	0.0	174.2	17.3	15.0	13.1	0.0	154.0	199.4	448.0
May-2016	52.5	12.5	4.9	136.7	0.0	0.0	154.2	18.9	16.6	17.3	0.6	168.3	221.8	428.5
June-2016	69.1	42.6	21.3	137.6	0.0	0.0	201.5	30.4	35.6	0.0	10.3	204.8	281.1	551.7
July-2016	37.7	30.5	12.5	221.6	0.0	0.0	264.7	23.3	30.6	12.4	15.0	206.8	288.1	590.5
August-2016	56.5	91.1	76.6	61.9	0.0	0.0	229.6	18.4	16.1	22.3	7.9	187.5	252.2	538.3
September-2016	41.4	78.4	67.7	65.7	0.0	0.0	211.8	18.0	10.1	17.8	3.5	179.9	229.4	482.6
October-2016	46.1	107.3	94.6	41.7	0.0	0.0	243.5	13.7	6.3	14.7	0.0	167.2	201.9	491.5
November-2016	48.1	106.5	87.4	26.9	0.0	0.0	220.8	11.3	6.7	12.6	0.0	128.4	159.0	427.9
December-2016	58.4	106.7	89.5	23.9	0.0	0.0	220.1	11.8	5.0	11.0	0.0	119.2	146.8	425.4
January-2017	69.4	49.9	42.7	106.1	0.0	0.0	198.7	12.2	4.5	11.0	19.6	440.6	487.8	755.9
February-2017	67.5	4.4	8.5	160.5	0.0	0.0	173.4	11.3	6.0	11.0	99.8	275.2	403.2	644.2
March-2017	74.4	5.3	9.9	143.5	0.0	0.0	158.7	11.3	7.1	11.0	98.2	406.8	534.3	767.3
April-2017	67.8	0.0	0.0	0.0	0.0	0.0	0.0	12.1	12.1	11.0	13.5	1460.2	1508.9	1576.7
May-2017	80.9	0.6	27.0	5.2	0.0	0.0	32.8	14.5	12.0	11.0	36.2	976.0	1049.7	1163.4
June-2017	26.5	56.4	34.8	102.1	0.0	0.0	193.3	16.1	15.6	16.5	54.5	161.4	264.1	483.9
July-2017	45.5	103.3	58.3	50.9	0.0	0.0	212.4	15.8	16.1	15.0	26.8	170.6	244.3	502.1
August-2017	47.1	100.2	94.3	54.8	0.0	0.0	249.3	17.1	15.0	24.6	26.8	170.6	254.1	550.5
September-2017	48.2	100.3	93.0	73.6	0.0	0.0	266.9	14.6	13.1	3.9	26.8	170.6	229.0	544.0
October-2017	69.6	71.7	30.5	114.7	0.0	0.0	216.9	13.9	8.1	12.5	26.8	170.6	231.9	518.4
November-2017	56.0	69.9	59.9	48.0	0.0	0.0	177.9	15.8	10.7	3.0	0.0	132.7	162.1	396.0
December-2017	55.7	88.7	81.3	16.5	0.0	0.0	186.4	17.2	8.5	6.5	0.0	116.5	148.7	390.9

Appendix A

Industrial Use and Municipal Use Pumping Records

	HMC Pumping	Tri-State Pumping						Municipal Pumping							
Date	Total Pumping from HMC Wells (#1 Deep Well, #2 Deep Well, 951, 951R, 943)	B-18	B-19	949	822	995	Total Tri-State Pumping	Milan Well #1	Milan Well #3	Milan Well #4	Grants Well #1	Grants Well #3	Total Municipal Pumping	Grand Total
January-2018	52.1	94.4	84.3	19.2	0.0	0.0	197.9	17.2	8.5	6.5	0.0	127.1	159.3	409.4
February-2018	37.6	84.0	77.6	8.6	0.0	0.0	170.2	17.2	8.5	6.5	0.0	111.2	143.4	351.2
March-2018	54.9	89.9	22.0	93.1	0.0	0.0	205.0	17.2	8.5	6.5	0.0	0.0	32.2	292.1
April-2018	50.8	65.4	75.3	17.8	0.0	0.0	158.4	17.2	8.5	6.5	5.4	300.3	337.8	547.0
May-2018	39.0	84.3	93.2	51.5	0.0	0.0	229.1	17.2	8.5	6.5	22.3	175.4	229.8	498.0
June-2018	33.7	109.2	109.9	50.5	0.0	0.0	269.5	17.2	8.5	6.5	54.6	176.9	263.6	566.9
July-2018	38.1	82.6	106.9	1.0	0.0	0.0	190.5	17.2	8.5	6.5	27.1	181.0	240.2	468.8
August-2018	30.5	17.9	32.1	111.8	0.0	0.0	161.8	19.5	7.6	16.4	20.6	168.6	232.7	425.0
September-2018	30.5	56.1	88.1	42.8	0.0	0.0	187.0	16.2	4.9	15.2	0.0	160.8	197.1	414.6
October-2018	40.7	10.9	37.3	158.6	0.0	0.0	206.7	18.2	6.1	2.2	0.1	134.8	161.4	408.8
November-2018	33.1	4.4	13.2	176.4	0.0	0.0	194.0	18.2	6.1	2.2	0.0	105.2	131.7	358.8
December-2018	26.8	3.2	52.2	126.6	0.0	0.0	182.0	16.4	7.3	1.7	0.0	111.0	136.4	345.2
Minimum	26.5	0.0	0.0	0.0	0.0	0.0	0.0	3.6	0.0	0.0	0.0	0.0	32.2	292.1
Maximum	281.1	126.9	119.0	221.6	0.0	0.0	310.7	32.8	43.1	29.5	99.8	1460.2	1508.9	1576.7
Mean	127.7	52.4	62.9	82.2	0.0	0.0	197.6	16.4	16.1	11.3	9.3	189.3	242.5	567.8

Notes:

All values are in acre-feet.

Cells are shaded where pumping records were divided equally between the months.

If pumping was reported from mid-month to mid-month an assumption was made that the pumping reported for that period was entirely for the first month.

If pumping was provided for a 2-month period or more the pumping rate was divided equally between each month for that period of record.

Appendix B

Well-by-Well Plots of Uranium, Total Dissolved Solids, and Sulfate Concentrations and Groundwater Elevations

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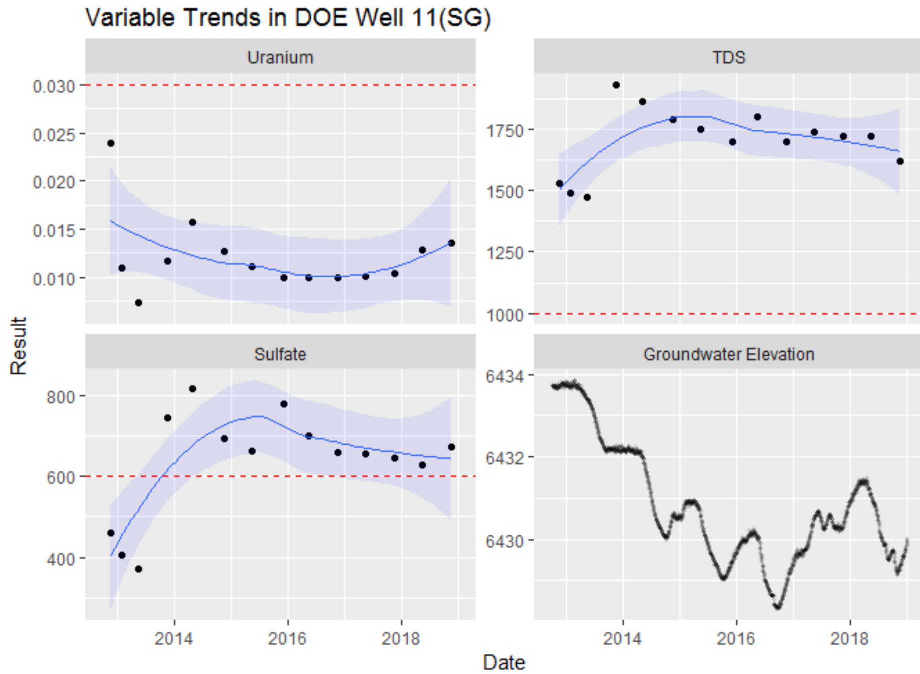
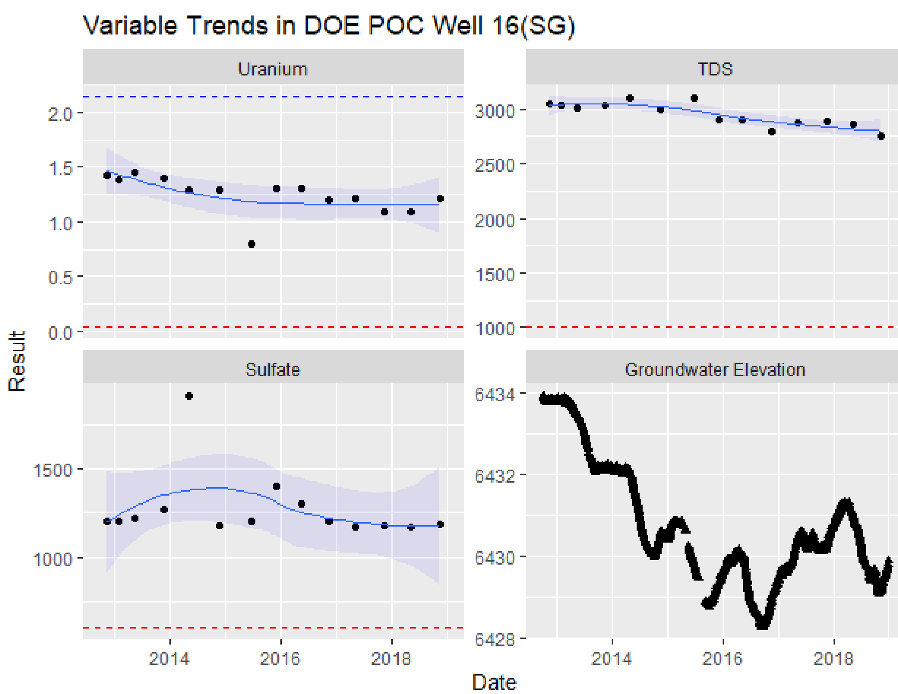
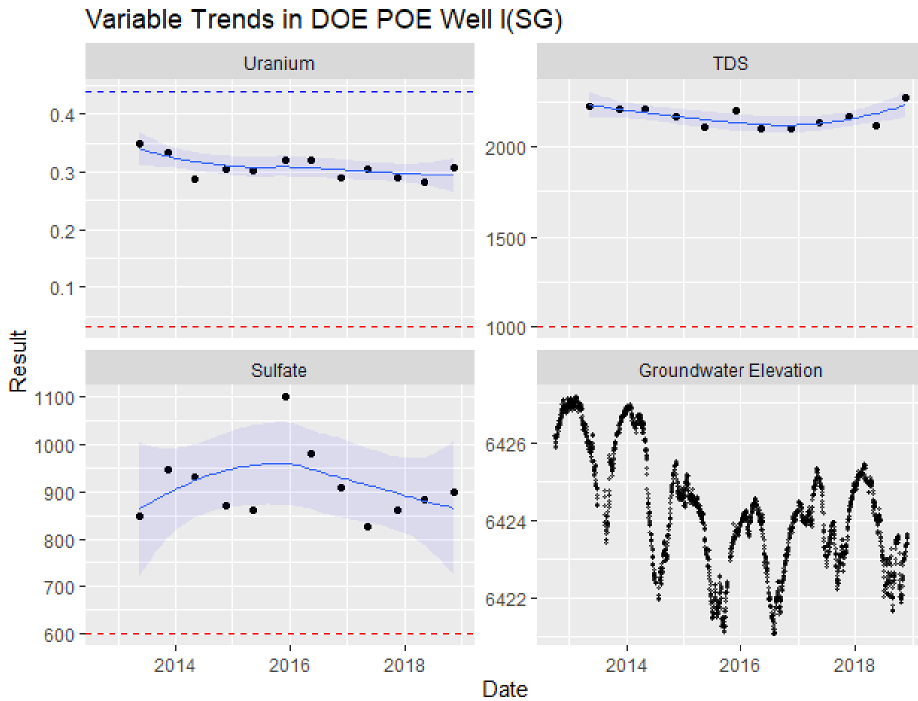


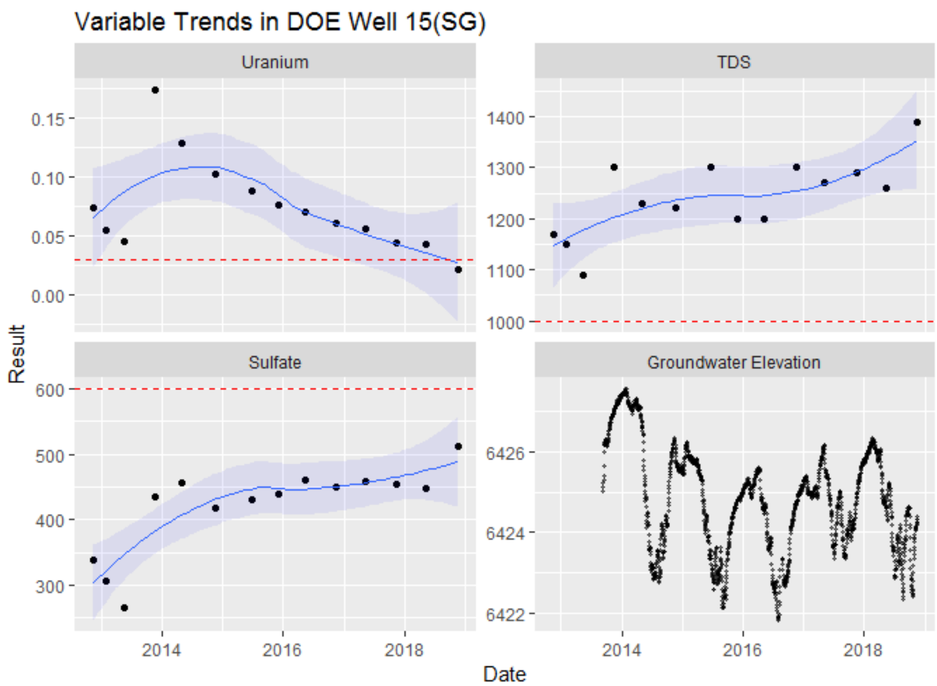
All units in mg/L except groundwater elevations (units = ft amsl).
——Blue line is a LOESS locally weighted regression line.
Shaded area is the corresponding 95% pointwise confidence interval.
- - - State of New Mexico groundwater standard in mg/L (uranium = 0.03; TDS = 1000; sulfate = 600), included as reference point, not intended to imply compliance requirement.



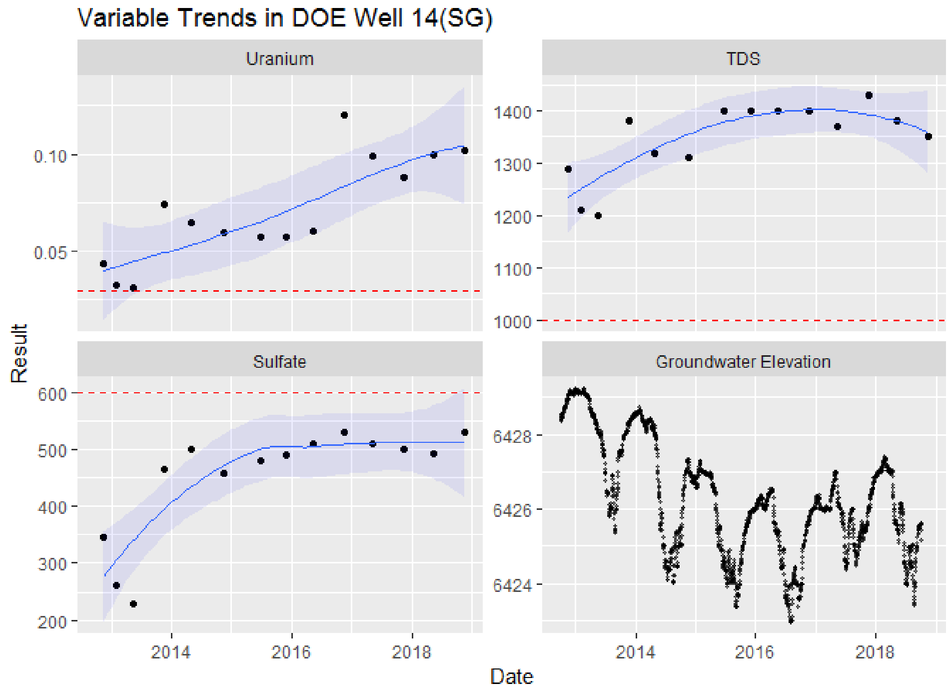
All units in mg/L except groundwater elevations (units = ft amsl).
——Blue line is a LOESS locally weighted regression line.
Shaded area is the corresponding 95% pointwise confidence interval.
- - - State of New Mexico groundwater standard in mg/L (uranium = 0.03; TDS = 1000; sulfate = 600), included as reference point, not intended to imply compliance requirement.
- - - Denotes the ACL limit (2.15 mg/L) for the SAG POC well (16(SG)).



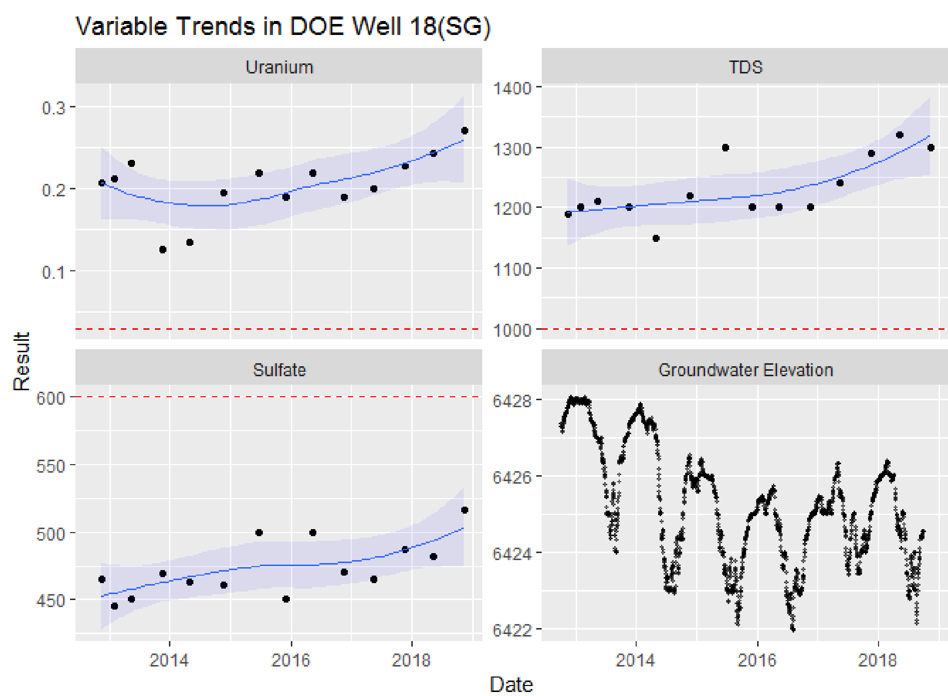
All units in mg/L except groundwater elevations (units = ft amsl).
——Blue line is a LOESS locally weighted regression line.
Shaded area is the corresponding 95% pointwise confidence interval.
- - - State of New Mexico groundwater standard in mg/L (uranium = 0.03; TDS = 1000; sulfate = 600), included as reference point, not intended to imply compliance requirement.
- - - Denotes the health-based concentration limit (0.44 mg/L) for the SAG POE well (I(SG)).
Scale limited to 2012–2019 for consistency with other wells (figures) and study time frame.



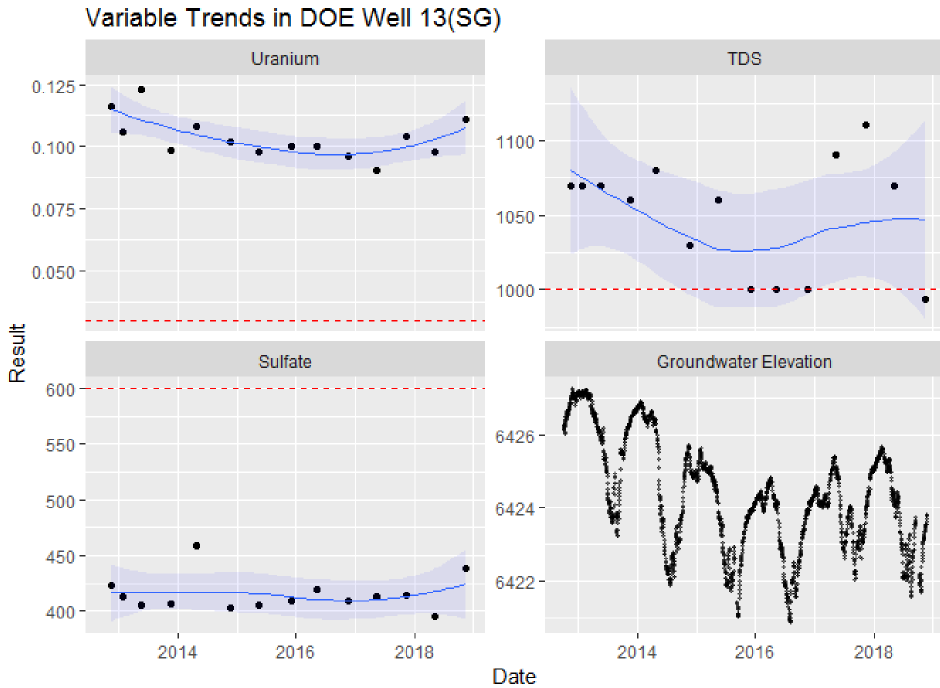
All units in mg/L except groundwater elevations (units = ft amsl).
——Blue line is a LOESS locally weighted regression line.
Shaded area is the corresponding 95% pointwise confidence interval.
- - - State of New Mexico groundwater standard in mg/L (uranium = 0.03; TDS = 1000; sulfate = 600), included as reference point, not intended to imply compliance requirement.



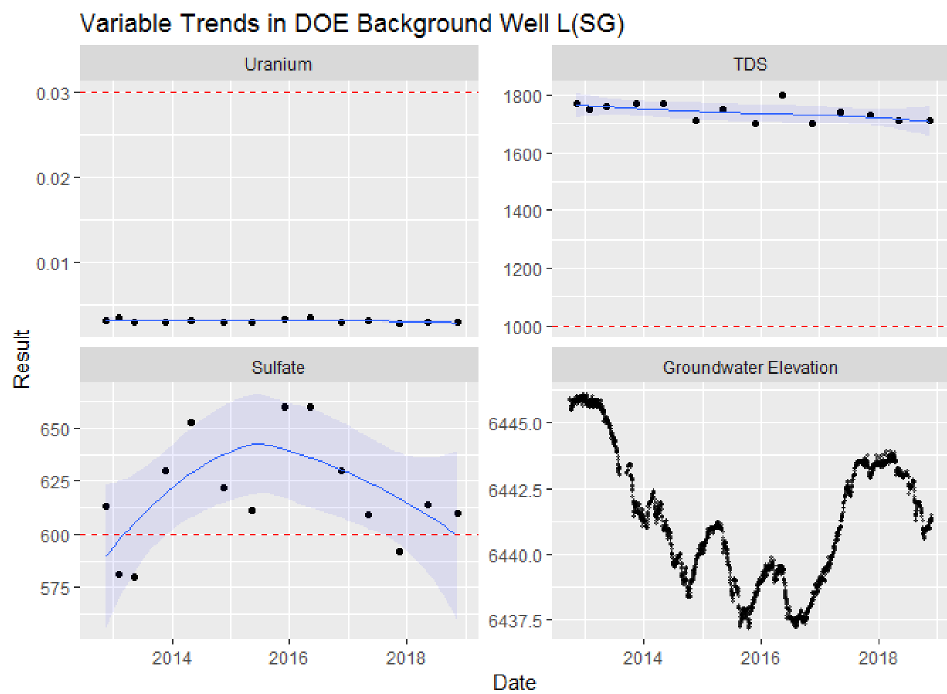
All units in mg/L except groundwater elevations (units = ft amsl).
——Blue line is a LOESS locally weighted regression line.
Shaded area is the corresponding 95% pointwise confidence interval.
- - - State of New Mexico groundwater standard in mg/L (uranium = 0.03; TDS = 1000; sulfate = 600), included as reference point, not intended to imply compliance requirement.



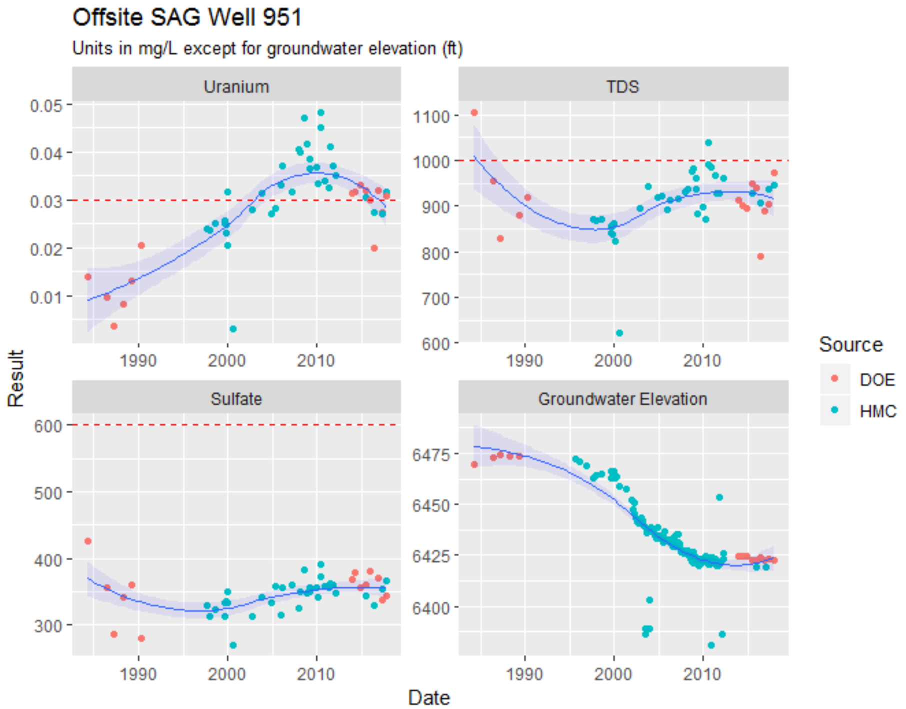
All units in mg/L except groundwater elevations (units = ft amsl).
——Blue line is a LOESS locally weighted regression line.
Shaded area is the corresponding 95% pointwise confidence interval.
- - - State of New Mexico groundwater standard in mg/L (uranium = 0.03; TDS = 1000; sulfate = 600), included as reference point, not intended to imply compliance requirement.



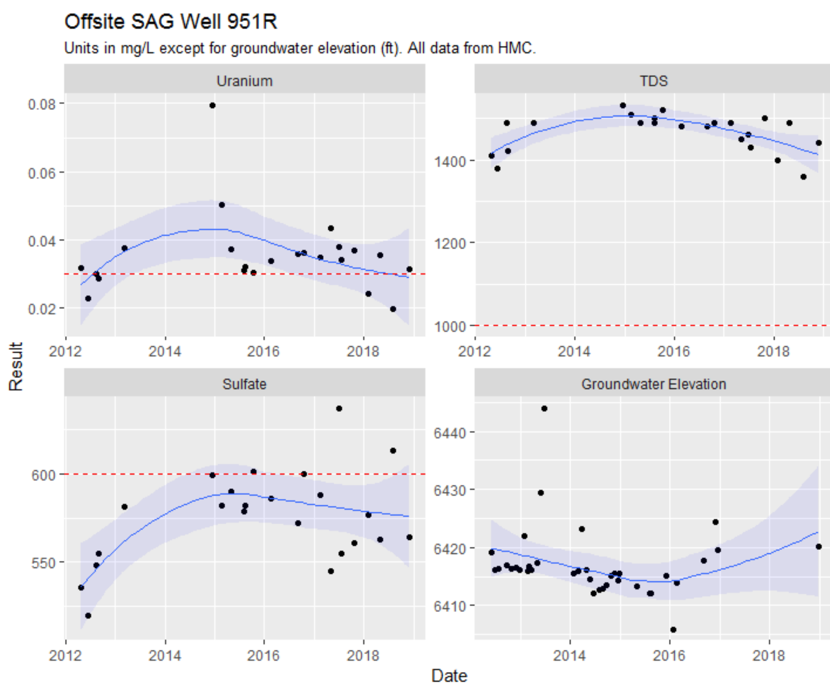
All units in mg/L except groundwater elevations (units = ft amsl).
——Blue line is a LOESS locally weighted regression line.
Shaded area is the corresponding 95% pointwise confidence interval.
- - - State of New Mexico groundwater standard in mg/L (uranium = 0.03; TDS = 1000; sulfate = 600), included as reference point, not intended to imply compliance requirement.



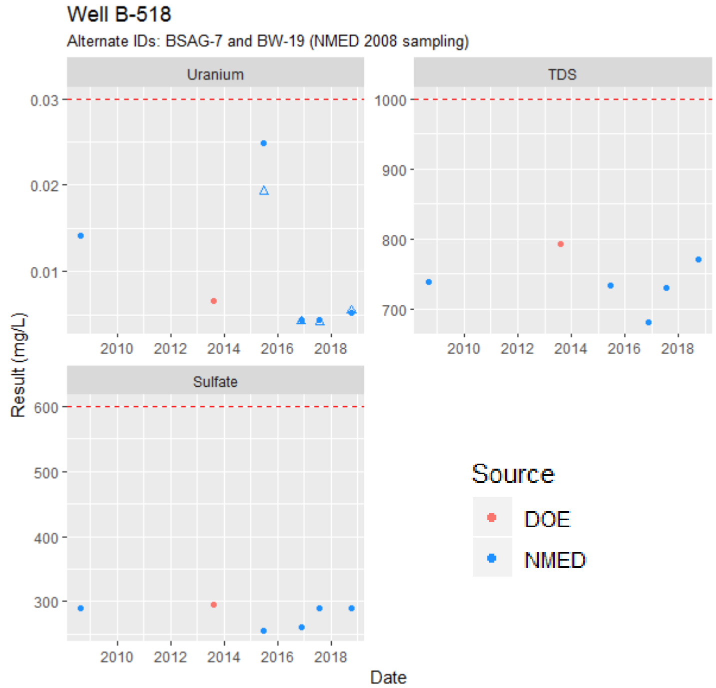
All units in mg/L except groundwater elevations (units = ft amsl).
——Blue line is a LOESS locally weighted regression line.
Shaded area is the corresponding 95% pointwise confidence interval.
- - - State of New Mexico groundwater standard in mg/L (uranium = 0.03; TDS = 1000; sulfate = 600), included as reference point, not intended to imply compliance requirement.
Scale limited to 2012–2019 for consistency with other wells (figures) and study time frame.



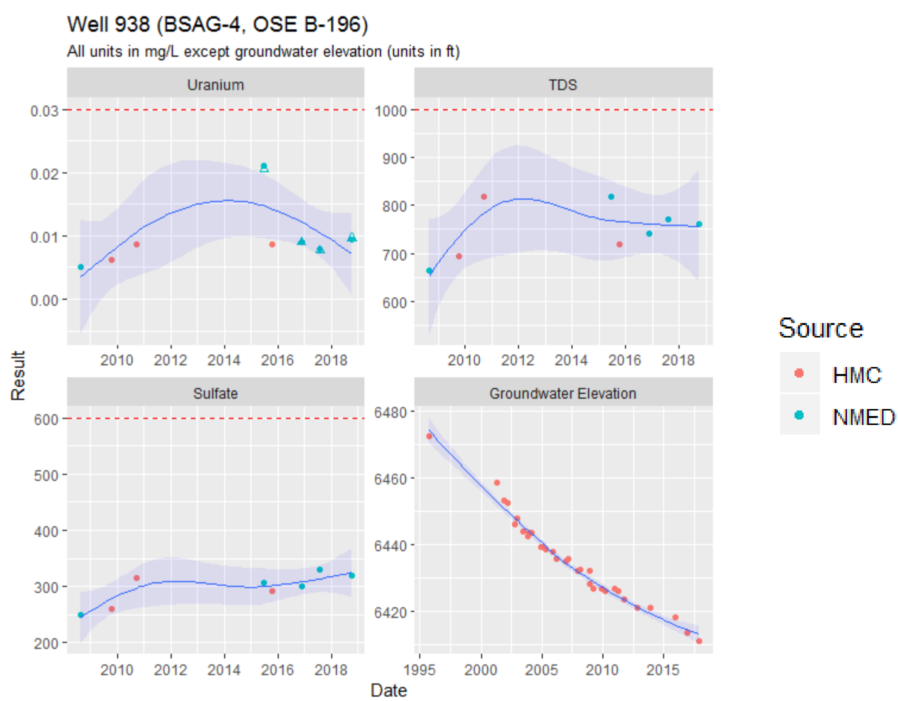
All units in mg/L except groundwater elevations (units = ft amsl).
——Blue line is a LOESS locally weighted regression line.
Shaded area is the corresponding 95% pointwise confidence interval.
- - - State of New Mexico groundwater standard in mg/L (uranium = 0.03; TDS = 1000; sulfate = 600), included as reference point, not intended to imply compliance requirement.



All units in mg/L except groundwater elevations (units = ft amsl).
——Blue line is a LOESS locally weighted regression line.
Shaded area is the corresponding 95% pointwise confidence interval.
- - - State of New Mexico groundwater standard in mg/L (uranium = 0.03; TDS = 1000; sulfate = 600), included as reference point, not intended to imply compliance requirement.
Plot excluded erroneous HMC outlier groundwater elevation datum: 6508.73 ft (for 10/8/2015).

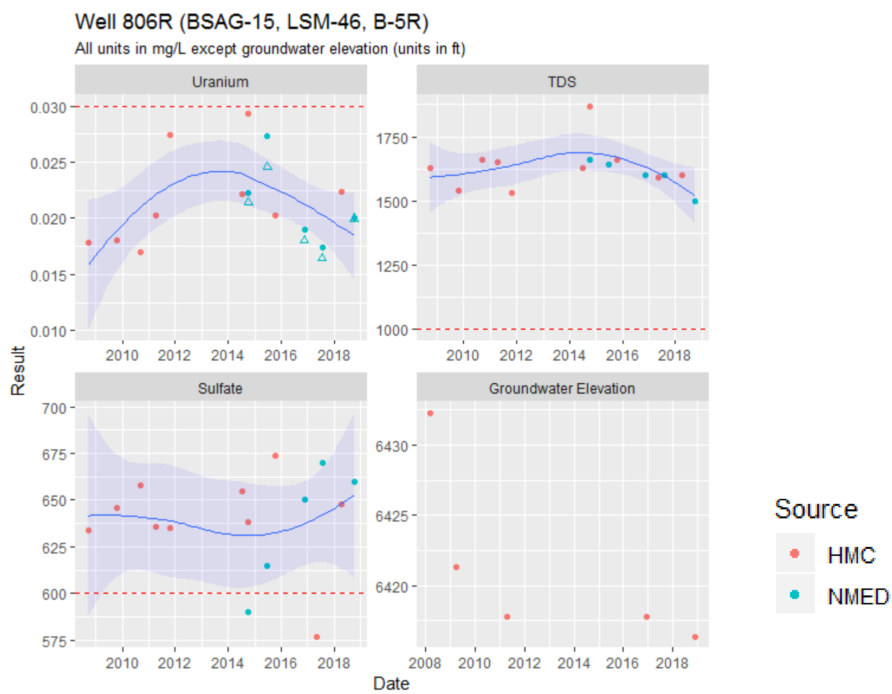


All units in mg/L.
- - - - State of New Mexico groundwater standard in mg/L (uranium = 0.03; TDS = 1000; sulfate = 600), included as reference point, not intended to imply compliance requirement.
Fraction: ● Total ∆ Dissolved

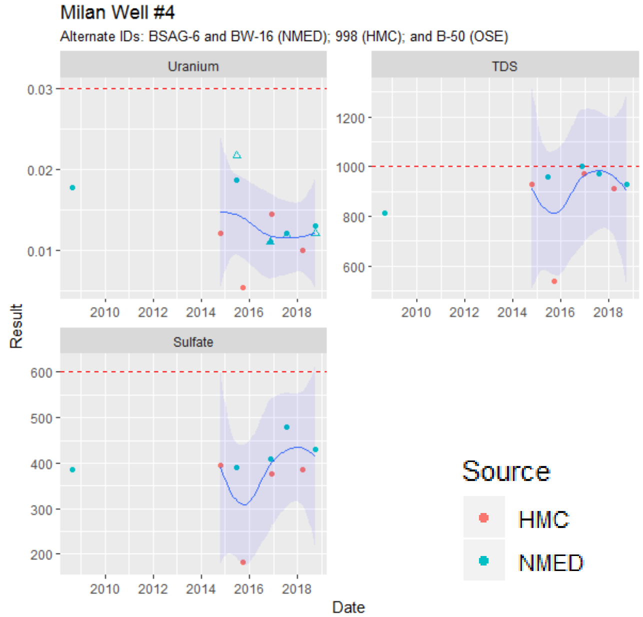


All units in mg/L except groundwater elevations (units = ft amsl).
——Blue line is a LOESS locally weighted regression line.
Shaded area is the corresponding 95% pointwise confidence interval.
- - - State of New Mexico groundwater standard in mg/L (uranium = 0.03; TDS = 1000; sulfate = 600), included as reference point, not intended to imply compliance requirement.
Fraction: ● Total ∆ Dissolved
Plot excluded erroneous HMC outlier groundwater elevation datum: 6550.2 ft (for 11/20/2012).

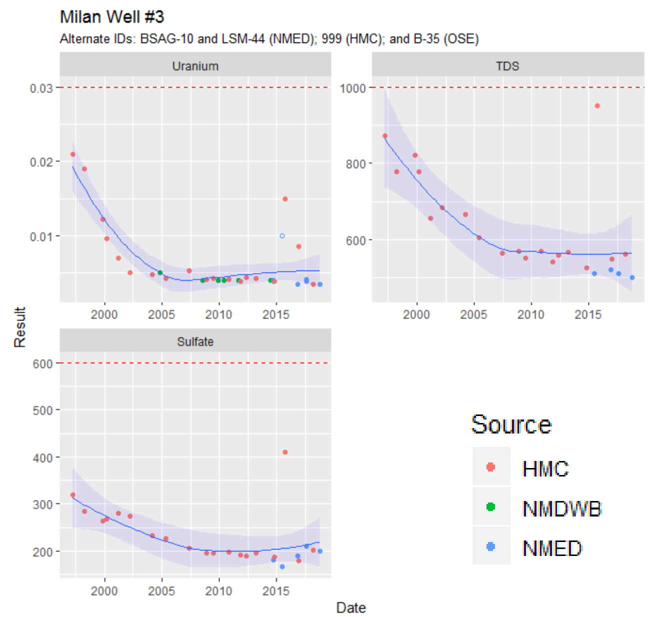
All units in mg/L.
- - - - State of New Mexico groundwater standard in mg/L (uranium = 0.03; TDS = 1000; sulfate = 600), included as reference point, not intended to imply compliance requirement.
Fraction: ● Total ∆ Dissolved



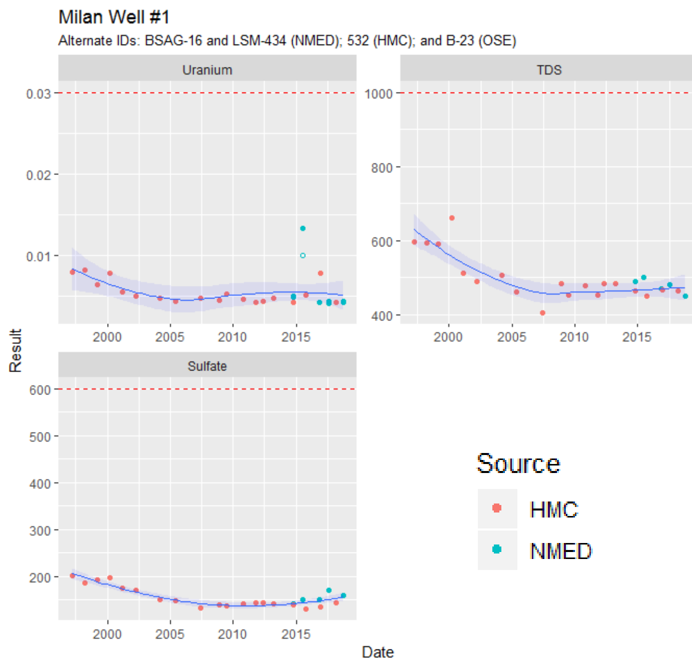
All units in mg/L except groundwater elevations (units = ft amsl).
——Blue line is a LOESS locally weighted regression line.
Shaded area is the corresponding 95% pointwise confidence interval.
- - - State of New Mexico groundwater standard in mg/L (uranium = 0.03; TDS = 1000; sulfate = 600), included as reference point, not intended to imply compliance requirement.
Fraction: ● Total ∆ Dissolved
Regression line and confidence band not shown for groundwater elevation because of insufficient data.
* For well 806R, HMC's most recent (5/4/2017) uranium result (0.114 mg/L) is not shown. Value is anomalous and inconsistent with the historical record.



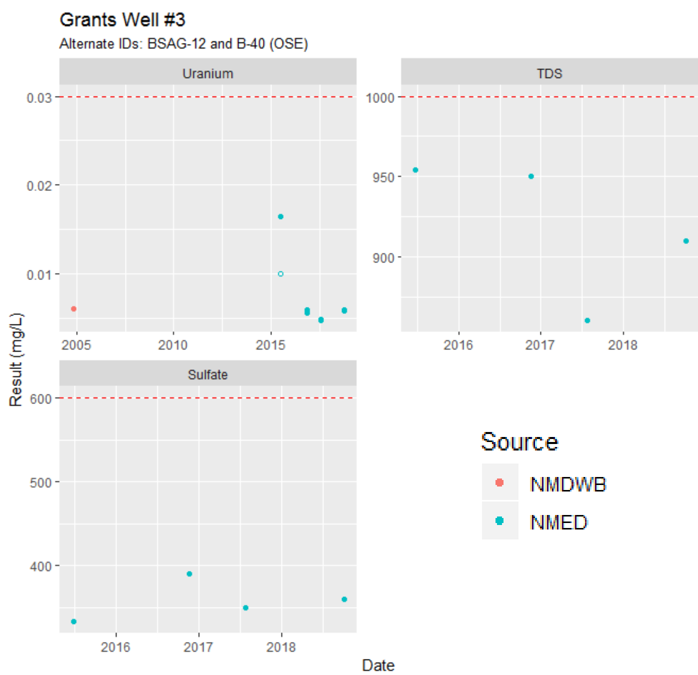
All units in mg/L except groundwater elevations (units = ft amsl).
——Blue line is a LOESS locally weighted regression line.
Shaded area is the corresponding 95% pointwise confidence interval.
- - - State of New Mexico groundwater standard in mg/L (uranium = 0.03; TDS = 1000; sulfate = 600), included as reference point, not intended to imply compliance requirement.
Fraction: ● Total ∆ Dissolved
Because of the large (>10-year) gap in data for Milan Well #4, the regression line and corresponding confidence interval is plotted only for the most recent (2014–2018) data.



All units in mg/L except groundwater elevations (units = ft amsl).
——Blue line is a LOESS locally weighted regression line.
Shaded area is the corresponding 95% pointwise confidence interval.
- - - State of New Mexico groundwater standard in mg/L (uranium = 0.03; TDS = 1000; sulfate = 600), included as reference point, not intended to imply compliance requirement.
○ Hollow symbol denotes nondetect result.
The uranium plot includes both total and dissolved fractions reported by NMED for samples collected since 2015. Because total and dissolved results were equivalent in most cases, symbol shapes are not distinguished.

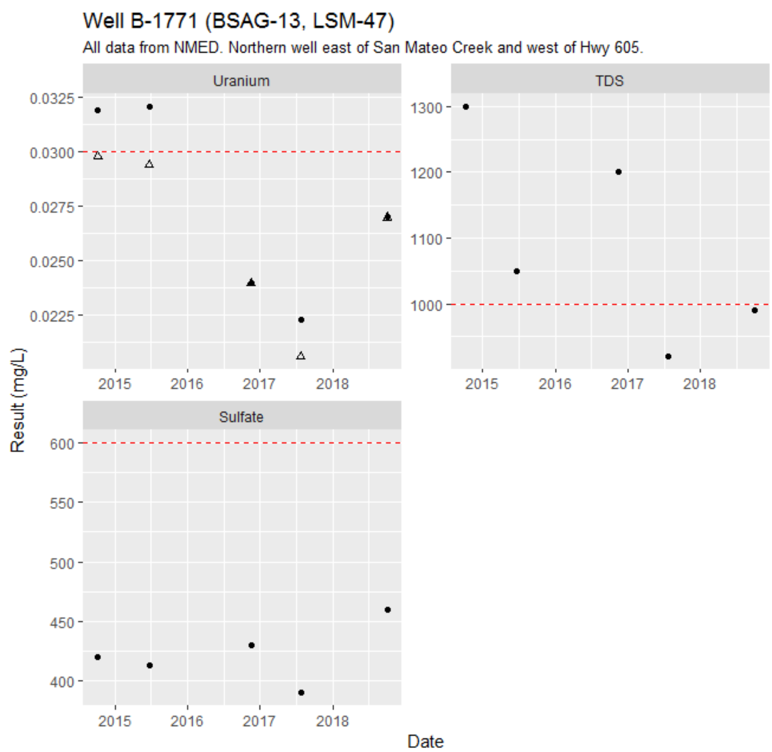


All units in mg/L except groundwater elevations (units = ft amsl).
——Blue line is a LOESS locally weighted regression line.
Shaded area is the corresponding 95% pointwise confidence interval.
- - - State of New Mexico groundwater standard in mg/L (uranium = 0.03; TDS = 1000; sulfate = 600), included as reference point, not intended to imply compliance requirement.
○ Hollow symbol denotes nondetect result.
The uranium plot includes both total and dissolved fractions reported by NMED for samples collected since 2015. Because total and dissolved results were similar in most cases, symbol shapes are not distinguished.

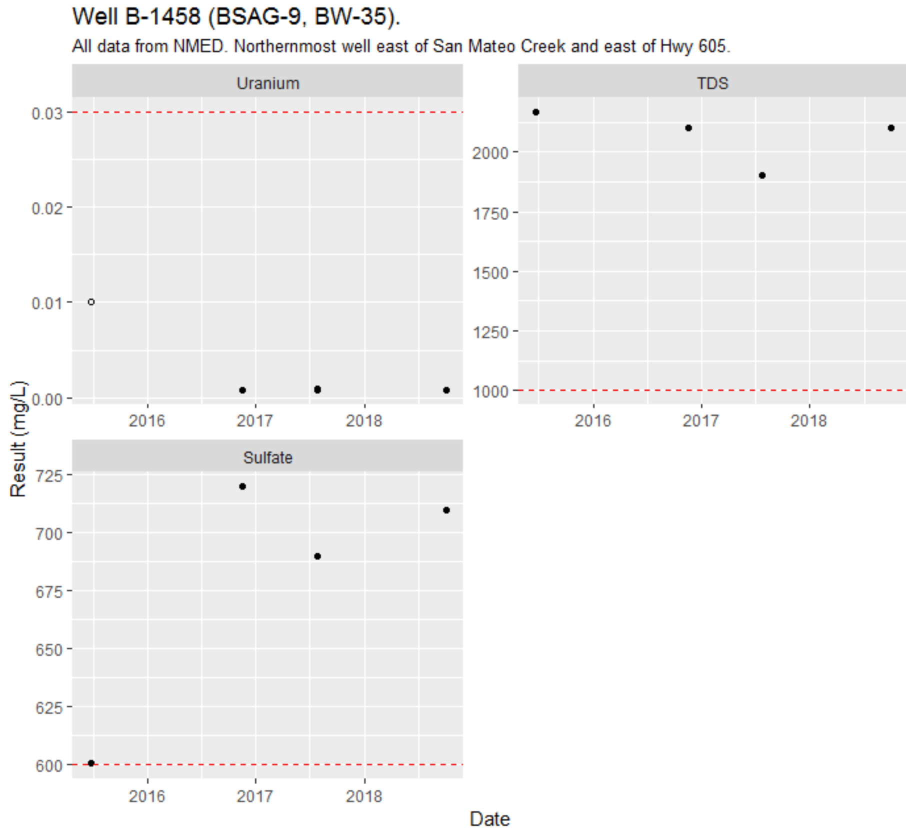


- - - - State of New Mexico groundwater standard in mg/L (uranium = 0.03; TDS = 1000; sulfate = 600), included as reference point, not intended to imply compliance requirement.
○ Hollow symbol denotes nondetect result.
The uranium plot includes both total and dissolved fractions reported by NMED for samples collected since 2015. Because total and dissolved results were similar in most cases, symbol shapes are not distinguished.

- - - State of New Mexico groundwater standard in mg/L (uranium = 0.03; TDS = 1000; sulfate = 600), included as reference point, not intended to imply compliance requirement.
Fraction: ● Total ∆ Dissolved



- - - - State of New Mexico groundwater standard in mg/L (uranium = 0.03; TDS = 1000; sulfate = 600), included as reference point, not intended to imply compliance requirement.
Fraction: ● Total ∆ Dissolved



- - - - State of New Mexico groundwater standard in mg/L (uranium = 0.03; TDS = 1000; sulfate = 600), included as reference point, not intended to imply compliance requirement.

○ Hollow symbol denotes nondetect result.

The uranium plot includes both total and dissolved fractions reported by NMED for samples collected since 2015. Because total and dissolved results were similar in most cases, symbol shapes are not distinguished.

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